Sub-Regimes of Vertical Two Phase Annular Flow

by

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Abstract

A convenient method to calculate pressure drop in wells producing natural gas with some water or hydrocarbon liquids is desired in order to design the initial well completion and to consider the technical and economic benefits of a subsequent intervention to extend the operating life of the well. In a laboratory flow loop, air and water have been used as fluid proxies to study two-phase behaviour.

Concurrent upward air-water flow has been measured in a 26.1mm internal diameter vertical test section at standard conditions over a range of superficial air and liquid velocities. Several sub-regimes of annular flow were newly observed or refined (pulse/disturbance wave, ripple-wave, partial-wetting, and rivulet) with both still and high speed video images recorded externally. The pressure gradients measured were consistent with previous work under similar conditions.

The liquid film within the pipe was examined through Planar Laser Induced Fluorescence (PLIF) imaging, measuring film thickness over a selected range of air and water flow rates. In addition, the onset of droplet entrainment has been observed directly. This data has enabled a new detailed map of sub-regime boundaries to be proposed. Most models for annular flow incorporate a single correlation for interfacial friction without regard to the annular sub-regimes. By observation of computed friction factor and relative roughness data, it is found that the annular region can be represented with three zones of distinct behaviour.

In non-entrained flow at high superficial gas Reynolds numbers ($Re_{sg} > 35,000$) and laminar superficial liquid Reynolds number ($Re_{sl} < 250$) the liquid film exhibits constant relative roughness for a given liquid input. A correlation was derived for superficial gas friction factor as a function of Re_{sl} alone. For entrained flow with $Re_{sg} > 35000$ and $Re_{sl} > 250$, the film shows relative roughness decreasing as gas rate increases. Another correlation for superficial gas friction factor were derived as a function of both Re_{sl} or Re_{sg} . Pressure gradients calculated with the new correlations compared well against the experimental database as well as with applicable published data. A third zone ($Re_{sg} < 35,000$), close to churn flow regimes, was not amenable to this approach.

Preface

Some of the results in Section 5 were originally presented at the 10th North American Conference, Multiphase 2016 in Banff, Alberta as "Observations of Sub-Regimes in Vertical Annular Flow" by J.R. Nichol and E. Kuru.

Dedication

This work is dedicated to my wife Tanice, who is waiting very patiently for the completion of this work!

Acknowledgements

"I love deadlines. I love the whooshing sound they make as they go by." Adams, D. (2002). *The salmon of doubt : Hitchhiking the galaxy one last time*. New York: Harmony Books.

This journey began in 2009 when as a part-time student I took the course PET E 632, Multiphase Flow taught by Dr. Petre Toma. Although the journey itself has been most enjoyable, after receiving two extensions the Faculty of Graduate Studies and Research has reminded me on several occasions that reaching a destination is also important.

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List of Symbols and Abbreviations (with nominal units)

А	Cross-sectional area [m ²]
d	pipe diameter [m]
E, FE	entrainment fraction
f	friction factor
g	gravity [9.8065m/s ²]
G	mass velocity [kg/m2-s]
Н	holdup
i.d.	inside diameter [m]
j	velocity [m/s]
j*	dimensionless velocity
L, 1	length [m]
m	mass [kg]
ṁ	mass flow rate [kg/s]
М	molecular weight [kg/kg-mol.]
mscfd	thousand standard cubic feet per day
Re, N _{Re}	Reynolds number
Р, р	pressure [Pa or kPa or kPaa]
p*	dimensionless pressure
Q, q	volumetric flow rate [m ³ /s]
r	radius [m]
R	universal gas constant [8.3145 kPa m ³ /kg-mole K]
S	saturation, perimeter [m]
Т	temperature [K or °C]
U, v	velocity [m/s]
V	volume [m ³]

Greek Symbols

δ	liquid film thickness [m]
8	pipe absolute roughness [m]
μ	viscosity (dynamic) [Pa-s]
ν	viscosity (kinematic) [m ² /s]
ε	insitu gas fraction
ρ	density [kg/m ³]
σ	interfacial tension, [N/m or dyne/cm]
τ	shear stress [Pa/m]

Subscripts

A, air	air
c	core
f	film, fluid
F	Fanning
G, g	gas
i	interfacial
L, l	liquid
LC	liquid in core
LF	liquid in film
m	mixture
М	Moody
p	pipe
SG, sg	superficial gas
SL, sl	superficial liquid
TP	two phase
W	water, wall
wirr	water, irreducible

1 Introduction

1.1 The Thesis

A simplified method can be devised to calculate pressure gradient in vertical wells producing gas with liquids.

1.2 Overview

In the province of Alberta alone, approximately 78% of ultimate conventional natural gas reserves have already been produced, leaving 49 standard billion cubic feet (BCF) for future production and discovery (AER, 2017.) There are becoming fewer discoveries among conventional gas pools and these are coming from smaller gas pools (Fig. 1.1.)



Then energy industry now turns its attention to the tight and unconventional gas resources, including coalbed methane and shale, whose in-place resource is estimated to be 3406 trillion cubic feet (TCF), subject to some uncertain recovery factors.

However, many of these wells will be producing some liquids with the gas. The chief sources of liquid production are:

- a) Connate water migration.
- b) Water breakthrough or coning.
- c) Condensed water or hydrocarbon vapour.
- d) Mobile liquid hydrocarbon.

If connate water saturation, S_w , is significantly higher than irreducible water saturation, S_{wirr} , in a reservoir, it is potentially mobile and may be drawn into the wellbore as gas is produced. At high gas rates, the additional drag of turbulent flow may also cause increased water production. Water breakthrough is also a consequence of high production rates: as flowing wellbore pressure is lowered, the pressure gradients in the reservoir may favour movement of water from lower water saturated zones into the wellbore. Fractured formations provide additional flow paths for movement of bottom water. At initial reservoir conditions, water vapour is in equilibrium with the formation gas. As reservoir pressure decreases with production, the amount of water vapour (as measured in water mass per unit standard volume of gas) increases; some of this water vapour condenses as the production stream cools on its way to the surface.



Figure 1.2 Life Cycle of a Gas Well Showing Progression of Flow Regimes.

The presence of liquids in the production string can impair the recovery of gas, in what is commonly referred to as liquid loading. With liquid loading the static and frictional pressure losses in the production tubing increase often resulting in the well "dying" as reservoir pressure declines, as shown in Fig. 1.2, adapted from Lea, Nickens, and Wells (2003). With liquids production, some of the operational responses are illustrated in Fig. 1.3. The path taken will be subject to economic analysis.



Figure 1.3 Liquid Management Options for Gas Wells.

Downhole separation of gas and water requires a suitable disposal zone and therefore is not widely applicable (Radwan, 2017.) Reducing water influx by deliberately reducing the gas rate is not economically appealing. Another approach is to introduce a viscous material into the reservoir to block the water path, however these treatments can be short lived (Wawro, Wassmuth, and Smith, 2000.) Most operators will implement some form of lift to bring the liquids to surface, especially if hydrocarbon liquids are present, for example:

a) Plunger lift in conventional gas (Ozkan, Keefer and Miller, 2003)

- b) Electrical Submersible Pump (ESP) in coalbed methane (Kraweic, Finn, and Cockbill, 2008.)
- c) Foam Lift in shale gas (Farina et al., 2012.)
- d) Plunger Lift in shale gas (Nascimento, Becze, Virues, and Wang, 2015.)

In order to design an appropriate well completion and to anticipate the onset of liquid loading, the production engineer makes use of software tools to calculate the initial gas flow rate of the well and its decline rate. An incorrect assessment of initial production rate will have immediate economic consequences; it may result in selection of undersized production tubing (which will constrict production rate, hence cash flow) or oversized tubing (unnecessary capital cost.) A reliable decline rate is necessary to determine when liquid loading problems require a change to the well design.

1.3 The Problem

Well behaviour is commonly assessed with nodal analysis, where the inflow characteristics of the reservoir are compared with the outflow of the production tubing. The intersection of the two defines the operation point (flow rate, and bottomhole flowing pressure) of the well. Calculations of pressure gradient in two phase flow are obviously more complex than those for a single phase fluid. A number of correlations are available for the two phase calculation, however their results are far from consistent. For example, Fig. 1.4 shows a typical nodal analysis result generated with the commercially available software SNAP by the Ryder Scott Company. A constant water-gas ratio has been used. Three popular correlations were used to calculate the bottomhole pressure in the production tubing as a function of gas flow rate:

- a) Gray (API, 1978)
- b) Ansari, Sylvester, Sarica, Shoham, and Brill (1994)
- c) Chokshi (1996) and Chokshi, Schmidt and Doty (1996)

In Fig. 1.3 observe that the three outflow correlations give different solutions for the initial gas flow rate. This presents the production engineer with a dilemma. Which correlation is to be believed? What is the uncertainty of the result from a selected correlation?



Figure 1.4 Example Nodal Analysis of Gas Well With Different Outflow Correlations.

The differences among the correlations is emphasized in Fig. 1.5. Gray (API, 1978) is excluded because it is very close to the Ansari et al. (1994) results. The range of initial operating rate is between 1730 and 2060 thousand standard cubic feet per day (MSCFD) depending on which model is selected. The SNAP software also calculates the minimum flow rate for liquid loading, which is usually considered to be the minima of the tubing outflow curve. Here the solutions range between 189 and 242 MSCFD. However those two rates will occur at different times in the life of the well and the production engineer must know when to schedule an intervention, such as a workover to install artificial lift. The importance of improving the accuracy of the multiphase correlation and the calculated point of liquid loading is now evident.



Figure 1.5 Example Nodal Analysis with Initial Operating Point and Loading Limit.

1.4 The Hypothesis

Examining the sub-regimes of annular flow in detail, along with published experimental results will provide insights that lead to new set of predictive models for pressure gradient.

1.5 Scope of Research

Initial work first determined distinct sub-regimes of annular flow vertical wells, based on the possible flow patterns of gas and liquid.

Laboratory experiments with a vertical two phase flow loop will measured a variety of parameters (differential pressure, gas flow rate, liquid flow rate, liquid velocity profile) for a test matrix of gas and liquid rates sufficient to explore each of the posed sub-regimes. The existing flow loop at the University of Alberta was modified to accommodate this work. This flow loop was originally used by Becaria (2004)

and Vargas (2006) to study slug to annular transitions in small diameter tubes. The work considered the behaviour of air-water systems at standard conditions. Extensions to the program with different liquids and at elevated pressures is possible.

1.6 Structure of this Thesis

This Section has set out the need for a better understanding of two phase vertical flow. Section 2 delves into the historical work on this issue. In Section 3 the experimental apparatus is described and its operation is outlined in Section 4. The results of the experimental programs are presented in Section 5 along with detailed analysis. A description of new correlations to calculate pressure gradient is presented in Section 6. Section 7 then summarizes the contributions of the work with the requisite recommendations for further work. The Appendices contain supplementary information as required.

2 Background

2.1 Historical Studies of Two-Phase Flow

Historically, the study of two-phase fluid flow has included both qualitative (visualizing the flow patterns of the fluids) and quantitative (pressure, velocity, film thickness, entrainment, etc.) measurements.

Different flow patterns were recognized early on by Versluys (1932) who summarized his notion of multiphase flow that ranges from a continuous liquid phase (the "foam condition," which we would now term bubble flow) to a continuous gas phase (the "mist condition.") His concepts are presented in Fig. 2.1; the dark portions represent liquid and the light portions represent gas.



Figure 2.1 Conceptual Depiction of Multiphase Flow in Vertical Pipe.

Versluys also hinted at the structure of an intermediate region, which he considered to be unstable, "The drops or the bubbles are evenly distributed... when they become larger...the shape of a jelly-fish is approached." This is a very clear description of slug flow! Versluys also noted the difference in velocity

between the gas and liquid (slip) and the importance of knowing the insitu proportions of the phases (holdup.)

An early combined quantitative and visual study of two-phase flow was performed by Gosline (1938.) Air and water pumping experiments were conducted with a 26 foot long, 1 inch i.d. glass tube. Gosline observed, "As the rate of air flow increased the unsteadiness decreased and finally the flow became quite steady. This steady motion, however, was accompanied by a change in the admixture of air and fluid. The fluid was [then] present in the tube as an annular ring in contact with the tube wall and air moved up through the central portion." This was a description of slug-to-annular flow transition, which was indicated in a graphical presentation of his laboratory measurements as the dashed line (Fig 2.2) The lines indicate conditions of constant submergence ratio, R_s , where,

(2.1)

 $R_{s} = \frac{liquid_level_in_tube}{liquid_level_in_tube+lift_height}$



Figure 2.2 Early Quantitative Measurement of Vertical Upward Air-Water Flow. With Flow Pattern Transition Indicated.

Vertical annular flow was also observed and photographed by Cromer and Huntington (1938) through a two foot section of glass pipe atop a suspended 98 foot iron production string. At high air flow rates they observed that, "...the water rippled upward along the sides of the flow tube in the annular ring reported by Gosline." In Fig. 2.3, this annular flow is recorded in a photograph – the glass tube is between two steel supports.



Figure 2.3 Photograph of Annular Flow from Cromer and Huntington (1938).

From their flow loop observations, Calvert and Williams (1955) were able to organize the various twophase vertical flow patterns by appearance (Fig. 2.4.) These have been refined only slightly over the years. However,he terminology has changed: "bubble" is used instead of "aerated"; "slug" instead of "piston"; and "annular-mist" instead of "drop entrainment."



Figure 2.4 Sketch of Vertical Two Phase Flow Patterns from Calvert and Williams (1955).

In Fig 2.4 the annular flow regime is portrayed in two sub-regimes: a true annular arrangement with liquid film and gas core (E); and an entrained configuration with some of the liquid contributing to the gas core (F). Fig 2.5, also from Calvert and Williams (1955) the authors acknowledged the work of Radford (1949) in which established that the pressure gradient could be associated with flow regime transitions. The transition to annular flow in the figure is indicated to occur at approximately at point E, the minima in measured pressure gradient (at a constant water flow rate.)



Figure 2.5 Pressure Gradients Associated with Flow Patterns in Fig. 2.4

Advancements in flow visualization have included high-speed motion pictures. Steen and Wallis (1964) photographed annular flow (in the downward direction) to obtain images of the air-water interface. It is notable that their apparatus was designed so that "the air-water interface could be viewed without looking through a water film, a principal difficulty with still films." At the interface they observed "ripple" waves at moderate air flow and then at high air rates, superimposed "roll" waves were seen.

ey associated the appearance of the "roll" waves with the onset of liquid entrainment in the central gas core. In Fig. 2.6, taken at about 2000 frames per second, a roll wave yields a filament of liquid, about to become an entrained droplet. To "see" inside the film itself, early workers employed dye tracers.



Figure 2.6 High Speed Film of Air-Water Interface.

Ho and Hummel (1970) were able to visualize and quantify a velocity profile of a vertically falling film inside a 28.4mm i.d. glass tube over a range of flow rates. Different alcohol-based fluid mixtures were used. In Fig. 2.7 the dye trace between the inside wall and the air-film interface indicates the velocity profile under laminar conditions. The film Reynolds number is defined as,

$$N_{\text{Re}F} = \frac{4Q}{v} \tag{2.2}$$

where Q is volumetric flow rate per unit of wetted perimeter. Photographs of the dye traces were analyzed to obtain velocity distribution within the film itself. The non-linearity at the air-fluid interface was attributed to the influence of surface waves.



Figure 2.7 Image of Laminar Velocity Profile in Falling Liquid Film.

Later, Hewitt, Jayanti, and Hope (1990) used similar methods obtain a qualitative impression of a developing velocity profile of the liquid film. In a horizontal flow segment, dye was added to the liquid phase. Then laser light was used to illuminate the dye and photograph the gas-liquid interface. While this work was focused on studying the wavy nature of the liquid film, the dye traces also provided the information on the velocity profile within the film itself (Fig. 2.8.)



Figure 2.8. Sketch of Liquid Film Velocity Profile.

More recently, the ability to "see through" the liquid film has been enabled through use of a transparent pipe in an optically compatible fluid with using particle image velocimetry (PIV) and planar laser-induced fluorescence (PLIF) techniques. Kopplin (2004) measured the velocity profile within the liquid film in a horizontal annular flow loop with PIV (Fig. 2.9.)



Figure 2.9 Measured Velocity Profile in Horizontal Annular Flow (Bottom of Pipe.)

Employing PLIF, Schubring (2009) was able to trace the surface of the liquid film in upward vertical pipe, as shown in Fig. 2.10 (the liquid film is lighter in colour.) In the figure there are four traces, with the bottom one measured at the highest gas flow rate (and exhibiting the thinnest film.) The window size is about 4mm wide by 0.4mm high.



Figure 2.10 Traces of Base Liquid Film in Vertical Annular Flow.



Figure 2.11 Pressure Gradient as a Function of Superficial Velocities. from Ashwood's data (contour interval 0.5 kPa/m.)

Ashwood (2010) also employed botj PIV and PLIF techniques to measure film thickness and pressure drop in vertical air-water flow with a 23.4mm i.d. quartz tubing. A contour plot of Ashwood's (2010) data, showing the pressure gradient as a function of superficial velocities in vertical tubing is presented in Fig. 2.11. Note that the minimum superficial liquid rate measured by Ashwood (2010) was 0.4 m/s, which therefore does not include the sub-regimes identified by Nedderman and Shearer (1963) or Hall Taylor, Hewitt and Lacey (1963.).

2.2 Flow Regimes

The flow patterns presented by Taitel, Barnea and Dukler (1980) (Fig 2.12) differ very little from those proposed 25 years earlier by Calvert and Williams (1955) in Fig. 2.4.



Figure 2.12 Flow Patterns from Taitel, Barnea and Dukler (1980).

Determination of flow regime is through calculated maps, such as that one shown in Fig. 2.13 from Barnea (1987.) This figure is especially useful as it closely the matches the expected conditions for the current work.



Figure 2.13 Flow Regime Map for Upward Vertical Flow of Air-Water in 2.54cm dia. Tube. at Standard Conditions.

The region of interest in the current work is that of annular flow (the region to the right of transition J in Fig. 2.13.) Transition J is adopted from Turner, Hubbard, and Dukler (1969) (in consistent units):

$$V_{crit} = 5.46 \left[\frac{\sigma(\rho_l - \rho_g)}{\rho_g^2} \right]^{1/4}$$
(2.3)

At standard conditions for air and water, the Turner et al. (1969) equation (without the recommended 20% upwards adjustment from Coleman, Clay, McCurdy, and Norris (1991)) gives a gas velocity of 14.6 m/s (47.9 ft/s) to commence annular flow. Note that the curvature of Transition J at high superficial liquid velocity is an adjustment proposed by Barnea (1987) to account for film bridging in smaller diameter pipe.

However, the annular flow regime is not amorphous. Hall Taylor et al. (1963) observed several subregimes of annular flow in 31.8mm i.d. vertical pipe; their data is redrawn in terms of superficial velocities

in Fig. 2.14. The onset of annular flow is about 12 m/s in this case. Note the relatively sparse data collected at low liquid velocity.



Figure 2.14 Annular Flow Sub-Regime Map of Hall Taylor et al. (1963).

Nedderman and Shearer (1963) defined three annular sub-regimes during experiments near standard conditions with the same pipe size (Fig. 2.15):

- a) De-wetted (100% entrainment.)
- b) Small ripple waves.
- c) Large disturbance waves.

Note in Fig. 2.15 the onset of "de-wetted" flow is read from the graph to be about 48 ft/s, which is the same as to the 14.6 m/s given by the Turner et al. (1969) equation. The condition for small to large ripple wave transition was found to be about the same as given by Hall Taylor et al. (1963). However, the transition to non-wetted flow was different; this was attributed to the differences in wettability to the pipe wall.



Figure 2.15 Annular Flow Sub-Regime Map of Nedderman and Shearer (1963).

Another example of annular flow sub-regimes is given by Woods, Spedding, Watterson, and Raghunathan, (1999) in Fig. 2.16, based on air-water experiments in 26mm pipe at assumed standard conditions. The initiation of annular flow is given by the equation,

$$\left[-(H-0.04)\sqrt{V_{sl}} + \sqrt{V_{sg}} = 1.48 \left[\frac{(g\sigma(\rho_L - \rho_G))^{1/4}}{\rho_g^{1/2}}\right]^{1/2}$$
(2.4)

Where H is a Heaviside step function (=0 if V_{sl} is negative, =1 if V_{sl} is positive.) Note the inclusion of a liquid rate term not found in the Turner equation. At very low liquid flow ($V_{sl} \ll V_{sg}$) the equation simplifies (in consistent units) to a form identical to equation 2.3:

$$V_{sg} = 1.48^2 \left(\frac{g\sigma(\rho_L - \rho_G)}{\rho_g^2}\right)^{1/4} = 3.88 \left(\frac{\sigma(\rho_L - \rho_G)}{\rho_g^2}\right)^{1/4}$$
(2.5)

The resulting superficial gas velocity at standard conditions with air-water becomes 10.4 m/s.



Figure 2.16 Annular Flow Sub-Regime Map of Woods Spedding, Watterson, and Raghunathan (1999).

Note that the maximum superficial liquid velocity explored in Fig. 2.16 is considerably higher than that of Nedderman and Shearer (1963) or Hall Taylor et al. (1963).

2.3 Two-Phase Flow Models

Modelling methods for multiphase flow can be classified very roughly as either homogeneous or mechanistic. In the nodal analysis example presented in Section 1.2, the Gray correlation (API, 1978) is homogeneous, in that no particular flow regime is considered. It has been found to be best suited to vertical natural gas wells producing hydrocarbon liquids (condensate.) The general solution for pressure gradient is

$$\frac{dp}{dl} = g\left[\xi\rho_s + (1-\xi)\right] + \frac{f_{tp}G^2}{2d\rho_m} + \frac{G^2d}{\rho_m dl}$$
(2.6)

where the terms on the right hand side of the equation represent static, frictional and kinetic energy losses respectively. To solve for pressure gradient empirical relationships derived from field data are required first to obtain a value for insitu gas fraction, ξ .

For annular flow, an upward moving film wetting the pipe wall is assumed. It is interesting to note that this was described mechanistically as early as 1955 by Calvert and Williams, as depicted in Fig. 2.17.



Figure 2.17 Force Balance on Element of Liquid Film in Vertical Annular Flow.

Examples of mechanistic models in use in the petroleum industry are Ansari et al. (1994) and Chokshi et al. (1996). They are part of a progression of models, developed at the University of Tulsa. In chronological order they are: Yao and Sylvester (1987) solving for gas core only; Alves, Caetano, Minami and Shoham (1991), Ansari et al. (1992), Chokshi et al. (1994), and Gomez et al. (1999).



Figure 2.18 Force Balances on of Liquid Film (left) and Gas Core (right) in Vertical Annular Flow.

Typically, the force balance is applied to the gas core in addition to the film, as shown in Fig. 2.18 from Shoham (2006.) From this assumption of annular flow geometry, the force balance equations are derived for core and film respectively:

$$A_c \left(\frac{dp}{dL}\right)_c - \tau_i S_i - \rho_c A_c g = 0$$
(2.7)

$$A_F \left(\frac{dp}{dL}\right)_F + \tau_i S_i - \tau_F S_F - \rho_L A_F g = 0$$
(2.8)

With these auxiliary equations, for perimeter and cross-sectional area,

$$S_F = \pi d \tag{2.9}$$

$$S_i = \pi (d - 2\delta) \tag{2.10}$$

$$A_F = \frac{\pi}{4} \left(d^2 - (d - 2\delta)^2 \right)$$
(2.11)

$$A_c = \frac{\pi}{4} \left(d - 2\delta \right)^2 \tag{2.12}$$
We can construct energy equations for core and film (simplified by neglected the kinetic component and interface velocity),

$$\left(\frac{dp}{dL}\right)_c = \frac{f_i \rho_c v_c^2}{2(d-2\delta)} + \rho_c g \tag{2.13}$$

$$\left(\frac{dp}{dL}\right)_{F} = \frac{2\mu_{F}v_{F}d}{\delta^{2}(d-\delta)} - \frac{f_{i}\rho_{f}v_{c}}{2\delta(d-\delta)} + \rho_{F}g$$
(2.14)

where average fluid velocities are given by

$$v_F = (1 - FE)v_I = \frac{q_L(1 - FE)}{A_F}$$
 (2.15)

$$v_c = v_g + FE \times v_l = \frac{q_g + FE \times q_L}{A_c}$$
(2.16)

It is common to assume no-slip conditions in the gas core. However, experimental work by Fore and Dukler (1995) measured the slip in the entrained gas droplets and found that "the droplets at the centerline [of the pipe] are travelling, on average, at 80% of the local mean gas velocity."

The gas-liquid interface differs from a pipe wall in that it has some velocity and its roughness may vary. While the mechanistic models developed by Ansari et al. (1994) and Chokshi (1994) assumed the interface velocity to be much smaller than core velocity, Alves (1991) accounted for it, so that the core velocity term became $v_c - v_F$. where v_F is average film velocity. Strictly speaking, the relative velocity of the gas core should be expressed as $v_c - v_i$, with v_i being the interface velocity, i.e. the velocity of the surface in contact with the core. Proper evaluation of v_i requires knowledge of the velocity profile in the liquid film.

Solution of equations 2.13 and 2.14 for pressure gradient requires knowledge of,

- a) film thickness, δ
- b) entrainment fraction, FE
- c) interfacial friction factor f_i

The solution is obtained iteratively by assuming an initial value of film thickness and setting the pressure gradients in the film and core equal to each other. However, empirical correlations for liquid entrainment and interfacial friction are required. Hence this is often termed as a *semi*-mechanistic approach.

For entrainment, the correlation by Wallis (1968, 1969) has been used almost exclusively. It was presented originally in graphical form (Fig. 2.19.) The correlating parameter is dimensionless gas velocity, termed π_2 by Wallis,

$$\pi_2 = \frac{V_{sg}\mu_g}{\sigma_L} \left(\frac{\rho_g}{\rho_l}\right)^{1/2}$$
(2.17)

Note that Wallis' correlation is a function of gas velocity but not liquid velocity.



Figure 2.19 Wallis' Correlation for Liquid Entrainment in Annular Flow.

For numeric and iterative solutions, the curve of Wallis has been approximated by the equation,

$$FE = 1 - \exp\left[-0.125(v_{crit} - 1.5)\right]$$
(2.18)

where,

$$v_{crit} = 10000 \times \pi_2 \tag{2.19}$$

Wallis' correlation shows a threshold or critical gas velocity that must be achieved before entrainment of the liquid film occurs. By inference there is a condition of annular flow for which there is no entrainment. Examination of the original dataset (Fig. 2.20, digitized from a graph in Steen and Wallis (1964)) used to construct this correlation shows some scatter, creating some uncertainty about the point of onset of entrainment.



Figure 2.20 Data Used to Construct Wallis' Correlation for Liquid Entrainment in Annular Flow.

When other flow loop data of Steen and Wallis (1964) is used, the result is less pleasing: Fig. 2.21 represents air-water tests between 1 and 4 atm.



Figure 2.21 Wallis' Correlation for Liquid Entrainment Compared with Air-Water Data.

The correlation for interfacial friction (in Moody form) is taken from Wallis (1969) for "thin" liquid films,

$$f_i = 0.02 \left(1 + 300 \frac{\delta}{d} \right) \tag{2.20}$$

This equation is based on an approximation of the Nikuradse [(NACA 1950) relationship for friction factor under fully turbulent conditions (i.e. not a function of Reynolds number). Ansari et al. (1994) interpreted "thin" films to be an entrainment fraction (FE) >90% in their mechanistic implementation of annular flow:

$$f_i = f_{SC} \left(1 + 300 \frac{\delta}{d} \right) \tag{2.21}$$

Where f_{sc} is the friction factor evaluated with superficial parameters. For "thick" films (FE<90%) the correlation of Whalley and Hewitt (1978) is suggested,

$$f_i = f_{sc} \left[1 + 24 \left(\frac{\rho_l}{\rho_g} \right)^{1/3} \frac{\delta}{d} \right]$$
(2.22)

When equation 2.21 is tested against the data reported by Asali (1984), the result is given in Fig. 2.22.



Figure 2.22 Interfacial Friction Calculated with Asali (1984) vs. Wallis (1969) correlation.

Many variants of the interfacial friction factor have been proposed. For example, Ashwood (2010), based on her data found that a better relationship for interfacial friction factor is found when a dependency on gas Reynolds number is introduced,

$$f_i = \operatorname{Re}_g^{-0.25} \left(1 + \frac{900\delta}{d} \right)$$
(2.23)

Another approach by Spedding et al. (1998) was to consider the friction factor as function of Re_{sl} and Re_{sg} . Their data analysis resulted in a parametric equation,

$$\frac{dP}{dl}\Big|_{TP} = \left[1.5457 \times 10^{-4} \,\mathrm{Re}_{sl}^{3.5683} \mathrm{Re}_{sg}^{(-0.6315\log \mathrm{Re}_{sl}+3.1909)}\right] \times \phi\left(\frac{0.0317}{d}\right)^{3}$$
(2.24)

The friction parameter, ϕ , is given graphically as a function of the superficial velocities in Fig. 2.23. While this method does free the pressure gradient solution from the need to determine entrainment and film thickness, it is limited to relatively high gas rates only (Re_{sg} > 8 × 10⁴.)



Figure 2.23 Friction Parameter ϕ in Spedding et al. (1998a) Pressure Gradient Correlation.

In summary, mechanistic models still require correlations for both entrainment and friction factor. Comparisons with experimental data show that these correlations do not always provide a good prediction.

3 The Experimental Apparatus

A vertical flow loop at the University of Alberta, has been modified from previous work. The loop is instrumented to record pressure and temperature continuously while metered air and water is flowing. Still and video cameras can observe the flow externally. Additional equipment is installed to measure liquid film thickness using the Planar Laser Induced Fluorescence (PLIF) method. Initial evaluation has established a performance envelope for the system.



Figure 3.1 Original Flow Loop Before Modifications.

3.1 Flow Loop Construction

The original vertical flow loop at the University of Alberta, as used by Becaria (2004) and Vargas (2006) for studies of slug to annular transitions, is shown in Figure 3.1. Airflow was measured with a rotameter and liquid rate was obtained by weighing the water stream returned to a bypass line.

Modifications to the loop began in 2012 to prepare it for this current program, and one to be conducted concurrently by Mamedulanov (2016.) The major changes are:

- a) The vertical test section of the loop now consists of a 31.8 mm o.d. by 26.1mm i.d. (average of two orthogonal measurements) cast acrylic pipe to allow for visual observation of the two phase flow. Cast acrylic has better optical clarity than extruded acrylic. Also, this also allows direct comparison with some previously published results, which use the same size tubing.
- b) The test section has been lengthened to 3.65 m (two sections chemically welded together) to minimize the impact of entrance effects.
- c) A viewing section has been fashioned from acrylic sheet material and installed near the top of the vertical section; this can be filled with glycerol for annular film imaging during PLIF experiments.
- d) The supply hose from the building compressed air outlet has been upgraded in order to reduce line losses and to ensure that flow velocities are well into the annular regime with the larger diameter test section.
- e) A manually operated valve has been added downstream of the liquid rotameters to provide adjustment to the input water rate.
- A manifold has been installed to accommodate three new rotameters to measure a wide range of liquid flow rates.
- g) A mist pad is added at the air vent to capture any droplets entrained during startup conditions.



Figure 3.2 Schematic of Vertical Flow Loop

Within a mixing tee at the bottom of the test section, compressed air is supplied to a short centralized stainless tube of approximately 6 mm i.d., which is perforated along its length and capped at the end. Water is gravity fed from the nominal 152 mm diameter reservoir section through one of the three selected rotameters mounted in parallel (Fig. 3.2.) The air and water mixture flows upwards through the 26 mm test section until it reaches a larger diameter (50 mm) horizontal separator section at the top of the loop. This 50mm pipe is set approximately at a 2° downward slope to encourage segregated flow; air exits the upper vent through a mist pad while water returns to the reservoir.

Guidance for this setting angle was taken from Barnea (1987) for air-water at standard conditions in a 51mm i.d. pipe at 1° downward from horizontal. When the flow loop performance envelope (with velocity re-calculated at the 51mm i.d. pipe diameter) is superimposed upon Barnea's flow regime map (Fig 3.3) observe that flow conditions in the separator section are expected to be either segregated-smooth (SS) or segregated wavy (SW) over the expected performance envelope of the loop. This indicates that the air and water will separate with the water returning to the reservoir.



Figure 3.3 Barnea's Horizontal Flow Regimes in 51mm i.d. Pipe. with Performance Envelope of University of Alberta Vertical Loop Superimposed.

Uniquely this flow loop does not feature a water pump. The reservoir maintains a nearly constant fluid head, which is sufficient to feed liquid back into the mixing section at a constant rate. Taps are mounted near the top of the test section to allow as much development length as possible before measurements are taken (Fig. 3.4). Differential pressure is measured over a 762 mm vertical interval, which is a compromise between achieving developed flow as high as possible at the top of the pipe and obtaining sufficient signal amplitude. The midpoint of the differential measurement segment is 2.8 m above the mixing tee, giving a development length to diameter ratio, L/d, of approximately 108. Since the thermocouple protrudes slightly into the test section, the tap for temperature measurement is downstream of the differential pressure taps to avoid disturbing the measured flow stream (Fig. 3.5.)



Figure 3.4 Vertical Flow Loop Taps and Instrumentation Locations.



Figure 3.5 Test Section Thermocouple Tap (Top) and Downstream Differential Pressure Tap (Below.)

3.2 Flow Loop Instrumentation and Measurement

Instrumentation mounted to the test section itself is as follows (Manufacturer data sheets for key instrumentation are provided in Appendix 2):

- a) Type K thermocouple
- b) Gauge pressure transducer (Omega PX419-2.5GI, S/N426582, +/-0.08% of full scale

accuracy) calibrated to 2.5psi (17.24 kPa) full scale (Figure 3.6.)



Figure 3.6 Gauge Pressure Transducer.

c) Differential pressure transducer (Omega PX2300-1DI, s/n 5119830, +/-0.25% of full scale

accuracy) calibrated to 1.0 psi (6.895 kPa) full scale (Figure 3.7.)



Figure 3.7 Differential Pressure Transducer with Taps Upstream (L) and Downstream (R.)

The pressure transducers, which are mounted well below their corresponding taps, are connected by 1.5mm i.d. perfluoroalkoxy (PFA) tubing. Signal wires from the transducers are connected to a terminal box where they are converted from a standard 4-20 ma to a 1-5v signal with a precision 250 ohm resistor. The analog signals are then sent to a data acquisition board on a PC, which has 16-bit resolution. Data is sampled and recorded using SignalExpressTM software by National Instruments, a simplified version of their LabViewTM application. Figure 3.8 shows an example of the display when the system is operating.



Figure 3.8 Screenshot of SignalExpress Software.

The pressure transducers were initially calibrated with a precision tester, and a calibration curve entered into SignalExpress (Figure 3.9.) During the course of the pressure gradient program, the calibration was checked directly by comparing the displayed pressure against a several different heights of static water column in the test section (Figure 3.10.) This confirmed the linearity of the pressure transducers but also revealed a small overall scale error along with a small offset error at very low pressure. This allowed further corrections to be made to the raw data. With a 30 inch (76.2cm) spacing between differential taps and a maximum pressure differential of 1 psi, the maximum pressure gradient that can be measured is about 9 kPa/m.



Figure 3.9 Original Pressure Calibration Curve for Differential Pressure Transducer.



Figure 3.10 Measured Fluid Level to SignalExpress Displayed Pressure.

Liquid flow is read manually through one of three high accuracy (+/- 1% of full scale) glass Kobold KDV series rotameters with ranges 2-20 standard litres per hour (SLPH), 16-160 SLPH and 100-1000 SLPH respectively (Fig. 3.11.) (See Appendix 4 for their corresponding calibration sheets.)



Figure 3.11 Three Water Rotameters with Isolation Valves.

Air flow was initially measured with a Cole-Parmer direct-reading rotameter, with a 30-300 standard litres per minute (SLPM) range on a 100mm scale. This was soon found to be unsuitable for experimental work because:

- a) The claimed accuracy for this rotameter is relatively coarse, only +/-3% of full scale.
- b) The scale is calibrated only for a standard condition specified by the manufacturer (14.7 psia, 70°F); for other conditions, the indicated flow rate must be calculated (see Appendix 5.)
- A total of three manual readings (with a corresponding number of potential reading errors) are required to calculate a flow rate: the rotameter scale reading, air temperature and gauge pressure.

A mass flow controller (Omega FMA 2621A, serial #105116) with a claimed accuracy of +/- 0.2% of full scale was added in series with the air rotameter (Fig. 3.12.) The controller has a maximum flow capacity of 1500 SLPM. Comparison of the two devices on two separate occasions (Figure 3.13) shows that while they are in good agreement at low flow rates, the rotameter overestimates flow rate compared with the mass flow controller at higher rates.



Figure 3.12 Mass Flow Controller for Air.



Figure 3.13 Comparison of Original Air Rotameter with Mass Flow Controller.

Flow rate data for air and water are adjusted and recorded manually. In addition, cameras are placed near the top of the test section (at approximately L/d = 128) for external observation and image taking. For high-definition video and stills, an Olympus OM-D M10 with an M.Zuiko Digital 14-150mm *f*1.4 lens is used. High-speed videos are taken with an iPhone 6s set to 240 frames/second at 720p resolution (Fig 3.14.)



Figure 3.14 iPhone 6s (L) and Olympus DSLR (R) Mounted for Imaging.

For the subsequent PLIF work, a Newwave Solo III laser and LaVision Imager Intense CCD camera (1376 x 1040 pixel) are employed (Fig. 3.15), in a configuration similar to that described by Mamedulanov (2016). This equipment has also been used by Zeinali (2012) and Bizhani (2013) in a horizontal loop located in the same lab. A diffuser changes the linear laser into a light "sheet." The laser and camera are controlled by a PC specially configured by LaVision Inc. and running their proprietary DaVis 8.3 software.



Figure 3.15 CCD Camera (L) and Laser (R) Acquiring Image Through Viewing Section.

Runs are to be conducted largely in the annular regime where liquid film is expected to be relatively thin. The laser sheet (about 0.5mm to 1mm width) is set at the centerline of the pipe. The camera is offset horizontally so that a portion of the pipe wall is included to provide a reference line; laser and camera are at zero angle of incidence to the viewing box sides to minimize refractive distortion. This arrangement is similar to that employed by Schubring (2009) and Zadrazil, Matar, and Markides (2014.) However for some work, Mamedulanov (2016) also located the laser laterally from the pipe centre line "in order to reduce obstruction of liquid film image by rough surface of the film and increasing air bubble concentration in the film with increasing liquid and gas flow rates." The camera employs a Nikor 65 mm f2.8 Micro lens with three extension tubes (total length 68mm) to give a small, high resolution window about the liquid film. An aperture setting of f16, is found to minimize the effects of ambient light in the lab. The laser/camera combination is located near the bottom of the viewing section where L/d is approximately 104.

The viewing box in the test section is filled with 99.5% glycerol (Sigma-Aldrich product G7893) which has a refractive index of 1.474 at 20°C (Hoyt, 1934.) which closely matches the refractive index of 1.49 for the acrylic of the test section pipe and the viewing box material. This is intended to further minimize image distortion. During image acquisition the back planes of the viewing box are covering in matte black construction paper to reduce stray reflections.





Figure 3.16 Calibration Target Before Trimming (L) and Closeup of Dot Pattern (R.) with 1mm Scale Markings Below.

For PLIF image calibration, a precision grid distortion target (Figure 3.16) was selected. The target has uniform dots of 0.0625mm diameter, spaced on 0.125mm apart. This is an improvement over the 0.5mm spacing target used by Mamedulanov (2016.) The target has been trimmed to fit the same target holder as used by Mamedulanov (Figure 3.17.) The target holder consists of a 150mm long half-cylinder constructed of nylon and semi-circular cross-section to fit tightly within the test section pipe. A bolt threaded into the top allows it to be lowered by string through the filling tee into the viewing box for calibration. It has three magnets installed to allow manipulation from the outside. With adhesive material, the face of the target is at the centerline of the test section pipe when installed for calibration.



Figure 3.17 Calibration Target Mounted to Target Holder.

The laser emits a green light at a wavelength of 532 nm. In order to obtain a bright image of the film over a narrow cross section, Rhodamine B dye (Acros #132311000) is added to the distilled water in the loop. The dye absorbs light energy from the laser and emits light (fluoresces) at a slightly higher wavelength (see Figure 3.18 from Kristofferson, Erga, Hamre, and Frette (2014) and well within the spectral range of the camera (290-1100 nm.). This dye has been used in several similar experiments, although the concentration has varied widely The current experiments followed those of Mamedulanov (2016) who used an initial Rhodamine-B dye concentration of 150mg/l.



Figure 3.18 Light Response of Rhodamine B in Water.

However, during the course of this work, system fluid losses (e.g. evaporation, leakage) required additional distilled water to be added to the reservoir. To estimate the current dye concentration, several reference mixtures were prepared in concentrations of 150, 120, 100, 80, 60, 40, 20 and 10 mg/l; these were compared with samples taken from the bottom of the rotameter section of flow loop (Figure 3.19) Two cleanup samples from the flow loop were intended to flush any accumulated solids and corrosion products before taking two "clean" samples. When illuminated from behind, the colour of the samples was compared against the reference mixtures to obtain an estimate of concentration in the flow loop.



Figure 3.19 Comparison of Flow Loop Rhodamine Sample vs. Prepared Concentrations. (Flow loop sample is marked with black plastic on top.)

In a more quantitative approach, the photograph was analyzed to establish a correlation between grey-scale image intensity of each known sample intensity and its corresponding dye concentration (Fig. 3.20.) For the grey-scale intensity, an average of a rectangle located in the centre of the sample image was calculated NIH ImageJ software. The grey-scale value of the flow loop samples was then fit to the curve; this yielded an estimated dye concentration of 40 mg/l. To account for uneven background illumination, the value from sample 2, which was placed closer to reference samples of the same concentration, was considered more accurate.



Figure 3.20 Colour Intensity Response of Rhodamine B Concentrations.

3.3 Flow Loop Performance Envelope

During functional testing of the flow loop, the air flow rate was set at intervals from 350 SLPM to 1500 SLPM. This covered the range from just below churn-annular transition to the maximum possible with the flow controller. For each air flow rate, the water flow was adjusted from the maximum stable rate to the minimum readable on the smallest rotameter (2 SLPH.) However, it was found that for the higher air rates, a high liquid feed caused considerable instability in the loop. This was attributed to the air feeding back into the liquid rotameters when the water head in the reservoir was too low. As a result, the reservoir was filled to a maximum safe level (about 2m), based on internal pressure and weight of the water. The resulting stable performance envelope of the apparatus was found, as shown in Figure 3.21.



Figure 3.21 Flow Loop Performance Envelope.

3.4 Flow Loop Teething Problems

Initial runs were made over the period December 4, 2014 to October 8, 2015. These early data were not used for further analysis because:

a) A rotameter was used initially for air flow measurement, with the accuracy concerns described earlier.

- b) Initial pressure offsets were not recorded.
- c) Poor cable shielding caused extremely high noise levels in temperature and pressure transducer signals.
- d) Pressure taps were not consistently purged before starting measurement runs.
- e) Municipal (hard) water was used at first. Scale buildup started to obscure viewing of flow regimes as well as potentially increasing the surface roughness of the pipe wall; attempts to clean with various solvents, such as acetic acid contributed to stress cracking and the test section had to be replaced in April, 2015.

4 The Experimental Programs

Two experimental programs were conducted. The first sought to collect finely-spaced measurements of pressure gradients within the performance envelope. In addition, images were taken externally to help identify sub-regimes of annular flow. Imaging took the form of high shutter speed stills, high resolution video and slow motion video.

In the second program the PLIF technique was used to capture internal images of the liquid film itself at various sample points within the test matrix. The objective was to measure average film thickness over a range of air and water flow rates and to observe the onset of liquid entrainment.

4.1 Pressure Gradient Program

To ensure consistent pressure measurements, the following preparation procedure was followed before beginning a series of runs:

- a) Ensure water level in the reservoir is close to the highest marked level.
- b) Close the water flow control valve to isolate the test section from the reservoir.
- c) Add demineralized water to the test section through the filling tee until the pressure taps are covered.
- d) After allowing time for any entrained air bubbles to rise and clear, drain the tap lines at the pressure transducers to remove any air bubbles.
- e) Purge the differential pressure transducer connections according to the manufacturer's instructions.
- f) Open isolation valve to the selected rotameter; close remaining isolation valves,
- g) Slowly open the water flow control valve to lower the liquid column in the test section,allowing the water to equalize with the level in the reservoir.
- h) When liquid column in the test section is below the pressure taps, record the offset values.
- i) Check that the filling tee cap is reinstalled!

For a series of measurements, the following steps were followed:

- a) Turn on power to the air flow controller, and set flow rate to less than 100 SLPM.
- b) Slowly adjust air rate on the controller in 100 SLPM increments until reaching desired rate (maximum is 1500 SLPM.) This avoids a surge which would otherwise cause a slug of water to "burp" out the air vent.
- c) Adjust the water flow control valve to maximum stable rate (directly read from the liquid rotameter); allow several minutes for system to stabilize. This ensures the maximum film thickness at the selected air rate so as to minimize air intake into the pressure transducer tap lines.
- In SignalExpress software, start recording of temperature, gauge pressure and differential pressure; record liquid rotameter reading.
- e) Take external still and video images.
- f) Stop recording and save data to MS-Excel file.
- g) Adjust water flow rate to next lowest increment, according to the test matrix and repeat stepsd) and e.)
- When water rate is at 20 SLPH, take readings on the "medium" range rotameter where this rate is marked at the bottom of the scale and repeat for the "small" range rotameter where this rate is marked at the top of the scale.

Flow loop runs were conducted intermittently between Dec 4, 2014 and Dec 16, 2016. This includes additional runs conducted to fill in data gaps or to confirm repeatability. Note also, some runs were done with air only. See Figure 4.1 for a plot of the final test matrix. Note that it is presented in terms of air flow rate (SLPM) and water flow rate (SLPH) as read from the instruments. A generally orthogonal approach was used in selecting the air rate and water rate increments for the test matrix, allowing results to be plotted as a functions of gas rate or liquid rate.



Figure 4.1 Test Matrix for Pressure Gradient Program.

The raw data collected for point of the test matrix were:

- a) Date.
- b) Air Flow Controller Set Point, SLPM referred to 15°C, 100 kPaa.
- c) Air Flow Controller outlet pressure, psia.
- d) Air Flow Controller outlet temperature, °C.
- e) Controller Air Flow Pressure, psia.
- f) Flow Loop Temperature, °C (input Ai5 on SignalExpress.)
- g) Flow Loop Pressure, psig (input Ai6 on SignalExpress.)
- h) Pressure Differential, psi (input Ai7 on SignalExpress.)
- i) Rotameter Water Flow rate ,SLPH.
- j) Gauge pressure Offset, psi.
- k) Differential pressure Offset, psi.
- l) Daily mean station pressure, kPaa.

