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UNIVERSITY OF ALBERTA

EVALUATION OF HUMIDITY SENSORS IN ANIMAL ENVIRONMENTS

by

ISMAIL HUSNU ERDEBIL ©

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF AGRICULTURAL ENGINEERING

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...Ismail Erdebil....
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....

J.J. Leonard

...John Feddes...

J.J. Feddes

..Gerald W. Sadler.....

G.W. Sadler

Date..April 6, 1990...

ABSTRACT

Humidity sensors for use in animal environments were selected for testing by comparing the requirements for a sensor in animal housing to the performance of sensors in similar environments presented in the literature.

In order to create animal environments with desired and repeatable levels of relative humidity and main contaminants present in the animal environments (dust and ammonia), a vented environmental chamber was built with continuous influx and exhaust of moist or dry air and dust and ammonia.

Static characteristics of the selected humidity sensors (two thin-film and one aluminum oxide sensors) were determined in nine different combinations of ammonia and dust with two replicates, since static characteristics of humidity sensors were considered to be vital for establishing the performance of humidity sensors for controlling humidity in barns.

Thin-film sensors were not affected by ammonia and dust levels but showed wider deviations than claimed by the manufacturer. The aluminum oxide sensor also showed wide deviations but its behaviour could be predicted with ammonia and dust levels

Response of the selected humidity sensors to step changes in relative humidity also were examined, at the same contaminant levels as for static characteristics tests and in the same vented environmental chamber. Response of the sensors was not affected by contaminant concentration levels.

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1. INTRODUCTION

1.1 Importance of Humidity Control

The measurement and control of water vapour quantities in the air is important in many areas of agriculture. For example, the moisture content of air in animal housing has considerable effect on livestock health. Humidity relates to heat stress during hot weather (Bouvier, Moliner and Vermorel, 1974) and, at low temperatures, excess humidity can cause wet bedding. High relative humidity (RH) levels in livestock environment have been linked to poor performance and high incidence of respiratory disease in housed calves (Parker, 1968). More recently Hellickson (1983), Oliveira and Esmay (1982) and Bundy (1984) have stressed the influence of humidity on livestock health.

Increasing incidence of disease in greenhouses has been attributed to high RH. Decrease in plant transpiration rate and nutrient uptake are due to high relative humidity levels (White, 1986). In food storage, proper measurement and control of RH has been second in importance only to measurement and control of temperature.

Moisture can damage agricultural building components and equipment and is a concern for the designers of agricultural facilities (Holmberg, 1972).

Clearly, there are many more examples of the importance of humidity control in agriculture. Measuring humidities and, therefore, humidity sensors are a vital element in controlling the humidity.

In animal environments the humidity levels range approximately between 40% to 90% RH and aerial contaminants include dust, ammonia, methane and hydrogen sulfide. Of these, methane and hydrogen sulfide concentrations are relatively low (Clark and McQuitty, 1985). However, because of pollutants, conventional humidity sensors such as wet and dry-bulb psychrometers and mechanical sensors have failed to perform satisfactorily in animal environments. The need for satisfactory humidity sensors in industry has given rise to considerable development in this field. However, literature on the behaviour and evaluation of humidity sensors under animal housing conditions is very scarce. There is a need to identify sensors which perform satisfactorily in polluted environments in other fields of the industry and evaluate these sensors in animal environments.

1.2 The Project and its Goals

The major goals of this project can be summarized in point form as follows:

1. Reviewing existing humidity sensing technologies
2. Identifying the humidity sensing technologies which are likely to perform satisfactorily in animal environments
3. Establishing the static and dynamic characteristics of sensors, which work on the humidity measurement techniques established in item 2, in animal environments.

It was decided that simulation of animal environments was more convenient for the purposes of this project than the use of animal facilities. Simulated animal environments can closely resemble the pollution levels in animal housing yet various combinations of pollutants can be consistently created throughout the test and repeated at will.

2. LITERATURE SURVEY

2.1 Basic Principles and Terminology

The humidity of air can be expressed in several ways which give rise to a number of methods of measuring humidity.

The simplest measure of humidity is absolute humidity (d_v) which may be defined as follows (ASHRAE, 1981):

$$d_v = m_w / V \tag{2.1}$$

where: m_w=mass of water vapor in volume V, and

V=total volume of the air sampled.

Humidity ratio (W) is defined as the ratio of the mass of water vapour to the mass of dry air contained in the sample:

$$W = m_w / m_a \tag{2.2}$$

where: m_w=mass of water vapour in the sample, and

m_a=mass of the dry air sampled

Dew or frost-point temperature (t_{dp}) is the temperature of the moist air, saturated at the sampling pressure with the same humidity ratio W as that of the given sample of moist air. It is defined by the solution of the following equation:

$$W_s(t_{dp}, p) = W \tag{2.3}$$

where: W_s=saturation humidity ratio of the sample at t_{dp}

Relative humidity (RH) is defined by the following equation:

$$RH = (X_w / X_{ws})_{t,p} \tag{2.4}$$

where: X_w=mole fraction of the water vapour in a given air sample, and

X_{ws}=mole fraction of the water vapour in the air sample saturated at the sampling pressure and temperature.

If dry air and water vapour are assumed to obey the perfect gas equation, RH can also be defined as follows:

$$RH=(p_w/p_{ws})_{t,p} \quad (2.5)$$

where: p_w=partial pressure of water vapour, and

p_{ws}=saturation pressure of water vapour at temperature t.

No method of measurement is perfect and some consistent terminology is required to describe the performance of a measurement system. The following definitions will be used in this thesis (ISA, 1979).