Flow loop temperature, gauge pressure and differential pressure signals were sampled by the SignalExpress software at the highest rate possible without overloading the computer's data buffer; this was in the range of 15-25 ms between samples. After each air/water rate run, the data was transferred to an Excel spreadsheet, where a mean value and standard deviation was calculated for the first 1000 samples. All other data were recorded manually.

The University of Alberta is at 675m (2214 ft) above sea level, where the atmospheric pressure is typically lower than at the usual reference, sea level (SL). Hence assuming standard pressure for air properties (density, viscosity) would introduce a significant error. For example, when atmospheric pressure at sea level is 101.7 kPaa, the true atmospheric pressure (also called station pressure) in Edmonton is only 94 kPaa. Station pressure data from Edmonton City Centre Airport (Blatchford Field), elevation 671m (2202ft) was obtained from https://edmonton.weatherstats.ca/charts/pressure_station-daily.html (last accessed August 16, 2017.) Figure 4.2 shows an historical comparison between the commonly reported sea level adjusted pressure and the actual barometric pressure for Edmonton for a period covering the pressure gradient program.



Figure 4.2 Edmonton Station Pressure (True Atmospheric) and Sea Level Reference Pressure.

For further analysis, the following were calculated from the raw data:

 Air Mass Flow Rate, g/s. The air flow controller was programmed to display air rate referenced to 15°C and 100 kPaa. For use at the slightly varying conditions in the flow loop test section, it was convenient to first calculate a mass flow rate by rearranging the ideal gas equation thus:

$$\dot{m}_{air} = \frac{P_{std}Q_{air}M_{air}}{RT_{std}} = \frac{100 \times Q_{air} \times 28.9625}{8.3451 \times (273.15 + 15)} \times 1000$$
(3.1)

where Q_{air} is in units of m^3/s .

b) Corrected pressure differential, psi. At low flow rates, the offset error becomes significant. Therefore the averaged differential pressure was corrected by adding the offset pressure reading recorded under static conditions before commencing a series of runs. The offset was also recorded after a series of runs and in many cases was found to have changed because a small amount of air had intruded into the tap tubing. If the discrepancy was large, repeat runs were conducted. Observe in Figure 3.10 that the pressure gradients (slopes) are greater than the water density at nominal lab temperature of 21°C which is 9.8745 kPa/m. Therefore the indicated differential pressure is adjusted as follows:

$$\Delta P_{diff_corrected} = \left(\Delta P_{diff_offset}\right) \times \frac{9.8745}{10.03081}$$
(3.2)

c) Corrected gauge pressure, psi. In a similar fashion, the indicated gauge pressure is adjusted as:

$$\Delta P_{gauge_corrected} = \left(\Delta P_{diff} - P_{gauge_offset}\right) \times \frac{9.8745}{10.00922}$$
(3.3)

- d) Corrected absolute pressure at P_0 . To account for the flow loop lab's elevation above sea level, the daily mean station pressure (actual barometric pressure) is added to the corrected gauge pressure.
- e) Corrected pressure gradient, psi/ft and Pa/m. The spacing between differential pressure transducers is 30 inches (0.762m). Therefore,

$$\frac{dP}{dl} = \frac{Corrected_Differential_Pr\,essure}{30/12} \frac{[psi]}{[ft]} \times \frac{6895}{3.28} \frac{[Pa]}{[m]}$$
(3.4)

- f) Water density, g/cc. Based on average measured temperature and differential section average pressure, water density was calculated with a correlation by McCain, Spivey, and Lenn (2011). For convenience, this correlation was implemented in an Excel spreadsheet as a Visual Basic for Applications (VBA) function macro (see Appendix 7 for VBA source code.)
 g) Water volumetric flow rate, m3/s.
- h) Superficial liquid velocity, m/s or cm/s. Calculated as:

$$V_{sl} = \frac{Q_w}{A_p}$$
(3.5)

i) Pressure at P_1 (beginning of differential pressure section), kPaa. Fluid properties were calculated for conditions at the mid-point of the differential pressure taps. The pressure at the beginning of the differential section (Fig. 4.3) was calculated by assuming the measured pressure gradient was constant in the upper portion of the test section. Since the pressure difference, ΔP , between P_1 and P_2 is measured, we can develop:

$$\frac{\Delta P}{L_2} = \frac{P_0 - P_1}{L_1}$$

$$P_1 = P_0 - \frac{L_1}{L_2} \times \frac{\Delta P}{\Delta L}$$
(3.6)

j) Pressure at P₂ (end of differential pressure section), kPaa. Pressures P₁ and P₂ are used to calculate the kinetic energy (KE) component of pressure drop. P₂ is evaluated as:

$$P_2 = P_1 - \Delta P \tag{3.7}$$

k) Average pressure for fluid properties, kPaa. Calculated as:

$$P_{avg} = \overline{P} = P_1 + \frac{\Delta P}{2}$$
(3.8)

 Average superficial air flow rate, m³/s. Calculated from the mass flow rate and adjusted to pressure at the midpoint of differential section by rearrangement of the ideal gas law:

$$Q_g = \frac{\dot{m}_{air}}{M_{air}} \frac{RT}{\overline{P}}$$
(3.9)

m) Average superficial air velocity, m/s.

$$V_{sg} = \frac{Q_g}{A_p} \tag{3.10}$$

n) Average air density, kg/m³ (for fluid property calculations):

$$\overline{\rho}_{air} = \frac{\overline{P}M_{air}}{RT}$$
(3.11)

o) Air density at P_1 , kg/m³:

$$\rho_{air}\Big|_{P_1} = \frac{P_1 M_{air}}{RT}$$
(3.12)

p) Air density at P_2 , kg/m³:

$$\rho_{air}\big|_{P_2} = \frac{P_2 M_{air}}{RT} \tag{3.13}$$

q) Superficial air velocity at P_1 , m/s

$$V_{sg}\Big|_{P_1=} \frac{Q_{sg}}{A_p} = \frac{\dot{m}_{air}}{M_{air}} \frac{RT}{P_1} \frac{1}{A_p}$$
(3.14)

r) Superficial air velocity at P_2 , m/s

$$V_{sg}\Big|_{P_{2}=} \frac{Q_{sg}}{A_{p}} = \frac{\dot{m}_{air}}{M_{air}} \frac{RT}{P_{2}} \frac{1}{A_{p}}$$
(3.15)

- s) Average air viscosity, μ_a , Pa-s. Calculated with T and P_{avg} from correlations published by Kadoya, Matsunaga, and Nagashima (1985). VBA code is provided in Appendix 7.
- Average water viscosity, Pa-s. Calculated with T and P_{avg} from correlations published by McCain et al. (2011.)
- u) Water density, g/cc. Based on average measured temperature and test section average pressure, water density was calculated with a correlation by McCain et al. (2011.)



Figure 4.3 Details of Pressure and Temperature Taps in Test Section.

4.2 PLIF Program

The pressure gradient program, with its external observations, provided data to construct a preliminary map of annular flow sub-regimes. The subsequent PLIF program, conducted March 24-28, 2017, aimed to obtain data otherwise not possible with external images, namely film thickness and onset of droplet entrainment. Air and water runs were conducted with a subset of the original test matrix (Figure 4.4.) No new pressure or temperature data were gathered during this phase. For the purpose of calculating superficial velocities, values matching runs during the pressure gradient program were used.



Figure 4.4 Test Matrix for PLIF and Pressure Gradient Runs.

The preparation procedure for PLIF was as follows:

- e) Close the water flow control valve to isolate the test section from the reservoir.
- Add demineralized water to the test section through the filling tee to the top of the viewing section.
- g) Lower the calibration target holder through the filling tee to near the bottom of the viewing section. Illuminate with bright spotlight.
- h) Ensure the viewing box is sufficiently filled with clean glycol.
- Using magnets held externally, orient the calibration grid so that it is normal to the CCD camera lens and visible on the PC monitor with DaVis software.
- j) Obtain a well-focused image as close as possible to the target, allowing a clear view of the target edge (which is the interior wall of the pipe.)
- k) Perform image calibration procedure.
- 1) Remove calibration target and reinstall filling tee cap.
- m) Establish desired air and water flow rates.

- n) With DaVis software (and special safety glasses on!), energize pulsed laser and adjust light sheet to about 0.5mm width and at centerline of pipe.
- o) Acquire images.

A calibration procedure is necessary to compensate for any distortions in the raw acquired image caused by curvature of the acrylic pipe. First a raw image of the target is obtained. Figure 4.5 shows an uncalibrated image of a previously used target with 0.25mm dot spacing. Observe the distortion on the right hand side of the image near the interior pipe wall. Then the DaVis software detects the dot centres and constructs a uniform grid which removes the distortion near the pipe wall (Figure 4.6.) On Figures 4.6 the horizontal and vertical scales are actually 1/10x indicated, i.e. 10mm is actually 1mm. Observe the target edge on the right side, touching the pipe wall. The image size is about 3.76 mm x 2.84 mm, with a resulting resolution of 2.73µm per pixel. For comparison, in other PLIF work Schubring (2009) with 23.4 mm quartz and 22.4 mm FEP vertical tubing, used two lenses giving resolutions of 6.5 and 3.14µm per pixel; Mamedulanov (2016) obtained a resolution of 6.45 µm per pixel. In a downward vertical annular flow study Zadrazil et al. (2014) employed a 22µm resolution in 32.4 mm tubing.



Figure 4.5 0.25 Dot Spacing Pattern Before Calibration.



Figure 4.6 0.125 Dot Spacing Pattern After Software Calibration.

Figure 4.7 compares the PLIF imaging window of the current work with recent experiments. Since the PLIF hardware was being shared with other concurrent research projects in the lab, it was mounted on a small mobile cart. Over the course of several sessions, therefore, this setup was performed several times. This resulted in image sizes being slightly different each time.

During image acquisition, the CCD camera lens was adjusted to a small aperture, f16, to improve the image depth of field and minimize the influence of ambient light. For each flow rate, between 750 and 1000 images were captured at rate of 5 per second. These were then exported in BMP format with 256 grey levels. Figure 4.8 shows an example at 1000 SLPM air and 25 SLPH water, where the liquid film shows brightly from the illuminated Rhodamine B dye in solution and entrained bubbles appear as dark ovals.



Figure 4.7 PLIF Imaging Window Sizes Compared: Current Work vs. Mamedulanov and Schubring.



Figure 4.8 Sample PLIF Image at 1000 SLPM Air and 25 SLPH Water.
5 Experimental Results and Analysis

5.1 Test Matrix

Over the course of the pressure gradient program, some air/water rate combinations were rerun because either some essential data had been forgotten to be recorded or to check the repeatability of the system. For pressure gradients and external images 222 useable air/water rate combinations were collected, including 6 data points run with air alone. For this program, pressures in the differential section ranged from 92.4 to 96.4 kPaa with temperatures spanning 10.8 to 24.3°C. Median values for pressure and temperature were 92.9 kPaa and 18.3°C respectively. In addition the PLIF program recorded images for 37 air/water rate combinations. The final test matrix for both programs is shown in Figure 5.1 in terms of superficial air and water velocity as described in Section 4.1.

In order to validate the experimental pressure gradients, the data was compared with published results in similar flow loops under the same conditions.



Figure 5.1 Test Matrix for Pressure Gradient and PLIF Program.

The test matrices of selected published work are given in Figure 5.2. Higher water rates studies by Radford (1949) are not included. Previous work studied the completion transition from bubble to slug to churn to annular flow. Note that while the current and previous studies have measured the nominal annular flow regime, the current work has concentrated on annular flow and has explored very low liquid rates more thoroughly.

While tabular data is preferred, some sources provide information only in graphic form. To capture this data for further analysis, the images were scanned and the data extracted. This will introduce some error, depending on the quality of the source material. See Appendix 6 for a fuller discussion.



Figure 5.2 Test Matrices from Similar Pressure Gradient Experiments.

5.2 Pressure Gradients

The complete table of data from the pressure gradient program is given in Appendix 1.

Within the pressure gradient program, a series of measurements was made with air alone, which allowed a check of the combined accuracy of the instrumentation and calculations using the measured data. The corrected pressure gradient was then compared with that calculated using an explicit form of the single phase mechanical energy equation,

$$\frac{dp}{dl} = \rho_g g + \frac{f_M \rho_g v_{SG}^2}{2d} + \frac{\rho_g v \Delta v}{\alpha dl}$$
(5.1)

The term, α , in the kinetic term of equation 5.1 is a velocity profile adjustment, which Govier and Aziz (2008) recommend approximating to 0.5.

Examination of the literature finds that seemingly smooth surfaces do in fact possess a small but finite hydraulic roughness. In Figure 5.3 from Moody (1944) drawn (nearly smooth) tubing is assigned an absolute roughness, of 0.000006 ft (0.0015mm.) More recently McGovern (2011) appears to have inferred that the same absolute roughness applies to other materials including plastic (Table 5.1)

Table 5.1 Absolute Roughness of Various Materials.

	$\epsilon/[mm]$
Smooth honed steel	0.00065
Drawn tubing: glass, brass, copper, lead, plastic	0.0015
Asphalted cast iron	0.12
Galvanized steel	0.15
Wood stave	0.18 - 0.91
Cast iron	0.26
Concrete	0.3 - 3
Heavy brush coat: asphalts, enamels, tars	0.45 - 0.6
General tuberculation 1-3 mm	0.6 - 1.9
Riveted steel	0.9 - 9
Severe tuberculation and incrustation	2.5 - 6.5



Figure 5.3 Relative Roughness for Various Materials and Dimensions of Pipe.

In another interpretation Flack and Schultz (2014) present a Moody friction factor chart with the legend indicating absolute roughness, ε , for drawn tubing and "Perspex" (plexiglass) at 0.0025mm (Fig. 5.4.)

For comparison the mass flow rate, temperature and pressure data for the air-only runs was used to calculate pressure gradient for the following cases:

- a) smooth pipe, no kinetic energy term.
- b) smooth pipe with kinetic energy term.



c) rough pipe ($\epsilon = 0.0025$ mm, as suggested by Flack and Schultz) with the kinetic energy term.

Figure 5.4 Moody Friction Factors and Absolute Roughness for Typical Materials.

For smooth pipe, the friction factor correlation of Prandtl, as given in Schlichting (1975) was used:

$$\frac{1}{\sqrt{f}} = 2.0 \log \left(N_{\rm Re} \sqrt{f} \right) - 0.8 \tag{5.2}$$

Although Prandtl requires an iterative solution, it is more accurate than the Blasius equation,

$$f = \frac{0.3164}{R_e^{0.25}}$$
(5.3)

at Reynolds numbers greater than about 10^5 , according to Schlichting (1975.) To evaluate the rough pipe case, the Swamee-Jain correlation (1976) was used:

$$\frac{1}{\sqrt{f}} = 1.14 - 2\log\left(\frac{\varepsilon}{d} + \frac{21.25}{N_{\rm Re}^{0.9}}\right)$$
(5.4)

In calculating the kinetic energy term, the differential velocity was calculated from the terms defined in Section 4 as,

$$\Delta v = V_{sg}\Big|_{P_2} - V_{sg}\Big|_{P_1}$$
(5.5)

Fig. 5.5 shows the measured vs. calculated pressure gradients over the range of air-only velocities in the vertical flow loop. The pressure offset error was not recorded at the time; instead the values found to be consistent during subsequent work were used (-0.018 psi for gauge, -0.022 psi for differential.)

In comparing measured versus calculated results, it is evident from Fig. 5.5 that inclusion of the oftneglected kinetic energy term is important, while the assumption of pipe roughness has a lesser impact on the calculated result. This is consistent with the assumption that the acrylic test section tubing is close to hydraulically smooth. For the five highest flow rates, the average absolute difference between measured and calculated with smooth pipe and KE is 2.2%. However if the pipe was assumed to be smooth with KE disregarded, the average discrepancy for the same four points becomes about 5.4%.

Note the measured pressure gradient at $v_g = 34$ m/s is about 15% lower than the calculated value. The measured differential pressure after correction at this rate was about 330 Pa. At about 5% of full scale of the differential pressure transducer, this is within a zone of poorer accuracy of the instrument. In addition, at lower pressure differentials the signal to noise ratio decreases, making it difficult to interpret an average value from the recorded data. If a signal to noise ratio (S/N) is defined as the ratio of the average value to the standard deviation, then for the case of air-only flow S/N declines rapidly below a corrected differential pressure of about 600 Pa (see Fig. 5.6.)

It is useful to present the two-phase pressure gradient data in graphic form. Fig. 5.7 shows pressure gradient as a function of v_{sg} , grouped by constant liquid rate. For reference, the air-only data along with theoretical air pressure gradient are included. A closeup of the more crowded data in the lower left corner of the graph is given in Fig. 5.8. The pressure gradient minima occurs at about 17 m/s. This generally reflects a transition from gravity-dominated flow at low gas velocities to friction-dominated flow at higher velocities. Increased liquid loading serves to magnify the pressure loss.



Average Gas Velocity, V_g [m/s] Figure 5.5 Calculated vs. Measured Pressure Gradient in Flow Loop with Air.



Figure 5.6 Measured Differential Pressure Error vs. Calculated Differential Pressure.

At the lowest superficial liquid rate measured (0.001 m/s) the pressure gradient asymptotically approaches air-only values as gas velocity decreases.

Figure 5.9 depicts the pressure gradients as a function of superficial liquid velocity, with Figure 5.10 providing an enlarged view for lower velocities. Note a prominent change in slope of the curves at approximately $v_{sl} = 0.01$ m/s.

The veracity of the two-phase pressure gradient data can also be inferred when compared with published work. These data were selected from experimental results with air and water obtained from nominal 25.4mm i.d. tubing at or near standard conditions (101.325 kPaa, 15°C.) For closely matching superficial liquid velocities, the experimental pressure gradients from the current work are very consistent with those of Radford (1949.) The greatest discrepancy is at V_{sl} =0.061 m/s , where Radford's data is about 10-15% higher (Fig. 5.11.) Pressure gradients data by Turner (1966) and Oshinowo (1971) also match very well with the current work as seen in Figs 5.12 and 5.13 respectively. Finally, the data from Spedding , Woods, Raghunathan and Watterson(1998a, 1998b) is in conformance with the current results for two different values of v_{sl} (Fig. 5.14.)



Figure 5.7 Pressure Gradient vs. Superficial Gas Velocity, Grouped by Constant vsl.



Figure 5.8 Pressure Gradient vs. Superficial Gas Velocity Grouped by Constant v_{sl} (Closeup.)



Figure 5.9 Pressure Gradient vs. Superficial Liquid Velocity, Grouped by Constant vsg.



Figure 5.10 Pressure Gradient vs. Superficial Liquid Velocity, Grouped by Constant v_{sg} . (Closeup.)



Figure 5.11 Pressure Gradients Compared: Current Work vs. Radford (1949).



Figure 5.12 Pressure Gradients Compared: Current Work vs. Turner (1966).



Figure 5.13 Pressure Gradients Compared: Current Work vs. Oshinowo (1971).



Figure 5.14 Pressure Gradients Compared: Current Work vs. Spedding et al (1998a).

5.3 Sub-Regimes of Annular Flow

For each air/water flow rate, external still images were taken at shutter speeds as high as 1/3600s sec, with video at both 30 and 240 frames per second. Based on examination of these images a number of distinct sub-regimes were observed (see Fig. 5.15, where actual size of each image is 38 x 90 mm):

- a) Churn flow (CH). A chaotic mix of liquid with large entrained bubbles, and gas.
- b) Churn-Ring (CH-RING). Intermittent churn or disturbance flow with large "rings" of liquid film with large entrained bubbles.
- c) Annular-Ring (ARING). Slow moving "rings" of liquid with large entrained bubbles.

These first three sub-regimes are usually mapped as a single flow regime, i.e. churn. However, observation of slow motion video has allowed a finer distinction to be made. These sub-regimes are to the left of the pressure gradient minima, as depicted in Figs. 5.7 and 5.8. The increase in pressure gradient with reducing gas velocity is attributed in part to increasing liquid holdup. This in turn results in a higher static component of the pressure loss. The interval between disturbances is marked by a falling film adjacent to the pipe wall. This is evident from the motion of entrained air bubbles in the liquid film, which can be followed until a disturbance wave or ripple wave arrives to propel the majority of the liquid film upward. The churn, churn-ring and annular-ring sub-regimes still provide a net upward movement of liquid at a superficial gas velocity as low as 11.6 m/s, which is between the values calculated with the methods of Turner et al. (1969) and Woods et al. (1999). Wallis (1969) provides a description of this condition as one "in which thin liquid films flow downward while thick ones flow upward. A net upflow of liquid then occurs as a result of 'waves' of thick film riding over a smoother and thinner falling film." This was observed in the high frame rate videos of this churn region. The flow rate at which this occurs is given by eq'n 5.6a and solves to 11.4 m/s.

Within the nominal annular regime itself, the following were identified:

 Annular Rivulet (ARIV). Liquid film moving as one or more thin bands or rivulets when liquid input is very low.

- e) Annular Partial Wetting (APW). The circumferential continuity of the liquid film breaks and liquid flows upwards in wide bands, generally wetting greater than half the pipe wall circumference.
- f) Annular Ripple Wave (AR). The liquid film appears as a thin continuous layer with smooth ripple-like waves; few bubbles are observed at lower gas rates. In slow motion video, distinct periodic bands appear; the varying colour of the dye indicates that these bands alternate in film thickness.
- g) Annular Ripple Wave (AR-b). At higher gas rates more and more air bubbles are entrained in the liquid film.
- h) Annular Pulse (AP). Liquid film with a large quantity of entrained bubbles, more variation in thickness, and frequent pulse or disturbance waves. See Fig. 5.16 for a closeup of this sub-regime.



Figure 5.15 Example External Images of Two Phase Flow Regimes.

Fig. 5. Identified sub-regimes of vertical annular two phase flow.

Based on the images obtained, each air/water rate was assigned to one of the defined flow sub-regimes. Note that the water colour is from remnant Rhodamine-B dye from the concurrent PLIF studies. There was some difficulty determining some of the sub-regime transitions. The transition from APW to ARIV was determined as follows: rivulet flow was assigned when less than about half the pipe wall was wetted with liquid. Also, the sub-regime transition from AP to AR was considered complete when the disturbance wave interval was longer than 30s apart. The annular flow sub-regimes are mapped as a function of superficial fluid velocities in Fig. 5.17. Note the transition to annular flow was observed to occur in the interval 11.5 $<v_{sg} < 13.5$ m/s.



Figure 5.16 Annular Pulse (AP) Sub-Regime at $v_{sg} = 16.7$ m/s and $v_{sl} = 0.031$ m/s. A composite of representative external images for the test matrix is provided in Appendix 8 in tabloid format (279 mm x 432 mm.)

Slow-motion video images revealed the following: The AP sub-regime exhibits air bubbles entrained in the liquid film up to a superficial gas velocity of 18 m/s. At higher gas velocity, the high frequency of disturbance waves makes it difficult to observe the film. The annular ripple wave sub-regime has two forms: entrained air bubbles are seen in the liquid film at higher water rates (AR-b) and at lower water rates, the film appears to be bubble free (AR). There is a continuum between AR and AR-b.



Figure 5.17 Annular Flow Sub-Regimes.

It is instructive to overlay the flow regime boundaries of Figure 5.17 onto the pressure gradient curves. In Fig. 5.18 shows that increased liquid input triggers the transition from AR to AP with a corresponding increase in pressure gradient. However, an increasing gas velocity inhibits that transition. In Figure 5.19, the boundaries between flow regimes are clearly controlled by liquid velocity.



Figure 5.18 Pressure Gradient vs. v_{sg}, with Sub-Regime Boundaries.



Figure 5.19 Pressure Gradient vs. v_{sb} with Sub-Regime Boundaries.

From a conceptual standpoint, the transition to annular flow is subject to the following:

- a) Upward flow of the liquid film.
- b) Upward transport of any entrained liquid droplets.
- c) Liquid holdup small enough to avoid bridging across the pipe.

The upward movement of the liquid film is a result of drag forces from the gas core. Wallis (1969) cited experimental work that led to an expression for minimum dimensionless gas velocity,

$$v_{sg}^* \approx 0.9$$
 (5.6a)

describing "a situation in which thin liquid films flow downward while thick ones flow upward."

Furthermore, Wallis contended that in the case of laminar liquid flow, the transition would occur at

$$v_{sg}^* \approx 0.8$$
 (5.6b)

The dimensionless superficial gas velocity is defined as,

$$v_{sg}^{*} = v_{sg} \frac{\rho_{g}^{1/2}}{\left[gD(\rho_{f} - \rho_{g})\right]^{1/2}}$$
(5.7)

With air and water properties at standard conditions in nominal 25 mm pipe, equation 5.6a gives a minimum gas velocity of 11.4 m/s while equation 5.6b solves to 10.1 m/s. This gives the range of minimum superficial velocity for net upward liquid film transport.

Recall the Turner et al. (1969) expression for annular flow based on the minimum lifting velocity (critical velocity) of liquid droplets (now showing the droplet coefficient of drag, C_D,

$$v_{crit} = 2.515 \left[\frac{\sigma g \left(\rho_l - \rho_g \right)}{C_D \rho_g^2} \right]^{1/4}$$
(2.3)

To arrive at a tractable solution, Turner assumed the droplets are spherical and moving at very high velocity so that their drag coefficient is constant at $C_D = 0.44$. Recent work has shown that additional considerations are required to used equation 2.3 properly:

a) entrained liquid droplets can become distorted or broken up by the gas stream, therefore the spherical drag coefficient no longer applies (Wang, Bai, Zhu, Zhong, and Li, 2012).

- b) At low gas flow rates, the particle Reynolds number, Re_p decreases so that the drag coefficient increases. Re_p is defined as $\rho v_p d_p / \mu$ where ρ is the fluid density, v_p is particle velocity, d_p is particle diameter and μ is fluid viscosity.
- c) Equation 5.7 will result in a single value for droplet diameter, whereas a wide range of diameters has been measured experimentally (Luan and He, 2012).

In spite of these concerns, equation 5.7 persists as one of the preferred estimates of minimum lifting velocity in the petroleum industry. Using air-water properties at standard temperature and pressure (with surface tension, $\sigma = 7.2 \times 10^{-2}$ N/m) air water properties equation 2.3 solves numerically to 14.4 m/s.

In general, the bridging criterion applies to very thick films, which is not the case for the current work. Therefore the transition to annular flow can be considered to occur in two stages: initially, the gas core develops sufficient drag force to lift a liquid film upwards; then with increasing gas velocity, droplets are sheared from the liquid film and entrained in the high speed gas core. Note that the film lifting equations (5.6a, 5.6b) account for pipe diameter while the droplet equation does not. Furthermore neither equation considers the effect of liquid velocity.

The test matrix from other 25mm id work is shown in Fig. 5.20. It is apparent that previous workers wanted to study the spectrum of flow regimes from bubble to annular mist. Observe that the current work was focused on annular flow at relatively low liquid rates. The annular transitions from several published works is depicted in Fig. 5.21, most from nominal 25.4mm i.d. tubing at or near standard conditions. Included are both the Wallis (1969) criteria for film stability and the Turner (1969) criteria for droplet lifting. The transition to annular flow among different sources exhibits obvious differences. This can be explained, in part, by different definitions. For example, Radford's "wall film flow" begins within the churn regime; the "mist" regime assumes fully entrained liquid in friction dominated flow. The annular transition from Barnea (1987) is based on a reinterpretation of his own data. Spedding et al. (1998a) defined a "semi-annular" condition that appears to correspond with Radford's (1949) onset of "wall film flow." The transitions shown are:

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- 1. Nedderman and Shearer (1963), 31.8mm pipe, dewetted region
- 2. Hall Taylor and Hewitt (1963), 31.8mm pipe, non-wetting
- 3. Radford (1949), mist flow
- 4. Turner et al (1969) equation 2.3, calculated for air-water in nominal 25mm i.d. pipe at standard conditions
- 5. Equation 5.6a from Wallis (1969)
- 6. Spedding et al. (1998a), annular transition
- 7. Barnea (1987), slug-churn transition
- 8. Radford (1949), beginning of wall film
- 9. Spedding et al. (1998a), semi-annular

Note the general agreement with the APW and ARIV sub-regimes identified in the current work.



Figure 5.20 Test Matrices for Experiments in Flow Regime Identification.



Figure 5.21 Transition to Annular Flow from Various Sources (see Legend in Fig 5.17)

5.3 Film Thickness

A limited number of PLIF runs were conducted to verify liquid film thickness (see the test matrix, Fig. 5.1.) The images were also examined for signs of liquid entrainment, something that was not possible with the external images. Previous work has used MatLab scripts to automate interpretation of large numbers of PLIF images, among them Schubring (2009), Zadrazil (2014), and Mamedulanov (2016) for vertical annular flow. The complexity of composing an intelligent script to interpret the images for all conditions let to a different approach: manually interpret a small number of images instead.

For each air/water case, the first 750 to 1000 images were exported from the DaVis software to 256-level greyscale files in BMP format. The first 50 images form each group were then imported to NIH ImageJ software (which is public domain) where it was scaled. The liquid film was identified by its brightness and then manually traced to obtain a film cross sectional area (Figure 5.22.)



Figure 5.22 PLIF Image from $v_{sg} = 26.7 \text{ m/s}$, $v_{sl} = 0.074 \text{ m/s}$ (1 of 50.)

The area was computed by the ImageJ software and copied to an Excel spreadsheet where the average film height was calculated. In the example in Fig. 5.22, the scale is 366 pixels per mm and the image height is 1024 pixels or 2.8mm. The film cross section area is 0.426 mm²; therefore the average film thickness in the sample is 0.426 mm²/2.8mm = 0.152mm. After 50 samples were processed in this fashion, a median value and standard deviation were determined. The median was used to reduce the influence of some of the extreme values obtained. A running average was calculated to check that the small number of data points would converge to a reliable value. Fig. 5.23 shows the results from a series of samples. The first data point is from Fig. 5.22. While the average film thickness varied considerably from image to image, the running average did not vary appreciably. A measure of convergence was also used, which was the percentage change in running average between samples. The results of the PLIF program are summarized in Tables 5.2 and 5.3.



Figure 5.23 Film Thickness from PLIF Images ($v_{sg} = 26.7 \text{ m/s}, v_{sl} = 0.074 \text{ m/s}.$)

Table 5.2	Median	Liquid	Film	Thickness	in mm,	from	PLIF	Images.
-----------	--------	--------	------	-----------	--------	------	------	---------

	Superficial Water Velocity, V _{si} [m/s]											
		0.0021	0.0042	0.0063	0.0074	0.0084	0.0095	0.0105	0.0131	0.0158	0.0184	0.0210
Superficial Gas Velocity, V _{sg} [m/s]	16.5	0.250	0.258	0.268		0.249						
	19.8		0.186	0.215		0.203		0.223	0.291			
	23.1			0.167		0.200		0.216	0.185	0.171		
	26.4			0.130	0.132	0.125	0.138	0.157	0.182	0.164	0.234	
	33.0			0.104		0.097		0.126	0.125	0.148	0.222	
	39.6			0.066		0.085		0.105	0.107	0.124	0.148	0.122
	49.5			0.045		0.097						

Table 5.3 Liquid Film Thickness Standard Deviation in mm, from PLIF Images.

		Superficial Water Velocity, V _{sl} [m/s]										
		0.0021	0.0042	0.0063	0.0074	0.0084	0.0095	0.0105	0.0131	0.0158	0.0184	0.0210
	16.5	0.126	0.172	0.155		0.238						
Superficial Gas Velocity, V _{sg} [m/s]	19.8		0.127	0.164		0.085		0.100	0.244			
	23.1			0.090		0.112		0.107	0.080	0.086		
	26.4			0.090	0.057	0.054	0.055	0.068	0.074	0.069	0.190	
	33			0.048		0.044		0.041	0.043	0.052	0.151	
	39.6			0.025		0.031		0.041	0.028	0.037	0.069	0.043
	49.5			0.018		0.042						

The film thickness results are presented graphically in Figures 5.24 and 5.25.



Figure 5.24 Film Thickness vs. v_{sg} from PLIF Program.



Figure 5.25 Film Thickness vs. v_{sl} from PLIF Program.

Although the relatively narrow laser beam illuminates only a sliver of liquid film cross section, image interpretation was found to be challenging. Examining an image by Hewitt and Hall-Taylor (1970) illustrates some of the difficulties in interpreting the liquid film images - Figure 5.26 is an axial view looking downward into the pipe. The authors did not provide flow rate data, only a comment that this was a disturbance wave.



Figure 5.26 Axial View of Disturbance Wave in Annular Flow from Hewitt and Hall-Taylor (1970). While there is considerable scatter in Fig. 5.24, a general trend is clear: the liquid film thins as gas velocity increases; and it thickens with increased liquid input. This is a result the increased gas velocity and subsequent drag causing the film velocity to increase - for a given volumetric flow rate of liquid film (as given by the area-velocity product), an increase in liquid velocity results in a decrease in area and hence thickness. These results are compared with the work of Mamedulanov (2016), who earlier used the same apparatus. He used a MatLab script to process about 1500 images for each air/water rate, although it appears that same result would have been obtained with 600 images. Three sets of PLIF images were obtained by Mamedulanov with the laser at the centerline of the test section, the same configuration of the current work. The manual interpretation does provide a reasonable match to the more rigorous method, as illustrated in the following figures (Fig. 5.27, 5.28 and 5.29.)



Figure 5.27 Film Thickness Results from Mamedulanov (2016) and Current Work at v_{sg} =0.0106 m/s.



Figure 5.28 Film Thickness Results from Mamedulanov (2016) and Current Work at v_{sg} =0.0131 m/s.



Figure 5.29 Film Thickness Results from Mamedulanov (2016) and Current Work at v_{sg} =0.0156 m/s.

5.4 Entrainment

Entrainment in two phase flow, FE, is defined as the fraction of input liquid mass flow in the gas core, or

$$FE = 1 - \frac{m_f}{\dot{m}_l} \tag{5.8}$$

Recall the dimensionless velocity gas parameter given by Steen and Wallis (1964) in their experimental work,

$$\pi_2 = v_g \frac{\mu_g}{\sigma} \left(\frac{\rho_g}{\rho_l} \right)^{1/2}$$
(2.16)

To initiate entrainment of liquid from the film into droplets, Steen and Wallis proposed that π_2 must equal 2.46 ×10⁻⁴, that is,

$$v_{crit} = 2.46 \times 10^{-4} \frac{\sigma}{\mu_g} \left(\frac{\rho_l}{\rho_g}\right)^{1/2}$$
(5.9)

From an examination of published work, Paleev and Filippovich (1966) correlated an entrainment-related term to another dimensionless group with data from several sources. It is notable that the data used presents considerable scatter – their original graph is given as Fig. 5.30.



Figure 5.30 Entrainment Correlation of Paleev and Filippovich (1966).

Paleev and Filippovich fitted the data to the following equation:

$$\frac{\dot{m}_f}{\dot{m}_l} = 0.985 - 0.44 \log \left[\frac{\bar{\rho}}{\rho_l} \left(\frac{\mu_l v_g}{\sigma} \right)^2 \times 10^4 \right]$$
(5.10)

where the density of the droplet-laden gas core is related to actual gas density by,

$$\overline{\rho} = \rho_g \left[1 + \frac{\dot{m}_l \left(1 - \dot{m}_f / \dot{m}_l \right)}{A_p \rho_g v_{sg}} \right]$$
(5.11)

Thus the solution for \dot{m}_f / \dot{m}_l is iterative. Wallis (1968) named the Pavleev dimensionless group as π_1 , defined by,

$$\pi_1 = \frac{\overline{\rho}}{\rho_l} \left(\frac{\mu_l v_g}{\sigma}\right)^2 \tag{5.12}$$

which gives rise to

$$\pi_2 = \frac{\mu_g}{\mu_l} (\pi_1)^{1/2}$$
(5.13)

Wallis assumed that $\overline{\rho} \approx \rho_g$. An expression for liquid entrainment fraction is obtained by adapting the Paleev and Filippovich equation,

$$FE = 1 - \frac{\dot{m}_f}{\dot{m}_l} = 1 - \left[0.985 - 0.44 \log \left[\frac{\overline{\rho}}{\rho_l} \left(\frac{\mu_l v_g}{\sigma} \right)^2 \times 10^4 \right] \right]$$

$$FE = 1 - \left[0.985 - 0.44 \log \left[\pi_1 \times 10^4 \right] \right]$$
(5.14) (5.15)

Rearranging equation 5.13 in terms of π_1 and substituting into 5.15 yields,

$$FE = 1 - \left[0.985 - 0.44 \log \left[\left(\frac{\mu_l \pi_2}{\mu_g} \right)^2 \times 10^4 \right] \right] = 1.775 + 0.88 \log \left(\frac{\mu_l \pi_2}{\mu_g} \right)$$
(5.16)

To find the minimum velocity for entrainment set FE = 0 to solve first for π_2 and then v_{crit} ,

$$1.775 + 0.88 \log\left(\frac{\mu_l \pi_2}{\mu_g}\right) = 0$$

$$\frac{\mu_l \pi_2}{\mu_g} = 10^{\frac{-1.775}{0.88}}$$

$$\pi_2 = 9.62 \times 10^{-3} \frac{\mu_g}{\mu_l}$$

(5.17) (5.18) (5.19)

Wallis assumed air and water properties near standard conditions (probably $\mu_g = 1.9 \times 10^{-5}$ Pa-s and $\mu_l = 1.0 \times 10^{-3}$ Pa-s) so that

$$\pi_2 = (9.615 \times 10^{-3})(1.9 \times 10^{-2}) = 1.83 \times 10^{-4}$$
(5.20)

This value of the π_2 term is which considerably lower than originally proposed by Steen and Wallis in 1964. Further solving for v_{crit} , the critical velocity to initiate droplet entrainment,

$$\pi_{2} = v_{crit} \frac{\mu_{g}}{\sigma} \left(\frac{\rho_{g}}{\rho_{l}}\right)^{1/2} = 1.83 \times 10^{-4}$$

$$v_{crit} = 1.83 \times 10^{-4} \frac{\sigma}{\mu_{g}} \left(\frac{\rho_{l}}{\rho_{g}}\right)^{1/2}$$
(5.21) (5.22)

Finally, for air-water at standard conditions, where the surface tension $\sigma = 7.2 \times 10^{-2}$ N/m, $\mu_g = 1.9 \times 10^{-5}$ Pa-s, $\rho_1 = 1000$ kg/m3, and $\rho_g = 1.22$ kg/m3, the critical velocity is 19.9 m/s. Compare with Turner's result of 14.4 m/s required to lift droplets. Wallis' original correlation for entrainment in graphic form is compared with the fitted curve from equation 5.16 and 5.23 in Fig. 5.31.



Figure 5.31 Entrainment Correlation Curve from Wallis (1969) and Fitted Curves.

While equation 5.16 is suitable to represent Wallis' entrainment correlation, a more popular fit, as used by Ansari et al. (1992) and Chokshi (1994) in their mechanistic models of annular flow is:

$$FE = 1 - \exp(-0.125(10^4 \pi_2 - 1.5))$$
(5.23)

Given the original data scatter in Figure 5.30, either equation 5.16 or 5.23 provides a reasonable representation. However, it is useful to re-examine the correlation against other experimental data. Figure 5.32 shows entrainment measurements from the data of Collier and Hewitt (1961), Asali (1984), and Schadel (1988) with air-water systems and four different pipe diameters, plotted against the Wallis correlation. Liquid input is given in terms of a superficial liquid Reynolds number, defined as,

$$\operatorname{Re}_{sl} = \frac{\rho_l v_{sl} d}{\mu_l} \tag{5.24}$$

We see in Figure 5.32 that the Wallis correlation appears to define the *minimum* value of entrainment for a given gas velocity. Furthermore, below a given threshold liquid rate, annular flow occurs with no entrainment. A more detailed look at Asali's (1984) data from 22.9 mm i.d. pipe is given in Figure 5.33.


Figure 5.32 Entrainment Fraction vs. π_2 Term for Various Pipe Sizes.



Figure 5.33 Entrainment Fraction vs. π_2 Term from Asali (1984), 22.9mm Pipe.

In Fig. 5.33, entrainment fraction increases with both gas rate and liquid rate. The entrainment values appear to converge to zero at some finite gas velocity. When replotted in terms of superficial Reynolds numbers (Fig. 5.34), it appears that the onset of entrainment occurs at about $Re_{sl} = 250$ for 22.9 mm pipe independent of gas rate.



Figure 5.34 Entrainment Fraction vs. Re_{SL} for 22.9 mm Pipe, from Asali (1984).

The relationship between liquid input and entrainment was examined more closely in experiments by Schadel (1988) and reported in Schadel, Leman, Binder, and Hanratty (1990.) Those results, along with additional data from Turner (1966) and Asali (1984) are shown together Fig. 5.35. For air-water systems at or near standard conditions, the critical film Reynolds number, Re_{LFC} , to initiate droplet entrainment was found to depend on tube diameter but weakly on gas rate. Overall, however, the critical film Reynolds number is roughly 250. This effectively defines the laminar turbulent transition for the liquid film. By contrast, Lockhart and Martinelli proposed that for viscous (laminar) film and turbulent gas phase flow in horizontal pipe, the maximum liquid Reynolds number is <1000.

Based on published work, it is found that liquid entrainment in the gas core of annular flow requires two conditions to be satisfied:

- a) A minimum gas velocity to lift droplets.
- b) A minimum liquid velocity to supply the system.



Figure 5.35 Onset of Entrainment: Experimental Results.



Figure 5.36 Annular Sub-Regime Map of Fig. 5.17 with Entrainment Threshold.

With respect to the current work, Re_{sl} =250 corresponds to s a superficial liquid velocity, v_{sl} of about 0.01 m/s for 26 mm nominal i.d. pipe. Therefore the flow regime mapping of the current results can be amended to include an inferred entrainment threshold – see Figure 5.36.

Another aim of the PLIF program was to confirm the onset of entrainment visually, since this was not possible from external observation. Zadrazil et al.(2014) lists five mechanisms of liquid entrainment:

- a) Shearing of wave crests ("ligament breakup.)
- b) Undercutting of liquid film by gas flow ("bag breakup".)
- c) Bubbles bursting within the film
- d) Droplets crashing into the liquid film.
- e) Disturbance or pulse waves.





Liquid becomes entrained in the gas core as a result of wave breakup. This takes the form of ligaments initially. An equilibrium between rates of entrainment and deposition sustains a droplet concentration in the core. Entrainment was evident in PLIF images as droplets illuminated by the laser along with the film itself, occurring between $v_{sl} = 0.0095$ and 0.0105 m/s (Fig. 5.37 b, c.) This allows the placement of an entrainment onset boundary in Fig. 5.36. Note also in Fig. 5.37 the occurrence of entrained air bubbles increases dramatically at the same time. Rodriguez (2004) listed two mechanisms for air bubble entrainment in horizontal two phase flow:

- a) impact of liquid droplets onto the film surface
- b) folding of air into pockets by collapsing liquid wave peaks

5.5 Interfacial Friction and Film Roughness

For single phase gas flow, the friction factor can be derived by rearranging the energy equation,

$$\frac{dp}{dl} = \rho_g g + \frac{f_M \rho_g v_g^2}{2d} + \frac{\rho_g v_g \Delta v_g}{\alpha dl}$$
(5.25)

to find,

$$f_M = \frac{2d}{\rho_g v_g^2} \left[\frac{dp}{dl} - \rho_g g - \frac{\rho_g v_g \Delta v_g}{\alpha dl} \right]$$
(5.26)

Similarly, the pressure gradient in the gas core of annular flow is given by,

$$\frac{dp}{dl}\Big|_{c} = \rho_{c}g + \frac{f_{i}\rho_{c}v_{c}^{2}}{2(d-2\delta)} + \frac{\rho_{c}v_{c}\Delta v_{c}}{\alpha dl}$$
(5.27)

and by a similar rearrangement, the interfacial friction factor could be found from experimental data,

$$f_i = \frac{2(d-2\delta)}{\rho_c v_c^2} \left[\frac{dp}{dl} - \rho_c g - \frac{\rho_c v_c \Delta v_c}{\alpha dl} \right]$$
(5.28)

However, information on film thickness and entrainment would still be required. For non-entrained twophase flow, $\rho_c = \rho_g$, $v_c = v_g$, and $\mu_c = \mu_g$. In this case equation 5.28 could be solved if the film thickness is assumed to be very small. Now if the mechanical energy equation is cast once again in terms of superficial gas quantities:

$$\left. \frac{dp}{dl} \right|_{sg} = \rho_g g + \frac{f'_{sg} \rho_g v_{sg}^2}{2d} + \frac{\rho_g v_{sg} \Delta v_{sg}}{\alpha dl}$$
(5.29)

All the terms in equation 5.29 can be evaluated, save the superficial gas friction factor, f'_{sg} which must be obtain using a correlation. The superficial friction factor concept was employed by Bergelin (1949) for horizontal and downward vertical flow for the gas phase, and by Govier and Short (1958) for upward two phase flow for the liquid phase.

With sufficient experimental data, a friction factor correlation may be created from,

$$f_{sg}' = \frac{2d}{\rho_g v_{sg}^2} \left[\frac{dp}{dl} - \rho_g g \right]$$
(5.30)

where the kinetic energy term has been removed for simplicity. Now expanding the earlier analysis with Asali (1984) and plotting data for entrained conditions (Figure 5.38) it is found that the superficial gas friction factor appears to be a monotonically decreasing function of Re_{sg} , for a given Re_{sl} .



Figure 5.38 Friction Factor vs. Superficial Gas Reynolds Number for 22.9mm Tubing.

The same exercise is now performed with the higher resolution data from the current work (Fig. 5.39.) Note that there is a region of nearly constant friction factor starting at about $\text{Re}_{sg} = 35000$. This corresponds with the beginning of gas friction dominated two phase flow (i.e. the positive slope portion of Fig. 5.7). The data stops at $\text{Re}_{sg}=82000$ which was the upper limit of the air flow controller. The region of constant friction factor is associated with non-entrained flow. To investigate further, the effective film roughness was calculated from the friction factor by rearranging the Swamee-Jain equation (5.4) thus:

$$\frac{\varepsilon}{d} = 3.7 \left(10^{-\sqrt{\frac{0.25}{f_M}}} - \frac{5.74}{\text{Re}_{sG}} \right)$$
(5.31)

Figure 5.40 shows the effective relative roughness of the film as a function of Re_{sg} . Some data dispersion is evident at very low liquid Reynolds numbers. Some key observations from this figure are:

- a) up to $Re_{sg} = 35000$ the film exhibits a decreasing relative roughness
- b) about Re_{sg} = 35000 and below the onset of entrainment, the film has a nearly constant roughness,
 i.e. it is behaving as a pipe wall.

c) In the entrained region, the effective relative film roughness is monotonically decreasing with values of Re_{sg} .



Figure 5.39 Superficial Gas Friction Factor vs. Superficial Gas Reynolds Number.



Figure 5.40 Effective Relative Roughness vs. Superficial Gas Reynolds Number.

6 New Friction Factor Correlations for Annular Flow

Semi-mechanistic models require correlations for entrainment and friction factor in order to arrive at a solution. In addition, a scheme to determine film thickness is required. Some of these correlations have been tested against published data and found to be an imperfect fit. Analysis of data from both the current experimental work and previous published results confirms that another approach is to find a correlative relationship for a superficial gas friction factor. Then pressure gradient can be solved with the superficial gas form of the mechanical energy equation. It is found that the sub-regimes of annular flow can be partitioned in to three "zones" for the purpose of finding a new friction factor:

- I) constant roughness, high gas rate, no entrainment
- II) variable roughness, high gas rate, entrained liquid



III) variable roughness, low gas rate

Figure 6.1 Annular Flow Zones for Pressure Gradient Calculation

6.1 Zone I Constant Roughness, High Rate, Non-Entrained Flow

This is "pure" annular flow, where the entire liquid portion flows in the film. The effective roughness of the film, and hence the friction factor are generally constant at for a given liquid input. It appears that the partial-wetting and rivulet sub-regimes exhibit similar behaviour, therefore they are included in this zone as well. From Fig. 5.41 the average friction factor in Zone I is found to be a a function of Re_{sl} only, with the resulting relationship (Fig. 6.2). It is striking that the extrapolation of the fit line to zero liquid rate has nearly the same value as originally proposed by Wallis (see equation 2.20.)



Figure 6.2 Friction Factor Correlation for Zone I.

The limits of the friction factor correlation for Zone I

$$f_{sg}' = 9.69 \times 10^{-5} \operatorname{Re}_{sl} + 0.0215 \tag{6.1}$$

are: $Re_{sg} > 35000$, and $Re_{sl} < 250$.

A comparison of measured vs. calculated results from the current work is given in Figure 6.3.



Figure 6.3 Calculated vs. Measured Pressure Gradient for Zone I.

6.2 Zone II Variable Roughness, High Gas Rate, Entrained Flow

The friction factor in Zone II is a function of both Re_{sl} and Resg. By inspection, the friction factors in Zone II demonstrate a linear trend on the log-log chart, therefore a simple linear relationship was adopted,

$$\log(f'_{sa}) = m\log(\operatorname{Re}_{sa}) + b \tag{6.2}$$

where m and b are functions of Re_{sl} . For each value of Re_{sl} , a slope was estimated for those data points. A curve found to fit well through the data points was,

$$m(\text{Re}_{sl}) = -0.5583 \ln(\text{Re}_{sl}) + 3.0934$$
(6.3)

Similarly, it was assumed that all the friction factor trends in this zone would converge with the maximum friction factor value in Zone I ($f'_{sg} = 0.045725$) at some higher value of Re_{sg}, (110000.) With this constraint, the y-intercept of equation 6.2 was determined for each Re_{sl} trend. A curve fit to those data was found to be

$$b(\text{Re}_{sl}) = 2.8144 \ln(\text{Re}_{sl}) - 16.935 \tag{6.4}$$

These relationships are valid for: $35000 < \text{Re}_{sg} < 110000$ and $\text{Re}_{sl} > 250$. The result of the fitting for slope and intercept is given in Fig. 6.4.



Figure 6.4 Determining Slope and Intercept Parameters for Zone II Friction Factor Correlation.

The friction factor may be determined with the following steps:

- a) calculate $m(Re_{sl})$ and $b(Re_{sl})$ from equations 6.3 and 6.4
- b) calculate $\log(f'_{sg})$ from equation 6.2
- c) calculate $10^{\log(f_{sg})} = f'_{sg}$.
- d) insert f'_{sg} into the mechanical energy equation (5.25) and solve for pressure gradient.

A comparison of calculated vs. measured pressure gradients for Zone II is given in Fig. 6.5 using data from the current work.



Figure 6.5 Calculated vs. Pressured Pressure Gradient for Zone II.

6.3 Zone III Variable Roughness, Low Gas Rate

Friction factors for Zone III are also expressed in the form given in equation 6.2. In addition, values of f'_{sg} must match those of the Zones I and II correlations at Re_{sg} =35000. The slope and intercept functions are given by

$$m(\text{Re}_{sl}) = -0.5583\ln(\text{Re}_{sl}) + 3.0934$$
(6.5)

and

$$b(\operatorname{Re}_{sl}) = -1.715 \times 10^{-9} (\operatorname{Re}_{sl})^3 + 6.498 \times 10^{-6} (\operatorname{Re}_{sl})^2 - 9.222 \times 10^{-3} (\operatorname{Re}_{sl}) + 11.098$$
(6.6)

These relationships are valid for: Resg <35000. The solution method is the same as for Zone II. Unfortunately, this model fails to match pressure gradients in Zone III (see figure 6.6)



Figure 6.6 Calculated vs. Measured Pressure Gradient for Zone III.

6.4 Application of New Correlations to Published Data

Published experimental results in air-water systems with nominal 25.4mm i.d. pipe at near standard conditions are found in Radford (1949), Turner (1966) and Spedding et al. (1998a.) In addition, the results from Oshinowo (1971) were included in spite of the data being acquired at about 150 kPaa. Only two data points met the criteria for the Zone I correlation while the rest were applicable to Zone II (Figure 6.7) Note that the match is best up to about 2000 Pa/m. The highest pressure gradient measured in the current work was about 3000 Pa/m. Note that most of the data stays within an arbitrary +/-20% error cone, even beyond 3000 Pa/m.



Figure 6.7 Measured vs. Calculated Pressure Gradient from Selected Published Results.

7 Conclusions, Contributions and Recommendations

7.1 Conclusions

The flow loop apparatus in the Drilling Engineering lab at the University of Alberta is capable of acquiring excellent quality pressure gradient data. Air-only gradients were consistent with calculations for single phase gas flow. The two phase data compared very well with published data from four different sources.

Several sub-regimes of annular flow were identified or confirmed by external observation, and a new flow regime map was drawn. High frame rate video was especially helpful in detecting falling film behaviour and discerning the three sub-regimes within the churn region.

Liquid lifting occurred at the lowest superficial gas rate in the test matrix (11.6 m/s), which is below that calculated with the Turner et al (1969) equation: 14.4 m/s. Although there is a net lifting of liquid, the layer next to the pipe wall is seen falling until the arrival of a strong wave.

For any given liquid input rate, the pressure gradient minima all occur at about 17m/s. It was found that the friction factor correlation worked best above this rate.

At high v_{sg} , the pressure gradient in rivulet flow is higher than for air alone. This is in spite of the liquid content being nearly undetectable at low liquid rates.

Analysis of PLIF images by manual interpretation was partially successful. Most running averages of film thickness were converging within the 50 samples analyzed. The accuracy of the method could be improved with a better interpretive guide.

The onset of entrainment indicates the liquid film in at the laminar – turbulent transition, and can be detected:

- a) directly by observing a sharp increase in the number of droplets.
- b) Indirectly by an increase in bubble concentration in the film

The ripple regime, which can appear smooth even in high speed video, experiences a wider range of film thickness and transient waves than originally thought.

7.2 Contributions to Knowledge

A new database has been created for vertical upward concurrent flow of air and water and near standard conditions in nominal 25mm i.d. pipe. Most of the measurements are provided in tabular form in Appendix

- 1. The database also includes the following:
 - a) A spreadsheet record of gauge pressure, differential pressure and temperature acquired at approx.
 15ms intervals for each test point. This can be used for post analysis to study signal noise and spectral content.
 - b) Still and video images for each air/water combination. Frame-by-frame analysis could yield further refinement of sub-regime boundaries and additional information on ripple wave and pulse wave frequency.
 - c) PLIF images for a subset of the test matrix (see Fig. 5.1.) Improved interpretations of film thickness, wave geometry, and air entrainment are possible.

Sub-regimes of annular flow have been mapped in greater detail. Some of the results are similar to those of Hall Taylor and Hewitt (1963); however, the churn regime is found to have three visibly distinct zones and the previously named non-wetting area has been sorted into a partial-wetting and a rivulet flow sub-regime.

The quality of the pressure gradient data allowed calculations to be made of superficial gas friction factor. An examination of the behaviour of the superficial gas friction factor, f'_{sg} , revealed that the annular regime can be simplified into three zones. An attempt to produce a convenient correlation for f'_{sg} was successful for two of those zones:

- a) stable annular flow (Resg>35000) and laminar film
- b) stable annular flow (Resg>35000) and turbulent film

The two correlations produced excellent predictions of pressure gradients measured with the current work, and more importantly, a reasonable match with two-phase pressure gradients with previously published data spanning several decades. The required inputs to perform a calculation of pressure gradient are easily available:

- a) gas flow rate
- b) liquid flow rate
- c) pipe diameter
- d) pressure
- e) temperature

From these inputs, gas density can be calculated along with superficial gas velocity. Superficial gas Reynolds number and superficial liquid Reynolds number are then calculated to use in the correlation for the superficial gas friction factor. Finally the mechanical energy equation evaluates the pressure gradient.

7.3 Future Work – Near Term

The applicability of correlations based on specific fluids under some given condition (i.e. temperature, pressure, pipe diameter) outside their original experimental range is uncertain. To establish the robustness of any conclusions, a number of paths are possible. The most obvious is to extend the test matrix to higher air flow rates, since the annular-mist region was not explored in this work. Given the operational problems at high air rates, a pump would be required to stabilize the loop; this would also allow the evaluation of high liquid loading.

The flow loop could also, without modification, investigate the loading limits of two-phase flow. Simply operating at lower air rates, the stability limit of the liquid film could be determined.

While the air is certainly in turbulence throughout, clarification of the laminar-turbulent transition of the

liquid film would yield useful information. The current work determined that the laminar-turbulent transition occurred at about $Re_{sl} = 250$. However application of PIV (Particle Image Velocimetry) could give greater detail on the change in liquid film velocity profiles. The question of whether the film surface (interface) velocity, v_i , is significant might also be answered.

New PLIF and PIV programs could be employed to investigate the influence of bubbles entrained in the liquid film. These are likely to be disruptive to the velocity distribution within the film and may also have an effect on the liquid properties (e.g. density, effective viscosity.)

7.4 Future Work – Long Term

The current work was accomplished with air and water only. Therefore the influence of other fluid properties is not known, and correlations are not likely to be universal. This was recognized by Steen and Wallis (1964) prompting them to conduct further experiments with silicone oil (different viscosity and surface tension.) They also conducted studies at elevated pressures (2 to 4 atm) to explore the effects of gas density. Given that the flow loop is located indoors, only benign fluids, such as water-glycerol mixtures, should be considered.

Another important variable has attracted less attention: pipe roughness. Virtually all laboratory flow loops have used plexiglass, glass, copper or polish stainless steel, which are effectively smooth pipes. Experiments with rough pipe, such as steel tubing, would provide better insights into two phase flow behaviour under field conditions. In addition, water wettability on a hydrophilic steel surface is quite different from wettability on plexiglass. For example Takamasa, Hazuku, and Hibiki (2008) have shown that hydrophilic pipe has a transition to annular flow at a lower velocity than with acrylic pipe.

"I took the degree of Doctor of Philosophy in 1903. The meaning of this degree is that the recipient of instruction is examined for the last time in his life, and is pronounced completely full. After this, no new ideas can be imparted to him."

Stephen Leacock in the Preface to "Sunshine Sketches of a Little Town," 1913.

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Appendices

Appendix 1 Flow Loop Pressure Gradient Program Data

		Controller							CORRECTED
		Air Flow Set		Average	Average	Average	Kobold		Average
		Point, SLPM	Air Mass	Flow Loop	Flow Loop	Pressure	Rotameter	Differential	Pressure
		@ 15C, 100	Flow Rate,	Temperature	Pressure,	Differential,	Water Flow	Pressure	Differential,
Line No.	Date	kPaa	g/s	, °C (Ai5)	psig (Ai6)	psi (Ai7)	rate SLPH	Correction	psi (Ai7)
1	15-12-11	700	14.1035211	15.8903047	0.17987701	0.03423117	20	-0.02235518	0.05520796
2	15-12-11	700	14.1035211	15.6378908	0.1736608	0.03108062	18	-0.02235518	0.052134152
3	15-12-11	700	14.1035211	15.2666021	0.16440215	0.02774199	16	-0.02235518	0.048876851
4	15-12-11	700	14.1035211	14.932775	0.14853438	0.0246214	14	-0.02235518	0.045832281
5	15-12-11	700	14.1035211	14.3045589	0.13466017	0.01737381	12	-0.02235518	0.038761229
6	15-12-11	700	14.1035211	13.8249607	0.12289326	0.01659065	10	-0.02235518	0.037997146
7	15-12-11	700	14.1035211	13.5330889	0.1151955	0.00995716	8	-0.02235518	0.031525248
8	15-12-11	700	14.1035211	13.0043547	0.10440436	0.00630425	6	-0.02235518	0.027961313
9	15-12-11	700	14.1035211	12.4219062	0.08926046	0.00562606	4	-0.02235518	0.027299644
10	15-12-11	700	14.1035211	13.117161	0.07931238	0.00572657	2	-0.02235518	0.027397708
11	15-12-18	700	14.1035211	19.7339138	0.30321712	0.09478214	60	-0.02409581	0.115307399
12	15-12-18	700	14.1035211	20.0974356	0.33148058	0.10777327	70	-0.02409581	0.128656872
13	15-12-10	700	14.1035211	20.4052473	0.35092064	0.12100031	80	-0.02409561	0.141620251
14	10-12-10	700	14.1035211	20.49/7207	0.37123300	0.12929227	100	-0.02409561	0.149051095
15	15 12 18	700	14.1035211	20.344007	0.39731013	0.14190785	110	-0.02409581	0.101959909
17	16-01-08	800	16 1183098	21 264194	0.50246097	0.10127333	140	-0.02405301	0.210043217
18	16-01-00	800	16 1183098	20 9095401	0.47247177	0.18165055	120	-0.02766161	0.213343217
10	16-01-08	800	16 1183098	19 8026068	0.42906266	0 15521583	100	-0.02766161	0.178422711
20	16-01-08	800	16 1183098	19.0587792	0.38196065	0 13124436	80	-0.02766161	0 155035167
20	16-01-08	800	16 1183098	18 2333673	0.32915071	0 10656872	60	-0.02766161	0.1309606
22	16-01-08	800	16 1183098	17.0675018	0.26984525	0.07804269	40	-0.02766161	0 103129434
23	16-01-08	800	16 1183098	15 3030217	0 19037801	0.0434087	20	-0.02766161	0.069339102
20	16-01-08	800	16 1183098	15 2959316	0 1930603	0.04426157	20	-0.02766161	0.070171191
25	16-01-08	800	16 1183098	14 7651079	0 17624142	0.03806022	16	-0.02766161	0.064120902
26	16-01-08	800	16.1183098	14.1421126	0.15262609	0.02670957	12	-0.02766161	0.053046744
27	16-01-08	800	16.1183098	13.4164142	0.13205413	0.02156388		-0.02766161	0.048026395
28	16-01-08	800	16.1183098	12.758385	0.08938805	0.01279597	2	-0.02766161	0.039472066
29	16-01-15	800	16.1183098	16.5214234	0.22476116	0.07724941	30	-0.02370879	0.098498952
30	16-01-15	900	18.1330986	18.5203024	0.45661323	0.19665006	100	-0.02370879	0.214991116
31	16-01-15	900	18.1330986	17.9184604	0.41124915	0.17542349	80	-0.02370879	0.194281604
32	16-01-15	900	18.1330986	17.0390708	0.35481316	0.14858279	60	-0.02370879	0.168094716
33	16-01-15	900	18.1330986	16.0403046	0.28641178	0.11377485	40	-0.02370879	0.134134666
34	16-01-15	900	18.1330986	15.2681455	0.24194319	0.09089874	30	-0.02370879	0.111815801
35	16-01-15	900	18.1330986	14.6088247	0.20134979	0.07128419	20	-0.02370879	0.092679038
36	16-01-15	900	18.1330986	14.3876164	0.19911912	0.07062194	20	-0.02370879	0.092032921
37	16-01-15	900	18.1330986	13.9943965	0.18333035	0.06359687	16	-0.02370879	0.085112213
38	16-01-15	900	18.1330986	13.4664589	0.15988785	0.05156697	12	-0.02370879	0.073442116
39	16-01-15	900	18.1330986	12.5963065	0.13192771	0.05469544	8	-0.02370879	0.076494375
40	16-01-15	900	18.1330986	12.9969396	0.07925264	0.03026262	2	-0.02370879	0.052656721
41	16-01-15	1000	20.1478873	16.5521501	0.44532268	0.20147077	80	-0.02370879	0.219694393
42	16-01-15	1000	20.1478873	15.972966	0.39413833	0.17488096	60	-0.02370879	0.193752293
43	16-01-15	1000	20.1478873	15.0898322	0.32302158	0.13/32358	40	-0.02370879	0.15/109//1
44	16-01-15	1000	20.1478873	14.3702087	0.26350957	0.10894775	30	-0.02370879	0.129425151
45	10-01-15	1000	20.14/00/3	13.6050097	0.22310915	0.09346536	20	-0.02370679	0.11433943
40	10-01-15	1000	20.14/00/3	13.5106755	0.200002200	0.06599636	10	-0.02370679	0.107032639
47	16 01 15	1000	20.1470073	12 2017609	0.17093042	0.07254054	12	-0.02370879	0.093904787
40	16 01 15	1000	20.1470073	11 9645622	0.14291404	0.0300431	0	-0.02370879	0.065000212
43 50	16 01 22	1100	20.1470073	10 1557022	0.030300000	0.24535401	100	0.02370073	0.005055515
51	16 01 22	1100	22.102070	18 81//83	0.04013307	0.24333491	80	0.02770474	0.200400174
52	16-01-22	1100	22 162676	17 6253862	0.43092542	0.19279088	00	-0.02770474	0.215124557
53	16-01-22	1100	22 162676	16 2268324	0.35876104	0 15852308	40	-0.02770474	0 181691488
54	16-01-22	1100	22.162676	14.2809903	0.26276928	0.1168185	20	-0.02770474	0.141002787
55	16-01-22	1100	22.162676	15.1672019	0.30500926	0.13404062	30	-0.02770474	0.157805392
56	16-01-22	1100	22,162676	13,9912765	0.25121456	0.1130986	18	-0.02770474	0.137373507
57	16-01-22	1100	22.162676	13.6340084	0.23450866	0.10583984	16	-0.02770474	0.130291556
58	16-01-22	1100	22.162676	13.2709318	0.22308806	0.1018374	14	-0.02770474	0.126386612
59	16-01-22	1100	22.162676	12.9955654	0.1972223	0.0888995	12	-0.02770474	0.113763873
60	16-01-22	1100	22.162676	12.677008	0.18378712	0.08662917	10	-0.02770474	0.111548846
61	16-01-22	1100	22.162676	12.2127576	0.16036815	0.07302833	8	-0.02770474	0.098279306
62	16-01-22	1100	22.162676	12.1919417	0.14446766	0.06419348	6	-0.02770474	0.089659664
63	16-01-22	1100	22.162676	11.8652242	0.12875407	0.06435832	4	-0.02770474	0.089820493
64	16-01-22	1100	22.162676	12.8006389	0.10888915	0.05440561	2	-0.02770474	0.08011022

		Controller							CORRECTED
		Air Flow Set		Average	Average	Average	Kobold		Average
		Point, SLPM	Air Mass	Flow Loop	Flow Loop	Pressure	Rotameter	Differential	Pressure
Line No	Date	@ 15C, 100 kPaa	riow Rate,	°C (Ai5)	nsia (Ai6)	nsi (Ai7)	rate SI PH	Correction	nsi (Ai7)
65	16-01-22	350	7.05176055	19.4287376	0.46666279	0.13638336	160	-0.02770474	0.160091071
66	16-01-22	350	7.05176055	18.7742661	0.43686159	0.1228485	140	-0.02770474	0.146885901
67	16-01-22	350	7.05176055	18.5404646	0.4123126	0.11267737	120	-0.02770474	0.13696253
68	16-01-22	350	7.05176055	18.47717	0.38615132	0.10062034	100	-0.02770474	0.125199205
69	16-01-22	350	7.05176055	18.2643957	0.35169458	0.08739232	80	-0.02770474	0.112293404
70	16-01-22	350	7.05176055	17.9722817	0.31615812	0.07186342	60	-0.02770474	0.097142774
71	16-01-22	350	7.05176055	17.523887	0.28006419	0.05575291	40	-0.02770474	0.0814247
72	16-01-22	350	7.05176055	16 7079358	0.23704813	0.04032215	20	-0.02770474	0.07417495
74	16-01-22	350	7.05176055	16.6031584	0.2281443	0.03723065	18	-0.02770474	0.063353625
75	16-01-22	350	7.05176055	16.3876986	0.21842818	0.03494225	16	-0.02770474	0.061120968
76	16-01-22	350	7.05176055	16.276455	0.21081928	0.03209987	14	-0.02770474	0.058347825
77	16-01-22	350	7.05176055	16.1319629	0.20771984	0.02917505	12	-0.02770474	0.055494253
78	16-01-22	350	7.05176055	15.9109152	0.19813362	0.02718516	10	-0.02770474	0.053552838
79	16-01-22	350	7.05176055	15.6233573	0.18914839	0.0243089	8	-0.02770474	0.050746633
80	16-01-22	350	7.05176055	15.4249235	0.17825632	0.02020331	6	-0.02770474	0.046741051
82	16-01-22	350	7.05176055	14 7473375	0.15517511	0.01090994	4	-0.02770474	0.043527911
83	16-01-22	1300	26.1922535	17.2910688	0.51832384	0.25682235	60	-0.0267145	0.276630153
84	16-01-29	1300	26.1922535	15.8811566	0.44885779	0.22483539	40	-0.0267145	0.245422367
85	16-01-29	1300	26.1922535	15.025348	0.37608933	0.19146073	30	-0.0267145	0.212860679
86	16-01-29	1300	26.1922535	13.7849445	0.3333057	0.17504018	20	-0.0267145	0.196840119
87	16-01-29	1300	26.1922535	13.5704245	0.31877775	0.16911189	18	-0.0267145	0.191056236
88	16-01-29	1300	26.1922535	13.1725647	0.30051608	0.16229676	16	-0.0267145	0.184407121
89	16-01-29	1300	26.1922535	12.7419446	0.28080104	0.15485561	14	-0.0267145	0.17714723
90	16-01-29	1300	26.1922535	12.5670619	0.25133386	0.13825143	12	-0.0267145	0.160947513
91	16.01.20	1300	20.1922030	12.1452024	0.23372200	0.1330596	10	-0.0267145	0.100002041
93	16-01-29	1300	26.1922535	11.4465518	0.18730635	0.10447678	6	-0.0267145	0.127995584
94	16-01-29	1300	26.1922535	10.9704621	0.16186837	0.08688234	4	-0.0267145	0.110829721
95	16-01-29	1300	26.1922535	12.0623718	0.14405232	0.08142035	2	-0.0267145	0.105500778
96	16-01-29	1400	28.2070422	16.888886	0.5593267	0.29943616	60	-0.0286069	0.320052238
97	16-01-29	1400	28.2070422	15.1995276	0.47631269	0.26093034	40	-0.0286069	0.282484386
98	16-01-29	1400	28.2070422	13.1725647	0.41586924	0.23263352	30	-0.0286069	0.254876847
99	16-01-29	1400	28.2070422	13.48/3/5	0.36921588	0.210/1/81	20	-0.0286069	0.233494985
100	16-01-29	1400	28.2070422	13.0015173	0.33385575	0.20049103	16	-0.0286069	0.223517323
101	16-01-29	1400	28.2070422	12,7013804	0.31613541	0.18428868	14	-0.0286069	0.20770964
103	16-01-29	1400	28.2070422	12.3300042	0.29211783	0.17238294	12	-0.0286069	0.196093919
104	16-01-29	1400	28.2070422	12.004816	0.27031038	0.15811909	10	-0.0286069	0.182177522
105	16-01-29	1400	28.2070422	11.7542816	0.2432516	0.1441761	8	-0.0286069	0.168574169
106	16-01-29	1400	28.2070422	11.468863	0.21849893	0.13687659	6	-0.0286069	0.161452467
107	16-01-29	1400	28.2070422	11.1547179	0.19219365	0.11348873	4	-0.0286069	0.138634315
108	16-01-29	1400	28.2070422	10.7829452	0.17478339	0.09765937	2	-0.0286069	0.123190538
109	16-01-29	1500	30.2218309	13 627172	0.40723310	0.25124447	20	-0.0286069	0.258101021
110	16-01-29	1500	30.2218309	14.3770335	0.52252108	0.2820589	40	-0.0286069	0.303098274
112	16-02-06	1500	30.2218309	16.7545574	0.56483222	0.32023813	60	-0.02689	0.338672417
113	16-02-06	1500	30.2218309	16.0714245	0.53512833	0.30732462	50	-0.02689	0.326073466
114	16-02-06	1500	30.2218309	15.5187653	0.48635065	0.27983118	40	-0.02689	0.299249736
115	16-02-06	1500	30.2218309	14.6978358	0.42358369	0.25005495	30	-0.02689	0.270198834
116	16-02-06	1500	30.2218309	13.8233474	0.37986429	0.23870899	20	-0.02689	0.259129251
117	16-02-06	1500	30.2218309	13.6932259	0.3611397	0.22803436	18	-0.02689	0.248714644
110	16-02-00	1500	30.2218309	13 2500176	0.33602472	0.21049438	10	-0.02089	0.237435707
120	16-02-06	1500	30.2218309	13.0223016	0.29440783	0.1898704	12	-0.02689	0.211480319
121	16-02-06	1500	30.2218309	12.7860195	0.26666372	0.17453084	10	-0.02689	0.196514421
122	16-02-06	1500	30.2218309	12.4962921	0.23831747	0.15443075	8	-0.02689	0.176903944
123	16-02-06	1500	30.2218309	12.2946698	0.21278291	0.14810187	6	-0.02689	0.170729229
124	16-02-06	1500	30.2218309	12.2539469	0.18424943	0.13004949	4	-0.02689	0.15311659
125	16-02-06	1500	30.2218309	12.4701372	0.16558487	U.11981612	2	-0.02689	0.143132493
126	16-02-12	1200	24.1//404/	19.2504179	0.54/49049	0.20013/56	100	-0.02928	0.28236/62
128	16-02-12	1200	24.1774647	17.6715322	0.45024969	0.21461684	60	-0.02928	0.237955738
		. 200					00		

		Controller							CORRECTED
		Air Flow Set		Average	Average	Average	Kobold		Average
		Point, SLPM	Air Mass	Flow Loop	Flow Loop	Pressure	Rotameter	Differential	Pressure
Line Ne	Dete	@ 15C, 100	Flow Rate,	Iemperature	Pressure,	Differential,	Water Flow	Pressure	Differential,
120	16.02.12	1200	g/s 24 1774647	16 0014570	0 3723346	0 17787844	rate SLPH	0.02028	0 202112250
129	16-02-12	1200	24.1774047	15 0882582	0.3723340	0.17767644	40	-0.02928	0.202112239
131	16-02-12	1200	24 1774647	14 1829647	0.27269967	0.14365155	20	-0.02928	0 168719099
132	16-02-12	1200	24.1774647	13,9855947	0.25917711	0.13814828	18	-0.02928	0.163349886
133	16-02-12	1200	24.1774647	13.6651026	0.23989546	0.12963278	16	-0.02928	0.155041816
134	16-02-12	1200	24.1774647	13.4519112	0.219195	0.12181575	14	-0.02928	0.147415199
135	16-02-12	1200	24.1774647	13.2675384	0.21162767	0.11829296	12	-0.02928	0.143978222
136	16-02-12	1200	24.1774647	12.9991197	0.18995061	0.10616149	10	-0.02928	0.132142258
137	16-02-12	1200	24.1774647	12.9047873	0.16785735	0.10318924	8	-0.02928	0.129242416
138	16-02-12	1200	24.1774647	12.5200538	0.1429824	0.09200578	6	-0.02928	0.118331372
139	16-02-12	1200	24.1774647	12.1016086	0.12774641	0.08677324	4	-0.02928	0.113226294
140	16-02-12	1200	24.1774647	12.7047067	0.10972329	0.07230049	2	-0.02928	0.09910608
141	16-02-12	1000	20.1478873	14.4201489	0.21350973	0.09044838	20	-0.02779594	0.115363992
142	16.02.12	1000	20.1470073	13 762/078	0.20400043	0.000340	10	-0.02779594	0.111303495
145	16-02-12	1000	20.1478873	13 4083515	0.1/35140	0.07310174	14	-0.02779594	0.004466682
145	16-02-12	1000	20.1478873	12,6940926	0.11033632	0.05722715	6	-0.02779594	0.082952
146	16-02-12	1000	20.1478873	12.8513199	0.09301978	0.04559438	4	-0.02779594	0.071602592
147	16-02-12	900	18.1330986	15.2022713	0.1992593	0.074832	20	-0.02779594	0.100128016
148	16-02-12	900	18.1330986	14.5419982	0.18309581	0.06919054	16	-0.02779594	0.09462398
149	16-02-12	900	18.1330986	14.563908	0.19138557	0.06701906	18	-0.02779594	0.092505392
150	16-02-12	900	18.1330986	14.1382317	0.16842523	0.05549724	14	-0.02779594	0.081264234
151	16-02-12	900	18.1330986	13.858018	0.14247179	0.04832467	10	-0.02779594	0.074266383
152	16-02-12	900	18.1330986	13.0648438	0.11677724	0.03504752	6	-0.02779594	0.061312651
153	16-02-12	900	18.1330986	12.9833536	0.09893033	0.0391198	4	-0.02779594	0.065285735
154	16-02-12	800	16.1183098	14.8792859	0.18039169	0.0488739	20	-0.02779594	0.074802231
155	16-02-12	800	16.1183098	14.8161102	0.17317141	0.044142	18	-0.02779594	0.070185595
150	16.02.12	800	16 1183098	14.4173511	0.1000001	0.03539446	14	-0.02779594	0.059099652
158	16-02-12	800	16 1183098	13 5145042	0.1231033	0.02341074	6	-0.02779594	0.031310421
159	16-02-12	800	16.1183098	13.1464741	0.09531116	0.02358218	4	-0.02779594	0.050126596
160	16-02-17	700	14.1035211	19.1490906	0.29311917	0.08953639	60	-0.02807278	0.11474432
161	16-02-17	700	14.1035211	16.5530444	0.18263628	0.03553	21	-0.02807278	0.062053478
162	16-02-17	700	14.1035211	15.9947323	0.17528727	0.03434905	20	-0.02807278	0.06090129
163	16-02-17	700	14.1035211	17.6850971	0.24286486	0.06525898	40	-0.02807278	0.091058286
164	16-02-17	700	14.1035211	17.0431575	0.21542131	0.05033942	30	-0.02807278	0.076502154
165	16-02-17	700	14.1035211	15.0585367	0.15379492	0.02624232	14	-0.02807278	0.052992037
166	16-03-05	600	12.0887324	21.7472293	0.38337705	0.12880347	120	-0.03131142	0.156214639
167	16-03-05	600	12.0887324	20.6422356	0.35130274	0.11193539	100	-0.03131142	0.139757457
168	16-03-05	600	12.0887324	20.0234265	0.31975579	0.09277121	80	-0.03131142	0.121060092
109	16.03.05	600	12.0007324	17 0267023	0.27459613	0.00940129	40	-0.03131142	0.09651796
170	16-03-05	600	12.0007324	17 14505	0.22751074	0.04717702	30	-0.03131142	0.064655541
172	16-03-05	600	12.0887324	16.4474897	0.17633255	0.02347863	20	-0.03131142	0.053455419
173	16-03-05	600	12.0887324	16.1249691	0.16935952	0.02102248	18	-0.03131142	0.051059099
174	16-03-05	600	12.0887324	15.9038211	0.16320563	0.01683613	16	-0.03131142	0.046974723
175	16-03-05	600	12.0887324	15.5631295	0.15282518	0.01384441	14	-0.03131142	0.044055881
176	16-03-05	600	12.0887324	15.3344389	0.14558988	0.01099385	12	-0.03131142	0.041274755
177	16-03-05	600	12.0887324	15.0155846	0.13728467	0.00908976	10	-0.03131142	0.039417051
178	16-03-05	600	12.0887324	14.9048559	0.13096407	0.0064547	8	-0.03131142	0.036846178
179	16-03-05	600	12.0887324	14.6142511	0.12037749	0.00349837	6	-0.03131142	0.033961858
180	16-03-05	600	12.0887324	14.2491282	0.10829139	0.0015101	4	-0.03131142	0.03202202
181	16-03-05	600	12.0887324	13.7806871	0.07423417	-0.00714424	2	-0.03131142	0.023578496
182	16-03-05	500	10.0739436	20.298886	0.37503294	0.11653382	120	-0.02975397	0.142724363
18/	16-03-05	500	10.0739430	10 6000251	0.34740005	0.10417300	100	-0.02975397	0.130000000
185	16-03-05	500	10 0739436	19 0177178	0 27181814	0.06667932	08	-0.02975397	0.094084265
186	16-03-05	500	10.0739436	18,2950818	0.23120059	0.04739103	40	-0.02975397	0.075265822
187	16-03-05	500	10.0739436	17.6156334	0.20906979	0.03748947	30	-0.02975397	0.065605451
188	16-03-05	500	10.0739436	16.8113255	0.18193503	0.02120679	20	-0.02975397	0.049719409
189	16-03-05	500	10.0739436	16.7287708	0.17901906	0.01920055	18	-0.02975397	0.047762037
190	16-03-05	500	10.0739436	16.6931234	0.17083081	0.01480898	16	-0.02975397	0.043477442
191	16-03-05	500	10.0739436	16.2861964	0.16250677	0.0124622	14	-0.02975397	0.041187826
192	16-03-05	500	10.0739436	16.0130639	0.15585654	0.00979209	12	-0.02975397	0.038582763

		Controller Air Flow Set Point, SLPM @ 15C, 100	Air Mass Flow Rate,	Average Flow Loop Temperature	Average Flow Loop Pressure,	Average Pressure Differential,	Kobold Rotameter Water Flow	Differential Pressure	CORRECTED Average Pressure Differential,
Line No.	Date	kPaa	g/s	, °C (Ai5)	psig (Ai6)	psi (Ai7)	rate SLPH	Correction	psi (Ai7)
193	16-03-05	500	10.0739436	15.9523575	0.14964753	0.00673613	10	-0.02975397	0.035601233
194	16-03-05	500	10.0739436	15.8294625	0.13978283	0.00385266	8	-0.02975397	0.032788006
195	16-03-05	500	10.0739436	15.6389186	0.12899381	0.00107652	6	-0.02975397	0.030079486
196	16-03-05	500	10.0739436	15.3079758	0.12011441	-0.00198877	4	-0.02975397	0.027088864
197	16-03-05	500	10.0739436	15.1727966	0.07645906	-0.00939432	2	-0.02975397	0.019863715
198	16-03-10	400	8.05915491	22.9632788	0.40103457	0.114087	140	-0.02875722	0.13936467
199	16-03-10	400	8.05915491	22.8878416	0.3805326	0.10362372	120	-0.02875722	0.129156261
200	16-03-10	400	8.05915491	22.2527924	0.35189561	0.09222039	100	-0.02875722	0.118030708
201	16-03-10	400	8.05915491	21.7796359	0.32112073	0.08299127	80	-0.02875722	0.1090264
202	16-03-10	400	8.05915491	21.1169827	0.28708512	0.06794093	60	-0.02875722	0.094342671
203	16-03-10	400	8.05915491	20.3294782	0.24853984	0.05106542	40	-0.02875722	0.077878235
204	16-03-10	400	8.05915491	19.7742576	0.22780867	0.04129585	30	-0.02875722	0.068346639
205	16-03-10	400	8.05915491	18.9496264	0.2026028	0.03243617	20	-0.02875722	0.059702777
206	16-03-10	400	8.05915491	18.2994307	0.19503836	0.02977785	18	-0.02875722	0.057109205
207	16-03-10	400	8.05915491	17.9181222	0.19248776	0.02760925	16	-0.02875722	0.054993438
208	16-03-10	400	8.05915491	17.7064303	0.18002889	0.02434399	14	-0.02875722	0.051807715
209	16-03-10	400	8.05915491	17.4233305	0.17573178	0.02240706	12	-0.02875722	0.049917966
210	16-03-10	400	8.05915491	17.0780134	0.16957683	0.02087138	10	-0.02875722	0.048419688
211	16-03-10	400	8.05915491	16.7201538	0.16366231	0.01877977	8	-0.02875722	0.046379028
212	16-03-10	400	8.05915491	16.4990656	0.15115245	0.01500221	6	-0.02875722	0.042693488
213	16-03-10	400	8.05915491	16.2199775	0.13975842	0.0115351	4	-0.02875722	0.039310837
214	16-03-10	400	8.05915491	15.6978082	0.12265337	0.0095976	2	-0.02875722	0.037420527

	Gage		Daily Mean	CORRECTED	Average		Water		Pressure at P1, Beginning
	Pressure	CORRECTED	Station	Absolute	Pressure	Water	Volumetric		of dP
	Correction,	Gauge	Pressure,	Pressure at	Gradient,	Density,	Flow Rate,		Section,
Line No.	psi	Pressure, psi	kPaa	P0, kPaa	Pa/m	g/cc	m3/s	Vsl, m/s	kPaa
1	-0.01836367	0.193805101	92.62	93.95628617	499.424457	0.99892251	5.56155E-06	0.01035585	93.8040226
2	-0.01836367	0.18//2/9/9	92.62	93.91438442	4/1.018051	0.99896272	5.00519E-06	0.00931989	93.7705984
3	-0.01836367	0.163163757	92.02	93.05197430	442.151720	0.99902050	4.4400E-00 3.8025E-06	0.00020307	93.717172
	-0.01836367	0.149599979	92.62	93 65149186	350 643377	0.99916306	3 33613E-06	0.00621201	93 5445884
6	-0.01836367	0.138096351	92.62	93.57217434	343.731303	0.99923007	2.77992E-06	0.00517633	93.4673782
7	-0.01836367	0.130570818	92.62	93.52028579	285.184963	0.99926955	2.22385E-06	0.0041409	93.4333392
8	-0.01836367	0.120021134	92.62	93.44754572	252.944746	0.99933848	1.66777E-06	0.00310546	93.3704284
9	-0.01836367	0.105216066	92.62	93.34546478	246.959136	0.9994105	1.11177E-06	0.00207016	93.2701724
10	-0.01836367	0.095490576	92.62	93.27840752	247.846241	0.99932397	5.55931E-07	0.00103517	93.2028446
11	-0.01639183	0.312457794	93.22	95.37439649	1043.09841	0.99822368	1.66963E-05	0.03108929	95.0563787
12	-0.01639183	0.340088868	93.22	95.56491275	1163.86094	0.99814941	1.94805E-05	0.03627354	95.2100771
13	-0.01039103	0.359093967	93.22	95.09595291	1201.13070	0.99606543	2.22046E-05	0.04145613	95.3053643
15	-0.01639183	0.404451374	93.22	96.00869222	1465,12875	0.99805632	2.78319E-05	0.05182418	95.5620066
16	-0.01639183	0.42325904	93.22	96.13837108	1547.80696	0.99812817	3.06129E-05	0.05700249	95.6664787
17	-0.01569702	0.506564355	94.31	97.80276123	1989.65913	0.9979024	3.89706E-05	0.07256504	97.1961578
18	-0.01569702	0.477246155	94.31	97.60061224	1847.36437	0.99797915	3.34008E-05	0.06219382	97.0373914
19	-0.01569702	0.434808309	94.31	97.30800329	1614.05467	0.99821046	2.78276E-05	0.05181618	96.8159135
20	-0.01569702	0.388760197	94.31	96.99050156	1402.48533	0.99835867	2.22588E-05	0.04144679	96.5629146
21	-0.01569702	0.337131865	94.31	96.63452421	1184.70102	0.99851628	1.66914E-05	0.03108018	96.2733349
22	-0.01569702	0.279153341	94.31	96.23476229	932.933609	0.99872638	1.11253E-05	0.02071576	95.9503313
23	-0.01569702	0.201404157	94.31	95.09909530	634 785433	0.99901577	5.56103E-06	0.01035486	95.5076561
25	-0.01569702	0.18764387	94.31	95.60380448	580.053069	0.99909699	4.44846E-06	0.00828323	95.426959
26	-0.01569702	0.164556926	94.31	95.44462001	479.873582	0.99918688	3.33605E-06	0.00621186	95.2983171
27	-0.01569702	0.144445259	94.31	95.30595006	434.458293	0.99928585	2.22381E-06	0.00414083	95.1734933
28	-0.01569702	0.102733816	94.31	95.01834966	357.073782	0.99937012	5.55906E-07	0.00103512	94.9094857
29	-0.01707723	0.23642733	93.88	95.51016644	891.045157	0.99881939	8.34318E-06	0.01553538	95.2385063
30	-0.01707723	0.463091778	93.88	97.07301781	1944.86124	0.99846224	2.78206E-05	0.05180311	96.4800723
31	-0.01707723	0.418742699	93.88	96.76723091	1757.51802	0.99857439	2.22539E-05	0.04143783	96.2314022
32	-0.01707723	0.363569449	93.88	96.38681135	1520.62515	0.9987312	1.008/8E-05	0.0310735	95.9232061
34	-0.01707723	0.290096551	93.88	95.92573037	1011 51257	0.99889895	8 3415E-05	0.02071218	95.555795
35	-0.01707723	0.213539776	93.88	95.35235675	838.396818	0.99911977	5.56045E-06	0.0103538	95.096748
36	-0.01707723	0.211359018	93.88	95.33732043	832.551891	0.99915181	5.56027E-06	0.01035347	95.0834936
37	-0.01707723	0.195923516	93.88	95.23089264	769.945509	0.99920734	4.44797E-06	0.00828232	94.9961532
38	-0.01707723	0.173005543	93.88	95.07287322	664.375011	0.99927903	3.33574E-06	0.00621129	94.8703199
39	-0.01707723	0.145671	93.88	94.88440154	691.986471	0.99938994	2.22358E-06	0.0041404	94.6734301
40	-0.01707723	0.094174518	93.88	94.5293333	476.34534	0.99933986	5.55923E-07	0.00103515	94.3841061
41	-0.01707723	0.452053851	93.88	96.99691131	1987.40821	0.99881457	2.22486E-05	0.04142787	96.3909942
42	-0.01/0//23	0.402014735	93.88	96.6518916	1/52./29/4	0.99891004	1.66849E-05	0.03106793	96.1175228
43	-0.01707723	0.332469202	93.88	90.17231303	1421.25209	0.99904833	8 34039E-06	0.02070909	95.7392043
45	-0.01707723	0.234812284	93.88	95,4990307	1034.34193	0.9992334	5.55982E-06	0.01035263	95.1836825
46	-0.01707723	0.21862624	93.88	95.38742792	968.244746	0.99927318	4.44768E-06	0.00828177	95.0922314
47	-0.01707723	0.191627905	93.88	95.2012744	849.485237	0.99932775	3.33558E-06	0.00621099	94.942285
48	-0.01707723	0.156412104	93.88	94.95846145	726.828094	0.99941473	2.22352E-06	0.0041403	94.7368675
49	-0.01707723	0.108111236	93.88	94.62542697	588.90401	0.99947612	5.55847E-07	0.00103501	94.4458831
50	-0.01675989	0.544433233	92.64	96.39386714	2409.99228	0.99833907	2.7824E-05	0.0518095	95.6591134
51	-0.01675989	0.495735473	92.64	96.05809608	2196.01755	0.99840542	2.22577E-05	0.04144485	95.3885785
52	-0.01675989	0.437668478	92.64	95.65772416	1946.06837	0.99862705	1.66896E-05	0.03107674	95.0644106
53	-0.01675020	0.30/118/03	92.64	90.17128387	1275 54505	0.99080/96	1.1123/E-05	0.020/1283	94.0/U1/0/ 04 1353/4
55	-0.01675989	0.31456966	92.04	94.80895781	1427 54545	0.99910053	8.34138E-06	0.01553201	94.130344
56	-0.01675989	0.261978596	92.64	94.44634242	1242.71371	0.99920725	5.00397E-06	0.00931761	94.0674663
57	-0.01675989	0.245646486	92.64	94.33373252	1178.64869	0.99925611	4.44775E-06	0.00828191	93.9743884
58	-0.01675989	0.234481419	92.64	94.25674938	1143.32363	0.99930422	3.8916E-06	0.00724632	93.9081751
59	-0.01675989	0.209194401	92.64	94.0823954	1029.1353	0.99933964	3.33554E-06	0.00621092	93.7686346
60	-0.01675989	0.196059834	92.64	93.99183255	1009.09763	0.9993795	2.7795E-06	0.00517556	93.6841808
61	-0.01675989	0.17316485	92.64	93.83397164	889.058194	0.99943541	2.22348E-06	0.00414021	93.5629173
62	-0.01675989	0.15/620135	92.64	93.72679083	811.082836	0.99943783	1.6676E-06	0.00310515	93.4795095
64	-0.010/5989	0.142200128	92.04	93.02000979	724 696279	0.99936401	5.55909E-06	0.00207002	93 2660218
	2.0.010000	5	52.04	50. IS50002		5.555500401	3.00000L 01	2.00.00010	20.2000210

									Pressure at P1,	
	Gage		Daily Mean	CORRECTED	Average		Water		Beginning	
	Pressure	CORRECTED	Station	Absolute	Pressure	Water	Volumetric		of dP	
Lino No	correction,	Gauge Proceuro nei	Pressure,	Pressure at	Ba/m	Density,	riow Rate,	Vel m/e	section,	
Line NO. 65	-0 01675989	0 472606244	92.64	95 89862005	1448 22225	0 99828512	4 45208E-05	0.08289968	95.4570889	
66	-0.01675989	0.443471832	92.64	95.69773828	1328,76511	0.99841328	3.89507E-05	0.07252791	95,292627	
67	-0.01675989	0.41947212	92.64	95.53226026	1238.99592	0.99845793	3.33848E-05	0.062164	95.1545176	
68	-0.01675989	0.393896192	92.64	95.35591424	1132.58206	0.99846988	2.78203E-05	0.05180271	95.0106148	
69	-0.01675989	0.360210411	92.64	95.12365078	1015.83308	0.99850983	2.22554E-05	0.04144051	94.8139456	
70	-0.01675989	0.325469067	92.64	94.88410922	878.776852	0.99856392	1.66906E-05	0.0310787	94.6161894	
71	-0.01675989	0.290182732	92.64	94.64080994	736.587381	0.99864518	1.11262E-05	0.02071745	94.4162406	
72	-0.01675989	0.268170458	92.64	94.48903531	671.004402	0.99873772	8.34387E-06	0.01553665	94.2844608	
73	-0.017	0.2444429214	92.04	94.32333943	573 112095	0.99878742	5.00598E-06	0.01033725	94.1434003	
75	-0.017	0.230160548	92.64	94.22695698	552,914944	0.99884124	4.4496E-06	0.00828535	94.0583853	
76	-0.017	0.22272189	92.64	94.17566743	527.828427	0.99885967	3.89333E-06	0.00724955	94.0147441	
77	-0.017	0.219691804	92.64	94.15477499	502.014335	0.99888341	3.33706E-06	0.00621375	94.0017218	
78	-0.017	0.210320063	92.64	94.09015684	484.451828	0.99891926	2.78078E-06	0.00517794	93.9424581	
79	-0.017	0.201535885	92.64	94.02958993	459.066224	0.99896508	2.22452E-06	0.00414216	93.8896307	
80	-0.017	0.190887518	92.64	93.95616944	422.830765	0.99899614	1.66834E-06	0.00310653	93.8272576	
81	-0.017	0.179655581	92.64	93.87872523	393.763929	0.99904969	1.11217E-06	0.00207091	93.7586753	
82	-0.017	0.168322742	92.64	93.80058531	370.536998	0.99909884	5.56057E-07	0.0010354	93.08/010/	
84	-0.01848099	0.524795962	92	95.0104045	2220 14963	0.99808043	1.00000E-05	0.03107469	94.8555085	
85	-0.01848099	0.385741931	92	94.65969062	1925.58879	0.99905722	8.3412E-06	0.01553168	94.0726209	
86	-0.01848099	0.343915571	92	94.37129786	1780.66296	0.99923546	5.55981E-06	0.0103526	93.8284128	
87	-0.01848099	0.329712673	92	94.27336888	1728.34056	0.99926444	5.00368E-06	0.00931707	93.7464358	
88	-0.01848099	0.311859602	92	94.15027196	1668.19108	0.99931677	4.44748E-06	0.00828141	93.6416771	
89	-0.01848099	0.292585687	92	94.01737831	1602.51636	0.99937128	3.89134E-06	0.00724584	93.5288063	
90	-0.01848099	0.263777822	92	93.81874808	1455.96983	0.99939276	3.33536E-06	0.00621059	93.3748548	
91	-0.01848099	0.246560869	92	93.70003719	1410.14907	0.99944309	2.77933E-06	0.00517523	93.2701137	
92	-0.01848099	0.224429732	92	93.547443	1332.82885	0.99948221	2.22337E-06	0.00414002	93.1410927	
94	-0.01848099	0 1763141	92	93 21568572	1002 59226	0.99957179	1 11159E-06	0.00206982	92 9100173	
95	-0.01848099	0.158896675	92	93.09559257	954.385362	0.99945259	5.5586E-07	0.00103504	92.8046214	
96	-0.01685419	0.563289005	92	95.88387769	2895.26936	0.99875648	1.66874E-05	0.03107271	95.0011736	
97	-0.01685419	0.482132408	92	95.32430295	2555.42155	0.99903086	1.11219E-05	0.02070945	94.545211	
98	-0.01685419	0.423041363	92	94.9168702	2305.67713	0.99931693	8.33903E-06	0.01552764	94.2139199	
99	-0.01685419	0.377431862	92	94.60239269	2112.25168	0.99927556	5.55958E-06	0.01035219	93.9584135	
100	-0.01685419	0.363633692	92	94.5072543	2021.99134	0.99929948	5.00351E-06	0.00931675	93.8907935	
101	-0.01685419	0.342862906	92	94.36403973	1940.84674	0.99933872	4.44739E-06	0.00828123	93.7723182	
102	-0.01085419	0.32353905	92	94.24459175	1773 9126	0.99937033	3.33526E-00	0.0072438	93.0717200	
100	-0.01685419	0.280739344	92	93,93569778	1648.02159	0.99945941	2.77928E-06	0.00517514	93.4332522	
105	-0.01685419	0.254285992	92	93.75330191	1524.96239	0.99948783	2.22336E-06	0.00414	93.2883744	
106	-0.01685419	0.230087164	92	93.58645099	1460.53776	0.99951926	1.66747E-06	0.0031049	93.1411651	
107	-0.01685419	0.204370457	92	93.4091343	1254.11928	0.99955273	1.11161E-06	0.00206986	93.0267809	
108	-0.01685419	0.187349744	92	93.29177648	1114.41118	0.99959076	5.55783E-07	0.00103489	92.952017	
109	-0.01685419	0.414598513	92	94.85865674	2335.38656	0.99936247	5.5591E-06	0.01035129	94.1466486	
110	-0.01685419	0.460460781	92	95.1/48//09	2469.93517	0.99925701	8.33953E-06	0.01552857	94.4218481	
112	-0.01083419	0.527300905	92 92	95.03578111	3063 71197	0.99915285	1.11203E-05	0.02070092	94.7990301	
113	-0.02019	0.542893243	92.73	96.47324891	2949.73884	0.99889359	1.39043E-05	0.02589037	95.5739383	
114	-0.02019	0.495206952	92.73	96.14445193	2707.08493	0.99898179	1.11224E-05	0.02071047	95.3191212	
115	-0.02019	0.433844381	92.73	95.72135701	2444.2835	0.99910637	8.34079E-06	0.01553091	94.9761486	
116	-0.02019	0.391103194	92.73	95.42665653	2344.14539	0.99923052	5.55983E-06	0.01035266	94.7119781	
117	-0.02019	0.372797557	92.73	95.30043916	2249.93236	0.99924822	5.00376E-06	0.00931723	94.6144842	
118	-0.02019	0.350199768	92.73	95.1446274	2148.08186	0.99926965	4.44769E-06	0.0082818	94.4897244	
119	-0.02019	0.329679062	92.73	95.00313713	2031.19961	0.99930701	3.89159E-06	0.0072463	94.383869	
120	-0.02019	0.30/558/99	92.73	94.85061792	1913.101/2	0.99933632	3.33555E-06	0.00621094	94.20/3552	
121	-0.02019	0.200430453	92.73	94 47252811	1600 31554	0.99930005	2.77904E-06	0.00317303	93 984627	
123	-0.02019	0.227760206	92.73	94.30040662	1544.45758	0.99942573	1.66762E-06	0.00310519	93.8295354	
124	-0.02019	0.199865156	92.73	94.10807025	1385.12942	0.99943052	1.11174E-06	0.00207012	93.6857747	
125	-0.02019	0.181618215	92.73	93.98225759	1294.81088	0.99940465	5.55887E-07	0.00103509	93.5874982	
126	-0.01975691	0.554555401	94.25	98.07365949	2554.36526	0.99832116	2.78245E-05	0.05181043	97.2948896	
127	-0.01975691	0.512278491	94.25	97.7821602	2376.51986	0.99841632	2.22575E-05	0.04144439	97.0576115	
128	-0.01975691	0.459490336	94.25	97.41818587	2152.60471	U.99861948	1.66897E-05	0.03107697	96.7619039	
Pressure Correction, Ball Conception Pressure,		Gage		Daily Mean	CORRECTED	Average		Water		Pressure at P1, Beginning
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correction Gauge Presure, Pesure, Peta Density, Flow Are, Peta 1129 0.0197569 0.383316579 94.25 96.8292816 1282.38 0.98989068 1.112.34E-03 0.0155311 95.340354 130 0.0197569 0.25581225 94.22 96.12207124 90.990146 5.56011E-00 0.0195311 55.746862 132 0.0197569 0.255842715 94.25 96.13027124 1427.7223 0.99031561 5.145662 55.746862 135 0.01975691 0.255842715 94.25 95.8468151 102.49151 0.0093153 3.256766 0.0041161 55.142058 135 0.01975601 0.226015378 95.5564624 100424251 95.2422794 102.42723 0.9993393 1.66776-0 0.0001201 95.1426244 140 0.01975601 0.12609806 94.25 95.1426944 102.42723 0.99931641 1.61776-0 0.0010201 94.33014 144 0.0197560 0.12609806 94.226 95.24247941 <t< th=""><th></th><th>Pressure</th><th>CORRECTED</th><th>Station</th><th>Absolute</th><th>Pressure</th><th>Water</th><th>Volumetric</th><th></th><th>of dP</th></t<>		Pressure	CORRECTED	Station	Absolute	Pressure	Water	Volumetric		of dP
Line No.psiPressure, psiPhesaPaPapdcmdsPhesaPhesa1290.01975600.33151579.42.29.6.829567128.2.3.00.990048638.34127-600.02071230.57604251310.01975600.2376220559.42.29.6.1202712142.72220.999024875.039662-800.00035176.57740421330.01975600.2378023059.42.296.1202712142.72220.99902675.039662-800.00281496.57740421330.01975600.2280274109.4.296.0024545143.4254400.99932501.4477.1260.00281496.5724021340.019756010.2280274109.4.29.68091015198.390610.99933091.5776060.00517576.2.29.663518109.9933892.727660.00517576.2.29.66351810199.390510.99933011.67776000.20702809.52026221390.019756010.184104499.2.59.54267401107.42000.99933701.5777600.00103529.5.4801411400.019756010.1442029729.5512270589.68351810.99914735.56032600.00103529.5.4801411410.01673060.22762689.622631811107.42000.99914735.56032600.00103529.5.4801411420.01673060.14720869.2249961.00742000.99914303.8916450.00103549.5.4901411420.01673060.147203660.227646649.8362670.99914		Correction,	Gauge	Pressure,	Pressure at	Gradient,	Density,	Flow Rate,		Section,
129 0.01976601 0.383316579 94.25 96.428297 1484.0728 0.9994688 1.11234-60 0.0153311 65.544324 13 0.01975601 0.25691285 94.25 96.2129679 1262.27340 0.9991814 5.660118-00 0.0153311 65.769649 13 0.01975601 0.2556422 94.25 96.0202454 1402.54440 0.9992583 14.447772-00 0.01974549 65.6796499 134 0.01975601 0.2556422 94.25 95.8495044 1303.5527 0.5992577 2.27861-60 0.00414056 65.592267 134 0.01975601 0.15906906 94.25 95.4496244 19993767 2.27861-60 0.00414056 65.5922677 0.00414056 55.592267 138 0.01976601 0.12608902 94.25 95.24227948 80.43394 14074276 0.0021627 94.33014 14 0.01975601 0.126807458 99.4226 95.5592267 0.00103517 95.433449 14 0.01975601 0.122680144 1143.63036 0.9993761 <th>Line No.</th> <th>psi</th> <th>Pressure, psi</th> <th>kPaa</th> <th>P0, kPaa</th> <th>Pa/m</th> <th>g/cc</th> <th>m3/s</th> <th>VsI, m/s</th> <th>kPaa</th>	Line No.	psi	Pressure, psi	kPaa	P0, kPaa	Pa/m	g/cc	m3/s	VsI, m/s	kPaa
130 0.01976601 0.25001726 94.25 94.2428977 1084.07280 0.9990485 8.34127E-00 0.0103517 95.760425 132 -0.01976601 0.22360242178 94.25 96.10201792 1407.70227 0.99902675 5.00386E-00 0.0082514 95.6774402 134 -0.01976601 0.223607419 94.25 95.8007046 133.55277 0.99922612 138.9082-00 0.00821419 96.412062 135 -0.01976601 0.223007419 94.25 95.8007006 130.55277 0.9992351 1677766 6.2092527 136 -0.01976601 0.1260906 94.25 95.801906 94.27 96.853736 0.00197169 0.5003227 139 -0.01976601 0.1260906 94.25 95.801360 0.9991769 5.500360 0.9991769 5.5003670 0.00101532 9.6209227 139 -0.01975601 0.126224081 94.25 95.1227068 9.6803736 0.9991769 5.5003760 0.9991769 5.5003760 9.5003165 9.4304161 144 <td>129</td> <td>-0.01975691</td> <td>0.383318579</td> <td>94.25</td> <td>96.8929816</td> <td>1828.356</td> <td>0.99889088</td> <td>1.11234E-05</td> <td>0.02071235</td> <td>96.335556</td>	129	-0.01975691	0.383318579	94.25	96.8929816	1828.356	0.99889088	1.11234E-05	0.02071235	96.335556
131 -0.01976601 0.22692255 94.25 96.2218979 1277.0227 0.0991781 5.5671466 133 -0.01976601 0.225842718 94.25 96.0024554 1402.54440 0.0992283 4.4477712-0 0.00931796 5.5674669 134 -0.01976601 0.22580422 94.25 95.00024554 1402.54440 0.0992283 4.4477712-06 0.00031767 65.2491327 134 -0.01976601 0.125004527 94.25 95.8496174 100935177 2.27561-06 0.00141056 65.1592056 138 -0.01976601 0.15004900 94.25 95.1496244 100424723 0.09937663 5.5502057 0.001035119 95.483144 140 -0.01976601 0.126583115 94.25 95.12492749 0.09937663 5.5502057 0.001035119 95.483144 141 -0.01673066 0.216574586 94.25 95.7140015 0.0848016 0.9992373 5.0911807 2.22981676 0.00123419 94.849461 144 -0.01673066 0.12642491 94.25 95.7140015 0.0024209 9.9992337 3.0917764 0.50031074 95	130	-0.01975691	0.318041726	94.25	96.4428977	1648.07298	0.99904863	8.34127E-06	0.01553181	95.9404364
132 -0.01976e91 0.2289285 442 56 0.0992263 44777E-06 0.0092179 644777E-06 0.0002149 95.764401 134 -0.01977691 0.223005432 442.25 65.8007046 133.5537 0.99922112 36.9168E-06 0.00021419 94.25 65.8007046 133.5537 0.99923033 33.5567E-66 0.000211719 94.6441383 135 -0.11977681 0.22307411 44.25 65.6448642 116.11797 0.99833033 15677E-06 0.000117169 65.1592256 138 -0.11975681 0.146202972 94.25 95.4427749 1024.2723 0.99833033 16677E-06 0.00107056 64.3320014 144 -0.01673066 0.25069022 94.25 95.744075 90.868618 0.9991431 50.001450-6 0.00017060 94.332014 144 -0.01673066 0.16564566 94.25 95.744075 90.868618 0.99914321 5.6408E-06 0.00072460 95.294396 144 -0.01673066 0.12424061 94.25 95.530876-07	131	-0.01975691	0.28591295	94.25	96.22136979	1526.27346	0.99918114	5.56011E-06	0.01035317	95.7560425
13 -0.0197690 0.233642/18 94.20 96.0024954 142,0124845 0.99822112 34417/15-06 0.00262114 95.224412 13 -0.01975691 0.223627141 94.22 95.8607005 130.246156 0.99823112 33.36655-06 0.00261131 94.4126022 13 -0.01975691 0.223627141 94.22 95.8607015 130.246156 0.99833177 77.978455-06 0.00261173 94.4126022 13 -0.01975691 0.14260927 94.25 95.2426784 10248573765 550025470 0.003110527 95.43026141 14 -0.01673068 0.216674586 94.25 95.571420177 1007.4209 0.99914739 5.560125-07 0.000311027 95.4302414 14 -0.01673086 0.126545947 94.25 95.57142017 100.74209 0.99912475 5.560125-07 0.00011561 94.374444 14 -0.01673086 0.165345947 94.25 95.50267607 75.0016736 0.0001764 95.6041647 14 -0.01673086 0.165345947 94.25<	132	-0.01975691	0.272692955	94.25	96.13021792	1477.70227	0.99920876	5.00396E-06	0.00931759	95.6796989
134 -0.01970691 0.23300432 94.29 95.8007046 133.3327 0.99830353 336656 0.0007499 95.491327 136 -0.01977661 0.223071419 94.29 95.6032103 119.30056 0.99830357 2305657-6 0.00017757 95.2991327 137 -0.01975661 0.142020972 94.25 95.5140647 110.1127 95.20972-07 0.00017066 41.322014 149 0.011975661 0.142020972 94.25 95.2427740 100.42723 5500726-07 0.00103552 95.4328146 144 0.011975680 0.126754566 94.25 95.7140015 90.8981441 0.011673086 0.00037068 41.322014 144 0.01173086 0.126754566 94.25 95.7140015 90.8981491 0.90017816 5.500226-07 0.001103532 94.239169 144 0.01173086 0.12672469 94.25 95.5074761 90.9902374 1.6077266 0.00031053 94.77744 145 0.011673086 0.12424061 94.25 95.5078476 99	133	-0.01975691	0.253842718	94.25	96.00024554	1402.54548	0.99925263	4.44///E-06	0.00828194	95.5726402
113 0.11975891 0.250214578 94.25 6.869329103 115.50026 0.9983317 2.7798115.06 0.0057177 85.3991327 133 0.011975891 0.15509806 94.25 95.3469647 11072560 0.0210727 85.0202622 134 0.011975891 0.1420972 94.25 95.242768 86.57385 0.99814729 5.500125.07 0.00101311 94.849456 141 0.01673086 0.216674586 94.25 95.71382177 1007.4209 0.99814729 5.500125.07 0.00031101 95.349143 142 0.01673086 0.216674586 94.25 95.5714807 50.8688181 10.8992397 2.77876E.00 0.0001746 95.040167 145 0.01673086 0.126345947 94.25 95.5032567 50.9992307 3.891850.00 0.00017427 94.7233141 147 0.01673086 0.10724498 94.25 95.50256767 50.991267 5.50047567 50.5094756 5.50047560 0.00017477 95.330039 144 0.01673086 0.150326925	134	-0.01975691	0.233005432	94.25	95.00070940	1333.00327	0.99926112	3.09109E-00	0.00724649	95.4541363
137 -0.01975691 0.18241644 94.25 95.5465642 1189.1571 2.22566.0 0.0141665 95.5020623 138 -0.01975691 0.16209301 0.14202972 94.25 95.54427491 102.42723 0.99944004 1.1172C6 0.0021708 94.320014 141 -0.01975691 0.1265715 0.42 95.54277486 80.9137865 0.99914729 5.50326-0 0.0103310 94.438141 142 -0.01673086 0.15674486 94.25 95.5714075 0.9902387 3.8918567 0.0072468 95.243274 144 -0.01673086 0.15634597 142.5 95.326771 105.670170 0.999378 3.8918567 3.8918577 105.71604 95.040171 145 -0.01673086 0.16355002 24.25 95.469678 15.6991247 5.6007606 0.0031819 94.372311 147 -0.01673086 0.1535502 42.5 95.469678 5.5991247 5.0017606 0.0031834 94.372311 147 -0.01673086 0.15640537 94.25	135	-0.01975691	0.220207419	94.25	95.60970015	1105 30058	0.99930535	2 77961E-06	0.00021113	95.4120082
138 -0.0197569 0.14202072 94.25 95.3468112 1077.4536 0.1697569 0.10207068 94.320014 140 -0.0197569 0.14268315 94.25 95.1227068 865.53385 0.9993765 5.55035-00 0.010351 94.84956 141 -0.0187308 0.225680022 94.25 95.74328177 1007.4206 0.9991423 5.0015206 0.00031801 94.84956 143 -0.0187308 0.125845947 94.25 95.74328177 1007.4206 0.9991423 5.891526 0.00031801 94.849153 144 -0.0187308 0.12240818 94.25 95.74328177 1007.4202 0.9993541 1.118276-0 0.00310527 94.229717 145 -0.0187308 0.1272408 0.425 95.55987787 85.991280 9.99912962 1.418276-0 0.0031829 95.3402775 146 -0.0187308 0.14835602 9.425 95.5498787 85.991280 9.99912962 1.4282760 0.0031829 95.347276 147 -0.0187308 0.148356022	137	-0.01975691	0.183416449	94.25	95 51465642	1169 15791	0.99935177	2.22366E-06	0.00414056	95 1582058
13 0.01975691 0.12658115 9422 9524427949 0.2242723 0.99944904 1.1172E-06 0.0027008 94 32001 141 0.011673080 0.12674868 0.425 95 537068 0.9993768 0.99944729 5500360 0.00331801 94 439465 142 0.01673080 0.12674868 0.425 95 537171 1007 4200 0.99914721 5500366 0.0072488 95 234354 144 0.01673080 0.12824011 42.5 95 3245711 85 463271 99993787 186776-06 0.00315744 95 046177 144 0.01673086 0.12724498 94 2.5 95 5365747 155 0403701 0.999378 1.66776-06 0.00315744 95 0460177 146 0.01673086 0.15335602 94 2.5 95 5625787 755 9913728 95 9991766 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726 3.9991726	138	-0.01975691	0.15909806	94.25	95.34698112	1070.45399	0.99939933	1.66767E-06	0.00310527	95.0206232
141 -0.01975@0 125603912 94.25 95.1227068 806.337385 0.5993766 5.55032-07 0.0103511 94.43465 142 -0.01673080 0.216574586 94.25 95.74328177 1007.4208 0.9991431 5.041580-06 0.00331801 95.434131 143 -0.01673080 0.156845947 94.25 95.74528771 85.468270 0.99928679 2.77976-06 0.0017548 95.244591 144 -0.01673080 0.122420401 94.25 95.96056767 75.043701 0.99937841 1.11827-06 0.00207247 94.227 94.255 95.96057687 85.991236 0.99912462 4.443207-06 0.0032429 95.3307378 149 -0.01673080 0.126335602 94.25 95.49566787 85.991236 0.99912763 3.27092-06 0.0032163 95.397728 150 -0.01673080 0.1360409888 44.25 95.4940663 7.313764 0.9991736 3.89165-06 0.0031649 95.397726 151 -0.01673080 0.136270958 94.25 95.49404633 <td>139</td> <td>-0.01975691</td> <td>0.144202972</td> <td>94.25</td> <td>95.24427949</td> <td>1024.27223</td> <td>0.99944904</td> <td>1.11172E-06</td> <td>0.00207008</td> <td>94.9320014</td>	139	-0.01975691	0.144202972	94.25	95.24427949	1024.27223	0.99944904	1.11172E-06	0.00207008	94.9320014
141 -0.01673080 0.25608022 94.25 95.24098217 1007.4200 9.99914729 5.5074804 5.00418E-00 0.0031801 95.243484 143 -0.01673080 0.156545947 94.25 95.255718 85.656270 9.9992387 3.898E-00 0.0027024 9.4277744 145 -0.01673080 0.12724998 94.25 9.9507801 47.77422 0.9993451 1.11182E-00 0.0021027 9.4277742 146 -0.01673080 0.12734998 94.25 9.95078678 755040315 0.9991247 5.0002226 2.77976E-00 0.0021027 9.427775 147 -0.01673080 0.1555602 94.25 9.5627878 55.975746 0.9991247 5.0072167 0.9991347 1.67782-00 0.0021247 9.52738568 151 -0.01673080 0.155640537 42.5 9.53077419 67.6784657 0.9991477 1.167782-00 0.0021747 9.52738568 151 -0.01673080 0.156405375 9.42.5 9.53077419 67.6784857 0.9992477 1.667782-00 0.0021747 9.52738568 152 -0.01673080 0.15665255 <td>140</td> <td>-0.01975691</td> <td>0.126583115</td> <td>94.25</td> <td>95.12279058</td> <td>896.537385</td> <td>0.99937665</td> <td>5.55902E-07</td> <td>0.00103511</td> <td>94.849456</td>	140	-0.01975691	0.126583115	94.25	95.12279058	896.537385	0.99937665	5.55902E-07	0.00103511	94.849456
142 -0.01673086 0.1673086 0.1673086 0.0072488 0.0072488 0.0072488 0.0072488 0.0072488 0.0072488 0.0072488 0.0072488 0.0072488 0.0072488 0.0072488 0.0072488 0.0072488 0.0015334 0.0015334 0.0015345 0.	141	-0.01673086	0.225089022	94.25	95.80198881	1043.61036	0.99914729	5.5603E-06	0.01035352	95.4838149
144 -0.01673066 0.155849547 94.25 95.2545781 95.656279 9.9992387 3.867E-06 0.00517604 9.650440187 145 -0.01673066 0.172242081 94.25 95.10562504 750.403701 0.999378 1.657E-06 0.0021027 9.47223191 147 -0.01673066 0.01724498 94.25 95.07633055 905.782061 0.99903155 5.50044-06 0.0020727 94.25 9.3300039 149 -0.01673066 0.023459866 94.25 95.65286501 338.62586 0.99912647 5.0002842 9.5337028 150 -0.01673066 0.155440557 94.25 94.25 95.3276740 99912747 1.11784-0 0.0021763 94.258 95.3772476 0.99931477 1.11784-0 0.0021703 94.25 95.5774918 676.678931 0.9991798 5.6007E-00 0.0021763 94.3286073 157 -0.01673066 0.16457283 94.25 95.0397229 540.05186 0.9991476 3.89226E-00 0.0021747 95.3366073 156 -0.01673066 0.16457283 94.25 95.03977227 540.056883 0.999147	142	-0.01673086	0.216574586	94.25	95.74328177	1007.4209	0.99916431	5.00418E-06	0.00931801	95.4361413
144 -0.01673086 0.158445447 94.25 95.0245574 56.456279 0.99926679 2.7776E-06 0.0031053 94.8777434 146 -0.01673086 0.177294988 94.25 95.056204 75.040210 99935841 1.1182E-06 0.0031053 94.8777434 147 -0.01673086 0.17673066 0.17637466 0.1035472 95.4220775 148 -0.01673086 0.16345786502 94.25 95.5685613 36.822586 0.99912862 2.47823147 6.101673086 0.0028138 5.597728 150 -0.01673086 0.136540537 94.25 95.4680663 73.135764 0.9991873 3.8078E-06 0.0021703 94.25 95.183148 151 -0.01673086 0.13624295 94.25 95.4374146 676.678031 0.9991798 5.5607E-06 0.0020703 94.8495824 155 -0.01673086 0.16457283 94.25 95.33772297 540.059185 0.9991476 3.89221E-06 0.0021714 95.336073 156 -0.01673086 0.166457283	143	-0.01673086	0.191659195	94.25	95.57149015	908.868818	0.99923937	3.89185E-06	0.0072468	95.294396
146 -0.0167308 0.17224088 94.25 94.8087901 64.774320 0.9993781 1.1182-06 0.0031053 94.87241 147 -0.01673086 0.211157441 94.25 95.70593055 905.7722061 0.99903115 55.6094E-06 0.00023472 95.4297775 148 -0.01673086 0.19335601 94.25 95.66285591 33.82584 0.9912647 50.0437E-06 0.0002747 95.735078 150 -0.01673086 0.155640537 94.25 95.62285491 35.815764 0.9911676 3.82025E-06 0.00021703 94.4988244 151 -0.01673086 0.130520895 94.25 95.50774918 676.679310 0.9990893 5.00466E-06 0.00020703 94.4988244 154 -0.01673086 0.13027303 94.25 95.5007719 54.059140 0.9990893 5.00466E-06 0.0002703 94.4988244 154 -0.01673086 0.130257726 94.25 95.5007919 0.9990893 5.0046E-06 0.0002703 94.498244 154 -0.01673086	144	-0.01673086	0.155845947	94.25	95.32455781	854.568279	0.99928679	2.77976E-06	0.00517604	95.0640187
147 -0.0167308 0.10729980 94.25 94.3639990 647.7342.22 0.993304115 5.56094-26 0.00027027 94.722151 148 -0.01673086 0.1993356022 94.25 95.509907280 0.99912962 4.44322-06 0.0028296 95.3390039 149 -0.01673086 0.181013275 94.25 95.4890863 735.13574 0.99912647 5.00437-06 0.00051763 95.7373958 151 -0.01673086 0.130520865 94.25 95.509420 0.9993147 1.11184-06 0.000724717 95.2739588 151 -0.01673086 0.130520865 94.25 95.57674918 67678931 0.99907998 5.5607E-06 0.0013542 95.3324460 154 -0.01673086 0.1325255 94.25 95.3007919 63.491574 0.99907998 5.5607E-06 0.0013542 95.3324460 158 -0.01673086 0.132527505 94.25 95.00524455 43.49174 0.999049176 3.89212-06 0.0013764 9.8609571 158 -0.01673086 0.19355716	145	-0.01673086	0.124224081	94.25	95.10652504	750.403701	0.999378	1.6677E-06	0.00310534	94.8///434
148 0.01673086 0.19535602 9425 95.095767 855.91236 0.993212647 0.44852266 0.0023128 0.4485216 0.0023128 0.4485216 0.0023128 0.4485216 0.0023128 0.4485216 0.0023128 0.4485216 0.0031128 0.0031138 95.3301317 0.0031138 95.3301317 0.0031138 95.3301317 0.00137768 0.0002703 94.25 95.3231415 617.315740 0.9991127647 0.00137768 0.00137763 95.1351348 152 0.01673086 0.13073030 9425 95.5007719 63.646875 0.9990938 5.5007760 0.0002147 95.3366073 156 0.01673086 0.18663255 9425 95.0037249 40.999041766 3.82216-00 0.0021474 94.386674 158 0.01673086 0.128277505 9425 95.0032445 453.45722 0.9993204 1.11187E-06 0.0021763 94.886894 160 0.01536921 0.30580739 92.54 95.0032445 453.45722 0.9993204 1.11187E-06 0.0021763 94.886934 <td>140</td> <td>-0.01673086</td> <td>0.107294996</td> <td>94.25</td> <td>94.96979901</td> <td>047.734232</td> <td>0.999335641</td> <td>5.56004E.06</td> <td>0.00207027</td> <td>94.7923191</td>	140	-0.01673086	0.107294996	94.25	94.96979901	047.734232	0.999335641	5.56004E.06	0.00207027	94.7923191
149 -0.01673080 0.203459886 94.25 95.65285591 836.82598 0.99912647 5.00437E-00 0.00931836 96.397726 150 -0.01673080 0.181013275 94.25 95.49808653 735.135764 0.99912626 2.77993E-00 0.00176339 91.183148 151 -0.01673080 0.130520805 94.25 95.14994157 55.464867 0.99931179 1.11847e-06 0.0020703 94.8495824 154 -0.01673080 0.192711991 94.25 95.57874918 676.67831 0.99909383 5.00456-06 0.0031171 95.3660773 156 -0.01673086 0.18655255 94.25 95.39772297 540.059185 0.99914677 2.78001E-06 0.0031167 95.366073 156 -0.01673086 0.18655255 95.39772297 540.059185 0.99914677 2.78001E-06 0.0031167 94.259 95.23344609 469.86443 0.99919677 2.78001E-06 0.00311667 94.227721 1.6678E-06 0.00311667 94.227721 1.6678E-06 0.00311657 94.3227729 1.607864 0.99914677 2.78001E-06 0.0021765 94.23070507 111817	147	-0.01673086	0.211157441	94.25	95.70593055	855 991236	0.99903115	4 44832E-06	0.01033472	95.4297775
150 -0.01673086 0.1810132275 94.25 95.4480.08633 735.135784 0.99918736 3.89205E-06 0.00724717 95.273695 151 -0.01673086 0.155640537 94.25 95.3231415 671.831523 0.99922626 2.77993E-06 0.00017635 95.1183148 152 -0.01673086 0.13271393 94.25 95.02964043 590.590429 0.99933147 1.66778E-0 0.0023703 94.849824 154 -0.01673086 0.182653255 94.25 95.5307919 63.401574 0.9990799 5.50045E-06 0.0021748 94.809824 157 -0.01673086 0.142631775 94.25 95.23344609 469.66443 0.99914766 3.89221E-06 0.0021446 54.3230708 158 -0.01673086 0.1425317755 94.25 95.0024454 54.34572 0.99932044 1.1187E-06 0.0021744 94.869984 160 -0.01536921 0.019853106 94.25 95.0024457 1.388470079 5.6164E-06 0.0018748 94.3023709 161 -0.0153692	140	-0.01673086	0.203459886	94.25	95.65285591	836.82598	0.99912647	5.00437E-06	0.00931836	95.397726
161 -0.01673066 0.156240837 94.25 95.14924157 55.4648977 0.99933147 1.66778E-06 0.0021763 94.249 95.14924157 153 -0.01673066 0.11307333 94.25 95.14924157 55.4648977 0.999331477 1.1114E-06 0.0021703 94.2498244 154 -0.01673066 0.1126711991 94.25 95.530771916 0.99903983 5.0607E-06 0.0021763 95.3366073 156 -0.01673066 0.164557283 94.25 95.3374196 676.078166 3.89221E-06 0.0021763 94.550602551 156 -0.01673066 0.12425177505 94.25 95.0999194 417.234812 0.9991767 2.7001E-06 0.00217637 94.8669954 160 -0.01536921 0.301586039 92.54 94.61943574 1038.00466 0.998341 5.640266 0.01087647 94.3029709 161 -0.01536921 0.301586039 92.54 94.61943574 1038.00466 0.998344 5.6442-06 0.01087643 93.7035573 162 -0.01536921 0.168307912 92.54 94.09569571 622.056446 0.9981649 <td>150</td> <td>-0.01673086</td> <td>0.181013275</td> <td>94.25</td> <td>95.49808653</td> <td>735.135764</td> <td>0.99918736</td> <td>3.89205E-06</td> <td>0.00724717</td> <td>95.2739598</td>	150	-0.01673086	0.181013275	94.25	95.49808653	735.135764	0.99918736	3.89205E-06	0.00724717	95.2739598
152 -0.01673066 0.13052095 94.25 95.14994157 554.64957 0.99934179 1.1114E-06 0.0020703 94.849524 154 -0.01673066 0.1392711991 94.25 95.57874918 676.678931 0.99903798 5.56067E-06 0.0031871 95.3376207 156 -0.01673066 0.16457233 94.25 95.3077297 540.059185 0.99914766 3.8921E-06 0.0031677 94.25 95.233708 156 -0.01673066 0.142631775 94.25 95.2394460 469.666433 0.9991476 7.8078E-06 0.0001567 94.2792727 156 -0.01673066 0.12227505 94.25 95.0993944 417.234812 0.9992744 1.6788E-06 0.00156767 94.2927927 156 -0.01536921 0.1935717 92.45 93.87470079 561.300665 0.998141 1.56426E-06 0.10136627 9.3254793 161 -0.01536921 0.18530512 92.54 93.82516314 550.2994814341 1.56426E-06 0.10136627 93.254944 1.4265125 0.994141 1.66944E-05 0.011087643 93.7035224 1.826586-06 0.01035	151	-0.01673086	0.155640537	94.25	95.3231415	671.831523	0.99922626	2.77993E-06	0.00517635	95.1183148
153 -0.01673066 0.113073303 94.25 95.02940403 590.0290429 0.9990798 5.56077-06 0.01035422 55.322446 155 -0.01673066 0.168653255 94.25 95.53007919 634.91574 0.99907898 5.560675-06 0.0031871 95.3365073 156 -0.01673066 0.1262577505 94.25 95.0394476 0.99917677 2.7801E-06 0.0020703 94.8669943 156 -0.01673066 0.122577505 94.25 95.0052455 453.45722 0.99932094 1.1187E-06 0.0020703 94.8669943 160 -0.01536921 0.301586039 92.54 94.61943574 1038.00466 0.998341 5.84026E-06 0.0103602 93.657174 152 -0.01538921 0.301586039 92.54 94.81943574 1038.00466 0.9984341 5.84026E-06 0.01087483 93.7035573 152 -0.01538921 0.252656644 92.54 94.26969576 692.056446 0.9982055 5.56146-0 0.10187428 93.871734 163 -0.01538921 0.252656644 92.54 94.0569571 692.056446 0.9987433	152	-0.01673086	0.130520895	94.25	95.14994157	554.648957	0.99933147	1.66778E-06	0.00310548	94.9808413
154 -0.01673086 0.18265235 94.25 95.57874918 676.678931 0.99900893 5.6067E-06 0.00931871 95.3360732 156 -0.01673086 0.142631775 94.25 95.23344609 469.666493 0.99919677 2.78001E-06 0.0031057 95.0902551 157 -0.01673086 0.123277505 94.25 95.0939994 417.234812 0.99927274 1.66788E-06 0.00310567 94.9727927 159 -0.01530821 0.30158039 92.54 95.09599994 417.234812 0.9992747 1.66788E-06 0.00310567 43.022709 161 -0.01530621 0.31058079 92.54 94.61943574 103.80466 0.998341 5.6404E-06 0.01037423 93.657137 162 -0.01530621 0.186305039 92.54 94.28068517 623.375107 0.998616 1.111265E-05 0.00271805 94.0295464 163 -0.01530621 0.252456152 92.54 94.28068517 623.3735107 0.9981640 9.39258E-06 0.0072475 93.847028 165 -0.01580624 0.58033749 92.04 94.52174144 122.056846 <td>153</td> <td>-0.01673086</td> <td>0.113073303</td> <td>94.25</td> <td>95.02964043</td> <td>590.590429</td> <td>0.99934179</td> <td>1.11184E-06</td> <td>0.0020703</td> <td>94.8495824</td>	153	-0.01673086	0.113073303	94.25	95.02964043	590.590429	0.99934179	1.11184E-06	0.0020703	94.8495824
155 -0.01673086 0.168652255 94.25 95.5307219 33.491574 0.9990838 5.00456E-06 0.0072474 95.2303706 156 -0.01673086 0.123277505 94.25 95.099984 417.234812 0.99927274 1.66788E-06 0.00310567 94.377227 159 -0.01673086 0.123277505 94.25 95.099984 417.234812 0.99927274 1.66788E-06 0.00310567 94.369944 160 -0.01536921 0.301586039 92.54 94.8194357 1038.00466 0.99834 1.66944E-05 0.0108763 93.20547173 162 -0.01536921 0.13550517 92.54 93.8276134 560.92769 0.9980585 5.66164E-06 0.01037602 93.671974 163 -0.01536921 0.2256266152 92.54 94.28068517 823.735107 0.998616 1.11265E-05 0.02071805 94.025464 164 -0.01536921 0.225252644 92.54 94.2806289671 692.056845 0.99872969 8.34393E-06 0.00724415 93.3407E-05 0.0207130 94.3074056 166 -0.01586648 0.391290154 92.04	154	-0.01673086	0.192711991	94.25	95.57874918	676.678931	0.99907998	5.56067E-06	0.01035422	95.3724446
166 -0.01673086 0.142631725 94.25 95.337/2297 540.054156 0.99914766 3.89221-08 0.00724/46 95.2337/08 157 -0.01673086 0.126317755 94.25 95.0394084 17.23412 0.99914766 3.89221-08 0.00105767 94.9727927 159 -0.01673086 0.139535106 94.25 95.0999844 163.300466 0.99821 1.66944-05 0.0310567 94.302270 161 -0.01536921 0.31586039 92.54 93.8747007 561.350686 0.99881341 5.84026E-06 0.01087483 93.7035573 162 -0.01536921 0.252456152 92.54 94.29068171 692.05846 0.998056 6.001018660 0.0015677 93.8847028 165 -0.01536921 0.252456152 92.54 94.09509571 692.058465 0.99972963 3.8427165 0.00274151 93.351437 166 -0.01568614 0.31990147 92.44 93.60508786 69.99779453 3.8407205 0.05182529 94.137904 166 -0.01686848	155	-0.01673086	0.185653255	94.25	95.53007919	634.91574	0.99908938	5.00456E-06	0.00931871	95.3365073
151 -0.01673060 0.123277605 94.25 95.0394400 463.060433 0.9992274 1.16788 0.0031769 95.0923014 159 -0.01673086 0.123277605 94.25 95.00524455 453.45722 0.9992274 1.11187E-06 0.00207034 94.8669954 160 -0.01536921 0.301586039 92.54 93.82476374 1038.00466 0.9983141 5.84026E-06 0.0108768 93.37035573 162 -0.01536921 0.19857517 92.54 93.82476314 550.92769 0.9980558 5.56164E-06 0.0103602 93.657197 163 -0.01536921 0.2522626644 92.54 94.09569571 692.056846 0.99972963 3.3407E-05 0.00157877 93.847028 166 -0.01686848 0.32992344 92.04 94.52174144 1264.27949 0.9990521 3.3407E-05 0.0161847 93.37352084 166 -0.01686848 0.32993449 92.04 94.2374461 1413.15512 0.9987451 3.4407E-05 0.00127847 93.34737621 176	156	-0.01673086	0.166457283	94.25	95.39772297	540.059185	0.99914766	3.89221E-06	0.00724746	95.2330708
159 -0.01673060 0.19535106 94.25 95.00529845 417.23412 0.998321214 1.010780-06 0.00310607 94.3669994 160 -0.01536921 0.310586039 92.54 94.61943574 1038.00466 0.99834 1.66944E-05 0.03108677 94.3029709 161 -0.01536921 0.186390593 92.54 93.82516314 550.92769 0.9986161 1.1126E-05 0.0207105 94.295644 162 -0.01536921 0.2256264612 92.54 94.2906817 622.373107 0.998616 1.1126E-05 0.02071805 94.0295644 164 -0.015636921 0.22562644 92.54 94.2806817 822.73107 0.9986164 1.1126E-05 0.02071805 94.0295444 166 -0.01666848 0.391920154 92.04 94.307461414 1264.27949 0.99805221 3.840728 93.037022 167 -0.01666848 0.328920401 92.04 94.3026821 109513865 0.9981740 2.2831E-05 0.0414547 93.735222 170 -0.01686848 0.238472165 92.04 93.3685878 692.734985 0.998717 <td< td=""><td>157</td><td>-0.01673086</td><td>0.142631775</td><td>94.25</td><td>95.23344609</td><td>469.666493</td><td>0.99919677</td><td>2.78001E-06</td><td>0.0051765</td><td>95.0902551</td></td<>	157	-0.01673086	0.142631775	94.25	95.23344609	469.666493	0.99919677	2.78001E-06	0.0051765	95.0902551
160 0.01536821 0.301586039 92.54 94.6194357 1038.0046 0.9981341 1.66944E-05 0.03108667 94.3029709 161 -0.01536821 0.19357517 92.54 93.87470079 561.350658 0.99801341 5.8402E-06 0.01087483 93.7035573 162 -0.01536821 0.22562644 93.8251614 500.27669 0.9980161 1.1126E-05 0.02071805 94.209444 164 -0.01536821 0.225626644 92.54 94.8086817 823.735107 0.998616 1.1126E-05 0.02071805 93.847028 166 -0.01568621 0.225626644 92.54 93.60828908 470.378685 0.999779453 3.3407E-05 0.06220533 94.3071056 166 -0.01686848 0.33993494 92.04 94.52174144 1264.27949 0.9980374 1.66941E-05 0.0018614 93.3735222 170 -0.01686848 0.23492165 92.04 93.6847022 61.8984509 0.998377 1.1127E-05 0.0201814 93.3735222 170 -0.01686648 <td>150</td> <td>-0.01673086</td> <td>0.123277505</td> <td>94.25</td> <td>95.0999964</td> <td>417.234012</td> <td>0.99927274</td> <td>1.00788E-00</td> <td>0.00310307</td> <td>94.9727927</td>	150	-0.01673086	0.123277505	94.25	95.0999964	417.234012	0.99927274	1.00788E-00	0.00310307	94.9727927
161 0.01536821 0.19357517 92.54 93.87470079 561350658 0.99881341 5.84026E-06 0.01087483 93.7035573 162 0.01536921 0.186300593 92.54 93.82516314 550.92769 0.9980558 5.56144-06 0.01035002 93.657197 164 0.01536921 0.252466152 92.54 94.20068171 692.056846 0.99907548 3.3433E-06 0.0105707 93.8847028 166 -0.01686848 0.391290154 92.04 94.52174144 1264.27949 0.9990349 2.2831E-05 0.016184747 93.37325084 166 -0.01686848 0.329932401 92.04 94.52174144 1264.27949 0.9990349 2.2831E-05 0.01618478 93.37325084 166 -0.01686848 0.23493179 92.04 94.3659041 969.74995 0.9983577 1.6941E-05 0.00185447 93.3732522 170 -0.01686848 0.214489398 92.04 93.34231529 883.50648 9.9983717 1.1127E-05 0.002071897 93.1474761 171 </td <td>160</td> <td>-0.01536921</td> <td>0.301586039</td> <td>92.54</td> <td>94.61943574</td> <td>1038.00466</td> <td>0.99834</td> <td>1.66944E-05</td> <td>0.03108567</td> <td>94.3029709</td>	160	-0.01536921	0.301586039	92.54	94.61943574	1038.00466	0.99834	1.66944E-05	0.03108567	94.3029709
162 -0.01536921 0.168309533 92.54 93.82516314 550.92769 0.99800558 5.56164E-06 0.01035602 93.6571974 163 -0.01536921 0.25526644 92.54 94.2086517 652.056846 0.9987268 8.343392-06 0.00724157 93.8847028 165 -0.0156821 0.1686848 0.391290154 92.04 94.73794561 1413.15512 0.99972453 3.3407E-05 0.00724157 93.847028 166 -0.01686848 0.3391990154 92.04 94.52171414 1264.27949 0.99805241 2.78325E-05 0.05182529 94.1362904 168 -0.01686848 0.23893344 92.04 94.309021 1995.13865 0.9987149 1.1127E-05 0.001185379 93.4747861 171 -0.01686848 0.23872165 92.04 93.35189044 548.880539 0.9987117 8.34408E-06 0.01553705 93.3405844 173 -0.01686848 0.182061206 92.04 93.25383029 44.944618 0.9989203 44.44082-06 0.0015727 93.405844 </td <td>161</td> <td>-0.01536921</td> <td>0.19357517</td> <td>92.54</td> <td>93.87470079</td> <td>561.350658</td> <td>0.99881341</td> <td>5.84026E-06</td> <td>0.01087483</td> <td>93.7035573</td>	161	-0.01536921	0.19357517	92.54	93.87470079	561.350658	0.99881341	5.84026E-06	0.01087483	93.7035573
163 -0.01536921 0.225426152 92.54 94.2966817 823.735107 0.9986716 1.11265E-05 0.20271805 94.0295644 164 -0.01536921 0.225626644 92.54 93.68028908 479.376855 0.99967127 3.38258E-06 0.00724815 93.5354137 166 -0.01686848 0.33993944 92.04 94.73794561 1413.15512 0.9987573 3.3407E-05 0.06220533 94.3071056 167 -0.01686848 0.329092401 92.04 94.3090921 1095.13865 0.99816409 2.22631E-05 0.04145487 93.3735222 170 -0.01686848 0.238972165 92.04 93.36189045 884.808053 0.9985171 8.147650 0.00178797 93.3475844 171 -0.01686848 0.188878214 92.04 93.34231529 484.895039 0.9987171 8.34408E-06 0.0103568 93.194852 173 -0.01686848 0.188878214 92.04 93.2533029 424.944618 0.9989203 44.492E-06 0.00032062 93.142441 174	162	-0.01536921	0.186390593	92.54	93.82516314	550.92769	0.99890558	5.56164E-06	0.01035602	93.6571974
164 -0.01536921 0.22626644 92.54 94.0950971 692.056846 0.99972969 8.3393E-06 0.01563677 93.8847028 166 -0.01568021 0.16537917 92.64 93.6020808 473.79665 0.999729453 3.8025E-06 0.00724815 93.534137 166 -0.01666848 0.39933494 92.04 94.52174144 1264.27949 0.99903494 2.2831E-05 0.016184747 93.3752084 168 -0.01666848 0.329092401 92.04 94.00468322 889.408044 0.2998357 1.66941E-05 0.00161847 93.37352224 170 -0.01666848 0.214489398 92.04 93.34231529 483.570548 0.99835717 1.1127E-05 0.002071897 93.1447861 171 -0.01686848 0.18087214 92.04 93.34231529 483.570548 0.99835717 8.3400564 0.01055605 0.03108514 93.1948852 173 -0.01686848 0.1370002 92.04 93.25383029 424.944618 0.99892003 4.44925E-06 0.00027472 93.1948852	163	-0.01536921	0.252456152	92.54	94.28068517	823.735107	0.998616	1.11265E-05	0.02071805	94.0295464
165 -0.01536921 0.165379127 92.54 93.680228008 479.378685 0.9997221 3.89258E-06 0.00724115 93.534137 166 -0.01686848 0.359933494 92.04 94.7374661 1413.1512 0.99779453 3.3407E05 0.00224015 93.63437 166 -0.01686848 0.329902401 92.04 94.309021 1095.13865 0.9980521 1.66941E-05 0.0314847 93.9752084 160 -0.01686848 0.23872165 92.04 93.68598578 692.734995 0.99857179 1.1127E-05 0.0021814 93.34747861 171 -0.01686848 0.18878214 92.04 93.3495344 884.89539 0.9987117 8.34408E-06 0.01553705 93.3405844 173 -0.01686848 0.18706120 92.04 93.25533029 424.944618 0.9989203 4.44925E-06 0.001274872 93.062354 176 -0.01686848 0.156704021 92.04 93.13508736 373.31330 0.9990088 3.3864E-06 0.0002127 93.0212516 177	164	-0.01536921	0.225626644	92.54	94.09569571	692.056846	0.99872969	8.34393E-06	0.01553677	93.8847028
166 0.01686848 0.339932044 92.04 94.73794561 1413.15512 0.9980344 2.245 94.307105 0.06220533 94.307105 168 -0.01686848 0.33993244 92.04 94.3090921 1095.13865 0.99816409 2.22631E-05 0.06142529 94.3071058 170 -0.01686848 0.23872165 92.04 93.8658578 692.739455 0.998357 1.66941E-05 0.03108514 93.3735222 171 -0.01686848 0.21827165 92.04 93.36189044 544.88553 0.9985717 8.147E-05 0.001797 93.3476844 172 -0.01686848 0.182061206 92.04 93.25331202 464.89530 0.9988717 8.3408E-06 0.00153705 93.3405844 173 -0.01686848 0.182061206 92.04 93.25331202 464.8982407 0.9988713 8.3408E-06 0.0002247 93.124274 175 -0.01686848 0.15886315 92.04 93.3685847 33.365447 33.246744 176 -0.01686848 0.158823403 <	165	-0.01536921	0.165379127	92.54	93.68028908	479.378685	0.99905221	3.89258E-06	0.00724815	93.534137
167 -0.01686848 0.339933494 92.04 94.201494 1294.27949 0.99803494 2.7332b-15 0.01182229 94.135294 168 -0.01686848 0.329052401 92.04 94.302021 1955.13865 0.9981547 2.22631E-05 0.0414547 93.3752084 169 -0.01686848 0.23493175 92.04 93.68598578 692.734995 0.998357 1.66941E-05 0.03108514 93.37352224 170 -0.01686848 0.214489398 92.04 93.34231529 483.570548 0.9983171 8.34400E-06 0.01553705 93.3405844 172 -0.01686848 0.13205120 93.34231529 483.570548 0.9988308 5.55206E-06 0.00153705 93.1942852 173 -0.01686848 0.16045002 92.04 93.25383029 424.944618 0.99882003 4.44925E-06 0.00022487 93.1623744 176 -0.01686848 0.158823403 92.04 93.17910423 3565.761 0.9990545 2.7804E-06 0.000271672 93.0623524 178 -0.01	166	-0.01686848	0.391290154	92.04	94.73794561	1413.15512	0.99779453	3.3407E-05	0.06220533	94.3071056
168 0.01686848 0.32992401 92.04 94.004821 1095.13865 0.99816409 22.251E-05 0.0414547 93.972.048 169 -0.01686848 0.284943179 92.04 94.0048222 889.08044 0.998357 1.66941-05 0.3018514 93.335222 170 -0.01686848 0.23472165 92.04 93.5189044 584.889539 0.99851767 1.1127E-05 0.02071897 93.4747681 171 -0.01686848 0.18878214 92.04 93.32531202 461.892864 0.99887178 5.5520E-06 0.00032062 93.144274 173 -0.01686848 0.176045002 92.04 93.25531202 461.892840 0.99889141 5.0559E-06 0.00032062 93.14274 176 -0.01686848 0.156596651 92.04 93.15308763 73.381339 0.9990098 3.3364E-06 0.00072472 93.062354 177 -0.01686848 0.15070021 92.04 93.0740423 356.571 0.9990098 3.3364E-06 0.0007272 92.970392 22.8747077	167	-0.01686848	0.359933494	92.04	94.521/4144	1264.27949	0.99803494	2.78325E-05	0.05182529	94.1362904
109 0.01686848 0.23872165 92.04 93.6858268 692.74985 0.9985717 1.038712-05 0.03106119 93.733222 171 -0.01686848 0.23872165 92.04 93.8199044 584.898530 .9985717 8.34408E-06 0.01553705 93.3472861 172 -0.01686848 0.182061206 92.04 93.2533202 481.870548 0.99887117 8.34408E-06 0.01553705 93.3405844 173 -0.01686848 0.182061206 92.04 93.22333029 424.944618 0.99882003 44.4925E-06 0.00032062 93.154491 174 -0.01686848 0.165806815 92.04 93.13508736 373.381339 0.9990703 4.44925E-06 0.0022477 93.124274 176 -0.01686848 0.158823403 92.04 93.0364771 33.3508761 0.99907083 2.33664E-06 0.00021277 93.0212516 178 -0.01686848 0.1452484 92.04 92.96613751 307.227116 0.99901802 1.6814E-06 0.00014171 2.934877 180 <td>100</td> <td>-0.01000040</td> <td>0.329092401</td> <td>92.04</td> <td>94.3090921</td> <td>1095.13005</td> <td>0.99616409</td> <td>2.22031E-05</td> <td>0.04145467</td> <td>93.9752064</td>	100	-0.01000040	0.329092401	92.04	94.3090921	1095.13005	0.99616409	2.22031E-05	0.04145467	93.9752064
171 -0.01686848 0.214489398 92.04 93.5189044 584.89539 0.9987117 8.34408E-06 0.01553705 93.3405844 172 -0.01686848 0.182081201 93.3190485 582.69539 0.9987117 8.34408E-06 0.01553705 93.3405844 173 -0.01686848 0.182061201 92.04 93.2513022 46.825646 0.9988308 5.56206E-06 0.0012056 93.1948852 174 -0.01686848 0.16045002 92.04 93.2533029 42.494618 0.99882003 4.44925E-06 0.0022487 93.124274 175 -0.01686848 0.158823403 92.04 93.1350873 373.31389 0.9990545 2.7804E-06 0.000274872 93.0623524 178 -0.01686848 0.134175129 92.04 93.057713 307.227116 0.9991760 1.11203E-06 0.00021297 93.0623524 178 -0.01686848 0.134175129 92.04 92.96513751 307.227116 0.9991706 1.11203E-06 0.00021706 92.7953517 166814E-06 0.00310615	170	-0.01080848	0.204943179	92.04	94.00408322	692 734995	0.998337	1 1127E-05	0.03108514	93.73332222
172 0.01686848 0.188878214 92.04 93.34231529 483.570548 0.99883088 5.56206E-06 0.0103568 93.1948852 173 0.01686848 0.182061206 92.04 93.292531202 461.892864 0.99883088 5.56206E-06 0.0033668 93.154491 174 -0.01686848 0.165096015 92.04 93.25833029 24.944618 0.99882017 5.00559E-06 0.00932622 93.154491 175 -0.01686848 0.165896815 92.04 93.13508736 373.381339 0.9990098 3.33664E-06 0.00621297 93.0623524 176 -0.01686848 0.150704021 92.04 93.07910423 356.5761 0.9990098 3.33664E-06 0.00611297 93.0212516 177 -0.01686848 0.134175129 92.04 93.03649877 33.319386 0.99911802 1.66814E-06 0.0031615 92.8714707 178 -0.01686848 0.38313274 92.04 92.65409803 713.22473 0.99923574 5.5598E-07 0.00103526 92.890655 18	170	-0.01686848	0.214489398	92.04	93.5189044	584.889539	0.9987117	8.34408E-06	0.01553705	93.3405844
173 -0.01686848 0.182061206 92.04 93.29531202 461.892844 0.9988417 5.00559E-06 0.00932062 93.124274 174 -0.01686848 0.176045002 92.04 93.2583029 424.944618 0.99892003 4.44925E-06 0.0082847 93.124274 175 -0.01686848 0.165896815 92.04 93.1350876 373.38139 0.9989748 3.3824E-06 0.0072472 93.023524 176 -0.01686848 0.1550704021 92.04 93.13508763 373.381339 0.9990098 3.3364E-06 0.0062127 93.0212516 177 -0.01686848 0.14452444 92.04 93.03649877 333.131368 0.99907507 2.2424E-06 0.001117 92.970392 178 -0.01686848 0.14452444 92.04 92.8643671 30.7227116 0.99901802 1.8614E-06 0.00310615 92.8714707 180 -0.01686848 0.03804252 92.04 92.65409803 2.1329673 0.9991802 3.3568E-05 0.0621855 94.2804665 182	172	-0.01686848	0.188878214	92.04	93.34231529	483.570548	0.99883088	5.56206E-06	0.0103568	93.1948852
174 -0.01686848 0.176045002 92.04 93.2583.029 424.944618 0.99892003 44.4925E-06 0.0082847 93.124274 175 -0.01686848 0.1558923403 92.04 93.13836854 398.54007 0.9989718 3.8288E-06 0.00724872 93.0623524 176 -0.01686848 0.155823403 92.04 93.13508736 373.381339 0.99900845 2.3764E-06 0.00621297 93.02212516 177 -0.01686848 0.1457124 92.04 93.0369477 33.33868 0.99907505 2.2242826 0.0001117 22.970392 178 -0.01686848 0.14457129 92.04 92.96513751 307.227116 0.9991706 1.1203E-06 0.0002106 92.7953517 181 -0.01686848 0.33614274 92.04 92.6850802 213.2673 0.9991706 1.11203E-06 0.0020706 92.7953517 181 -0.01686848 0.3361274 92.04 94.686170024 129111884 0.9991705 3.3366E-05 0.0021852 92.89068547 1.85018207 0.00	173	-0.01686848	0.182061206	92.04	93.29531202	461.892864	0.99888417	5.00559E-06	0.00932062	93.154491
175 -0.01686848 0.165896815 92.04 93.13836584 398.5407 0.99897418 3.89288-06 0.0072472 93.0623524 176 -0.01686848 0.158823403 92.04 93.13306736 373.81339 0.9990084 3.33642-06 0.0072472 93.0212516 177 -0.01686848 0.14527424 93.03649877 333.31936 0.9990507 2.22428E-06 0.00517722 92.970392 178 -0.01686848 0.134175129 92.04 93.03649877 333.19368 0.99907507 2.22428E-06 0.00011015 92.8714707 180 -0.01686848 0.12235546 92.04 92.8656848 2.9997507 1.11203-06 0.00207066 92.7953517 181 -0.01686848 0.38013274 92.04 92.6840037 1182.02673 9.99923574 5.5598E-07 0.0013526 92.5890685 182 -0.01686848 0.3811227 92.04 94.2656391 1030.92541 9.9982352 2.2616E-55 0.05118129 94.351017 184 -0.01686848 0.32429138 <td>174</td> <td>-0.01686848</td> <td>0.176045002</td> <td>92.04</td> <td>93.25383029</td> <td>424.944618</td> <td>0.99892003</td> <td>4.44925E-06</td> <td>0.0082847</td> <td>93.124274</td>	174	-0.01686848	0.176045002	92.04	93.25383029	424.944618	0.99892003	4.44925E-06	0.0082847	93.124274
176 -0.01686848 0.158023403 92.04 93.13508736 373.381339 0.9990098 3.33664E-06 0.00021297 93.0212516 177 -0.01686848 0.150704021 92.04 93.0740423 356.5761 0.9990098 2.7804E-06 0.0001172 22.970392 178 -0.01686848 0.14452484 92.04 93.03649677 333.319368 0.99907507 2.22428E-06 0.0041171 92.970392 178 -0.01686848 0.14452484 92.04 92.98513751 307.227116 0.99911802 1.6814E-06 0.00310515 92.8714707 180 -0.01686848 0.038064253 92.04 92.68540868 0.9991706 3.33965E-05 0.0021826 92.88746707 181 -0.01686848 0.3561247782 92.04 92.68540871 122014202 0.99810718 3.33965E-05 0.0621855 94.2880665 183 -0.01686848 0.321429138 92.04 94.25625391 103.092541 0.99850547 1.6694E-05 0.0310484 93.724731 186 -0.01686848	175	-0.01686848	0.165896815	92.04	93.18385854	398.54007	0.99897418	3.89288E-06	0.00724872	93.0623524
177 -0.01666848 0.14572444 92.04 93.054977 3356.5761 0.9990545 2.7804E-06 0.00517722 92.970392 178 -0.01666848 0.14457444 92.04 93.054977 333.13868 0.99907507 2.22428E-06 0.0041171 92.934877 179 -0.01666848 0.14157129 92.04 92.96613751 307.227116 0.99901706 1.11203E-06 0.00207066 92.7953517 180 -0.01666848 0.03804253 92.04 92.68409803 213.26673 0.99921574 5.5598E-07 0.00103526 92.7953517 181 -0.01666848 0.336142742 92.04 94.686170024 129111884 0.99910761 3.33965E-05 0.06218559 92.484280665 183 -0.01666648 0.321429138 92.04 94.49548037 1182.04202 0.99810718 3.33965E-05 0.061145212 93.4914974 185 -0.01666648 0.2321429138 92.04 93.2652591 1030.92541 0.99825057 1.01278E-05 0.0214888 93.7264751 680.75671	176	-0.01686848	0.158823403	92.04	93.13508736	373.381339	0.9990098	3.33664E-06	0.00621297	93.0212516
1/8 -0.01686848 0.144452484 92.04 93.0364987/3 33.3133868 0.9991/507 2.24282-06 0.00414171 92.94887/1 179 -0.01686848 0.134175129 92.04 92.96837/51 307.22116 0.9991100 1.66814-06 0.003105 92.8714707 180 -0.01686848 0.12235946 92.04 92.88366848 289.67888 0.9991706 1.11203E-06 0.00207066 92.7953517 181 -0.01686848 0.38016223 92.04 92.66409803 213.29673 0.99923574 5.5598E-07 0.00103526 92.5890685 182 -0.01686848 0.336124782 92.04 94.49548037 1182.04202 0.99810718 3.3366555 0.05181929 94.1351017 184 -0.01686848 0.326124782 92.04 93.26525311 1030.92541 0.99823023 2.22616E-05 0.04145212 9.9419474 185 -0.01686848 0.2222518595 92.04 93.56228805 593.428653 0.99830534 1.11278E-05 0.00072039 93.5045826 <td< td=""><td>177</td><td>-0.01686848</td><td>0.150704021</td><td>92.04</td><td>93.07910423</td><td>356.5761</td><td>0.99905845</td><td>2.7804E-06</td><td>0.00517722</td><td>92.970392</td></td<>	177	-0.01686848	0.150704021	92.04	93.07910423	356.5761	0.99905845	2.7804E-06	0.00517722	92.970392
1/19 0.01686648 0.1235946 92.04 92.9561373 0.0122116 0.99911602 1.160814E-06 0.00310615 92.04 92.88365848 290.71201 1.10203E-06 0.00310615 92.04 1.01203E-06 0.00310615 92.04 1.01203E-06 0.00310615 92.04 1.01203E-06 0.00310615 92.04 1.01203E-06 0.00310615 92.04 1.01203E-07 0.00103526 92.8836565 1.0212111884 0.99815052 2.7529E-07 0.00103526 92.8836655 92.04 94.68170024 129111884 0.99815052 2.7529E-05 0.0511859 94.2880655 11030.92541 0.99815052 2.72829E-05 0.0511859 94.2880655 93.9418474 185 -0.016866848 0.3227344 92.04 93.7126571 16030.92541 0.99830554 1.11278E-05 0.0130848 93.9418474 186 -0.016866848 0.2227344 92.04 93.716671 680.876633 0.9985054 1.11278E-05 0.010270239 93.3024825 186 -0.016866848 0.2248265 92.04 93.36204825	178	-0.01686848	0.14452484	92.04	93.03649877	333.319368	0.99907507	2.22428E-06	0.00414171	92.934877
180 -0.01686648 0.089064253 92.04 92.6850646 229.07866 0.99923574 121205-03 0.00201606 92.785311 181 -0.01686648 0.089064253 92.04 92.68509685 1291.01884 0.99923574 5.55986-07 0.0010366 92.28509685 182 -0.01686848 0.38513274 92.04 94.468170024 1291.11884 0.99923575 5.759826 0.06218655 94.2800665 183 -0.01686848 0.3521429138 92.04 94.25625391 1030.92541 0.99836547 1.6694E-05 0.03108488 93.7264731 186 -0.01686848 0.242518595 92.04 93.761761 60.8767683 0.99836547 1.6694E-05 0.03108488 93.7264731 186 -0.01686848 0.242518595 92.04 93.356298605 99.9856547 1.6694E-05 0.03108488 93.7264731 186 -0.01686848 0.242518595 92.04 93.356298605 99.9865645 1.9847640 0.0153355 93.3204232 188 -0.01686848 0.1945	1/9	-0.01000040	0.1341/5129	92.04	92.90313/31	200 67000	0.99911602	1.00014E-00	0.00310615	92.07 14707
181 0.01686648 0.38313274 92.04 94.68170024 1291.1844 0.99810718 3.33965-05 0.0010326 92.059008 183 -0.01686648 0.38313274 92.04 94.68170024 1291.1844 0.99810718 3.33965-05 0.0011326 94.3820665 183 -0.01686848 0.356124782 92.04 94.49548037 1182.04202 0.9981058 2.78292E-05 0.06181299 94.1351017 184 -0.01686848 0.32227344 92.04 93.89595754 851.108842 0.99830547 1.6694-05 0.00144868 93.724731 186 -0.01686848 0.22227344 92.04 93.71216571 680.872693 0.99850354 1.11278E-05 0.0027029 93.5045826 186 -0.01686848 0.2242518595 92.04 93.36629805 93.482653 0.99870853 8.34478E-06 0.0105335 93.3820482 188 -0.01686848 0.194355342 92.04 93.3060808 449.77379 0.99878545 4.44983E-06 0.0032156 93.22866666 190 <td>181</td> <td>-0.01686849</td> <td>0.12230940</td> <td>92.04</td> <td>92.00300040</td> <td>209.07000</td> <td>0.9991700</td> <td>5 5598E-07</td> <td>0.00207000</td> <td>92.7900017</td>	181	-0.01686849	0.12230940	92.04	92.00300040	209.07000	0.9991700	5 5598E-07	0.00207000	92.7900017
183 -0.01686848 0.356124782 92.04 94.49548037 1182.04202 0.99815058 2.78292-05 0.05181929 94.1351017 184 -0.01686848 0.32612933 92.04 94.25625391 1030.92541 0.99815058 2.782922-05 0.05181929 94.1351017 184 -0.01686848 0.321227344 92.04 93.9859575 851.108842 0.99836547 1.6694E-05 0.014145212 93.9419474 185 -0.01686848 0.22227344 92.04 93.71216571 680.872693 0.99850554 1.11278E-05 0.0210209 93.3045826 187 -0.01686848 0.2242518595 92.04 93.5629805 593.482653 0.99862826 8.34478E-06 0.0105335 93.3024252 188 -0.01686848 0.194355342 92.04 93.362042632 493.77379 0.9987694 5.5624E-06 0.0103574 93.3420851 188 -0.01686848 0.194355342 92.04 93.30624232 432.066853 0.99878953 4.44983E-06 0.00032156 93.2286966	182	-0.01686848	0.38313274	92.04	94.68170024	1291.11884	0.99810718	3.33965E-05	0.06218585	94.2880665
184 -0.01686848 0.321429138 92.04 94.25625391 1030.92541 0.99823023 2.22616E-05 0.04145212 93.9419474 185 -0.01686848 0.22227344 92.04 93.98695754 851.108842 0.998236547 16.694E-05 0.03108488 93.7264731 186 -0.01686848 0.242518595 92.04 93.761761 680.87683 0.998536547 16.694E-05 0.03108488 93.7264731 187 -0.01686848 0.242518595 92.04 93.76268630 998503548 1.11278E-05 0.01053355 93.30264252 188 -0.01686848 0.194555342 92.04 93.36024263 0.9987694 5.5624E-06 0.0103744 93.22289566 189 -0.01686848 0.191504615 92.04 93.30622392 433.066835 0.99878953 5.6624E-06 0.00032516 93.2286966 190 -0.016866848 0.191504615 92.04 93.30522959 93.3037378 0.99878953 4.44983E-06 0.0082876 93.1853188 191 -0.016866848 <t< td=""><td>183</td><td>-0.01686848</td><td>0.356124782</td><td>92.04</td><td>94.49548037</td><td>1182.04202</td><td>0.99815058</td><td>2.78292E-05</td><td>0.05181929</td><td>94.1351017</td></t<>	183	-0.01686848	0.356124782	92.04	94.49548037	1182.04202	0.99815058	2.78292E-05	0.05181929	94.1351017
185 -0.01686848 0.282227344 92.04 93.98595754 851.108842 0.99836547 1.6694E-05 0.03108488 93.7264731 186 -0.01686848 0.242518595 92.04 93.71216571 680.872633 0.99850354 1.11278E-05 0.02072039 93.5045826 187 -0.01686848 0.242082967 92.04 93.56458265 593.482653 0.99850354 1.11278E-05 0.02072039 93.5045826 188 -0.01686848 0.194365542 92.04 93.3604242 432.066853 0.99878453 5.5624E-06 0.01035744 93.2426539 189 -0.01686848 0.191504615 92.04 93.30522959 393.307378 0.99878543 5.00609E-06 0.0032156 93.2286966 190 -0.01686848 0.133499578 92.04 93.30522959 393.307378 0.9987853 4.44983E-06 0.0082878 93.1853188 191 -0.01686848 0.133499578 92.04 93.30522959 393.307378 0.9987853 4.44983E-06 0.0082878 93.1853188	184	-0.01686848	0.321429138	92.04	94.25625391	1030.92541	0.99823023	2.22616E-05	0.04145212	93.9419474
186 -0.01686848 0.242518595 92.04 93.71216571 680.872693 0.99850354 1.11278E-05 0.02072039 93.5045826 187 -0.01686848 0.220882967 92.04 93.56298805 593.482653 0.99850354 1.11278E-05 0.02072039 93.5045826 188 -0.01686848 0.194355342 92.04 93.36020805 493.7709 0.99876945 6.34478E-06 0.0105335 93.3820482 189 -0.01686848 0.191504615 92.04 93.36042432 432.066853 0.99878453 5.00609E-06 0.0032156 93.2286966 190 -0.01686848 0.134399578 92.04 93.30522595 93.307378 0.99878953 4.44983E-06 0.0082878 93.1853188 191 -0.01686848 0.1735177 0.92877895 39.307378 0.99878953 4.44983E-06 0.0082878 93.1853188 191 -0.01686848 0.17351777 0.9287789 3.8937406 0.99878953 4.44983E-06 0.0082878 93.1853188	185	-0.01686848	0.282227344	92.04	93.98595754	851.108842	0.99836547	1.6694E-05	0.03108488	93.7264731
187 -0.01666648 0.22082267 92.04 93.56228805 593.482653 0.99862826 8.34478E-06 0.01553835 93.38204825 188 -0.01666648 0.194355342 92.04 93.38008008 449.773709 0.9987694 5.5624E-06 0.0103574 93.3242452 189 -0.01666648 0.191504615 92.04 93.36024232 432.066853 0.99873943 5.00609E-06 0.00032156 93.2286966 190 -0.01666648 0.13195074615 92.04 93.30522959 93.307378 0.99873953 4.44983E-06 0.00082876 93.1853188 191 -0.01666648 0.17394177 0.904 93.30522959 93.307378 0.99873953 4.44983E-06 0.00082876 93.1853188 191 -0.01666648 0.17394177 0.904 0.32451762 3.2932405 3.89324052 3.893240523 3.893240523 3.893240525 3.8932405255 3.8932405255 3.8932405255 3.8932405255 3.8932405255 3.893240555 3.893240555 3.8932405555 3.8932405555 3.8932405555 3.8	186	-0.01686848	0.242518595	92.04	93.71216571	680.872693	0.99850354	1.11278E-05	0.02072039	93.5045826
188 -U.01868648 U.194365342 92.04 93.38008008 449.773709 0.9987634 5.5624E-06 0.01035744 93.2429539 189 -0.01686848 0.191504615 92.04 93.36042432 432.066853 0.99876348 5.0609E-06 0.00932156 93.2286966 190 -0.01686848 0.183499578 92.04 93.30522953 393.307378 0.99878953 4.44983E-06 0.00828578 93.1853188 191 -0.01686848 0.175361787 92.04 93.30522953 352.05406 0.09878578 3.8937406 0.00828578 93.1853188 191 -0.01686848 0.175361787 92.04 93.24011952 372.56406 0.0987578 3.8937406 0.00828578 93.1853188 191 -0.01686848 0.175361787 92.04 93.24011952 372.56406 0.0987578 3.8937406 0.00974056 0.2155792	187	-0.01686848	0.220882967	92.04	93.56298805	593.482653	0.99862826	8.34478E-06	0.01553835	93.3820482
189 -UUTB66648 U.T3FJU4615 92.04 93.30642432 432.066853 U.99878953 4.44983E-06 0.00932156 93.2286966 190 -0.01686848 0.183499578 92.04 93.30522959 393.307378 0.99878953 4.44983E-06 0.00828578 93.1853188 191 -0.1686848 0.175361787 92.04 93.201927 325.5046 0.00828578 9.3823456 0.0028578 9.3823456 0.00828578 9.3825	188	-0.01686848	0.194355342	92.04	93.38008008	449.773709	0.9987694	5.5624E-06	0.01035744	93.2429539
191 -U.10000960 U.100489316 92.04 93.30022939 393.307376 U.99676933 4.44983E-06 U.00826578 93.1853188 101 -D.11686848 D.17561787 02.04 03.2001905 373.50.06 D.00885788 3.0034E.06 D.0073405E 03.95E39E	189	-0.01686848	0.191504615	92.04	93.36042432	432.066853	0.99878348	5.00609E-06	0.00932156	93.2286966
	190	-0.01000048	0.100499078	92.04	93.30322939	372 59496	0.990/0903	4.44903E-00 3.89334E.06	0.00020078	93.1003166
192 -0.01868648 0.1688660353 92.04 93.20429213 349.028931 0.99890238 3.337E-06 0.00621363 93.0978809	192	-0.01686848	0.168860353	92.04	93.20429213	349.028931	0.99890238	3.337E-06	0.00621363	93.0978809

Line No.	Gage Pressure Correction, psi	CORRECTED Gauge Pressure, psi	Daily Mean Station Pressure, kPaa	CORRECTED Absolute Pressure at P0. kPaa	Average Pressure Gradient, Pa/m	Water Density, g/cc	Water Volumetric Flow Rate, m3/s	Vsl. m/s	Pressure at P1, Beginning of dP Section, kPaa
193	-0.01686848	0.162790263	92.04	93.16243887	322.057301	0.99891219	2.7808E-06	0.00517798	93.0642507
194	-0.01686848	0.153146286	92.04	93.09594364	296.608172	0.99893193	2.2246E-06	0.0041423	93.0055143
195	-0.01686848	0.142598666	92.04	93.02321781	272.106251	0.99896221	1.6684E-06	0.00310663	92.9402586
196	-0.01686848	0.133917943	92.04	92.96336422	245.052363	0.99901384	1.11221E-06	0.00207098	92.8886531
197	-0.01686848	0.091239367	92.04	92.66909543	179.691931	0.99903446	5.56092E-07	0.00103547	92.6143113
198	-0.01713707	0.408815177	91.86	94.67878065	1260.72625	0.99751571	3.89857E-05	0.07259317	94.2944129
199	-0.01713707	0.388771926	91.86	94.54058243	1168.37854	0.9975334	3.34158E-05	0.06222162	94.1843695
200	-0.01713707	0.36077568	91.86	94.34754832	1067.73411	0.99768033	2.78424E-05	0.05184371	94.0220196
201	-0.01713707	0.330689384	91.86	94.1401033	986.278982	0.99778715	2.22715E-05	0.04147053	93.8394085
202	-0.01713707	0.297415312	91.86	93.91067857	853.44644	0.997933	1.67012E-05	0.03109835	93.6504815
203	-0.01713707	0.259732471	91.86	93.65085539	704.5052	0.99810051	1.11323E-05	0.02072875	93.4360672
204	-0.01713707	0.239465154	91.86	93.51111224	618.2801	0.99821478	8.34824E-06	0.01554479	93.3226122
205	-0.01713707	0.214823254	91.86	93.34120634	540.085653	0.99837853	5.56458E-06	0.01036149	93.1765461
206	-0.01713707	0.207428069	91.86	93.29021653	516.62357	0.99850258	5.0075E-06	0.00932418	93.1327093
207	-0.01713707	0.204934538	91.86	93.27302364	497.483835	0.99857323	4.45079E-06	0.00828758	93.1213517
208	-0.01713707	0.192754435	91.86	93.18904183	468.665022	0.99861174	3.8943E-06	0.00725135	93.0461562
209	-0.01713707	0.188553465	91.86	93.16007614	451.569902	0.99866252	3.3378E-06	0.00621513	93.0224024
210	-0.01713707	0.182536232	91.86	93.11858732	438.016118	0.99872326	2.78133E-06	0.00517896	92.9850458
211	-0.01713707	0.176754045	91.86	93.07871914	419.555822	0.99878482	2.22493E-06	0.00414291	92.9508058
212	-0.01713707	0.164524097	91.86	92.99439365	386.215536	0.99882212	1.66863E-06	0.00310707	92.876645
213	-0.01713707	0.153385003	91.86	92.91758959	355.615265	0.99886844	1.11237E-06	0.00207128	92.8091703
214	-0.01713707	0.136662671	91.86	92.80228912	338.515071	0.99895276	5.56138E-07	0.00103555	92.6990833

		dP Section		Test Section					
		Average		Average	Loop Test	Flow Loop	Flow Loop		
	Pressure at	Pressure for	Test Section	Superficial	Section	Diff. Section	Diff. Section	Flow Loop	Flow Loop
	P2, End of	Fluid	Average Air	Air Velocity,	AverageAir	Inlet Air	Outlet Air	Diff. Section	Diff. Section
	dP Section,	Properties,	Flow Rate,	Vsg, m/s =	Density,	Density,	Density,	Inlet Air	Outlet Air
Line No.	kPaa	kPaa	Actual m3/s	Q/A	ka/m3	ka/m3	ka/m3	Velocity. m/3	Velocity. m/3
1	93,4233637	93,6136932	0.01250213	23,2795265	1.12808907	1.13038263	1.12579551	23,2322921	23.3269534
2	93 4111334	93 5908659	0.01249426	23 26487	1 12879976	1 13096751	1 126632	23 2202776	23 3096339
3	93 3801661	93 5486691	0.01248383	23 2454394	1 12074331	1 13177824	1 12770838	23 2036442	23 2873854
4	93 3025951	93 4606019	0.01248000	23 2404126	1 12008766	1 13189805	1 12807728	23 2011881	23 27977
	03 2773207	03 / 100501	0.01240113	23.2404120	1.12330700	1 13347485	1.12007720	23 1680125	23 2352061
5	02 2052970	02 226202	0.01240033	23.2020300	1 1220421	1.13347403	1.12025049	23.1003123	22 21 4 4 2 4 2
0	93.2053679	93.330303	0.01244900	23.1010333	1.1320421	1.13443202	1.13123219	23.1493030	23.2144342
/	93.2159720	93.3240359	0.01243656	23.101100	1.13305297	1.1351/342	1.13233232	23.1342445	23.1001903
0	93.1776352	93.2740316	0.01242236	23.1310109	1.13533162	1.13050510	1.13415040	23.1071302	23.154947
9	93.0819413	93.1760568	0.01241013	23.1082081	1.13645244	1.13760035	1.13530453	23.0848904	23.1315729
10	93.0139374	93.108391	0.01244938	23.181302	1.13286905	1.13401828	1.131/1981	23.1578096	23.2048421
11	94.2613342	94.6588564	0.01252851	23.3286379	1.125/1422	1.13044169	1.12098676	23.2310784	23.4270203
12	94.322988	94.7665325	0.01252981	23.3310535	1.12559767	1.13086591	1.12032944	23.2223637	23.4407654
13	94.3288926	94.8171284	0.01253627	23.3430804	1.12501774	1.13081072	1.11922476	23.2234971	23.4639016
14	94.3883031	94.9042273	0.01252871	23.3290041	1.12569655	1.13181613	1.11957697	23.2028673	23.4565199
15	94.4452926	95.0036496	0.01251757	23.3082678	1.12669803	1.13331988	1.12007618	23.1720805	23.4460654
16	94.4867478	95.0766133	0.01249334	23.2631586	1.1288828	1.13588651	1.12187909	23.1197214	23.4083867
17	95.6796494	96.4379036	0.01412759	26.3061957	1.14091013	1.14988067	1.13193959	26.1009737	26.5146703
18	95.6293393	96.3333653	0.01412588	26.3030193	1.14104791	1.14938694	1.13270887	26.1121856	26.496663
19	95.5856889	96.2008012	0.0140921	26.2401154	1.14378328	1.15109668	1.13646987	26.0734009	26.4089756
20	95,4939471	96.0284308	0.01408155	26.2204711	1.14464019	1.15101114	1.13826925	26.0753386	26.3672282
21	95.3703615	95.8218482	0.01407205	26.2027744	1.14541326	1.15081013	1.14001638	26.079893	26.3268193
22	95,2392539	95.5947926	0.01404903	26,1599209	1.1472896	1.15155663	1.14302257	26.0629868	26.2575788
23	95 029765	95 2688116	0.0140114	26 0898396	1 1503714	1 15325788	1 14748491	26 0245393	26 1554683
24	95 0398135	95 2817287	0.01400915	26 0856614	1 15055565	1 15347685	1 14763445	26 0195991	26 1520601
25	94 9848454	95 2059022	0.01399451	26.0583939	1 15175959	1 15443384	1 14908534	25.9980296	26 1190392
26	04 0325508	05 115/38/	0.01307751	26.0267387	1 15316043	1 15537761	1 15004325	25.0767031	26.0768768
20	04 8423513	05 0070223	0.01305708	25 0003742	1 15/77388	1 15678631	1 15276144	25.9707931	26.0357460
27	94.0423313	95.0079225	0.01395796	25.9903742	1.104//300	1.10070031	1.15270144	20.9401094	20.0337409
20	94.0373230	94.7734038	0.01390039	20.9940091	1.10407404	1.10020240	1.10291000	20.907000	20.0322374
29	94.5593561	94.0909312	0.01412542	20.3021566	1.14106524	1.14510630	1.13/00212	20.2003/70	20.3900133
30	94.9977086	95.7388904	0.01586037	29.5327173	1.14329577	1.15214683	1.13444472	29.3058402	29.7631345
31	94.8918306	95.5616164	0.01585701	29.5264509	1.14353841	1.15155341	1.13552342	29.3209421	29.7348608
32	94.7641931	95.3436996	0.01584523	29.5045257	1.14438819	1.15134387	1.13743251	29.3262783	29.6849532
33	94.6309344	95.0933637	0.01583227	29.4803818	1.14532542	1.15089502	1.13975582	29.3377155	29.6244425
34	94.5466278	94.9321128	0.01581682	29.4516085	1.14644437	1.15109967	1.14178908	29.3324998	29.5716884
35	94.457726	94.777237	0.01580645	29.4322994	1.1471965	1.1510639	1.14332909	29.3334112	29.5318566
36	94.4489266	94.7662101	0.01579613	29.413096	1.14794549	1.15178888	1.14410209	29.3149477	29.5119038
37	94.4093044	94.7027288	0.0157851	29.3925617	1.14874747	1.15230672	1.14518822	29.3017738	29.4839138
38	94.3639365	94.6171282	0.01577034	29.3650638	1.14982317	1.15290005	1.14674629	29.2866938	29.4438544
39	94.1460013	94.4097157	0.015757	29.3402305	1.15079637	1.15401089	1.14758186	29.2585028	29.422416
40	94.021038	94.202572	0.01581379	29.4459744	1.14666373	1.14887342	1.14445404	29.3893394	29.5028281
41	94.8762013	95.6335977	0.01752299	32.6285895	1.14979707	1.1589032	1.14069093	32.372209	32.8890634
42	94.7816007	95.4495617	0.01752168	32.6261424	1.1498833	1.15793025	1.14183636	32.3994097	32.856071
43	94.6559324	95.1975684	0.0175144	32.6125845	1.15036134	1.15690644	1.14381625	32.4280817	32,7991988
44	94,5220179	94,9682111	0.01751287	32,6097293	1,15046206	1,15586733	1,1450568	32,4572341	32,7636642
45	94.3953122	94,7894974	0.01751143	32,6070617	1.15055618	1,15534081	1.14577156	32,4720258	32,7432255
46	94 3542399	94 7232356	0.01750568	32 5963502	1 15093427	1 15541775	1 14645079	32 4698633	32 7238263
40	94 2948115	94 6185482	0.01749952	32 5848808	1 15133038	1 15527868	1 14740008	32 473772	32 6967525
49	04 1828827	04.0100402	0.01748506	32 5506211	1 15223250	1 15561137	1 1/188538	32 464423	32 6553701
40	02 0070222	04 2214522	0.01740390	22.5550211	1.15225255	1 15410201	1 14070754	22.404423	22.0000701
49	02 022220	94.2214032	0.01/49/04	32.3017441	1.10140022	1.10419291	1.140/0/04	32.3043207	32.0393371
50	93.022229	94.7400712	0.01903183	30.55553314	1.12091000	1.13903937	1.11797100	30.2043304	30.9131779
51	93.7 147047	94.0010010	0.0190461	30.3630291	1.12790000	1.13790400	1.11799007	30.2040431	30.9123401
52	93.5811268	94.3227687	0.01961557	36.5250536	1.12985138	1.138/3518	1.12096757	36.2401046	36.8145191
53	93.4174159	94.0437973	0.01957913	36.4572044	1.1319541	1.13949352	1.12441469	36.2159868	36.7016568
54	93.1631298	93.6492369	0.01952941	36.3646247	1.13483591	1.14072653	1.1289453	36.1/68408	36.5543682
55	93.2856624	93.8296964	0.01955195	36.4065901	1.1335278	1.14010011	1.12695549	36.1967179	36.6189103
56	93.120276	93.5938711	0.01952127	36.3494612	1.13530932	1.14105411	1.12956453	36.166455	36.5343289
57	93.0760281	93.5252083	0.01951129	36.3308876	1.13588973	1.14134515	1.13043431	36.1572327	36.5062186
58	93.0367394	93.4724573	0.01949759	36.305369	1.13668813	1.14198676	1.13138951	36.1369183	36.4753975
59	92.9842327	93.3764337	0.01949887	36.3077635	1.13661317	1.14138719	1.13183915	36.155901	36.4609071
60	92.9150515	93.2996162	0.0194932	36.2972036	1.13694384	1.14163013	1.13225756	36.148207	36.4474335
61	92.8852815	93.2240994	0.01947731	36.2676034	1.13787177	1.1420073	1.13373624	36.1362681	36.3998968
62	92.8613061	93.1704078	0.01948711	36.2858564	1.13729938	1.14107248	1.13352629	36.1658726	36.4066389
63	92.7538326	93.0634887	0.01948716	36.2859494	1.13729647	1.14108067	1.13351227	36.1656132	36.4070891
64	92.7136619	92.9898419	0.0195666	36.4338716	1.13267902	1.13604308	1.12931497	36.3259834	36.5424026

		dP Section		Test Section					
		Average		Average	Loop Test	Flow Loop	Flow Loop		
	Pressure at	Pressure for	Test Section	Superficial	Section	Diff. Section	Diff. Section	Flow Loop	Flow Loop
	P2, End of	Fluid	Average Air	Air Velocity,	AverageAir	Inlet Air	Outlet Air	Diff. Section	Diff. Section
	dP Section.	Properties.	Flow Rate.	Vsa. m/s =	Densitv.	Density.	Density.	Inlet Air	Outlet Air
Line No	kPaa	kPaa	Actual m3/s	Q/A	ka/m3	ka/m3	ka/m3	Velocity m/3	Velocity m/3
65	94 3532609	94 9051749	0.00624149	11 6219229	1 12982076	1 13639115	1 12325038	11 5547272	11 6899046
66	94 2798487	94 7862378	0.00623534	11 6104762	1 13093465	1 13697659	1 1248927	11 5487776	11 6728375
67	04 210161	04 6823303	0.00623718	11 6130078	1 13060048	1 13623876	1 12/06221	11 5562760	11 6721163
68	04 1473663	94.0020000	0.00023710	11 6240757	1 12061152	1.13023070	1.12430221	11 5712686	11 677367
60	94.1473003	94.3769900	0.00024204	11.02407.57	1.12901132	1.134/0003	1.12440000	11.57 12000	11 6022000
09	94.0390620	94.4200141	0.00024614	11.0343141	1.12001743	1.13324433	1.12399032	11.0000100	11.0022009
70	93.94039	94.2012097	0.00625151	11.0405910	1.1200000	1.13201504	1.12400196	11.599369	11.0020079
71	93.8548173	94.135529	0.00625155	11.6406591	1.12800226	1.13136595	1.12463856	11.6060499	11.6/54/53
72	93.7730245	94.0287427	0.00624732	11.632794	1.12876492	1.13183468	1.12569516	11.6012435	11.6645165
73	93.6887624	93.9161114	0.00624856	11.6351025	1.12854096	1.1312729	1.12580903	11.6070047	11.6633367
/4	93.6808981	93.8993097	0.00624742	11.6329778	1.12874708	1.13137257	1.1261216	11.6059821	11.6600994
75	93.6369563	93.8476708	0.00624621	11.6307237	1.12896584	1.13150068	1.12643099	11.604668	11.6568968
76	93.6124359	93.81359	0.00624608	11.6304787	1.12898962	1.13141039	1.12656886	11.6055941	11.6554702
77	93.619089	93.8104054	0.00624317	11.625067	1.12951519	1.13181872	1.12721167	11.6014071	11.6488235
78	93.5732113	93.7578347	0.0062419	11.6226972	1.12974549	1.13197013	1.12752085	11.5998554	11.6456293
79	93.5397327	93.7146817	0.00623856	11.6164816	1.13034998	1.13246015	1.12823982	11.594836	11.6382081
80	93.5049781	93.6661178	0.00623751	11.6145179	1.13054109	1.13248603	1.12859615	11.5945711	11.6345336
81	93.4585503	93.6086128	0.00623379	11.6076001	1.13121487	1.1330283	1.12940143	11.5890219	11.6262379
82	93.4051952	93.546406	0.00623083	11.6020748	1.13175358	1.13346199	1.13004517	11.5845876	11.6196149
83	92.9481436	93.9018261	0.02325918	43.3096243	1.12610382	1.13754072	1.11466692	42.874187	43.7539972
84	92,7811407	93.6272344	0.02321416	43.2257855	1.12828796	1.13848411	1.11809181	42.8386597	43.6199719
85	92,6049465	93,3387837	0.02321695	43,2309837	1,12815229	1,13702192	1,11928267	42,8937495	43,5735626
86	92 4712002	93 1498065	0.02316391	43 1322301	1 13073526	1 13897279	1 12249773	42 8202798	43 448759
87	92 429103	93 0877694	0.02316202	43 1287068	1 13082763	1 13882909	1 12282617	42 8256827	43 4360497
88	92 37019	93 0059336	0.02315023	43 1067566	1 13140346	1 13913718	1 12366973	42 8141002	43 4034415
89	92 3073761	92 9180912	0.02313727	43 0826162	1 13203741	1 13947786	1 12459697	42 8012006	43 3676552
00	02 2651217	02.0100012	0.02010727	42 101760	1 12152/20	1 12020055	1 12400001	42.0012000	42 2600766
01	02 105205	02 7227002	0.02314733	43.101705	1 12214100	1 12020000	1 12559101	42.0430425	43.3003730
91	92.190300	92.7327093	0.02313313	43.0700303	1.13214199	1.130/0290	1.12000101	42.0304237	43.3297409
92	92.1232171	92.0331349	0.02313229	43.0733300	1.13220092	1.13040939	1.12007220	42.0304330	43.3100303
93	92.1516146	92.5926796	0.02311333	43.0360367	1.13320994	1.13001042	1.12/0094/	42.6339075	43.2441246
94	92.1458464	92.5279319	0.02309086	42.9962011	1.13431262	1.13899666	1.12962858	42.8193825	43.1744861
95	92.0771936	92.4409075	0.02320142	43.2020732	1.12890724	1.13334899	1.1244655	43.0327584	43.3727256
96	92.7944134	93.8977935	0.02501474	46.5785488	1.12761691	1.14086738	1.11436643	46.0375676	47.1323951
97	92.5974812	93.5713461	0.0249558	46.4688023	1.13028003	1.14204367	1.11851638	45.9901494	46.9575233
98	92.456544	93.3352319	0.02484306	46.258876	1.13540932	1.14609843	1.12472021	45.8274417	46.6985109
99	92.3484656	93.1534396	0.02491891	46.4001126	1.13195327	1.1417349	1.12217163	46.0025869	46.8045685
100	92.3496416	93.1202176	0.02491203	46.3872946	1.13226606	1.14163563	1.12289648	46.006587	46.7743555
101	92.2930143	93.0326662	0.02490897	46.3815969	1.13240515	1.14140828	1.12340201	46.0157508	46.7533069
102	92.2395706	92.9556496	0.02490346	46.3713368	1.1326557	1.14138106	1.12393035	46.0168484	46.7313291
103	92.1898012	92.865835	0.02489516	46.3558809	1.13303335	1.14128147	1.12478523	46.0208636	46.6958116
104	92.1771382	92.8051952	0.02488305	46.3333321	1.13358476	1.14125627	1.12591325	46.0218801	46.6490283
105	92.1260555	92.7072149	0.02488746	46.3415498	1.13338374	1.14048865	1.12627883	46.0528554	46.6338865
106	92.0279503	92.5845577	0.02489547	46.3564569	1.13301927	1.13983085	1.12620769	46.0794328	46.636832
107	92.0708973	92.5488391	0.02487759	46.3231627	1.13383362	1.13968897	1.12797826	46.0851691	46.5636271
108	92 1026182	92 5273176	0.02485083	46,2733484	1,13505421	1,1402641	1,12984433	46.0619247	46,486722
109	92,3666284	93.2566385	0.02660664	49.5427362	1.13587559	1,14671601	1.12503517	49.0743867	50.0201114
110	92 5392755	93 4805618	0.02661838	49 5645993	1 13537455	1 14680701	1 1239421	49 0704925	50 0687579
111	92 7099735	93 7549048	0.02660989	49 5487864	1 13573689	1 14839508	1 12307871	49 0026348	50 1072493
112	03 4042608	04 571843	0.02650816	40 5260433	1 13623770	1 15026565	1 12220003	48 02200402	50 1460406
112	02 2256617	04 4409	0.02033010	40.474092	1 127/610	1 15020303	1.12220333	40.3223402	50.1400400
113	93.3250017	94.4490	0.02050977	49.474003	1.1374310	1.15096971	1.12391309	40.0921701	50.0700140
114	93.255/942	94.26/45//	0.02050400	49.4045001	1.13/0/004	1.15011667	1.12522201	40.9291903	50.0117791
115	93.11312//	94.0440361	0.02055751	49.4512469	1.13/9//02	1.14924666	1.120/053/	46.9002391	49.9459626
116	92.9252819	93.81863	0.02654061	49.4197805	1.13870163	1.14954443	1.12785883	48.9536402	49.8948834
117	92.8995967	93.7570404	0.026546	49.4298216	1.13847032	1.14888206	1.12805857	48.9818639	49.8860485
118	92.8524669	93.6710956	0.02655557	49.4476421	1.13806002	1.14800598	1.12811407	49.0192436	49.8835946
119	92.8356985	93.6097837	0.02654668	49.4310839	1.13844124	1.14785533	1.12902716	49.025677	49.8432515
120	92.8091984	93.5382768	0.02654585	49.4295398	1.13847681	1.1473506	1.12960302	49.047244	49.8178419
121	92.7666487	93.4441322	0.02655065	49.4384865	1.13827078	1.14652341	1.13001815	49.0826304	49.7995404
122	92.7648743	93.3747507	0.02654346	49.4250902	1.1385793	1.14601592	1.13114268	49.1043655	49.7500321
123	92.6523574	93.2409464	0.02656279	49.4610805	1.13775081	1.14493293	1.13056869	49.1508131	49.77529
124	92.6300358	93.1579053	0.02658267	49.4981076	1.13689972	1.14334184	1.1304576	49.2192121	49.7801818
125	92.6005996	93.0940489	0.02662105	49.56958	1.13526047	1.14127797	1.12924297	49.3082195	49.833726
126	95.3479648	96.3214272	0.02107189	39.2367839	1.14738017	1.15897605	1.13578429	38.844209	39.6373748
127	95.2462396	96.1519255	0.02107376	39.2402648	1.14727839	1.15808497	1.1364718	38.8740972	39.6133961
128	95.1211991	95.9415515	0.02104109	39.1794327	1.14905972	1.1588848	1.13923463	38.8472674	39.5173273

		dP Section		Test Section					
		Average		Average	Loop Test	Flow Loop	Flow Loop		
	Pressure at	Pressure for	Test Section	Superficial	Section	Diff. Section	Diff. Section	Flow Loop	Flow Loop
	P2, End of	Fluid	Average Air	Air Velocity,	AverageAir	Inlet Air	Outlet Air	Diff. Section	Diff. Section
	dP Section,	Properties,	Flow Rate,	Vsg, m/s =	Density,	Density,	Density,	Inlet Air	Outlet Air
Line No.	kPaa	kPaa	Actual m3/s	Q/A	kg/m3	kg/m3	kg/m3	Velocity, m/3	Velocity, m/3
129	94.941992	95.638774	0.02099302	39.0899274	1.15169075	1.16008146	1.14330004	38.8071953	39.3768095
130	94.6842832	95.3123598	0.02099185	39.0877547	1.15175476	1.15934444	1.14416509	38.8318657	39.3470386
131	94.5927243	95.1743834	0.02095626	39.021477	1.15371101	1.16076193	1.1466601	38.7844455	39.2614236
132	94.5534015	95.1165502	0.0209546	39.0183828	1.1538025	1.16063373	1.14697128	38.7887295	39.2507716
133	94.5036269	95.0381335	0.02094848	39.00699	1.15413949	1.16063052	1.14764847	38.7888366	39.2276112
134	94.4377105	94.9459244	0.02095324	39.0158504	1.15387739	1.16005372	1.14770107	38.8081234	39.2258131
135	94.4198784	94.9162433	0.0209463	39.002944	1.15425922	1.16029543	1.14822302	38.800039	39.2079823
136	94.3880118	94.8435723	0.02094271	38.9962489	1.15445739	1.16000258	1.14891221	38.8098343	39.1844629
137	94.2670794	94.7126426	0.02096475	39.0372835	1.15324387	1.15866915	1.14781858	38.8544976	39.2217973
138	94.2047284	94.6126758	0.02095867	39.0259706	1.1535/81/	1.15855212	1.14860421	38.8584223	39.1949701
139	94.1513061	94.5416537	0.02094369	38.9980803	1.15440317	1.15916952	1.14963683	38.8377255	39.1597649
140	94.1661196	94.5077878	0.02099549	39.0945368	1.15155496	1.155/1811	1.14739181	38.9537099	39.2363857
141	94.6883802	95.0860976	0.01749419	32.5749573	1.15169012	1.1565073	1.1468/294	32.4392733	32./11/811
142	94.66829	95.0522156	0.01749319	32.5730867	1.151/5626	1.15640832	1.14/1042	32.44205	32.7051863
143	94.6016606	94.9480283	0.01747956	32.5477216	1.15265385	1.1568587	1.148449	32.42942	32.6668894
144	94.4126709	94.7383448	0.01749663	32.5794954	1.1515297	1.15548821	1.14/5/118	32.4678833	32.6918775
145	94.3057694	94.5917664	0.01746006	32.5460460	1.15262102	1.15010571	1.14913032	32.4505417	32.0473500
140	94.2900192	94.5454691	0.01749624	32.3624991	1.15142354	1.1044290	1.14041/2/	32.4970000	32.00//919
147	94.7 393940	95.0645602	0.01576765	29.3970033	1.14034004	1.152/1/06	1.14437039	29.2913273	29.0047763
140	94.0055710	95.0097878	0.01575385	29.3334411	1.15027645	1.10422794	1.14032097	29.2330009	29.40407.04
143	04 7136420	04 0038013	0.01574462	29.3343047	1.15170128	1 15500723	1.147 10373	20.2300686	29.4038062
150	94 6062481	94.8622815	0.01575107	29.3291887	1 15122962	1 15433679	1 14812245	29.2503000	29.4085624
152	94 5580906	94 7694659	0.01572292	29 2767798	1 15329046	1 15586278	1 15071814	29 2116257	29.3422252
153	94 3994372	94 6245098	0.01574253	29.3132808	1 15185438	1 15459416	1 14911459	29 2437221	29 3831712
154	94 8566832	95 1145639	0.0140135	26.0937616	1 15019849	1 15331698	1 14708	26.0232058	26 164701
155	94 8525776	95 0945425	0.01401338	26 0935309	1 15020866	1 15313533	1 14728199	26.0273053	26 1600943
156	94.8214403	95.0272555	0.01400388	26.0758488	1.15098862	1.15348149	1.14849575	26.0194943	26.1324478
157	94,7322776	94,9112663	0.01400411	26.0762635	1.15097031	1.15314087	1.14879975	26.0271801	26.1255325
158	94.6547783	94.8137855	0.01399135	26.0525056	1.15201991	1.1539519	1.15008792	26.0088874	26.0962702
159	94.5213725	94.694184	0.01399103	26.0519213	1.15204575	1.15414817	1.14994333	26.0044646	26.0995514
160	93.5118088	93.9073899	0.01260355	23.4683637	1.11901195	1.12372574	1.11429816	23.3699189	23.5676415
161	93.2756986	93.4896279	0.01254743	23.363868	1.12401677	1.12658883	1.12144472	23.3105273	23.4174534
162	93.237283	93.4472402	0.01252893	23.3294189	1.12567654	1.12820571	1.12314737	23.2771199	23.3819534
163	93.4016995	93.715623	0.01256608	23.3986033	1.12234817	1.12610775	1.11858859	23.3204856	23.4772461
164	93.3572204	93.6209616	0.01255103	23.3705636	1.12369474	1.12686032	1.12052916	23.304911	23.4365872
165	93.1687569	93.351447	0.01250118	23.2777448	1.12817542	1.13038328	1.12596757	23.2322789	23.323389
166	93.2300057	93.7685557	0.0109152	20.3245899	1.10751331	1.1138742	1.10115242	20.2085244	20.4419964
167	93.1726627	93.6544765	0.01088755	20.2730971	1.11032635	1.11603852	1.10461418	20.1693341	20.3779332
168	93.140499	93.5578537	0.01087584	20.2512894	1.11152201	1.11648043	1.10656359	20.1613511	20.3420337
169	93.0556198	93.394571	0.01085909	20.2201057	1.11323621	1.11727641	1.10919601	20.1469875	20.2937566
170	92.9467868	93.2107865	0.01083826	20.1813215	1.11537562	1.11853468	1.11221655	20.1243236	20.2386431
171	92.8947845	93.1176844	0.01081996	20.1472506	1.11726182	1.11993626	1.11458738	20.0991384	20.1955937
172	92.8263101	93.0105977	0.01080639	20.1219787	1.11866503	1.12088151	1.11644855	20.0821886	20.1619267
173	92.8024385	92.9784648	0.01079809	20.1065154	1.11952536	1.12164484	1.11740588	20.0685218	20.1446532
174	92.8003833	92.9623286	0.0107917	20.0946315	1.12018744	1.12213887	1.11823601	20.0596865	20.1296986
175	92.7585871	92.9104698	0.010785	20.0821499	1.12088367	1.122716	1.11905134	20.0493748	20.1150324
176	92.7366622	92.8789569	0.01078012	20.0730511	1.12139175	1.12310977	1.11967373	20.0423453	20.1038511
177	92.6986114	92.8345017	0.01077336	20.0604665	1.12209524	1.12373775	1.12045272	20.0311451	20.0898739
178	92.6808226	92.8078498	0.01077231	20.0585168	1.1222043	1.12374028	1.12066833	20.0311	20.0860087
179	92.6373037	92.7543872	0.01076764	20.0498306	1.12269048	1.12410765	1.12127331	20.0245536	20.0751714
180	92.5745599	92.6849558	0.01076204	20.0393913	1.12327533	1.12461325	1.12193741	20.015551	20.0632884
181	92.4264948	92.5077817	0.01076508	20.045046	1.12295845	1.1239452	1.12197171	20.0274479	20.0626752
182	93.303982	93.7960242	0.00904868	16.8490382	1.11330558	1.11914584	1.10/46532	16.7611115	16.9378923
183	93.234155	93.0846284	0.00905297	10.85/0278	1.112///92	1.1181286	1.10/42/23	16.7/63603	10.9384748
184	93.1501811	93.5490642	0.00905402	16.8589847	1.112048/5	1.11/3216	1.10/9/59	16.7884/72	16.9300869
185	93.0777021	93.4UZ1170	0.00904717	10.0402240	1.11349152	1.11730632	1.109024/2	10./0/9255	16 8708272
100	02.0000247	03 1558724	0.00903999	16 8006091	1 11501107	1 11862044	1 11320172	16 7680244	16 85061
10/	92.9290900	93.1556734	0.00902755	16 7783879	1 117003/0	1 12005247	1 1150345	16 7475442	16 8093/52
180	92.8001380	93 064037	0.00001074	16 7749643	1 11822165	1 12000247	1 11624316	16 7453365	16 8046071
109	92 8855418	93 0354303	0.00901056	16 7780588	1 11801541	1 11981663	1 11621410	16 7510713	16 8051333
101	92 8515334	92 9935285	0.00900196	16 7620525	1 11908301	1 12079178	1 11737425	16 736497	16 7876862
192	92.8318527	92,9648668	0.00899624	16.7513976	1.11979482	1.12139702	1.11819262	16.727464	16.7753998

		dP Section Average		Test Section Average	Loop Test	Flow Loop	Flow Loop		
	Pressure at	Pressure for	Test Section	Superficial	Section	Diff. Section	Diff. Section	Flow Loop	Flow Loop
	P2, End of	Fluid	Average Air	Air Velocity,	AverageAir	Inlet Air	Outlet Air	Diff. Section	Diff. Section
	dP Section,	Properties,	Flow Rate,	Vsg, m/s =	Density,	Density,	Density,	Inlet Air	Outlet Air
Line No.	kPaa	kPaa	Actual m3/s	Q/A	kg/m3	kg/m3	kg/m3	Velocity, m/3	Velocity, m/3
193	92.8187802	92.9415154	0.00899661	16.7520887	1.11974862	1.12122732	1.11826992	16.7299957	16.7742402
194	92.779441	92.8924777	0.00899753	16.7538072	1.11963377	1.1209962	1.11827133	16.733445	16.774219
195	92.7328605	92.8365596	0.00899702	16.7528449	1.11969808	1.12094879	1.11844737	16.7341527	16.7715789
196	92.7018754	92.7952643	0.00899071	16.7410934	1.12048406	1.12161171	1.1193564	16.7242621	16.7579585
197	92.477351	92.5458312	0.00901071	16.7783482	1.11799613	1.1188234	1.11716885	16.765942	16.7907727
198	93.3334935	93.8139532	0.00730327	13.5990169	1.10349908	1.10915055	1.0978476	13.5297256	13.6690216
199	93.293837	93.7391033	0.00730724	13.6064084	1.10289962	1.10813845	1.09766078	13.5420827	13.6713481
200	93.2081979	93.6151088	0.00730123	13.5952037	1.10380859	1.10860645	1.09901074	13.536366	13.654555
201	93.0876715	93.46354	0.00730135	13.5954396	1.10378943	1.10822838	1.09935048	13.5409839	13.6503352
202	92.9999888	93.3252351	0.00729574	13.5849959	1.10463799	1.10848775	1.10078824	13.5378154	13.6325063
203	92.8990968	93.167582	0.00728853	13.5715666	1.10573105	1.10891749	1.10254462	13.5325692	13.6107894
204	92.8513621	93.0869872	0.00728104	13.5576192	1.10686857	1.10967032	1.10406683	13.5233883	13.5920238
205	92.7648954	92.9707208	0.00726962	13.5363592	1.108607	1.11106131	1.10615268	13.5064577	13.5663935
206	92.7389414	92.9358254	0.00725616	13.5112994	1.11066317	1.1130161	1.10831023	13.4827363	13.5399838
207	92.742172	92.9317619	0.00724699	13.4942124	1.11206954	1.11433827	1.10980081	13.4667389	13.5217982
208	92.688942	92.8675491	0.00724672	13.4937218	1.11210997	1.11424883	1.10997111	13.4678199	13.5197236
209	92.678218	92.8503102	0.00724102	13.4830908	1.11298684	1.11504969	1.11092399	13.458147	13.5081273
210	92.6511921	92.8181189	0.00723492	13.4717382	1.11392475	1.11592807	1.11192143	13.4475537	13.4960098
211	92.6310224	92.7909141	0.00722812	13.459072	1.11497305	1.11689431	1.1130518	13.43592	13.4823039
212	92.5822734	92.7294592	0.00722739	13.4577195	1.11508511	1.11685504	1.11331518	13.4363925	13.4791144
213	92.5381221	92.6736462	0.00722477	13.4528496	1.11548876	1.11712003	1.11385749	13.4332052	13.4725516
214	92.4410688	92.570076	0.00721981	13.4435982	1.11625641	1.11781204	1.11470077	13.424889	13.4623596

	Loop Test Section Water	Loop Test	Loop Test Section Water	Apparent Friction	Apparent Friction	Superficial Gas Reynolds	Superficial Liquid Reynolds	Effective
l in a Ma	Density,	Section Air	viscosity,	Factor, fisg	Factor, fisg	Number,	Number,	relative
Line No.	g/cm3	1 80336E 05	Pa-S 0.00111085	(INCI KE)	(NU KE)	38070 7746	243 512861	0.011445753
2	0.998962724	1.80212E-05	0.00111817	0.03915922	0.03942964	38106 0041	217 727352	0.009447247
3	0.999020564	1.8003E-05	0.00112907	0.03668332	0.03693695	38144.6724	191.66694	0.007508296
4	0.999071199	1.79865E-05	0.00113901	0.03434623	0.03458427	38179.5366	166.244656	0.005850048
5	0.999163058	1.79556E-05	0.00115809	0.02894719	0.02914859	38245.3391	140.147476	0.002681796
6	0.999230074	1.79319E-05	0.001173	0.02838169	0.02857927	38295.7783	115.305672	0.002406139
7	0.999269551	1.79175E-05	0.00118221	0.02340515	0.02356907	38326.5492	91.5254471	0.000410376
8	0.999338475	1.78914E-05	0.0011992	0.02067691	0.02082237	38382.4595	67.6719653	-0.000352605
9	0.999410504	1.78626E-05	0.00121834	0.02018388	0.02032604	38444.301	44.4055907	-0.000464994
10	0.999323966	1.7897E-05	0.00119554	0.02019843	0.02034119	38370.5563	22.6262788	-0.000464457
12	0.996223662	1.02222E-05	0.00100805	0.00775885	0.008/1831	37640 0878	047 622803	0.00188732
12	0.990149409	1 8255E-05	0.00093331	0.03773003	0.10837444	37618 0711	1091 16525	0.09100732
14	0.998066044	1.82595E-05	0.00098939	0.11387639	0.11464242	37608.7488	1230.32733	0.120932789
15	0.998056325	1.82618E-05	0.00098828	0.12343022	0.12425844	37604.067	1368.57179	0.138603358
16	0.998128169	1.8245E-05	0.00099658	0.13070216	0.13157652	37638.5988	1492.88875	0.152189043
17	0.997902402	1.82971E-05	0.00097121	0.12997527	0.13107724	42893.1757	1949.66858	0.15100705
18	0.997979147	1.82798E-05	0.00097956	0.12064033	0.12166456	42933.7963	1656.90536	0.133600961
19	0.998210455	1.82257E-05	0.00100635	0.10556223	0.10645833	43061.164	1343.99935	0.10598456
20	0.998358674	1.81893E-05	0.001025	0.09169486	0.09247486	43147.3169	1055.63321	0.081516586
21	0.998516275	1.81489E-05	0.00104634	0.07739101	0.07805126	43243.4398	775.577801	0.05782024
22	0.998726381	1.80917E-05	0.00107769	0.06088346	0.06140459	43380.1281	502.012565	0.033539172
23	0.999015766	1.60049E-05	0.00112799	0.0407905	0.04114603	43589.1045	239.01243	0.011/12/49
24	0.99909699	1 79785E-05	0.00114406	0.03771433	0.03803962	43653 3142	189 156179	0.008476776
26	0.999186875	1 79478E-05	0.00116311	0.03110729	0.03137663	43727 9867	139 543271	0.004018922
27	0.999285849	1.7912E-05	0.00118593	0.02812995	0.02837406	43815.3813	91.2387615	0.002467863
28	0.999370124	1.78794E-05	0.00120722	0.02297994	0.02318103	43895.0504	22.4073055	0.000459324
29	0.998819386	1.80648E-05	0.00109288	0.0577997	0.05830095	43444.6899	371.276626	0.029499045
30	0.998462243	1.81629E-05	0.00103884	0.10035234	0.10143259	48611.2544	1301.9575	0.09680713
31	0.998574391	1.81334E-05	0.00105467	0.09064657	0.09162453	48690.3427	1025.94092	0.079865627
32	0.998731204	1.80902E-05	0.00107847	0.0784057	0.07925373	48806.4835	752.472333	0.059581079
33	0.998898953	1.80412E-05	0.00110654	0.06249589	0.06317433	48939.2516	488.924336	0.035869499
34	0.999020976	1.80032E-05	0.00112902	0.05204875	0.05261523	49042.5197	359.390193	0.022623148
30	0.999119771	1.79707E-05	0.00115554	0.04306706	0.04355753	49131.1429	235.470693	0.013202596
30	0.999131812	1.79598E-05	0.0011677	0.04279040	0.04323751	49100.9557	185 326379	0.012940450
38	0.999279035	1.79144E-05	0.00118433	0.03408168	0.03445495	49285.6317	137.042533	0.006001131
39	0.999389938	1.78714E-05	0.00121256	0.03555188	0.03594152	49404.1675	89.2347677	0.007015906
40	0.999339859	1.78912E-05	0.00119944	0.02420072	0.02446947	49349.5961	22.5528001	0.001000648
41	0.998814566	1.80664E-05	0.00109201	0.0833412	0.08444297	54301.0793	990.854058	0.067705926
42	0.998910037	1.80379E-05	0.00110847	0.07344688	0.07442037	54386.803	732.107604	0.051932653
43	0.999048333	1.79944E-05	0.00113432	0.05948825	0.06027967	54518.1704	476.950753	0.031952879
44	0.999154405	1.7959E-05	0.00115608	0.04892349	0.04957699	54625.8235	350.98023	0.019234255
45	0.999233402	1.79311E-05	0.0011736	0.04316725	0.04374564	54/10.6561	230.492446	0.013413706
40	0.9992/31/6	1.79166E-05	0.00118292	0.04039084	0.04093264	54/55.0/8/	182.941739	0.010926097
47	0.999327747	1.7690E-05	0.00119031	0.03030940	0.03064034	54024 5622	88 7381006	0.007014024
40	0.999476119	1 78352E-05	0.00123711	0.02438647	0.0247177	55004 9075	21 8659615	0.001183687
50	0.998339067	1.81939E-05	0.00102254	0.08183469	0.08317988	59312.55	1322.72005	0.065323719
51	0.998405421	1.81772E-05	0.00103125	0.07446999	0.07569813	59367.1138	1049.24076	0.053598566
52	0.998627047	1.81189E-05	0.00106251	0.06605819	0.06714915	59558.0581	763.776954	0.041060497
53	0.998867957	1.80502E-05	0.00110121	0.05583418	0.05675829	59784.6566	491.289486	0.027375604
54	0.999166528	1.79544E-05	0.00115882	0.04335199	0.04407213	60103.6161	233.432901	0.013680747
55	0.999035919	1.79981E-05	0.00113201	0.04850932	0.04931375	59957.8128	358.4402	0.018880175
56	0.999207249	1.79401E-05	0.0011678	0.0422435	0.04294552	60151.4758	208.474737	0.012656238
57	0.999256108	1.79225E-05	0.00117901	0.04006586	0.04073217	60210.6294	183.547606	0.010743869
58	0.999304223	1.79046E-05	0.00119059	0.03888053	0.03952723	60210.8901	159.043049	0.009761044
59	0.999339042	1.7091E-05	0.00119948	0.03495501	0.03033631	60369 8302	111 788797	0.0000000000000000000000000000000000000
61	0.999435406	1.78523E-05	0.00122534	0.03017749	0.03068168	60447 434	88.3044644	0.003860462
62	0.999437828	1.78513E-05	0.00122603	0.02748243	0.02794266	60450,9389	66.1905771	0.002523279
63	0.999475491	1.78351E-05	0.00123709	0.02753184	0.02799341	60505.734	43.7326994	0.002546528
64	0.999364014	1.78813E-05	0.00120584	0.0244134	0.02482538	60349.3331	22.4330305	0.001285343

Density, Density, Sector AI Sector AI Viscosity, Viscosity, P Feltu, Niso Number, N		Loop Test Section Water	Loop Test	Loop Test Section Water	Apparent Friction	Apparent Friction	Superficial Gas Reynolds	Superficial Liquid Reynolds	Effective
Link PC. gr/s/h sets of the PL in the P	Line Me	Density,	Section Air	viscosity,	Factor, fisg	Factor, fisg	Number,	Number,	relative
66 0.994113277 1.81752E-05 0.09412328 0.48129877 0.4812987 0.481297 0.4812987 0.4812987 0.4812987 0.58313853 0.026297189 60 0.99446875 1.81607E-05 0.00113987 0.3336159 0.3843419 198034715 180434751 0.10149205 0.578102358 70 0.99853918 1.81535E-05 0.0010756 0.2964027 1.9984787 1.81355-05 0.0010756 0.2964027 1.9984787 1.81356-05 0.0010756 0.2269076 1.99825968 375.841257 0.38077422 1.80787405 0.2004027 0.29894782 1.80787405 0.200405 1.9024777 0.12678674 0.22893076 1.92232341 0.23204841 74 0.998806161 1.80687E-05 0.0010766 0.226479 1.9536748 1.9733344 0.23303887 76 0.998854114 1.8005E-05 0.0011426 0.1162797 1.6156479 1.9224621 19038.4006 1.2145149 0.23033887 76 0.998854114 1.20056E-05 0.00114745 0.1614979 1.9224421<	Line No.	g/cm3	1 82073E 05	Pa-S 0.00101566	(Incl KE)	(NO KE)	18858 310	2130 60048	0 716377604
67 0.99445722 1.81638-05 0.0010382 0.42902746 0.4211773 1990.6705 0.005316 0.67610236 68 0.996508311 1.81502-05 0.00104550 0.3441201 0.3440318 1990.67055 1990.5208 775.0500309 0.44534223 71 0.996645778 1.81139E-05 0.00106525 0.24763426 0.2482845 1990.55188 57.641257 0.34642188 70 0.998645742 1.80738E-05 0.00106766 0.22509304 0.2593590 44.706752 0.2000541 0.200462 1990.73394 44.706752 0.28024491 76 0.998841244 1.8058E-05 0.0010986 1.1672315 0.16823214 1900.84914 1.2821599 0.20099613 76 0.99885061 1.30247E-05 0.0011026 0.161792315 0.16823214 1903.8306 1.712171844 0.22303041 70 0.99885061 1.30247E-05 0.0011424 0.1402526 1.903.7134 1.813267 1.932271 1.7051616 0.7009479 70 9.998850671 1.80205E-05	66	0.998413277	1.81752E-05	0.00103228	0.45128997	0.45210138	18891 5549	1834 33271	0.666426451
B 0.9994/0987 1.8107E-05 0.0013987 0.3395139 0.33494149 1990.5095 1.034.9028 0.57720518 70 0.99650311 1.81050-05 0.0010524 0.29640877 1.8991.5282 70.50309 0.445342238 71 0.99664717 1.81051-05 0.0010766 0.22658074 0.22593076 19987.53714 0.326054422 72 0.9967717 1.80687E-05 0.0010766 0.22658074 0.22593076 19987.5372 2.80753324 0.2302642 74 0.998806161 1.80687E-05 0.0010966 1.80247F70 1.9569744 1.90733324 0.2303887 76 0.998859661 1.80526E-05 0.0011026 0.161477 1.9124461 19024721 1.9033340 0.2333841 0.2303887 76 0.99885131 1.80106E-05 0.0011426 0.161477 0.15224621 19036.743 0.3303840 0.21782178 0.33324185 76 0.99886731 1.80108E-05 0.00114450 0.12341675 1906.747 7.2175174 0.157644224	67	0.998457926	1.81638E-05	0.00103832	0.42042046	0.42117773	18903.4715	1563.13653	0.626307189
e0 0.996509631 181502E-05 0.00106525 2.9440247 0.99326287 0.0340220 0.44534223 71 0.99664578 1.81139E-05 0.0010766 2.2569304 1.98325283 77.0500309 0.44534223 73 0.99877422 1.80738E-05 0.0010766 2.2569304 1.99024712 2.266422 73 0.99877422 1.80738E-05 0.0010806 1.912444 1.9024712 2.2324612 2.66695045 76 0.99884124 1.80581E-05 0.0010806 1.16722315 1.9052324 1.9073324 1.47.05744 2.2334812 2.2334812 2.2334812 70 0.99886307 1.80026E-05 0.00110361 1.61722315 1.9832254 1.9334276 1.3534276 1.9338256 1.9053,743 6.73134861 70 0.99866371 1.80026E-05 0.0011445 1.3141626 1.2314267 1.9382561 1.9033,743 6.7315422 0.193748221 80 0.9996731 1.70271-50 0.011446 0.1324164 1.241446 1.231444 0.90174111	68	0.998469878	1.81607E-05	0.00103997	0.38365139	0.38434419	18906.7095	1300.55316	0.576102326
70 0.99663371 1.13596-05 0.0010524 0.2960472 1.905277 0.506477 0.14524228 70 0.998737716 1.80681F-05 0.0010766 0.2265807 0.2258074 0.2259306 19982.5665 37.5.81257 0.206442218 70 0.998805181 1.80687E-05 0.0010965 1.821444 1.92244715 19002471 22.325412 0.266695045 70 0.998805181 1.8052E-05 0.0010965 1.812476 1.9169734 190149889 172.171844 0.237134861 70 0.99885071 1.2005E-05 0.00111026 0.161477 0.1524422 19033.8006 121.82159 0.20958612 70 0.99886173 1.30108E-05 0.0011244 0.14092611 0.1412268 11902470 1.213457 13103277 0.15154224 80 0.99896173 1.2008E-05 0.00117476 0.402475617 19094531 2.3534265 0.011758 1.0132247 0.1307856 1.30247567 1.93324456 1.3234475 1.90984333 1.377445.45 0.01247687 1.93334	69	0.998509831	1.81502E-05	0.00104553	0.34341201	0.34403418	18917.5824	1034.90926	0.517920518
1 0.99864517 1.8139E-05 0.0010625 0.2482845 1895.518 50.75.4125 0.32665422 7 0.99877476 1.800738E-05 0.0010876 0.225087 2.23024431 223.234612 2.23024431 7 0.99885164 1.80581E-05 0.0010986 1.6257246 0.16568051 1901.4088 172.171844 2.23134861 7 0.998856561 1.80258E-05 0.0011039 1.16722446 1.16324274 1911.8484 172.171844 2.23134861 7 0.998865613 1.80108E-05 0.00111426 1.16147470 1.6124241 19038.6021 121.821599 2.02080941 80 0.999049866 1.79936E-05 0.00114450 1.01412624 1.0341734 123.6334224 1.033417934 80 0.999049812 1.80108E-05 0.00114450 1.0342656 10908177 170.9174650 0.001244 1.4098127 123.633424 1.03347834 80 999052171 1.79911E-05 0.0011362 0.4614077 0.4746774 70886.443 357.10778 1.0342756<	70	0.998563918	1.81359E-05	0.00105324	0.29640877	0.29694762	18932.5283	770.500309	0.445343223
72 0.998774/22 10.998774/22 10.998774/22 10.998774/22 10.90876 0.200951 0.20042 18997.5332 248.706752 0.236094391 74 0.99880516 10.0010665 0.18247447 10.902.9471 223.323461 2.255033887 76 0.998859168 1.80526E-05 0.00106965 0.1824757 1.01824731 10191.8489 172.171444 0.237134861 76 0.998859168 1.80347E-05 0.00111391 0.1672475 1.08246211 1902.3322 147.025745 2.02696432 76 0.998696173 18.0056E-05 0.00111469 0.1324276 1.53265 1003.4776 1908.4721 1.716668 0.1384734 80 0.998069138 1.70774E-05 0.00111473 0.13146624 0.12346624 1.02347677 1.5154424 80 0.998052194 1.80332E-05 0.00111473 0.13146764 0.0420717 1.728473 0.33244165 1.03348444 0.13485847 1.03644144 0.033254165 1.03344442 0.013485847 1.036444444 0.0424759678 1.	71	0.998645178	1.81139E-05	0.00106525	0.24783426	0.24828645	18955.5198	507.876401	0.364822188
7 0.9987742 1.80738E-05 0.0010875 0.200961 0.20042 1897.535 248.70752 0.280284314 76 0.99884124 1.8058TE-05 0.0010986 0.1652479 0.1555803 1911.4088 172.171844 0.237134861 76 0.998856561 1.8025E-05 0.0011098 0.1672215 0.16823214 1902.7332 147.171844 0.237134861 70 0.998865129 180.016E-05 0.00111426 0.1614479 0.1534256 1905.743 987.316688 0.193417934 80 0.998045686 1.80205E-05 0.00111445 0.1334276 0.1313207 1908.2721 47.6777 0.1514422 80 0.998045984 1.8025E-05 0.001114450 0.1234824 0.234757 0.20475878 80 0.9980254444 1.79135E-05 0.00111450 0.1348242 0.234747 70854843 357.1072 0.1618234 80 0.9980254444 1.79135E-05 0.00111363 0.4042873 0.0474724 7088.543 357.1078 0.33874455 80	72	0.998737716	1.80881E-05	0.0010796	0.22558074	0.22599306	18982.5695	375.841257	0.326054422
1 0.99880516 1.0000805 0.19214745 1.092.9471 223.234612 0.2565036897 76 0.998854124 1.056511-05 0.0010908 0.17667246 0.17669734 1910.8489 17217844 0.237134861 76 0.998859163 1.80347E-05 0.0011189 0.1532472 1.5122421 1902.3322 147.025745 0.209598632 76 0.998859613 1.80045E-05 0.0011189 0.1532472 0.1512422 1.97774E-05 0.0111443 0.140653 0.1312475 1908.2721 47.6777 1.5154422 80 0.99908853 1.79774E-05 0.00111473 0.13168624 0.12314652 0.13241465 1.03324445 1.9094.531 23.03324445 1.30332E-165 0.00111113 0.0452412 7021.339 486.10101 0.042475667 80 0.9990236454 1.79299F-05 0.00111130 0.04247540 0.424714 7033.51864 0.909777 70457.733 456.10237986 10.03486347 71458.043 20.1014254 0.04247547 7133.535 156.7614442 0.0314856 <t< td=""><td>73</td><td>0.998787422</td><td>1.80738E-05</td><td>0.00108765</td><td>0.2000951</td><td>0.200462</td><td>18997.5359</td><td>248.706752</td><td>0.280294391</td></t<>	73	0.998787422	1.80738E-05	0.00108765	0.2000951	0.200462	18997.5359	248.706752	0.280294391
76 0.98854668 1.00281E-03 0.01010980 0.165246-03 0.0010980 0.165246-03 0.237134681 1.2217184 0.237134681 77 0.998855668 1.0045E-05 0.00111026 0.1614970 0.16522546 10030.000 11282159 0.209586502 79 0.998951526 1.0026E-05 0.00111450 0.1534278 0.1532256 10055.733 66.7310688 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.13700898 0.0370187 0.03254165 0.0471455 0.04640977 0.04749724 70866.9433 3.717206 0.0327866 0.0142510 0.04749724 71308675 1.758797-650 0.0117425 0.04271471 71086.7463 1812.81449 0.032354165 3.859 15.878046 0.0127765 86 0.999317575 1.7597E-650 0.00117256 0.03403001 0.0348315 71451.6753 11281440 0.00627723 <	74	0.99880516	1.80687E-05	0.00109058	0.19211464	0.19246715	19002.9471	223.234612	0.265695045
17 0.98983411 1.0465E-36 0.00110391 0.17692315 0.1682321 190152469 147.025745 0.228060941 76 0.989891275 1.003E-05 0.00111850 0.1582276 1.1582256 19005.743 96.7310686 0.2280694632 70 0.989991251 1.0108E-05 0.00113470 0.1382478 0.1522556 19005.743 96.7310686 0.1393417934 80 0.9999998363 1.79774E-05 0.0011449 0.12316624 0.1231475 19099.4531 3.3334224 0.13328478 0.1333244 0.033254155 84 0.98982344 1.0332E-05 0.0011111 0.0535615 0.04640977 0.474727 70864433 357.107206 0.0162821 85 0.9990251271 7.17918-05 0.00118103 0.04172543 0.04270411 17106767 20.138848 0.0123758 0.0356516 7138.0559 156.780946 0.002775648 86 0.999311284 1.78784E-05 0.00122716 0.03261836 0.0356516 7138.0559 156.780946 0.009770549 0.099707549	75	0.998841244	1.80581E-05	0.00109665	0.18524579	0.18558603	19014.0889	197.333364	0.253038897
17 0.938919238 1.80347E-05 0.0011120 0.161479 0.1622452 1903.8006 12.82199 0.20939632 79 0.938996139 1.80347E-05 0.0011142 0.1602419 0.1522452 1905.743 67.7310698 0.13741734 80 0.999049586 1.79336E-05 0.0011445 0.13218624 0.12341475 10909.4531 2.3334224 0.13744252 81 0.999049586 1.79336E-05 0.00114450 0.12318624 0.1241475 10908.4511 2.3334243 0.03354185 84 0.999052171 1.7991E-05 0.00117425 0.4640977 0.04749724 7086.9433 3.717206 0.01247567 85 0.9990521724 1.7879E-05 0.00117425 0.4299403 0.0440168 7128.755 181281449 0.01077569 90 0.99932755 1.7869E-05 0.00122761 0.03370812 0.0336157 71383.753 156.780344 0.00077649 90 0.999371244 1.7874E-05 0.00122716 0.03370812 0.03361577 71383.753 157.78158<	70	0.99883411	1.80320E-03	0.0010998	0.17007240	0.17099734	19019.0409	1/2.171044	0.237 134601
79 0.998965077 1.802055.00 0.00111850 0.15334278 0.1532556 19053.743 96.7310692 0.193417334 80 0.998096180 1.80108E-65 0.00113470 0.1106353 0.15132297 19064.074 72.1753116 0.17053112 81 0.999098853 1.7774E-05 0.00111450 0.0106320 0.15134227 1909.4531 2.3334224 0.1332476 0.15784221 82 0.9990988534 1.00332E-05 0.0011111 0.0535615 0.06481152 70721.339 486.01002 0.0168221 0.061877 1.78794E-05 0.00111322 0.0440097 0.0474722 7088.4433 0.01323614 0.01833347 0.0183334 0.011823 0.0442913 0.01172545 0.0275761 0.011823 0.04122541 0.0122011 0.01170525 0.011823 0.03276112 0.033354183 0.0118335 0.0118215 0.01122516 0.0327612 0.03354183 0.0414657 1.0176324 0.000777542 90 0.999372551 1.7868E-05 0.00122716 0.03281517 0.14137315 0.714030011	78	0.990000411	1.80347E-05	0.00111026	0.1619479	0.16224621	19038 8006	121 821599	0.200508632
81 0.999804888 1.80108E-05 0.00113443 0.14002011 0.1414228 10004.074 72.1735116 0.170009479 81 0.99904888 1.79774E-05 0.00113473 0.13108035 0.13312907 19092.2721 72.1735116 0.1303264182 83 0.998058482 1.8033E-05 0.0011145 0.0602922 0.06184115 777.32173 466.91001 0.02475678 84 0.999057317 1.79291E-05 0.0011742 0.04400186 71128.6419 230.36442 0.0116325 85 0.999057177 1.79971E-05 0.00119375 0.04229143 0.0427041 71170.676 0.0123578 86 0.99937754 1.78698E-05 0.0012766 0.03870812 0.03985167 1.0317484 0.01707262 90 0.999347254 1.78698E-05 0.0012276 0.03470301 0.03483154 71451.4657 10.176324 0.00077242 91 0.999452173 1.78688E-05 0.00122761 0.034287155 7159.122 6.844565 0.00227723 92 0.999452637 <td>79</td> <td>0.998965077</td> <td>1.80205E-05</td> <td>0.00111859</td> <td>0.15334278</td> <td>0.15362556</td> <td>19053.743</td> <td>96,7310698</td> <td>0.193417934</td>	79	0.998965077	1.80205E-05	0.00111859	0.15334278	0.15362556	19053.743	96,7310698	0.193417934
81 0.99904986 1.7993E-05 0.00114459 0.1312307 19022.272 47.6777 0.15124422 82 0.99908836 1.87025-05 0.0011715 0.0062922 0.0616971 70450.7301 77.321783 0.032254185 84 0.998023444 1.80322-05 0.00117142 0.04400977 0.04749724 70868.9483 357.10720 0.01622144 86 0.999025444 1.791915-05 0.00117325 0.04270417 71170.6677 206.13884 0.01322786 88 0.99931285 1.78987E-05 0.0012776 0.03870812 0.0398127 133.5359 156.780046 0.007770549 90 0.99932755 1.78698E-05 0.0012376 0.0321615 0.0329103 71518.055 133.745439 0.00707252 91 0.9994321781 1.7843E-05 0.00123761 0.0342010 0.02473155 71688.051 133.745439 0.00027204 92 0.999452167 1.7843E-05 0.0012341 0.02473155 71688.051 13.745439 0.00027204 93 <	80	0.998996139	1.80108E-05	0.0011244	0.14096211	0.14122263	19064.074	72.1735116	0.170099479
82 0.99906836 1.79774E-05 0.00147459 0.12316822 0.1231682 0.02847567 3.8334224 0.1367882214 84 0.99986343 1.81025E-05 0.00111110 0.056292 0.0616971 7.0721.339 466 910051 0.024756678 85 0.999057217 1.79911E-05 0.00113624 0.04299403 0.04400168 7128.6413 220.613884 0.012337986 87 0.999225464 1.79997E-05 0.0011975 0.03870812 0.03996171 7133.5539 165.78994 0.0112353 0.0012758 0.0358516 71386.0651 133.74544 0.0012778 0.0398172 7133.5539 165.78994 0.000277282 91 0.99942213 1.784826-05 0.0012261 0.0328103 71519.125 87.317334 0.00513335 92 0.999425293 1.78448E-05 0.00122614 0.02287142 0.02871053 71580-1322 68.445655 0.00287544 93 0.999571785 1.78448E-05 0.00122041 0.02487144 0.02487144 0.024287147 71615.033227 748.5825	81	0.999049686	1.79936E-05	0.00113473	0.13108635	0.13132907	19082.2721	47.6777	0.151544224
83 0.99862394 1.81023E-05 0.00111311 0.0536115 0.05481152 7721.333 486.510061 0.024759678 85 0.9990235458 1.79299E-05 0.001114120 0.04420413 0.04420168 71128.6413 230.364482 0.013495387 87 0.999236444 1.79193E-05 0.00118130 0.04270411 71170.6676 206.138844 0.011237986 88 0.999371284 1.78784E-05 0.00127751 0.03870812 0.0398172 71333.5359 181.281449 0.01707549 90 0.999337255 1.7898E-05 0.00122761 0.03481345 71451.4657 110.176324 0.006327723 91 0.99943204 1.78348E-05 0.0012814 0.02287753 71590.1322 64.8445855 0.00287784 91 0.999421691 1.778148E-05 0.00128410 0.02471515 71650.0164 2.04275193 71451.4657 10.176324 0.006327723 92 0.999427551 1.778148E-05 0.00128410 0.02471515 71651.034 44.45855 0.000287502	82	0.999098836	1.79774E-05	0.00114459	0.12318624	0.12341475	19099.4531	23.6334224	0.136788221
84 0.998622994 1.80332E-05 0.00413624 0.0444977 7072133 486.610051 0.022475867 85 0.9990254444 1.79918E-05 0.0011324 0.04220411 71170.6676 206.138844 0.01233786 87 0.99932444 1.78997E-05 0.0011375 0.04220411 71170.6676 206.138844 0.0173755 99 0.99932755 1.78784E-05 0.00121375 0.03595316 71383.0551 10.745434 0.00773262 91 0.999422513 1.78698E-05 0.00122161 0.03215215 0.03291053 71519.132 64.8445855 0.006237723 92 0.9994521679 1.78143E-05 0.00123148 0.02271642 0.02871753 71590.1322 64.8445855 0.000287184 94 0.999571795 1.778448E-05 0.00123648 0.0227412 0.02847162 71467.9953 21.99822644 0.00087502 96 0.99857664 1.80627E-05 0.00113075 0.04630931 0.06452492 7463.93227 748.58264 0.0022426193 90	83	0.998686432	1.81025E-05	0.00107156	0.0602922	0.0616971	70450.7301	757.321783	0.033254185
85 0.9990521458 1.7991E-05 0.00117425 0.0440166 7128.6419 20.364422 0.013495387 87 0.999236458 1.79193E-05 0.001118103 0.04122313 0.04122918 7128.6763 181.281449 0.01233796 88 0.999316775 1.78784E-05 0.00120776 0.03370812 0.0396112 7133.3539 156.70946 0.007073529 91 0.999432041 1.78784E-05 0.00122761 0.03403161 17458.0657 117167324 0.006327723 92 0.999420541 1.78143E-05 0.00122614 0.02477155 71590.1322 64.8445855 0.0026877 93 0.999521679 1.78143E-05 0.0012814 0.02473155 71650.0046 24.610344 0.00287723 96 0.999452633 1.78448E-05 0.00128471 0.02473155 71465.7993 21.9852844 0.02287544 97 0.999036893 1.79977E-05 0.00118375 0.04630940 0.0247552 222 743.88244 0.0228754 98 0.999316931 1.789977E-0	84	0.998923984	1.80332E-05	0.00111111	0.0535615	0.05481152	70721.339	486.910051	0.024759678
86 0.999254448 1.79298-00 0.00118103 0.04270411 71128.6476 20.64482 0.01349538 88 0.999316247 1.78978-05 0.00120750 0.0367061 0.0336126 71333.5359 156.76946 0.00777649 90 0.999312245 1.78698E-05 0.001227761 0.03401301 0.03349513 71333.5359 156.76946 0.000777654 90 0.9993422413 1.78328-05 0.001223761 0.03349513 71519.125 87.377834 0.005138335 93 0.999571765 1.77808E-05 0.0012617 0.02416044 0.02437155 71685.0064 21.9852264 0.002872743 96 0.999452593 1.78448E-05 0.00128617 0.02416044 0.02437155 71685.0064 21.9852264 0.00227502 96 0.99875648 1.80627E-05 0.00113075 0.04309815 0.04530921 7463.3227 748.382644 0.02426149 99.0.999030891 1.7897E-05 0.00113075 0.04309815 0.04509765 75663.74 180.444892 0.01128105	85	0.999057217	1.79911E-05	0.00113624	0.04640977	0.04749724	70886.9483	357.107206	0.016828144
87 0.99924444 1.79135-05 0.00113703 0.4472243 0.427241 711248 7635 151.281449 0.011078295 88 0.999317675 1.78698E-05 0.00120776 0.03870812 0.0396172 71335.359 156.780946 0.0007072649 90 0.999342755 1.78698E-05 0.00122716 0.0334012 0.0396172 71335.359 156.780946 0.0007072629 91 0.999443084 1.78449E-05 0.00122918 0.032451515 0.15757 71580.1322 64.844585 0.002827444 92 0.9994521677 1.778448E-05 0.00128617 0.022416044 0.02473155 71685.0046 2.6610344 0.001327502 96 0.999452593 1.78948E-05 0.00128047 0.02481422 76303.327 748.325644 0.002327512 97 0.999306951 1.78947E-05 0.00118367 0.44390381 0.445097674 76503.372 28.532615 0.0148267 90 0.999276562 1.78154E-05 0.00112804 0.0442029 0.04317242 76701.1638 20.457335 <td>86</td> <td>0.999235458</td> <td>1.79299E-05</td> <td>0.00117425</td> <td>0.04299403</td> <td>0.04400168</td> <td>71128.6419</td> <td>230.364482</td> <td>0.013495387</td>	86	0.999235458	1.79299E-05	0.00117425	0.04299403	0.04400168	71128.6419	230.364482	0.013495387
88 0.999317124 1.7874E-05 0.0012775 0.03870812 0.0385516 7138.055 161.261449 0.000773262 91 0.99934725 1.78688E-05 0.0012353 0.03512636 0.03595316 7138.0661 133.745439 0.00703262 91 0.999442213 1.7832E-05 0.00122761 0.0321515 0.0321515 71519125 71313.3559 13.745424 0.006327723 93 0.999571765 1.771431-05 0.00122148 0.022791842 0.02287757 715901322 64.8445855 0.000382724 96 0.99977654 1.780448E-05 0.00113076 0.024061937 0.05166744 75952.2822 749.586256 0.002285193 96 0.99937564 1.80627E-05 0.00113075 0.4400815 0.4939906 76922.2778 33.9902768 0.0148247 90 0.99937552 1.78162E-05 0.00118366 0.042029 0.4339816 0.4414336 76765.6374 80.44692 0.0141274 100 0.999375262 1.78152E-05 0.00122414 0.03686598 <t< td=""><td>87</td><td>0.999264444</td><td>1.79193E-05</td><td>0.00118103</td><td>0.04172543</td><td>0.04270411</td><td>/11/0.66/6</td><td>206.138884</td><td>0.012337986</td></t<>	87	0.999264444	1.79193E-05	0.00118103	0.04172543	0.04270411	/11/0.66/6	206.138884	0.012337986
90 0.9993/2175 1.7869E-05 0.0012/176 0.0336/012 71368.0651 133.745439 0.000703262 91 0.999432215 1.78489E-05 0.00122761 0.0340301 0.03483154 71451.4657 110.176324 0.0060327723 92 0.9994521679 1.78143E-05 0.0012818 0.03217515 71590.1322 64.8445855 0.002872844 94 0.999521679 1.78143E-05 0.00128017 0.02416044 0.02273155 71580.165 21.9852264 0.000327523 96 0.999452931 1.7849E-05 0.0012047 0.02416044 0.022473155 71680.652.8222 748.35644 0.02245193 97 0.9990308591 1.7997E-05 0.00119375 0.04609815 0.04939906 76729.2778 33.9902758 0.018652393 98 0.999236261 1.79152E-05 0.0011929 0.04430381 0.0459786 7666.8307 228.532615 0.01441274 100 0.999297632 1.78154E-05 0.001291 0.04303081 0.045077637 71503.3227 783.532661 0.01	88	0.999316775	1.78997E-05	0.00119375	0.04028373	0.04122918	71248.7635	181.281449	0.011078295
91 0.999443094 1.78489E-05 0.0012133 0.0333154 71451.4657 110.176324 0.006327723 92 0.999443094 1.7832E-05 0.00123918 0.03215215 0.03291053 71519.125 73.178334 0.006138335 93 0.999521679 1.78143E-05 0.0012304 0.02247573 71590.1322 C4.8445655 0.000927502 94 0.999521679 1.77908E-05 0.0012304 0.02287121 0.02341825 71467.9953 21.9852264 0.000927502 96 0.999316931 1.78997E-05 0.00113075 0.044099910 06545242 76303.3227 748.382684 0.022481933 98 0.999316931 1.78997E-05 0.00113075 0.043093081 0.04509786 76662.8307 228.532615 0.01441274 100 0.99924766 1.79063E-05 0.0011294 0.0430381 0.0445366 76765.6374 180.444692 0.01116837 1010 0.999459414 1.78581E-05 0.001291 0.03305161 0.04011603 76829.3226 156.608095 0.011108477	09	0.999371204	1.78608E-05	0.00120770	0.03512636	0.03505316	71368 0651	133 745430	0.009770349
92 0.999482213 1.7832E-05 0.0012918 0.03215215 0.02857753 71519.125 67.3178334 0.000287284 94 0.999571765 1.78143E-05 0.00123148 0.02278142 0.02857753 71590.1322 64.8445855 0.0002872844 95 0.999571765 1.78042E-05 0.0012304 0.02287122 0.02341825 71485.5044 0.02472844 96 0.99957648 1.80827E-05 0.00118026 0.06004397 0.06166784 75952.8222 749.588286 0.032985164 97 0.999306057 1.79105E-05 0.00113075 0.04430906 76752.8222 749.588285 0.014652393 98 0.99927562 1.79105E-05 0.00119276 0.0430906 76756.6374 180.444692 0.01110247 100 0.99927561 1.78581E-05 0.00122141 0.0386698 0.03787183 76980.8078 128.82265 0.008393815 104 0.999459414 1.7828E-05 0.0012241 0.033683 0.03787183 76976.6308 192.5266 0.0060532869	90	0.999332733	1 78489E-05	0.00121333	0.03403001	0.03483154	71451 4657	110 176324	0.007073202
93 0.999521679 1.78143E-05 0.00125148 0.02791842 0.02857753 71590.1322 64.8445855 0.002872844 94 0.999521679 1.78408E-05 0.00120817 0.02416044 0.02473155 71650.1322 64.8445855 0.001348806 96 0.999452593 1.78442E-05 0.00108262 0.06004397 0.06166784 75052.8222 749.586286 0.032985164 97 0.999030659 1.7997E-05 0.00119375 0.04809815 0.04939906 76729.2778 339.902758 0.018652393 98 0.99923661 1.7905E-05 0.0011929 0.04403881 0.04409786 76662.8307 228.532615 0.01441274 100 0.9992947634 1.78676E-05 0.00112921 0.0430381 0.04403784 10.844692 0.01118237 102 0.999376326 1.78764E-05 0.00122414 0.03842413 0.0351842 7697.5038 109.752462 0.006532869 104 0.999421354 1.78581E-05 0.00122414 0.036083 0.03714833 76908.3078 132.882	92	0.999482213	1.7832E-05	0.00123918	0.03215215	0.03291053	71519.125	87.3178334	0.005138335
94 0.9995/1785 1.77908E-05 0.00128617 0.02416044 0.02473155 71685.0046 42.6610304 0.001348066 95 0.999452593 1.78448E-05 0.0012304 0.0228712 0.02341825 71487.9983 21.9852264 0.0000927502 96 0.99930659 1.79997E-05 0.00113076 0.05309121 0.05452942 76303.3227 478.3825644 0.024261993 98 0.999316931 1.7897E-05 0.00118367 0.04309308 0.04509786 76662.8307 228.532615 0.011862393 99 0.9993275562 1.79152E-05 0.00118964 0.04317242 76701.1638 20.477335 0.012670408 101 0.999459414 1.78581E-05 0.0012019 0.03305161 0.04011603 76829.3226 156.608095 0.01108477 103 0.999459414 1.78581E-05 0.0012241 0.0336659 0.0377183 76098.374 182.8252 0.00833815 104 0.999459414 1.7829E-05 0.0012408 0.0326339 77092.914 44.8864892 0.004130204	93	0.999521679	1.78143E-05	0.00125148	0.02791842	0.02857753	71590.1322	64.8445855	0.002872844
95 0.999452593 1.78448E-05 0.0012304 0.0228712 0.0234125 71487.9953 21.9852264 0.000927502 96 0.99875648 1.80827E-05 0.0011306 0.05309121 0.0646397 75952.8222 749.588285 0.032285164 97 0.999306831 1.78997E-05 0.00113075 0.04430961 0.0493906 7672.2778 339.902756 0.01662393 90 0.99927562 1.79152E-05 0.00118970 0.0430981 0.04039766 7662.8307 228.532E10 0.01414274 100 0.999294761 1.79063E-05 0.00118929 0.040381 0.04143536 7676.65374 180.444692 0.01110247 102 0.99937632 1.78764E-05 0.00122141 0.0386698 0.03787183 76982.322 166.803090 0.0043020 104 0.999459414 1.7828E-05 0.0012241 0.0366698 0.03787183 76977.6308 109.752462 0.006632869 105 0.99945934 1.78280E-05 0.0012561 0.0233083 0.02374503 7723.95596	94	0.999571785	1.77908E-05	0.00126817	0.02416044	0.02473155	71685.0046	42.6610304	0.001348806
96 0.99875648 1.8027E-05 0.00108262 0.06004397 0.06166784 7.952.8222 749.588285 0.032985164 97 0.999030659 1.7997E-05 0.00111375 0.44809815 0.045039900 76729.2776 339.902768 0.0148652393 98 0.999239465 1.79152E-05 0.00119375 0.44809815 0.04509786 7665.62307 228.532615 0.01441274 100 0.999237632 1.78152E-05 0.0011929 0.4430381 0.0443536 7675.6374 180.444692 0.01118237 102 0.999376326 1.78764E-05 0.0012241 0.0366598 0.0377183 76908.3078 132.882252 0.006532869 105 0.999421354 1.78561E-05 0.00122414 0.03666598 0.03767183 76908.3078 132.882252 0.006532869 105 0.99947834 1.7829E-05 0.00122461 0.033083 0.3113893 77092.2914 64.8846892 0.002100644 106 0.999459256 1.78154E-05 0.0012167 0.02200983 0.02672334 7715.96551	95	0.999452593	1.78448E-05	0.0012304	0.02287412	0.02341825	71467.9953	21.9852264	0.000927502
97 0.999030659 1.79997E-05 0.00113106 0.05309121 0.05452942 7630.3227 478.325644 0.024261993 98 0.999316931 1.78997E-05 0.00118367 0.04300381 0.04509786 76662.8307 228.532615 0.0141274 100 0.999337632 1.7815E-05 0.00118946 0.042029 0.04317242 7671.1638 204.677335 0.0122670408 101 0.9993376326 1.78764E-05 0.0012291 0.03305161 0.04011603 7665.6374 180.444692 0.01108477 103 0.999459141 1.78581E-05 0.0012215 0.032424193 0.03767183 76908.078 132.88252 0.00839315 104 0.999459414 1.78581E-05 0.0012408 0.03767183 76977.6308 109.752426 0.004908075 105 0.999459256 1.77159.655 0.0012406 0.0422849 0.0311389 77092.2914 64.884692 0.004139204 107 0.99954242 1.7739E-05 0.0012466 0.0227403 7159.6551 42.8807139 0.00224284113<	96	0.99875648	1.80827E-05	0.00108262	0.06004397	0.06166784	75952.8222	749.588285	0.032985164
98 0.999376631 1.7897E-05 0.00119375 0.0430906 76292778 339.902756 0.01662393 99 0.99927562 1.79152E-05 0.00118946 0.042029 0.04317242 76701.1638 204.677335 0.01162243 101 0.999376326 1.78764E-05 0.0011929 0.0403381 0.0414356 767656374 180.444692 0.01110247 102 0.999376326 1.78764E-05 0.00122141 0.03666598 0.03787183 76982.3226 0.00833815 104 0.999459414 1.7829E-05 0.00122011 0.03366598 0.0325339 77031.173 87.1983066 0.004090075 106 0.999459256 1.77845E-05 0.00125071 0.0303083 0.02374503 77239.778 42.880719 0.00106409075 107 0.99952756 1.77845E-05 0.0012647 0.0230803 0.02374503 77239.5596 212189969 0.00106209 109 0.99952756 1.77845E-05 0.00117923 0.4472808 0.0430704 229.1622 24.41130 0.01256414 <td>97</td> <td>0.999030859</td> <td>1.79997E-05</td> <td>0.00113106</td> <td>0.05309121</td> <td>0.05452942</td> <td>76303.3227</td> <td>478.325644</td> <td>0.024261993</td>	97	0.999030859	1.79997E-05	0.00113106	0.05309121	0.05452942	76303.3227	478.325644	0.024261993
99 0.999229562 1.79152E-05 0.00118367 0.04309381 0.04509786 76652.8307 228.532615 0.01441274 100 0.999229562 1.79063E-05 0.0011992 0.0430381 0.04143536 76701.1633 204.677335 0.01108247 102 0.999376326 1.78764E-05 0.0012991 0.03905161 0.04011603 76829.3226 156.608095 0.01108477 103 0.999421354 1.78561E-05 0.00122141 0.03666598 0.0377183 76908.3078 132.882525 0.006532869 105 0.999421354 1.78154E-05 0.00125071 0.0303083 0.03113833 77082.2914 64.8846892 0.004109204 106 0.999550755 1.77815E-05 0.00126167 0.02620938 0.02672334 7719.65651 42.807139 0.02100604 108 0.999550755 1.77815E-05 0.00126167 0.0260983 0.0267234 7719.59.651 42.807139 0.02100604 109 0.999520708 1.7852E-05 0.00121656 0.025360812 0.7291.8622 22.4	98	0.999316931	1.78997E-05	0.00119375	0.04809815	0.04939906	76729.2778	339.902758	0.018652393
100 0.999299476 1.79053E-05 0.00118948 0.042229 0.04317242 76756.5374 80.74358 0.0172670408 101 0.999338722 1.78913E-05 0.00112914 0.03305161 0.04011603 7665.5374 180.444092 0.011108437 102 0.9993459414 1.78581E-05 0.0012014 0.03305161 0.04011603 76698.3076 132.882525 0.008393815 104 0.999459414 1.78526-05 0.00122035 0.03263393 77092.791.173 87.1983066 0.004090875 106 0.999459256 1.78154E-05 0.0012408 0.03166725 0.0325339 77015.0514 4.8846892 0.004139204 107 0.999552765 1.7715E-05 0.00124167 0.02374503 7735.9551 42.8807139 0.00106209 109 0.999362468 1.7822E-05 0.0011567 0.04472089 0.04611118 82106.9716 344.088633 0.015253414 111 0.99952708 1.78252-05 0.00110565 0.05356612 0.05122774 8137.8253 468.058229 0.02	99	0.999275562	1.79152E-05	0.00118367	0.04390381	0.04509786	76662.8307	228.532615	0.01441274
101 0.399336122 1.7813E-05 0.00119923 0.0443361 0.04143363 760413364 76283222 1.78444092 0.011102437 102 0.999437632 1.78764E-05 0.0012141 0.03686598 0.03787183 76829.3226 0.00833078 132.882525 0.00833078 104 0.999459144 1.7829E-05 0.00122017 0.03686598 0.0351842 76977.6308 109.752462 0.006532869 105 0.999459144 1.7829E-05 0.00124088 0.03168725 0.0323333 77031.173 87.1983066 0.00490075 106 0.999552765 1.77815E-05 0.0012164 0.0231086 0.02374503 7738.556 2.12189969 0.00102908 107 0.999525706 1.77815E-05 0.00117923 0.044228938 0.0430706 82291.3622 224.411938 0.012564 109 0.999257068 1.7852E-05 0.0011565 0.0436703 6219.372.253 480.68229 0.02425635 110 0.99925705 1.80762E-05 0.001110565 0.05536612 0.0552062	100	0.999299476	1.79063E-05	0.00118946	0.042029	0.04317242	76701.1638	204.677335	0.012670408
102 0.999421354 1.78581E-05 0.0012214 0.9380101 0.0401003 7698.3926 10300835 0.00653265 0.00683265 0.0012046 0.036142 7677.506 10.752462 0.00683265 0.00120466 0.02672334 7715.0551 42.880713 0.002100684 0.0062099 0.001006209 0.001006209 0.001006209 0.001006209 0.001295657 10.0260988 0.04360766 2224.411938 0.01295857 1100.999257068 1.7852E-05 0.00112567 0.04226938 0.04360766 221.818996 0.441118 201.8272 224.411938 0.01295561 1102553414 1110.999152853 1.7952E-05 0.0011567 0.04268512 0.05526812 0.5558812 0.05726994 81407.371 771.333.55027336 <td>101</td> <td>0.999338722</td> <td>1.78913E-05</td> <td>0.00119929</td> <td>0.04033681</td> <td>0.04143536</td> <td>76705.0374</td> <td>180.444692</td> <td>0.011182837</td>	101	0.999338722	1.78913E-05	0.00119929	0.04033681	0.04143536	76705.0374	180.444692	0.011182837
103 0.999459414 1.7842E-05 0.00122147 0.0331642 76977.6308 10.9.752422 0.000430375 106 0.999459414 1.7842E-05 0.00122037 0.03316672 0.0325339 77032.2914 87.383066 0.004908075 106 0.999519256 1.77159.655 0.0012017 0.030316672 0.0325339 77092.2914 64.8846892 0.004139204 107 0.999519256 1.7719E-05 0.00126167 0.0231086 0.02374503 7729.2914 64.8846892 0.00162099 109 0.999362486 1.7852E-05 0.0011723 0.04472089 0.04611118 82106.9716 344.088633 0.01256385 110 0.999352486 1.80762E-05 0.0011567 0.04472089 0.0411118 82106.9716 344.088633 0.0125734 111 0.9998152853 1.80762E-05 0.00116565 0.05528612 0.0512774 81407.371 74.013235 0.022425636 112 0.99879793 1.80762E-05 0.00111265 0.0552062 8158.1361 6116.464146 0.224875716	102	0.999370320	1.78581E-05	0.0012091	0.03903101	0.04011003	76008 3078	132 882525	0.010100477
105 0.99948783 1.7829E-05 0.0012208 0.033672 0.033083 0.0313893 77031.173 87.1893062 0.00409075 106 0.999542763 1.7819E-05 0.00125071 0.033083 0.0313893 77031.173 87.1893062 0.004090075 107 0.999552765 1.77915E-05 0.0012547 0.02374503 7723.173 87.1893069 0.00106209 109 0.999562765 1.77815E-05 0.001254 0.04228938 0.04360706 82291.3622 224.411938 0.01256967 110 0.999257068 1.7822E-05 0.00117923 0.04472089 0.04611118 82106.9716 344.088633 0.012554314 111 0.999479733 1.80762E-05 0.0011565 0.0512774 8137.8253 468.058229 0.02425635 112 0.998479763 1.80762E-05 0.001110565 0.05520612 0.05520628 8155.8316 611.648146 0.0242875716 114 0.99980673 1.80762E-05 0.0011705 0.44968658 0.4573423 81865.442 361.05234	103	0.999421334	1.78301E-05	0.00122141	0.03080598	0.03767163	76977 6308	109 752462	0.006532869
106 0.999519256 1.78154E-05 0.00125071 0.0303083 0.03113893 77092.2914 64.8846892 0.004139204 107 0.999551256 1.77919E-05 0.00126167 0.02672334 77159.6551 42.880713 0.002100684 108 0.99950755 1.77815E-05 0.00120167 0.02672334 77159.6551 42.880713 0.002100684 109 0.999362468 1.7882E-05 0.0012014 0.04228938 0.04360706 82291.3622 224.411938 0.01255341 110 0.999257084 1.7952E-05 0.00112567 0.0496882 0.05122774 81937.8253 468.058229 0.02425636 112 0.9985179793 1.80762E-05 0.0011265 0.05558812 0.05728944 81407.371 747.01323 0.027236147 113 0.998930571 1.7975E-05 0.0011765 0.49414954 0.0566039 8165.6442 354.032293 0.014906695 116 0.999260461 1.7915E-05 0.00117714 0.40436553 0.40429626 209.19055 20.6.819278 0.011663	104	0.99948783	1.78296E-05	0.00124088	0.03166725	0.03253339	77031.173	87,1983066	0.004908075
107 0.999552726 1.7799E-05 0.00126167 0.02600983 0.02672334 77159.6551 42.8807139 0.002100684 108 0.999550755 1.77815E-05 0.00127483 0.0231108 0.02374503 772.93.5566 21.2189969 0.00106209 109 0.999362468 1.7882E-05 0.00117243 0.04472089 0.04611118 2210.622 224.41193 0.01258957 110 0.999527008 1.7952E-05 0.00117923 0.04472089 0.04611118 210.69.716 344.086833 0.01253414 111 0.999152853 1.80762E-05 0.00110565 0.05556812 0.05728994 81407.317 747.013235 0.022425636 114 0.999891766371 1.8076EE-05 0.0011656 0.0549444 0.0550962 8158.8316 611.648146 0.024275716 114 0.999891766371 1.7975E-05 0.00117305 0.04436658 0.0437777 82062.4967 236.01429 0.13209051 117 0.999246218 1.79176E-05 0.0011822 0.03896239 0.04016959 8212	106	0.999519256	1.78154E-05	0.00125071	0.0303083	0.03113893	77092.2914	64.8846892	0.004139204
108 0.999560755 1.77815E-05 0.00127483 0.02311086 0.02374503 77239.5596 21.2189969 0.001062099 109 0.999362468 1.7882E-05 0.0012054 0.04228938 0.04360706 82291.3622 224.411938 0.01162298957 110 0.999257008 1.7922E-05 0.00117923 0.04472089 0.04611118 8210.6.9716 344.086833 0.015253414 111 0.99877973 1.80762E-05 0.0011557 0.0496882 0.05122774 8137.3253 468.058229 0.02425635 112 0.99877973 1.80762E-05 0.00110565 0.05520612 0.05520962 8158.8316 611.648146 0.024875716 114 0.998891786 1.80154E-05 0.0011705 0.04949454 0.0506039 8168.0234 482.337731 0.01983186 115 0.999106371 1.7975E-05 0.0011705 0.0426501 0.04387977 82062.4967 230.61429 0.01302051 116 0.999248218 1.79375E-05 0.0011726 0.04383637 0.037861 82128.0242	107	0.999552726	1.77999E-05	0.00126167	0.02600983	0.02672334	77159.6551	42.8807139	0.002100684
109 0.999362468 1.7882E-05 0.0012054 0.04220938 0.04300706 82291.3622 224.411938 0.012958657 110 0.999257008 1.7922E-05 0.0011256 0.0428098 0.04411118 82106.9716 344.086833 0.012553414 111 0.999152853 1.7952E-05 0.00110567 0.05558812 0.0572894 81407.371 747.01323 0.0227326147 113 0.99889359 1.80426E-05 0.00112165 0.05518612 0.05508612 8158.8316 411.644146 0.024375716 114 0.99880359 1.80426E-05 0.00114609 0.04436658 0.04573423 8165.6442 354.032293 0.0119305 116 0.999230623 1.79319E-05 0.00117716 0.04209326 20042976 20.0116229051 1116337977 2062.4967 23.061429 0.013209051 117 0.999269646 1.79176E-05 0.0011774 0.0408353 0.04209268 209.91055 206.819278 0.01166374 118 0.999269646 1.79176E-05 0.00111826 0.03376548	108	0.999590755	1.77815E-05	0.00127483	0.02311086	0.02374503	77239.5596	21.2189969	0.001062099
110 0.999257008 1.79222E-05 0.00117923 0.0447208 0.04611118 82106.8716 344.08683 0.01523414 111 0.999152653 1.79502E-05 0.00115637 0.04472088 0.04611118 82107.8253 488.058229 0.02242563 112 0.9998779793 1.80762E-05 0.00110565 0.05536512 0.05728944 81407.371 747.013235 0.027326147 113 0.998893786 1.80154E-05 0.00110565 0.05536612 0.05520962 8158.9316 611.648146 0.02475716 114 0.9998981786 1.80154E-05 0.00114609 0.04436658 0.04573423 81865.6442 354.038293 0.01490695 116 0.999240518 1.7957E-05 0.00117305 0.04256501 0.0438777 82062.4967 230.601429 0.013209051 117 0.999248218 1.7935E-05 0.0011822 0.0386530 0.0429926 82091.9055 206.819278 0.011068747 118 0.9992456184 1.79305E-05 0.0011822 0.03846330 0.0378518 8212	109	0.999362468	1.7882E-05	0.0012054	0.04228938	0.04360706	82291.3622	224.411938	0.012958957
111 0.999152853 1.79592E-05 0.0011557 0.04968822 0.05122774 8137.8253 468.058229 0.020425635 112 0.99877973 1.80762E-05 0.00110565 0.05520542 81407.371 747.013235 0.022326147 113 0.99889359 1.80426E-05 0.00110565 0.05520942 81407.371 747.013230 0.0193318 114 0.998891786 1.80154E-05 0.00111265 0.04914944 0.05066039 8186.5.844 254.03229 0.0193318 116 0.999208523 1.79319E-05 0.00117050 0.44266501 0.4387977 82062.4967 230.601429 0.013209051 117 0.999248946 1.79176E-05 0.0011822 0.0388437 0.04387977 82062.4967 230.601429 0.013029051 118 0.999248946 1.79176E-05 0.0011822 0.0388437 0.0379518 82122.4424 188.953344 0.000680259 120 0.999366153 1.78037E-05 0.00112632 0.0321462 82243.9168 154.09731 0.006880259	110	0.999257008	1.79222E-05	0.00117923	0.04472089	0.04611118	82106.9716	344.088633	0.015253414
112 0.998779793 1.80762E-05 0.001108635 0.05528812 0.05728944 81407.371 747.013235 0.027326147 113 0.99889359 1.80426E-05 0.00110865 0.05558512 0.05728944 81407.371 747.013235 0.027326147 114 0.998891786 1.80154E-05 0.0011265 0.04914954 0.05066039 81681.9235 482.337731 0.01983186 115 0.9992306231 1.79375E-05 0.0011705 0.04436658 0.0443777 2062.49677 230.601429 0.011209061 117 0.999248218 1.7925E-05 0.00117714 0.04083653 0.0420926 82091.9055 206.819278 0.011663747 118 0.9992306315 1.78925E-05 0.0011821 0.03886233 0.04016959 2212.0242 188.953344 0.00168274 119 0.999307014 1.7903E-05 0.00112621 0.03247863 0.0388628 2243.9168 135.409731 0.006880259 121 0.999336515 1.78807E-05 0.0012637 0.03221263 0.0321362 82293	111	0.999152853	1.79592E-05	0.00115587	0.04968882	0.05122774	81937.8253	468.058229	0.020425636
113 0.99898178 1.801426E-05 0.00110565 0.00530612 0.00520962 8158.8316 611.648146 0.024875716 114 0.998981786 1.80154E-05 0.00111605 0.04336944 0.0506039 81881.9235 482.337731 0.014906955 115 0.9999106371 1.7975E-05 0.001117005 0.04436658 0.0436797 230.601429 230.601429 0.013209051 117 0.999248218 1.7925E-05 0.00117305 0.0436797 20.0436797 230.601429 0.013209051 117 0.999248218 1.7975E-05 0.00117205 0.0438797 20.0436797 20.618277 20.011663747 118 0.9992306151 1.78252E-05 0.0011822 0.03386233 0.04016959 82192.240342 158.95344 0.000882629 120 0.9993366151 1.78252E-05 0.00119261 0.03321628 82243.9166 135.409731 0.006880259 121 0.9993366151 1.78654E-05 0.00122569 0.02298453 0.0288658 82363.5931 88.9917274 0.00588275 <td>112</td> <td>0.998779793</td> <td>1.80762E-05</td> <td>0.00108635</td> <td>0.05558512</td> <td>0.05728994</td> <td>81407.371</td> <td>747.013235</td> <td>0.027326147</td>	112	0.998779793	1.80762E-05	0.00108635	0.05558512	0.05728994	81407.371	747.013235	0.027326147
114 0.9980637160 1.0018E-03 0.00112163 0.004914944 0.0000039 618.1223 442.37731 0.01982180 115 0.999106371 1.7975E-05 0.0011705 0.044914944 0.0000039 618.1223 442.37731 0.011920166 116 0.999208253 1.79319E-05 0.0011705 0.04256501 0.0438777 82062.4967 230.601429 0.013209061 117 0.999248946 1.79175E-05 0.00119216 0.03884337 0.0379851 82128.0242 183.05344 0.01068724 118 0.9993269564 1.79375E-05 0.00119216 0.03884337 0.0379518 82128.0242 183.593344 0.00682629 120 0.999366153 1.78807E-05 0.0011262 0.03221263 0.03321362 82243.9166 135.409714 0.005880259 121 0.999366153 1.78608-05 0.00121637 0.028986128 0.02368128 82243.9166 63.370711 0.005480259 122 0.999401621 1.78654E-05 0.00121587 0.028986128 0.02263.5931 88.99	113	0.99889359	1.80426E-05	0.00110565	0.05356612	0.05520962	81558.8316	011.048140	0.024875716
116 0.999230623 1.79319E-05 0.001170305 0.04425650 0.0437523 782062.447 230.801422 0.0132029051 117 0.999230623 1.79319E-05 0.001177305 0.04403653 0.0420926 2208.201422 0.0118209051 117 0.9992468218 1.79255E-05 0.00117714 0.04083653 0.0420926 82019.0055 206.819278 0.011663747 118 0.999260646 1.79176E-05 0.0011820 0.03896293 0.04010659 82128.0242 183.05344 0.01085724 119 0.999307014 1.79036E-05 0.00119861 0.03846393 0.03379851 82192.2443 158.953344 0.006880259 121 0.999336053 1.78607E-05 0.00112625 0.0321162 0.03284638 82263.5931 1112.12635 0.00528275 122 0.999401621 1.78658E-05 0.0012259 0.02794345 0.02881496 82409.6206 66.3770711 0.00292537 124 0.999404551 1.786543E-05 0.0012259 0.0251913 0.02580159 82148.9544	114	0.990901700	1 7075E-05	0.00112105	0.04914954	0.05000039	81865 6442	402.337731	0.01903100
117 0.999248218 1.79255E-05 0.0011734 0.442030 0.4210397 62091905 206.819278 0.01163747 118 0.999248218 1.79255E-05 0.0011734 0.4420365 0.4016959 82192.2421 183.05344 0.011085747 118 0.999248218 1.79255E-05 0.0011822 0.03386239 0.4016959 82192.2423 183.05344 0.010085724 119 0.999306015 1.78252E-05 0.00118661 0.03486932 0.0379851 82192.2443 158.953344 0.00842632 120 0.999336615 1.78825E-05 0.00112861 0.03221263 0.03321362 82243.9168 135.409731 0.006880259 121 0.999401621 1.78654E-05 0.00112259 0.02281436 0.0321362 82297.6311 112.120635 0.00528275 122 0.999401621 1.78654E-05 0.00112259 0.02794345 0.02881496 82409.6206 66.3770711 0.00292537 124 0.999404521 1.78564E-05 0.00112259 0.0250193 0.02580159 82418.9544<	115	0.000230523	1 70310E-05	0.00117305	0.04450050	0.04373423	82062 4967	230 601/20	0.013200051
118 0.999269646 1.79176E-05 0.0011822 0.03896293 0.04016959 82128.0242 183.05344 0.010085724 119 0.999306154 1.79036E-05 0.00118126 0.03896293 0.0379851 82128.0242 183.05344 0.0008426322 120 0.999336615 1.78923E-05 0.00119126 0.03864337 0.0379851 82129.0243 158.953344 0.0068426329 121 0.999366053 1.78807E-05 0.00121687 0.022896453 0.02386128 82297.6311 112.120635 0.00528275 123 0.999426733 1.78664E-05 0.00121587 0.022896453 0.02886628 82409.6206 66.370711 0.003496308 124 0.999426733 1.78564E-05 0.00122359 0.0250193 0.02580159 82409.6206 66.3707011 0.007942533 124 0.99940652 1.7865E-05 0.0012167 0.0233393 0.0240710 82369.698 22.2320547 0.00176423 125 0.999404651 1.81987E-05 0.0010214 0.07330683 0.07530724 646	117	0.999248218	1 79255E-05	0.00117714	0.04083653	0.04209926	82091 9055	206 819278	0.011663747
119 0.999307014 1.79036E-05 0.00119126 0.03684337 0.0379851 82192.2443 158.953344 0.008426232 120 0.9993360315 1.78803E-05 0.00119861 0.03468932 0.0376548 82247.43168 135.409731 0.006880259 121 0.999366053 1.78605E-05 0.00112637 0.03428932 0.0372162 82297.6311 112.120635 0.00528275 122 0.999401621 1.78663E-05 0.0012259 0.02784345 0.0288628 8263.5931 88.9917274 0.003466308 123 0.999430517 1.78664E-05 0.0012259 0.02784345 0.0288628 8248.9520 66.3770711 0.00292537 124 0.999430517 1.78654E-05 0.0012259 0.0250193 0.02880496 68.470711 0.00292537 124 0.999430517 1.78654E-05 0.00121267 0.0233393 0.02407107 82366.688 22.2320547 0.00116206 126 0.99832116 1.81987E-05 0.0010214 0.07330683 0.07530724 64687.5198 1325.8242	118	0.999269646	1.79176E-05	0.0011822	0.03896293	0.04016959	82128.0242	183.05344	0.010085724
120 0.999336315 1.7892E-05 0.00119861 0.03468932 0.03576548 82243.9168 135.409731 0.006880259 121 0.99936053 1.78607E-05 0.00120632 0.0321263 0.03217263 0.2327631 112.120635 0.00528275 122 0.999401621 1.78663E-05 0.0012259 0.02794345 0.02884828 82363.5931 88.9917274 0.0032496308 123 0.999405733 1.78564E-05 0.0012259 0.02794345 0.02881496 82409.6206 66.3770711 0.00292537 124 0.999404551 1.78564E-05 0.0012259 0.0250159 8214954 44.2020747 0.00167643 125 0.999404552 1.786576 0.0012246 0.0250159 821496.444 44.2020747 0.00176403 126 0.999404651 1.81987E-05 0.0010204 0.0730068 0.07530724 64687.5198 1325.82425 0.05280807 127 0.998619481 1.81213E-05 0.0010326 0.0687295 0.07030466 6477.12.8864 1047.8638 0.04501092 <td>119</td> <td>0.999307014</td> <td>1.79036E-05</td> <td>0.00119126</td> <td>0.03684337</td> <td>0.0379851</td> <td>82192.2443</td> <td>158.953344</td> <td>0.008426232</td>	119	0.999307014	1.79036E-05	0.00119126	0.03684337	0.0379851	82192.2443	158.953344	0.008426232
121 0.999360653 1.78807E-05 0.00120632 0.03221263 0.03321362 82297.6311 112.120635 0.00528275 122 0.999401621 1.78664E-05 0.00121587 0.20288423 82363.5931 88.9917274 0.0032496308 123 0.999425733 1.78564E-05 0.00122359 0.02794345 0.02580159 82409.6206 66.3770711 0.00292537 124 0.999405652 1.78564E-05 0.00122359 0.0250133 0.0250159 82149.5424 44.2020747 0.00176433 125 0.99940652 1.7855E-05 0.00112259 0.0250133 0.0250159 82149.544 44.2020747 0.00176433 126 0.999404652 1.7855E-05 0.00112674 0.0233393 0.02407107 82369.698 22.2320547 0.00178028 126 0.99832116 1.81987E-05 0.0010326 0.07033466 0.0773746 64867.5198 1325.82425 0.05260537 127 0.998619481 1.8121478E-05 0.0010326 0.07033466 6477.28864 1447.838 0.46501092	120	0.999336315	1.78923E-05	0.00119861	0.03468932	0.03576548	82243.9168	135.409731	0.006880259
122 0.999401621 1.78663E-05 0.00121587 0.0288463 0.02988628 82363.5931 88.9917274 0.003496308 123 0.999425733 1.78564E-05 0.00122259 0.02794345 0.02881496 82408.0206 66.3770711 0.002992537 124 0.999430517 1.78543E-05 0.00122259 0.022794345 0.02881496 82418.9544 44.202074 0.001976443 125 0.999404652 1.7865E-05 0.00121674 0.0233393 0.02407107 82369.698 22.2320547 0.001182068 126 0.998416315 1.81748E-05 0.0010214 0.07330683 0.07530724 64867.5198 322.820547 0.00182068 127 0.998416315 1.81748E-05 0.0010216 0.07330783 0.07503724 64867.5198 1325.82425 0.052808307 127 0.998416315 1.81748E-05 0.0010326 0.07303663 64772.6664 1047.8638 0.045010092 128 0.998619481 1.81213E-055 0.0010326 0.0637255 64963 666 764 670122 0.	121	0.999366053	1.78807E-05	0.00120632	0.03221263	0.03321362	82297.6311	112.120635	0.00528275
123 0.999425733 1.78654E-05 0.00122259 0.02784345 0.02881496 82408.06206 66.3770711 0.002992537 124 0.999430517 1.78654E-05 0.00122395 0.0250193 0.02881496 82418.9544 44.2020747 0.00176433 125 0.999404652 1.7865E-05 0.001221674 0.0233393 0.02407107 82369.688 22.2320547 0.00118206 126 0.99832116 1.81987E-05 0.0010201 0.07390683 0.07530724 64687.5198 1325.82425 0.52808307 127 0.998619481 1.81213E-05 0.0010326 0.0703466 0.477.26864 1047.8638 0.04501092 128 0.998619481 1.81213E-05 0.0010326 0.0763476 64983.666 1047.76388 0.04501092 128 0.998619481 1.81213E-05 0.0010326 0.0703265 54983.666 1047.76388 0.04501092 128 0.998619481 1.81213E-05 0.0010326 0.07032655 64983.666 764.77122 0.039313692	122	0.999401621	1.78663E-05	0.00121587	0.02898453	0.02988628	82363.5931	88.9917274	0.003496308
124 0.999430517 1.78543E-05 0.00172395 0.0250193 0.02580159 82418.9544 44.2020747 0.00176443 125 0.999404652 1.7865E-05 0.001162408 0.02580159 82369.698 22.2320547 0.00176443 126 0.999404652 1.7865E-05 0.00102014 0.07390683 0.07530724 64687.5198 1325.82425 0.052808307 127 0.998619481 1.812174E-05 0.0010326 0.0687295 0.07003466 6477.28664 1047.8638 0.04501092 128 0.98619481 1.81213E-05 0.0010127 0.0637178 0.06350255 64963.666 764.770129 0.03913692	123	0.999425733	1.78564E-05	0.00122259	0.02794345	0.02881496	82409.6206	66.3770711	0.002992537
120 0.999404652 1.7865E-05 0.00121674 0.023393 0.02407107 82336.698 22.2320547 0.001182068 126 0.99832116 1.81987E-05 0.00102014 0.07390683 0.07530724 64687.5198 1325.82425 0.052808307 127 0.998416315 1.81748E-05 0.0010326 0.0687295 0.07003466 64772.6864 1047.8638 0.045010092 128 0.998619481 1.81213E-05 0.00108127 0.063376 0.06350255 64963.666 764.670122 0.035913692	124	0.999430517	1.78543E-05	0.00122395	0.0250193	0.02580159	82418.9544	44.2020747	0.00176443
120 0.9962100 1.01987E-05 0.00102014 0.07390683 0.07530724 69695.5198 1325.82425 0.052808307 127 0.998416315 1.81748E-05 0.00108127 0.0687295 0.07003466 64772.6864 1047.8638 0.045010092 128 0.998619481 1.81213E-05 0.00108127 0.0623178 0.06350255 64963.666 764.670122 0.036913692	125	0.999404652	1.7865E-05	0.00121674	0.0233393	0.02407107	82369.698	22.2320547	0.001182068
121 0.0004 10313 1.01740E-00 0.0010320 0.0007290 0.07003400 04772.0004 1047.6038 0.045010092 128 0.998619481 1.81213E-05 0.00106127 0.0623178 0.06350255 64963.668 764.670122 0.035913692	126	0.99832116	1.8198/E-05	0.00102014	0.07390683	0.07002466	64772 6964	1325.82425	0.052808307
	12/	0.998619481	1.81213E-05	0.00106127	0.0623178	0.06350255	64963.668	764.670122	0.035913692

	Loop Test Section Water	Loop Test	Loop Test Section Water	Apparent Friction	Apparent Friction	Superficial Gas Reynolds	Superficial Liquid Reynolds	Effective
	Density,	Section Air	viscosity,	Factor, fisg	Factor, fisg	Number,	Number,	relative
Line No.	g/cm3	1 90427E 05	Pa-s	(INCI KE)	(NO KE)	Resg	490 572561	Rougnness, e
129	0.990090002	1.00437E-05	0.00113436	0.05299995	0.05400939	65422 0302	357 608288	0.024024476
130	0.999040020	1 79498E-05	0.00116184	0.04774040	0.04510886	65584 5984	232 825215	0.014628053
132	0.999208758	1.794E-05	0.00116797	0.04284579	0.04366606	65620,1875	208.443231	0.013289065
133	0.999252628	1.79242E-05	0.00117803	0.04066086	0.04144004	65678.076	183,700864	0.011332979
134	0.999281121	1.79137E-05	0.0011848	0.03863456	0.03937612	65716.6721	159.820419	0.009641477
135	0.99930535	1.79046E-05	0.00119069	0.03773833	0.03846283	65750.0768	136.310208	0.008932303
136	0.999339886	1.78913E-05	0.00119936	0.03461377	0.03527921	65798.7985	112.770686	0.006650482
137	0.999351769	1.78867E-05	0.00120244	0.03380998	0.0344617	65815.9869	89.9861922	0.006112684
138	0.999399329	1.78677E-05	0.00121508	0.03093565	0.03153296	65886.0269	66.7871075	0.004358041
139	0.999449039	1.7847E-05	0.00122908	0.02960739	0.03017936	65962.4039	44.0178813	0.003637779
140	0.999376652	1.78768E-05	0.00120899	0.02580865	0.02630945	65852.4514	22.3746228	0.001889832
141	0.999147265	1.79014E-05	0.00115454	0.0430032	0.04416499	54616.3001	234.297060	0.013622230
142	0.999104313	1.79550E-05	0.0011382	0.04207003	0.04203043	54717 0979	161 158348	0.012408803
144	0.999286786	1.79115E-05	0.00118619	0.03561059	0.03608869	54770.5364	114.023691	0.007170061
145	0.999378004	1.78762E-05	0.00120934	0.03123994	0.0316604	54878.623	67.104492	0.004356389
146	0.999358412	1.7884E-05	0.00120418	0.0268715	0.0272346	54854.811	44.9278711	0.002156387
147	0.999031151	1.8E-05	0.00113097	0.04663248	0.04713896	49051.3045	239.18014	0.016696442
148	0.999129621	1.79674E-05	0.00115082	0.04410227	0.04458127	49140.0717	188.043884	0.014182718
149	0.999126466	1.79685E-05	0.00115016	0.04312979	0.04359774	49137.0991	211.672109	0.013261283
150	0.999187364	1.79475E-05	0.00116323	0.03783798	0.03824941	49194.547	162.783651	0.008717637
151	0.99922626	1.79337E-05	0.00117196	0.03451372	0.03489023	49232.4806	115.407739	0.006290259
152	0.999331466	1.78946E-05	0.00119723	0.02843976	0.02875089	49340.1738	67.7828982	0.002759239
153	0.999341760	1.70905E-05	0.00114062	0.03026352	0.03001531	49301.3140	40.0090117	0.003706216
154	0.999079978	1.7984TE-05	0.00114002	0.04400299	0.044444283	43639.0935	213 087207	0.014001394
156	0.99914766	1.79613E-05	0.00115463	0.03503818	0.03534159	43694,9916	163,995786	0.006506475
157	0.999196768	1.79442E-05	0.00116532	0.03037212	0.03063627	43736.5942	116.065664	0.003608794
158	0.999272736	1.79168E-05	0.0011828	0.02692111	0.02715601	43803.6002	68.609846	0.001918978
159	0.999320944	1.78986E-05	0.00119459	0.02932421	0.02957982	43848.0793	45.2884535	0.003057385
160	0.998339998	1.81935E-05	0.00102271	0.08657299	0.08716628	37745.2218	793.50009	0.072629725
161	0.998813414	1.80662E-05	0.00109199	0.04659421	0.04691641	38011.1678	260.105028	0.016328046
162	0.998905576	1.80387E-05	0.00110785	0.04577805	0.04609442	38068.978	244.1735	0.015501153
163	0.998615995	1.81218E-05	0.0010609	0.0687119	0.06918366	37894.6012	509.954864	0.044368284
104	0.996729691	1.00903E-05	0.00107636	0.03070685	0.05604297	38166 4267	3/0.2/32/0	0.029110901
166	0.997794531	1.83203E-05	0.00096002	0.15951283	0.16032891	32129 0481	1690 62112	0 206147004
167	0.998034944	1 82664E-05	0.00098593	0 14293731	0 14366831	32223 864	1371 83927	0 174943254
168	0.998164094	1.82362E-05	0.00100091	0.12377943	0.12441326	32277.2813	1081.03753	0.139014704
169	0.998356999	1.81891E-05	0.00102494	0.1004442	0.10095981	32360.8044	791.770357	0.096401492
170	0.998571787	1.81335E-05	0.00105445	0.07810318	0.07850552	32459.974	513.076839	0.058530484
171	0.998711705	1.80952E-05	0.00107556	0.06585728	0.06619729	32528.7517	377.254915	0.03999876
172	0.998830885	1.80609E-05	0.00109496	0.05429667	0.05457807	32590.4497	247.04698	0.024716827
173	0.998884165	1.80451E-05	0.00110411	0.05184484	0.05211371	32619.0735	220.498661	0.021821589
1/4	0.998920027	1.80342E-05	0.00111046	0.04762363	0.04787102	32638.7364	194.878626	0.01/162243
175	0.996974161	1.60175E-05	0.00112035	0.04461249	0.04464462	32689.0929	144 005761	0.014110047
170	0.999009793	1 79905E-05	0.00112700	0.04173431	0.04193103	32718 0301	119 005163	0.011420333
178	0.999075072	1.79851E-05	0.00113985	0.03714582	0.03734015	32727.9516	94,9271151	0.007620261
179	0.999118024	1.79707E-05	0.00114862	0.03415248	0.03433168	32754.0235	70.6513618	0.005483688
180	0.999170602	1.79528E-05	0.0011598	0.03214492	0.032314	32786.8564	46.6470376	0.004209305
181	0.999235736	1.79296E-05	0.00117439	0.02332577	0.02345044	32829.1211	23.0338175	0.000146728
182	0.998107183	1.82497E-05	0.0009942	0.2111179	0.21187458	26877.8641	1632.50978	0.301059292
183	0.998150576	1.82394E-05	0.0009993	0.19303776	0.19373125	26892.9637	1353.4793	0.268193848
184	0.99823023	1.82203E-05	0.00100891	0.16810817	0.16871379	26921.139	1072.465	0.22194986
185	0.998365475	1.8187E-05	0.00102605	0.13857474	0.13907544	26970.484	/90.917841	0.166407376
186	0.998503541	1.81516E-05	0.00106277	0.11058199	0.11098314	27023.0754	517.853105	0.11434236
10/	0.99002020	1.01103E-05	0.00100277	0.09020039	0.09003035	27131 850	240 366021	0.000742070
189	0.998783481	1.80748E-05	0.00108707	0.06974549	0.07000044	27137.9441	223.955715	0.045330876
190	0.998789527	1.8073E-05	0.00108807	0.06331388	0.063546	27140.577	198.889737	0.036100127
191	0.998857676	1.8053E-05	0.00109952	0.05993925	0.06015923	27170.6306	172.215114	0.031536281
192	0.998902378	1.80396E-05	0.00110732	0.05606728	0.0562734	27190.8505	146.573714	0.026563509

	Loop Test Section Water Density,	Loop Test Section Air	Loop Test Section Water Viscosity,	Apparent Friction Factor, fiSG	Apparent Friction Factor, fiSG	Superficial Gas Reynolds Number,	Superficial Liquid Reynolds Number,	Effective relative
Line No.	g/cm3	Viscosity Pa-s	Pa-s	(incl KE)	(NO KE)	ReSG	ReSL	Roughness, e
193	0.998912192	1.80366E-05	0.00110906	0.05159128	0.05178149	27195.3527	121.952645	0.021202238
194	0.998931931	1.80306E-05	0.00111261	0.04736533	0.04754057	27204.4731	97.2513068	0.01656336
195	0.998962208	1.80212E-05	0.00111814	0.04330399	0.04346482	27218.6259	72.577712	0.012530596
196	0.99901384	1.80049E-05	0.00112785	0.03884286	0.03898774	27243.2421	47.9686765	0.008624509
197	0.999034461	1.79982E-05	0.00113185	0.02793602	0.02804243	27253.3529	23.8995117	0.001623747
198	0.997515714	1.83795E-05	0.00093274	0.31961413	0.32037245	21350.3584	2030.09169	0.482125818
199	0.997533404	1.83759E-05	0.0009344	0.29583922	0.29654245	21354.6319	1736.99298	0.444740544
200	0.997680326	1.83449E-05	0.00094853	0.27033698	0.27098042	21390.6292	1425.92443	0.403142461
201	0.997787152	1.83219E-05	0.00095928	0.2494967	0.25009191	21417.5584	1127.95414	0.367984322
202	0.997933003	1.82895E-05	0.00097466	0.21568389	0.21619961	21455.4089	832.613549	0.308761131
203	0.998100512	1.82511E-05	0.00099346	0.17773102	0.17815734	21500.6129	544.576019	0.239417156
204	0.998214776	1.8224E-05	0.00100705	0.15579486	0.15616928	21532.6259	402.918887	0.198345032
205	0.998378529	1.81836E-05	0.00102778	0.13594738	0.1362748	21580.3975	263.193619	0.160981165
206	0.998502582	1.81518E-05	0.00104461	0.13015624	0.13046957	21618.2476	233.059308	0.150118505
207	0.99857323	1.81331E-05	0.00105468	0.12538553	0.12568726	21640.5216	205.186317	0.141202847
208	0.998611743	1.81227E-05	0.00106033	0.11796291	0.11824733	21652.921	178.580535	0.127418182
209	0.998662517	1.81088E-05	0.00106797	0.11364481	0.11391889	21669.5222	151.974493	0.119466739
210	0.998723257	1.80919E-05	0.0010774	0.11023967	0.11050561	21689.8174	125.536738	0.113240812
211	0.998784819	1.80743E-05	0.00108731	0.10557126	0.10582605	21710.9001	99.5138649	0.104778539
212	0.998822123	1.80634E-05	0.00109351	0.09696633	0.09720099	21723.9573	74.212573	0.089457085
213	0.998868444	1.80497E-05	0.00110141	0.08909039	0.08930655	21740.4656	49.120229	0.075842357
214	0.998952761	1.80241E-05	0.00111642	0.08472634	0.0849323	21771.4383	24.2297067	0.068511688

Appendix 2 Chemical Safety Data Sheets (SDS)

The following data sheets are included (first page only):

- 1. Glycerol.
- 2. Rhodamine B.

SIGMA-ALDRICH

sigma-aldrich.com

SAFETY DATA SHEET

Version 5.3 Revision Date 06/27/2014 Print Date 07/04/2017

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	: Glycerol		
Product Number Brand Product Use	: G7893 : Sigma-Aldrich : For laboratory research purposes.		
Supplier	: Sigma-Aldrich Canada Co. M 2149 Winston Park Drive e OAKVILLE ON L6H 6J8 CANADA	/anufactur er	: Sigma-Aldrich Corporation 3050 Spruce St. St. Louis, Missouri 63103 USA
Telephone	: +1 9058299500		
Fax	: +1 9058299292		
Emergency Phone # (For both supplier and manufacturer)	: +1-703-527-3887 (CHEMTREC)		
Preparation Information	 Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956 		

2. HAZARDS IDENTIFICATION

Emergency Overview

Target Organs

Kidney

WHMIS Classification

Not WHMIS controlled.

GHS Classification Skin irritation (Category 3) Eye irritation (Category 2B)

GHS Label elements, including precautionary statements

I	Pictogram	none	
:	Signal word	Warning	
	Hazard statement(s) H316 H320	Causes mild skin irritation. Causes eye irritation.	
i	Precautionary statement(s) P305 + P351 + P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses present and easy to do. Continue rinsing.	s, if
HMI	S Classification Health hazard: Chronic Health Hazard: Flammability: Physical hazards:	0 * 1 0	
Pote	ential Health Effects		
l Sigma-Aldr	Inhalation Skin ich - G7893	May be harmful if inhaled. May cause respiratory tract irritation. May be harmful if absorbed through skin. May cause skin irritation. Page 1	of 6

Page 1 of 6



SAFETY DATA SHEET

1. Identification

AC296570000; AC296570010; AC296570100; AC296570250;

Creation Date 12-December-2006

Revision Date 26-May-2017

Revision Number 3

Cat No. :

Product Name

Rhodamine B

AC296571000

C.I. 45170; Basic Violet 10

Synonyms

Recommended Use Uses advised against

Laboratory chemicals.

Not for food, drug, pesticide or biocidal product use

Details of the supplier of the safety data sheet

Company Importer/Distributor Fisher Scientific 112 Colonnade Road, Ottawa, ON K2E 7L6, Canada Tel: 1-800-234-7437

Acros Organics One Reagent Lane Fair Lawn, NJ 07410

Manufacturer Fisher Scientific One Reagent Lane Fair Lawn, NJ 07410 Tel: (201) 796-7100

Emergency Telephone Number For information US call: 001-800-ACROS-01 / Europe call: +32 14 57 52 11 Emergency Number US:001-201-796-7100 / Europe: +32 14 57 52 99 CHEMTREC Tel. No.US:001-800-424-9300 / Europe:001-703-527-3887

2. Hazard(s) identification

Classification

WHMIS 2015 Classification Classified as hazardous under the Hazardous Products Regulations (SOR/2015-17)

Acute oral toxicity Serious Eye Damage/Eye Irritation

Category 4 Category 1

Label Elements

Signal Word Danger

Hazard Statements Harmful if swallowed Causes serious eye damage

Page 1/6

Appendix 3 Equipment Data Sheets

The following data sheets are included

- 1. Omega pressure transducer
- 2. Omega differential pressure transducer
- 3. Omega mass flow controller
- 4. Cole-Parmer rotameter (air)
- 5. Kobold rotameter (liquid)
- 6. LaVision Imager Intense CCD camera
- 7. New Wave Research Solo Nd:YAG Laser System

4 TO 20 mA OUTPUT HIGH PERFORMANCE PRESSURE TRANSMITTERS PIEZORESISTIVE DESIGN WITH HIGH TEMPERATURE PERFORMANCE

						-
4 to 20 mA Output 0-10 inH ₂ 0 to 0-5000 psi 25 mb to 0-345 bar	PX409-100 shown act	GI, ual size.				
PX409 Series				PX419-100Gl, shown actual siz	Stock Delivery for most Ranges! e.	
	To Ord	er				
	BAN	GE	2 m (6') CABLE	MINI-DIN	TWIST-LOCK	
	psi	bar	TERMINATION	TERMINATION	TERMINATION	
His Hereit	4 to 20 m	A OUTPUT,	GAGE PRESSURE	RANGES		
PX429-015GI,	10 in-H ₂ O	25 mb	PX409-10WGI	PX419-10WGI	PX429-10WGI	
shown actual	1	69 mb	PX409-001GI	PX419-001GI	PX429-001GI	
H	2.5	172 mb	PX409-2.5GI	PX419-2.5GI	PX429-2.5GI	
	5	345 mb	PX409-005GI	PX419-005GI	PX429-005GI	
	15	1.0	PX409-015GI	PX419-015GI	PX429-015GI	
	30	2.1	PX409-030GI	PX419-030GI	PX429-030GI	
4 to 20 mA	50	3.4	PX409-050GI	PX419-050GI	PX429-050GI	
Specifications	100	6.9	PX409-100GI	PX419-100GI	PX429-100GI	
Output: 4 to 20 mA	150	10.3	PX409-150GI	PX419-150GI	PX429-150GI	
Supply Voltage: 9 to 30 Vdc	250	17.2	PX409-250GI	PX419-250GI	PX429-250GI	
maximum loop res $\Omega = (Vs-9)x50$	500	34.5	PX409-500GI	PX419-500GI	PX429-500GI	
[9 to 20 Vdc above 105°C (229°F)]	750	51.7	PX409-750GI	PX419-750GI	PX429-750GI	
Hysteresis and Repeatability): ±0.08%	1000	69	PX409-1.0KGI	PX419-1.0KGI	PX429-1.0KGI	
BŚL maximum	1500	103	PX409-1.5KGI	PX419-1.5KGI	PX429-1.5KGI	
Zero Balance: ±0.5% FS typical	2500	241	PX409-2.5KGI	PX419-2.5KGI	PX429-2.5KGI	
for 2.5 psi and below)	5000	241	PX409-3.5KGI	PX419-3.5KGI	PX429-3.3KGI	
Span Setting: ±0.5% FS typical 1%	4 to 20 m		E PRESSURE BAN	IGES	PA429-5.0KGI	
maximum (1% typical, 2% max for 2.5 psi	5	345 mb	PX409-005AI	PX419-005AI	PX429-005A1	
with fitting down	15	10	PX409-015AI	PX419-015AI	PX429-015AI	
Operating Temperature Range:	30	2.1	PX409-030AI	PX419-030AI	PX429-030AI	
-45 to 115°C (-49 to 240°F)	50	3.4	PX409-050AI	PX419-050AI	PX429-050AI	
Compensated Temperature:	100	6.9	PX409-100AI	PX419-100AI	PX429-100AI	
Ranges >5 psi: -29 to 85°C (-20 to 185°F)	150	10.3	PX409-150AI	PX419-150AI	PX429-150AI	
Hanges \leq 5 psi: -17 to 85°C (0 to 185°F) Thermal Effects Zero	250	17.2	PX409-250AI	PX419-250AI	PX429-250AI	
(Over Compensated Range):	500	34.5	PX409-500AI	PX419-500AI	PX429-500AI	
Ranges >5 psi: ±0.5% span	750	51.7	PX409-750AI	PX419-750AI	PX429-750AI	
Ranges ≤5 psi: ±1.0% span	1000	69	PX409-1.0KAI	PX419-1.0KAI	PX429-1.0KAI	
Thermal Effects Span	2m (6') cab	Examples: PX	409-1.0KGI, 4 to 20 m/ PX429-015AL 4 to 20	A output, 1000 psi gag mA output, 15 psi abs	e pressure range, olute pressure, twist lock	
Bandes >5 nsi: +0.5% snan	termination	, PT06F10-6S,	mating twist lock conr	nector (sold separately), and DP25B-E, 4-digit	
Ranges ≤5 psi: ±1.0% span	meter, syst (See B-25h	em with meter. I for informati	on on meters).			

B-25f

WET/WET DIFFERENTIAL PRESSURE TRANSDUCER UNI-DIRECTIONAL AND BI-DIRECTIONAL RANGES

50 (1.9

ţ 78

1/4-18 NPT

RANGE

(psid)

0 to 1

0-1 to 0-100 psid Uni-Directional ±0.5 to ±50 psid Bi-Directional

PX2300 Series



✓ 0.25% Accuracy NEMA 4 (IP65) Rating Wet/Wet Corrosive Environments Ideal for Measuring Pressure Drop Across Filters

OMEGA's PX2300 Series high-output, low differential pressure transducers are compatible with most media, from dry air to corrosive liquids. All wetted parts are stainless steel with elastomer seals. The electronics are housed in a NEMA 4 (IP65) enclosure. A high working pressure and high overpressure ratings ensure dependability in harsh industrial environments. These transducers are ideal for measuring pressure drop across filters and other process devices.

SPECIFICATIONS

Excitation: 24 Vdc nominal **Max:** 30 + 0.004 x(loop resistance Ω) Vdc Min: 11 + 0.02 x(loop resistance Ω) Vdc Loop Resistance: 0 to 1000 Ω Output: 4 to 20 mA Accuracy: ±0.25% RSS FS at constant temperature (includes linearity, repeatability and hysteresis) Linearity: ±0.20% FS Hysteresis: 0.10% FS Repeatability: ±0.05% FS **Operating Temperature Range:** -18 to 80°C (0 to 176°F) **Compensated Temperature Range:** -1 to 65°C (30 to 149°F) Thermal Zero Effect: <±0.02% FS/°F Thermal Span Effect: <±0.02% FS/°F

I/4-18 NPT ow Pressure Port 62 (2.44) ure Port Metric thread adaptors and snubbers Sensor: Capacitive available, Maximum Line Pressure: 250 psig Maximum Overpressure: High Side: 1 to 5 psi = 20 x FS, 10 to 25 psi = 10 x FS, 50 psi = 5 x FS, 100 psi = 2.5 x FS

To Order Visit omega.com/px2300 for Pricing and Details

MODEL NO

PX2300-1DI

Dimensions: mm (in)

٢

25.4

(1.00)

Low Side: 2.5 x FS (shift recoverable) The zero will shift slightly when high differential pressure is applied. The shift may be as much as $\pm 10\%$ FS with overpressure applied to the low port. (Other parameters will not shift.) The shift may be recovered by a positive overpressure or if the overpressure is always in one direction, the user may apply this pressure to pre-set the sensor. Subsequent overloads of less pressure will not cause any further shift.

PX2300-1DI, shown smaller than actual size. visit omega.com Wetted Parts: Air and fluids compatible with 17-4 and 300 stainless steel, FKM, and silicone O-rings

22.2 DIA. Condu (0.875) Opening

DIFFERENTIAL PRESSURE TRANSDUCERS

B

Cavity Volume: 0.27/0.08" pos./neg. port Case: NEMA 4 (IP65) Pressure Port: 1/4 NPT internal Electrical Connection: Internal barrier strip with 22.2 mm (0.875") conduit opening Response Time: 50 ms (water) Weight: 410 g (14.4 oz)

COMPATIBLE METERS

DP41-E, DP25B-E, DP-7700

0 to 2	PX2300-2DI	DP41-E, DP25B-E, DP-7700
0 to 5	PX2300-5DI	DP41-E, DP25B-E, DP-7700
0 to 10	PX2300-10DI	DP41-E, DP25B-E, DP-7700
0 to 25	PX2300-25DI	DP41-E, DP25B-E, DP-7700
0 to 50	PX2300-50DI	DP41-E, DP25B-E, DP-7700
0 to 100	PX2300-100DI	DP41-E, DP25B-E, DP-7700
BI-DIRECTIC	NAL RANGE	
±0.5	PX2300-0.5BDI	DP41-E, DP25B-E, DP-7700
±0.5 ±1	PX2300-0.5BDI PX2300-1BDI	DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700
±0.5 ±1 ±2.5	PX2300-0.5BDI PX2300-1BDI PX2300-2.5BDI	DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700
±0.5 ±1 ±2.5 ±5	PX2300-0.5BDI PX2300-1BDI PX2300-2.5BDI PX2300-5BDI	DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700
±0.5 ±1 ±2.5 ±5 ±10	PX2300-0.5BDI PX2300-1BDI PX2300-2.5BDI PX2300-5BDI PX2300-10BDI	DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700
± 0.5 ± 1 ± 2.5 ± 5 ± 10 ± 25	PX2300-0.5BDI PX2300-1BDI PX2300-2.5BDI PX2300-5BDI PX2300-10BDI PX2300-25BDI	DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700 DP41-E, DP25B-E, DP-7700

Comes complete with operator's manual. Ordering Examples: PX2300-5BDI, bi-directional range -5 to 5 psid transducer with

PX2300-1DI, 0 to 1 psid range transducer with current output.

B-242



- ✓ 30+ Gas Calibrations, Including He, O₂, Neon, N₂O, N₂, Air, Argon, CO, CO₂, Methane, Ethane, H₂, Propane, Butane, iso-Butane, Ethylene, Acetylene, Krypton, Xenon, Sulfur Hexafluoride
- Pressure, Temperature, and Volumetric and Mass Flow Simultaneously Displayed
- Easy-to-Use Pushbutton Interface
- NIST Traceability Standard
- ✓ Full Scale Ranges from 0.5 SCCM to 3000 SLM
- Response Time of 50 to 100 ms Typical
- Turndown Ratio of 200:1
- Position Insensitive
- ✓ ±0.8% Reading Accuracy
- RS232 Standard

The FMA-2600A Series mass and volumetric flow controllers use the principle of differential pressure within a laminar flow field to determine and control mass flow rate. A laminar flow element (LFE) inside the meter forces the gas into laminar (streamlined) flow. Inside this region, the Poiseuille equation dictates that the volumetric flow rate be linearly related to the pressure drop. A differential pressure sensor is used to measure the pressure drop along a fixed distance of the LFE. This, along with the viscosity of the gas, is used to accurately determine the volumetric flow rate. Separate absolute temperature and pressure sensors are incorporated and correct the volumetric

flow rate and is reported in units such as standard cubic feet per minute (SCFM) or standard liters per minute (SLM).

The controller uses a true proportional valve coupled to the flow body to control flow using the integral PID loop controller. Standard units include a 0 to 5 V output (4 to 20 mA optional) and RS232 communications. The gas-select feature and the setpoints can be adjusted from the front keypad or via RS232 communications. Volumetric flow, mass flow, absolute pressure, and temperature can all be viewed or recorded through the RS232 connection. It is also possible to multi-drop up to 26 units on the same serial connection to a distance of 46 m (150').

SPECIFICATIONS

Accuracy: ±(0.8% of reading + 0.2%FS) Repeatability: ±0.2% FS Turndown Ratio: 200:1 Control Response Time: 100 ms Input Control Signal: 0 to 5 Vdc, RS232 Output Signal: 0 to 5 Vdc, RS232 Optional Input/Outputs: 4 to 20 mA, 0 to 10 Vdc Operating Temperature: -10 to 50°C (14 to 122°F) Zero Shift: 0.02%/ATM FS/°C Span Shift: 0.02%/ATM FS/°C Humidity Range: 0 to 100% RH, non-condensing Excess Flow Rate: 2.4% FS Wetted Materials: 303 and 302 SS, FKM, silicone RTV (rubber), glass-reinforced nylon, aluminum, brass, 410 SS, silicone, glass; >250 SLM: 416 SS and nickel replace brass Maximum Pressure Mass Flow Controllers: 145 psig To Use in Volumetric Mode: Near atmosphere, 15 psig

recommended maximum. Volumetric flowmeters and controllers not certified for accuracy at mass flow rates above the rated flow range of the meter. They are designed for near atmospheric pressure conditions only. The recommended maximum operating pressure is 15 psig

D-29



Flowmeters

Variable-Area, Direct Reading

Cole-Parmer[®] Valved Acrylic Flowmeters for Bench or Panel Mount

Meter with valve provides flow control through a highly durable meter body

- Ideal for process plant applications on air sampling equipment, gas analyzers and chemical feed systems for water treatment
- Integrated precision valve allows precise manual flow across the full scale
- The flexible design allows for panel or bench mounting

Machined from solid acrylic blocks, these meters have integral metering tubes that provide precise readings even in aggressive plant environments. The meters' inlet/outlet ports and mounting studs are extended for easy panel installation. An alternate option is a tripod base (sold separately below) which allows for mobility from bench to bench.

Note: There are many additional types of acrylic flowmeters not listed here. Contact our Application Specialists for quotes on acrylic meters with special requirements.

Maximum pressure: 100 psi

Max operating temp: 150°F (65°C) Dimensions (not including

Jimensions (not including valve stem): 2° and 50-mm flowmeters: 1°W x 4°H x 2%D 4° and 100-mm flowmeters: 1%°W x 6%°H x 2%D 5° and 127-mm flowmeters: 1%°W x 10%°H x 4%°D

Specifications

Accuracy 2" and 50-mm flowmeters: ±5% full-scale 4" and 100-mm flowmeters: ±3% full-scale 5" and 127-mm flowmeters: ±2% full-scale

Repeatability: ±0.5% full-scale

Media type: liquids or gases

Connections

2", 4", 50-mm, and 100-mm flowmeters: ½" NPT(F)† 5" and 127-mm flowmeters: 1" NPT(F)

Materials of Construction

English-Unit Scales

Part	2" and 50 mm	4" and 100 mm	5" and 127 mm
Body		Acrylic	
Fittings	Bra	ass	PVC
Valve		Brass	
0-rings		Buna N	
Float (for air)	Glass (BG)	316 S	S (SS)



[‡]Float material key: BG = black glass, SS = stainless steel







GO to page(s) 602-670 For our selection of barbed and compression fittings

32461-08

Metric-Unit Scales

F	For liquid applications			For a	For air applications		
Cat. no.	Float [‡]	Flow range	Price	Cat. no.	Flow range	Price	
Flowmeters	with 50	-mm scale					
R-32460-30	BG	5 to 50 mL/min		R-32460-40	0.04 to 0.5 LPM		
R-32460-32	SS	10 to 100 mL/min		R-32460-42	0.1 to 1 LPM		
R-32460-34	SS	20 to 240 mL/min		R-32460-44	0.4 to 5 LPM		
_	-	—	—	R-32460-46	1 to 10 LPM		
_	-	—	_	R-32460-48	2 to 25 LPM		
_	_	_	_	R-32460-50	4 to 50 LPM		
	_	_	_	R-32460-52	10 to 100 LPM		
Flowmeters	with 10	0-mm scale					
R-32461-30	SS	4 to 50 mL/min		R-32461-50	0.4 to 5 LPM		
R-32461-32	SS	10 to 120 mL/min		R-32461-52	1 to 10 LPM		
R-32461-34	BG	25 to 225 mL/min		R-32461-54	2 to 20 LPM		
R-32461-36	SS	40 to 400 mL/min		R-32461-56	3 to 30 LPM		
R-32461-38	SS	40 to 660 mL/min		R-32461-58	4 to 50 LPM		
R-32461-40	SS	100 to 1500 mL/min		R-32461-60	10 to 100 LPM		
R-32461-42	SS	200 to 3000 mL/min		R-32461-62	14 to 140 LPM		
R-32461-44	SS	0.8 to 9 LPM		R-32461-64	30 to 280 LPM		
R-32461-46	SS	1.5 to 20 LPM		_	_	_	
Flowmeters	with 12	7-mm scale					
R-32466-54	SS	4 to 36 LPM		R-32466-66	100 to 700 LPM		
R-32466-56	SS	5 to 75 LPM		R-32466-68	100 to 1400 LPM		
_	_	_	_	R-32466-70	400 to 3400 LPM		

Tripod Bases Durable acrylic	base with three leveling screws and	spirit level.
Catalog number	Description	Price
ED-32462-50	For one flowmeter with 2" or 50-mm scale	
ED-32462-55	For one flowmeter with 4" or 100-mm scale	
ED-32462-60	For one flowmeter with 1/4" connections	

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- Industrial and Sanitary Designs
- Body Sizes 1/2" Through 2" Reliable, Time Proven Glass
- Tube Design
- Flanged, Threaded or Tri-Clamp Fittings • ±1.0% of Full Scale Accuracy
- Optional Surface Finishes for Food and Pharmaceutical Applications
- Optional Switches
- Special Calibrations for Compressed Gases and Viscous Media

The KDV series are high quality glass tube variable-area flowmeters (rotameters). This classic design is still the most widely used flowmeter style in the world today. The simple variable-area design makes the flowmeter a perfect choice when ease of installation and operation is a must.

The KDV features a tempered glass measuring tube which is inert to most chemicals. This tube is suitable for measurement of both liquids and gases. Liquid flow ranges are available from 0.01 to 0.1 GPH through 265 to 2645 GPH water. Gas flow ranges are available from 0.025 to 0.25 SCFH through 670 to 6700 SCFH air.

Custom Calibrations are Standard

Each KDV series is built specifically for the application. The KDV will arrive with a direct reading scale which is calibrated for your operating conditions. The KDV can be calibrated for viscous media, chemicals, and various compressed gases. The scale will be provided in any measuring units the user specifies when ordering. The application datasheet provided with the operating conditions will provide all the data required to properly factory calibrate the flowmeter.

A KDV for Every Application

The KDV is ideal for industrial and sanitary applications. The standard model is available with NPT threaded or flanged connections. Polished finishes and Tri- $\operatorname{clamp}\nolimits \mathbbm{R}$ fittings for food and pharmaceutical applications are available.



KDV - High Accuracy Glass Tube Rotameter

KDV Series Glass Tube Rotameter

Body Materials (Non-Wetted)

Specifications

A

		Tube	Housing:	316L SS
Flow Ranges		Unio	n Nut:	Painted aluminum
Water:	0.01 to 0.1			or 316 SS based
	2645 GPH			
Air:	0.025 to 0.25	Note:	Electropolished	finish for food
	through 670 to		and pharmace	utical applications
	6700 SCFH		available for all	stainless steel
Body Size:	1/2", 1", 1-1/2" and 2"		surfaces.	
Maximum Operating F	Pressure:	Switch	Specifications	
1/2" through 1":	145 PSIG			
1-1/2":	131 PSIG	The KD	V can be fitted v	with up to two
2":	102 PSIG	adjusta	ble switches. S	witch types
Process Temperature	Range:	availab NAMUF	le are bistable re R proximity sens	eed contacts and ors.
w/o Switch Contact:	-4°F to 212°F			
Ambient Temp. Range:		Reed C	Contact:	Bistable reed
				Max 12 VA
Switch:	-13 F to 212 F			101ax. 12 VA, 20 VDC 0.5 Amp
Wotted Materiala	-4 F 10 165 F			NEMA 3R/IP44
Measuring Tuber	Rorociliaato Glaco			
Float:	316 SS, Hastelloy®, aluminum, PTFE or PP, based on model code	Proxim	ity Sensor:	Intrinsically safe output, NAMUR per DIN 19234 (use the REL-6003,
Seals:	NBR, FKM, EPDM or FFKM			-6004 or -6005 as a proximity sensor isolation
Fittings:	316 SS or PVDF based on model code			relay/intrinsic safety barrrier) NEMA 6/IP67
Float Stops:	PVDF	Electic	al Connection:	Terminal box

Subject to change without prior notice.



Imager intense

most sensitive camera for PIV systems Imager Intense is a high sensitivity, high resolution digital camera used in the LaVision **FlowMaster** PIV system. It features an interline transfer chip with progressive scan readout. The camera delivers 12 bit digital images and it features a built in electronic shutter with exposure times as short as 500ns.



General System Specifications

Double Shutter	Two images with 500ns interframing time
Exposure time A/D-converter	500 ns 1 ms or 1ms1000s (software selectable) 12 bit @ 16 MHz
Serial link	coaxial (≤ 10 m) or fiber optic (≤ 300 m)

CCD Sensor

Number of pixels Pixel size Sensor format Full-well capacity Spectral range Max. QE Cooling type CCD temperature 1376 x 1040 pixels 6.45 μm x 6.45 2/3" 18.000 electrons 290 – 1100 nm 65 % @ 500 nm 2-stage Peltier, forced air (optional liquid) -12°C

CCD Control and A/D- Converter

Dynamic range A/D conversion factor Readout (scan) rate Readout noise 12 bit 2 e- /count (high gain), 4 e- /count (low gain) 16 MHz 4-5 e- @ 16 MHz (high gain), 5-6 e- @ 16 MHz (low gain)

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Solo PIV **Nd:YAG Laser Systems**



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- Thermally compensated resonator assures stable operation.
- Requires minimal maintenance, increasing system up-time.
- Field-proven reliability permits users to concentrate on their applications, rather than on system upkeep.

Exceptional Performance

- Superior, proven design provides stable, highenergy output with excellent beam guality and pulse-to-pulse stability.
- Compact resonator design provides excellent beam pointing and energy stability.
- Predictable, high performance ensures that your work gets done faster.

olo PIV is a compact, dual laser-head system designed to provide a highly stable green light source for Particle Image Velocimetry (PIV) applications. It is ideally suited for most liquid and many air-based PIV experiments, and its small size provides excellent flexibility in setting-up such experiments.

Features

- Small laser head requires minimum space
- Single power supply simplifies setup and enhances mobility
- High output energy □ 15 - 120 mJ at 532 nm
- Highly flexible design with repetition rates
 - From 1 to 15, 30, or 50 Hz, depending on model selected
- Operating convenience provided through multiple triggering capabilities
 - Continuous internal trigger
 - External TTL trigger
 - □ Single input pulse activating laser lamp and Q-switch
 - □ Separate pulses to control lamp & Qswitch independently for precise laser pulse timing control
- Easy set up:
 - □ Single power supply features internal, closed-loop cooling system
 - □ Operates on 95-240 VAC single phase source
- Convenient operation made possible with:
 - Remote positioning of a single power supply - saves valuable lab space
 - □ Local control panel on power supply with all system controls, including optional optical attenuator
- Hi/Lo power switch permits energy reduction during optics alignment



Appendix 4 Calibration Certificates for Liquid Rotameters

Calibration sheets are included for the following:

- 1. 2-20 LPH
- 2. 16-160 LPH
- 3. 100-1000 LPH

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Appendix 5 Derivation of Rotameter Flow Equation for Gases

Description

A rotameter is an instrucment for measuring liquid or gas flow (Fig. A5.1.) It consists of a vertical metering tube with diameter increasing from bottom to top (also known as a variable area meter.) A "float" is placed insite the tuge to serve as a marker against an external scale. Fluid enters the bottom of the metering tube, exiting at the top. Flow rate is read from the position of the float against the external scale. The float can be made of metal or plastic material.



Figure A5.1 Rotameter Basic Structure (from Omega)

Principle of Operation

Drag forces from the upward flow of fluid and buoyancy forces from float-fluid density difference lift the float within the metering tube against gravity. The float reaches a static position when the fluid flowing past the float limits the upward drag force. At this point, the balance between upward and downward forces on the float is

$$F_d + F_b = F_g \tag{A5.1}$$

where drag force, buoyancy force and gravity force are given respectively by

$$F_d = \frac{C_D \rho_g A_s U_g^2}{2} \tag{A5.2}$$

$$F_b = V_s \rho_g g \tag{A5.3}$$

$$F_g = m_s g = V_s \rho_g g \tag{A5.4}$$

Substituting equations A5.2 through A5.4 into A5.1 gives

$$\frac{C_D \rho_g A_s U_g^2}{2} + V_s \rho_g g = V_s \rho_g g \tag{A5.5}$$

Solving for gas velocity, U_g ,

$$U_g = \left[\frac{2}{C_D A_s} g V_s \frac{\left(\rho_s - \rho_g\right)}{\rho_g}\right]^{1/2}$$
(A5.6)

Now, for simplicity, assume the float has a circular cross section (i.e. a sphere or cylinder,) allowing us to

say

$$A_s = \frac{\pi}{4} D_s^2 \tag{A5.7}$$

Substituting A5.7 into A5.6 yields

$$U_g = \left[\frac{8}{C_D \pi D_s^2} g V_s \frac{\left(\rho_s - \rho_g\right)}{\rho_g}\right]^{1/2}$$
(A5.8)

While rotameter floats come in various shapes, most of them exhibit a region of constant drag coefficient over a wide range of flow rates. For simplicity, assume it is a sphere. With its drag coefficient given in Fig. A5.2 below (from Schlichting, 1974):



Figure A5.2 Drag Coefficient vs. Sphere Reynolds Number for Spheres.

Note that there is a range of Reynolds numbers for which C_D is constant. Making that assumption, we can develop the equations further. For gas flow, the float density will be greater than the gas density, i.e.

$$\rho_s - \rho_g \cong \rho_s \tag{A5.9}$$

Then equation A5.8 can be simplified to,

$$U_g = k \left[\frac{V_s \rho_s}{\rho_g} \right]^{1/2}$$
(A5.10)

where k represents some lumped constant terms,

$$k = \left[\frac{8g}{C_D \pi D_s^2}\right]^{1/2}$$
(A5.11)

The volumetric flow rate, Q_g , can be expressed as

$$U_g = \frac{Q_g}{A_m} = k \left[\frac{V_s \rho_s}{\rho_g} \right]^{1/2}$$
(A5.12)

where A_m is the flow area between the tube and the float, i.e.

$$A_{m} = A_{p} - A_{s} = \frac{\pi}{4} \left(D_{p}^{2} - D_{s}^{2} \right)$$
(A5.13)

Note that tube area, Dp increases with height in the rotameter. Rearranging to obtain an expression for volumetric flow rate,

$$Q_g = kA_m \left[\frac{V_s \rho_s}{\rho_g}\right]^{1/2}$$
(A5.14)

The density of the float can be expressed as

$$\rho_s = \frac{m_s}{V_s} \tag{A5.15}$$

and when substituted into A5.14 gives,

$$Q_g = kA_m \left[\frac{V_s m_s}{V_s \rho_g}\right]^{1/2} = kA_m \left[\frac{m_s}{\rho_g}\right]^{1/2}$$
(A5.16)

Assuming relatively low pressure operation, gas density can be well described by the ideal gas law,

$$\rho_g = \frac{PM}{RT} \tag{A5.17}$$

Substituting this into A5.16 above gives,

$$Q_g = kA_m \left[\frac{m_s RT}{PM}\right]^{1/2} \tag{A5.18}$$

Lumping constant terms by letting

$$k' = kA_m \left[m_s R \right]^{1/2} \tag{A5.19}$$

we find that

$$Q_g = k' A_m \left[\frac{T}{PM} \right]^{1/2} \tag{A5.20}$$

In a variable flow area rotameter, the annular flow area is a function of height (although not necessarily linear, i.e.

$$A_m = f(h) \tag{A5.21}$$

Thus, for a given temperature, pressure and gas, the flow rate can be indicated by the height of the float.

$$Q_g \propto h$$

Direct reading rotameters are calibration so that the scale indicates the flow rate correctly with a specified gas (usually air) under specified conditions (usually standard temperature and pressure.) In this case we can say,

$$Q_{std} = k' A_m \left[\frac{T_{std}}{P_{std} M_{air}} \right]^{1/2}$$
(A5.22)

At other than standard conditions, the flow rate is

$$Q_2 = k' A_m \left[\frac{T_2}{P_2 M_2} \right]^{1/2}$$
(A5.23)

This flow rate can be expressed using the calibrated scale by applying the following, as indicated in Fig A5.3.



Figure A5.3 Equilibrium Conditions for Rotameter Float.

Note that the float will be at the same height (i.e. scale reading) when A_m is the same, therefore, by equating A_m in equations A5.2 and A5.23 we have

$$A_{m} = \frac{Q_{std}}{k'} \left[\frac{P_{std} M_{air}}{T_{std}} \right]^{1/2} = \frac{Q_{2}}{k'} \left[\frac{P_{2} M_{2}}{T_{2}} \right]^{1/2}$$
(A5.24)

Rearranging to obtain an expression for Q2 gives,

$$Q_{2} = \left[\frac{P_{std}M_{air}}{T_{std}}\frac{T_{2}}{P_{2}M_{2}}\right]^{1/2}Q_{std}$$
(A5.26)

in which Q2 is the flow rate in actual volumes at T2 and P2 with gas of molecular weight M2 using the calibrated scale reading of Qstd.

While a useful result, the rate Q2 is commonly expressed at standard conditions. This is accomplished by again employing the real gas law,

$$\frac{P_2Q_2}{T_2} = \frac{P_{std}Q_{2std}}{T_{std}} \quad \therefore \quad Q_{2std} = \frac{T_{std}P_2}{P_{std}T_2}Q_2$$

Finally, substituting into equation A5.26,

$$Q_{std\,2} = \frac{T_{std}P_2}{P_{std}T_2}Q_2 = \frac{T_{std}P_2}{P_{std}T_2} \left[\frac{P_{std}M_{air}}{T_{std}}\frac{T_2}{P_2M_2}\right]^{1/2}Q_{std}$$
(A5.27)

and finally (really this time) combining and simplifying terms,

$$Q_{std2} = \left[\frac{T_{std}^2 P_2^2}{P_{std}^2 T_2^2} \frac{P_{std} M_{air}}{T_{std}} \frac{T_2}{P_2 M_2}\right]^{1/2} Q_{std}$$

$$Q_{std2} = \left[\frac{T_{std} P_2}{P_{std} T_2} \frac{M_{air}}{M_2}\right]^{1/2} Q_{std}$$
(A5.28)

When measuring air, equation A5.28 reduces to

$$Q_{std2} = \left[\frac{T_{std}P_2}{P_{std}T_2}\right]^{1/2} Q_{std}$$
(A5.29)

Vendor-Supplied Equations

The derivation given is consistent with the equations recommended by vendors. For example, Cole Parmer (ref) gives the gas flow, corrected for temperature and pressure as,

$$Q_{std2} = Q_{std} \sqrt{\frac{P}{760} \frac{530}{T}}$$
(A5.30)

where Qstd is the rotameter scale reading at standard conditions with standard pressure is 760 mmHg (101.325 kPaa) and standard temperature is 530°R (21.3°C.) ABB (2003) gives the following,

$$Q_{2std} = Q_{std} \sqrt{\frac{G_1 P_2 T_1}{G_2 P_1 T_2}}$$
(A5.31)

where

Qstd is the indicated flow rate on the rotameter scale

G1 is specific gravity of calibration gas (usually air)

G2 is specific gravity of gas being measured

P1 is standard pressure (14.7 psia)

P2 is actual pressure

T1 is standard temperature (70°F)

T2 is actual temperature

Appendix 6 Extracting Data from Printed Graphs

In many cases where data was wanted for analysis it was unavailable in table form, often because the original source could not be obtained (e.g. early AERE internal reports.) However, the information was frequently published later in journals in graphic form. These graphic presentations could be scanned and tabular data then extracted with GraphClick, a software application for Macintosh OSX. When both graphic and tabular data were available together, an opportunity to assess the accuracy of the scanning method was available. This is especially important in the case of distorted images or logarithmic scales.



For an example of a scanned graph with linear scales, consider Figure A5.1 from Turner (1966) below:

Figure A6.1 Original Graph of Pressure Gradient vs. Gas Flow from Turner (1966.)

This was plotted from data presented in a table in Turner's thesis. The measured data points are clearly visible. When selected data is scanned from the figure and compared with the original table (Turner's Table A-1) we find that the scanning process has retained the fidelity of the data (Figure A6.2.)

The average absolute error for these scanned data points was found to be 0.49%.



Figure A6.2 Scanned vs. Tabular Data from Turner's Fig. 8.

A more challenging example is that of a non-linear (e.g. logarithmic) scale, and where the axes are slightly tilted, such as the graph from Asali (1984) (Figure A5.3.)



Figure 26. Pressure drop measurements for single-phase gas flow.

Figure A6.3 Original Graph of Friction Factor vs. Gas Reynolds Number from Asali (1984.)

When the data points in the figure are scanned and compared with those presented in Asali's thesis (his Table 16 for air-filled manometer) we find in Figure A6.4 that the correspondence exhibits only a small discrepancy; the average error in the value of f_s is only 0.71%.



Figure A6.4 Comparison of Scanned vs. Tabular Data from Asali (1984.)

Appendix 7 Visual Basic for Applications (VBA) Code for Fluid Properties

```
Static Function Log10(x)
  Log10 = Log(x) / Log(10#)
End Function
Function CFJain(e, d, Nre)
'Calculate turbulent friction factor for rough pipe
'Inputs: e, roughness
      d, diameter
     Nre, reynolds no.
'Outputs: f, friction factor
CFJain = (1.14 - 2 * Log10(e / d + 21.25 / Nre ^ 0.9)) ^ -2
End Function
Function FBlas(Re)
'Blasius friction factor for smooth pipe
'Inputs: Reynolds number (dimensionless)
'Outputs: friction factor, f (Moody)
FBlas = 0.3164 / Re ^ 0.25
End Function
Function FPrandtl(Re)
'Prandtl friction factor for smooth pipe (iterative)
'Inputs: Reynolds number (dimensionless)
'Outputs: friction factor, f (Moody)
f = FBlas(Re) 'initial guess
For i = 1 To 100
fnew = (2# * Log10(Re * f ^ 0.5) - 0.8) ^ -2#
diff = Abs(fnew - f) / fnew
f = fnew
If diff < 0.0001 Then GoTo done
Next i
done:
FPrandtl = fnew
End Function
Function CFZig(e, d, Re)
'Friction factor from Zigrang and Sylvester, 1982
'Inputs: abs. roughness, e; pipe diameter, D; Reynolds Number, Re
'Outputs: friction factor, lamda
'Note: explicit calculation
Rough = e / d
Part1 = Rough / 3.7 + 14 / Re
Part2 = Rough / 3.7 - 5.2 / Re * Log10(Part1)
Part3 = -2\# * Log10(Part2)
CFZig = 1\# / Part3 \wedge 2
End Function
```
```
Function AirVisc(T, P)
' Dry air viscosity from Kadoya et al, 1985
'Inputs:
   Temperature, T, deg C
    Pressure, P, kPaa
'Outputs:
    Air viscosity, Pa-s x 1E-6
'NOTE: This version good for P \sim 1 atm, and T from 250-300K; for higher pressures,
temps, include z factor in calculation of rhoair
T = T + 273.15 ' change to absolute temperature
Tr = T / 132.5
rhoair = P * 28.9644 / (8.3145 * T) ' air density at given T, P
P = P / 1000 ' change to MPa
rhored = rhoair / 314.3
NuoTr = 0.128517 * Tr + 2.60661 * Sqr(Tr) + (-1) + -0.709661 * Tr ^ (-1) +
0.662534 * Tr ^ (-2) - 0.197846 * Tr ^ (-3) + 0.00770147 * Tr ^ (-4)
NuoRhor = 0.465601 * rhored + 1.26469 * rhored ^ 2 - 0.511425 * rhored ^ 3 +
0.2746 * rhored ^ 4
AirVisc = 6.1609 * (NuoTr + NuoRhor)
End Function
Function WtrVisc(T, P)
'Pure Water viscosity from McCain et al book, 2011
'Inputs:
   Temperature, T, deg C
    Pressure, P, kPaa
'Output:
۰.
   Water Viscosity, Pa-s
TK = T + 273.15 ' calculate temperature in Kelvin
rhow = WtrDens(T, P) 'need to obtain density of pure water
LNUW1 = 2885317# * TK ^ -2 - 11072.577 / TK - 9.0834095 + 0.030925651 * TK -
2.74071e-05 * TK ^ 2
LNUw2 = -1928385.1 / TK ^ 2 + 5621.6046 / TK + 13.82725 - 0.047609523 * TK +
3.5545041e-05 * TK ^ 2
LNUw = LNUW1 + rhow * LNUw2
WtrVisc = Exp(LNUw)
End Function
Function WtrDens(T, P)
'Pure Water density from McCain et al book, 2011
'Inputs:
    Temperature, T, deg C
    Pressure, P, kPaa
'Output:
   Water Density, g/cm3
```

```
TH = T / 100 ' create term for intermediate use
```

 $\begin{array}{l} \mathsf{PM} = \mathsf{P} \; / \; 1000 \; ' \; \text{need to have pressure in MPa for this correlation} \\ \mathsf{Rhow70} = \; (-0.127213 \; * \; \mathsf{TH} \; \wedge \; 2 \; + \; 0.645486 \; * \; \mathsf{TH} \; + \; 1.03265) \; / \; (-0.070291 \; * \; \mathsf{TH} \; \wedge \; 2 \; + \; 0.639589 \; * \; \mathsf{TH} \; + \; 1) \\ \mathsf{Ew} = \; (4.221 \; * \; \mathsf{TH} \; \wedge \; 2 \; + \; -3.478 \; * \; \mathsf{TH} \; + \; 6.221) \; / \; (0.5182 \; * \; \mathsf{TH} \; \wedge \; 2 \; - \; 0.4405 \; * \; \mathsf{TH} \; + \; 1) \\ \mathsf{Fw} = \; (-11.403 \; * \; \mathsf{TH} \; \wedge \; 2 \; + \; 29.932 \; * \; \mathsf{TH} \; + \; 27.952) \; / \; (0.20684 \; * \; \mathsf{TH} \; \wedge \; 2 \; + \; 0.3768 \; * \; \mathsf{TH} \; + \; 1) \\ \mathsf{Iw70} = \; 1 \; / \; \mathsf{Ew} \; * \; \mathsf{Log}(\mathsf{Ew} \; + \; \mathsf{Fw}) \; \; \mathsf{'Log} \; \mathsf{is actually the natural log function in VBA, i.e. \\ \mathsf{LN}(\mathsf{x}) < \\ \mathsf{Iw} = \; 1 \; / \; \mathsf{Ew} \; \; \mathsf{Log}(\mathsf{Ew} \; \; \mathsf{PM} \; / \; 70 \; + \; \mathsf{Fw}) \\ \mathsf{WtrDens} = \; \mathsf{Rhow70} \; \; \mathsf{Exp}(\mathsf{Iw} \; - \; \mathsf{Iw70}) \\ \mathsf{End \; Function} \end{array}$

Appendix 8 Test Matrix External Images Poster

(Larger format to be supplied in final version (the file is about 100MB!)