Accuracy is defined as the degree of conformity of an indicated value to a recognized accepted standard value, or ideal value. Accuracy rating is a number or quantity that defines a limit that errors will not exceed when a device is used under specified operating conditions (Figure 2.2). It is usually expressed in terms of the measured variable or percent of span. The absence of sign before accuracy indicates a + and a - sign (ISA, 1979). Drift is an undesired change in output over a specified period of time, which change is unrelated to the environment. In time the instrument gives different outputs even though there is no change in the actual humidity value.

Hysteresis is the property of an element evidenced by the dependence of the output, for a given excursion of the input, upon the history of prior excursions and the direction of the current traverse. Hysteresis is approximately expressed as the separation between increasing and decreasing indications of the measured variable for the same indicated value. In Figure 2.1 the hysteresis at an input y is shown.

Reliability is the probability that a device will perform its objective adequately, for a specified period of time and operating conditions.

Reproducibility is the closeness of agreement among repeated measurements of the output for the same value of input made under the same operating conditions over a period of time. If indicated outputs lie closely together, then the instrument is said to be of high precision.

Dynamic response can be described very briefly as the behaviour of the output of a device as a function of the input, both with respect to time. Dynamic response will be defined in detail later.

2.2 Humidity Sensors

Even though the principles of operation for humidity sensors are very few, a multitude of sensors are available for humidity measurements. Some of the main types, either in use or having potential for application in agriculture, and the advantages and disadvantages indicated in the literature are presented briefly below.

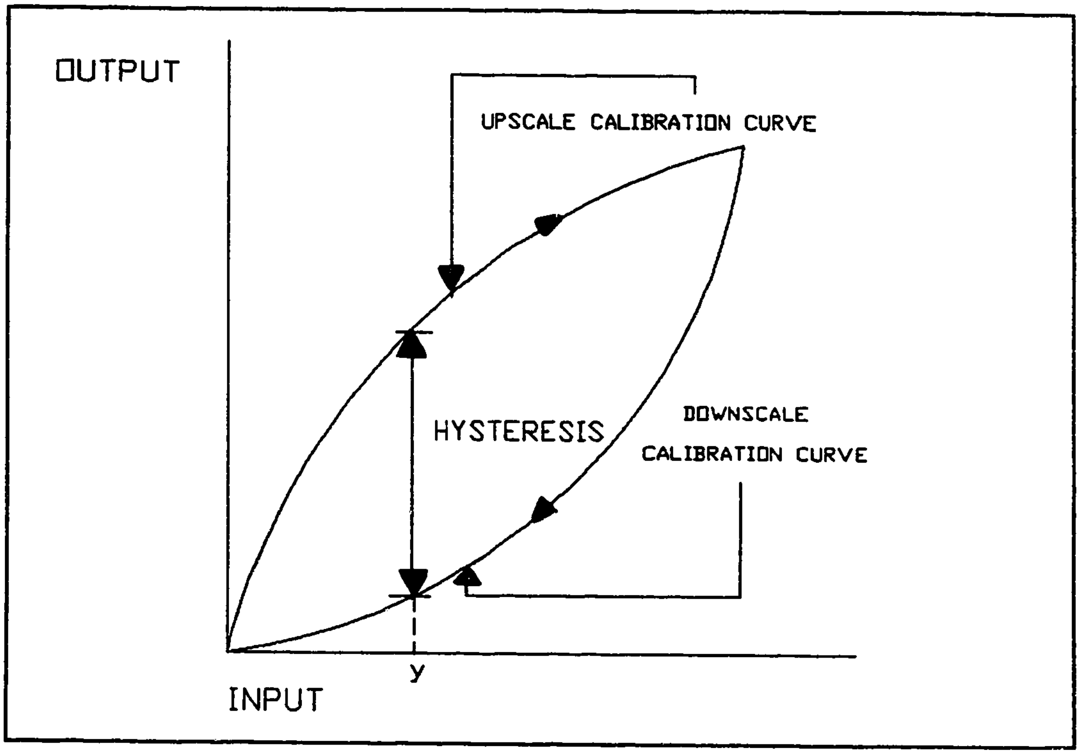

Figure 2.1 Occurrence of hysteresis on a calibration cycle

2.2.1 Infrared and Ultraviolet Humidity Sensors

The absorption of infrared (IR) or ultraviolet (UV) light by water molecules can be used to detect humidity levels in the air. These sensors make use of the selective absorption of certain wavelengths of light by water vapour. The rate of the reduction in the intensity of light at the wavelength selectively absorbed by water is compared to a wavelength or wavelengths not selectively absorbed by water. A light beam for detection of humidity can be directed across a duct, a pipe or a sample passing through a flow cell.

The application of these IR or UV light sensors has been limited mostly to transparent samples. However, performance tests of an ultra violet absorbtion humidity (UVAH) sensor demonstrated that it is possible to measure humidity of the air containing 7.8 gm/m^3 silica dust with velocities up to 8.9 m/s (Gersh, 1985).

These sensors cover ranges from a few ppm of water to 100% RH and can be used with corrosive gases. However, they are expensive and a number of gases, such as derivatives of ammonia, which are present in a livestock environment, interfere with measurements. Also, calibration is a function of gas temperature (Carr-Brion, 1986).

2.2.2 Lithium Chloride Sensors

Lithium chloride sensors work on the principle that lithium chloride salt picks up the moisture in the air until the absorbed moisture reaches an equilibrium with the water vapour in the atmosphere. The moisture content of the lithium chloride is proportional to the humidity of the atmosphere surrounding the sensor.

A typical lithium chloride sensor consists of a thin layer of lithium chloride with additives between two electrodes. An a.c. source is connected to the electrodes. Lithium chloride picks up the water vapour in the air and becomes conducting. Because the current is alternating, it does not cause electrolysis, but heats up the sensing element, the moisture is driven off and the conduction drops sharply. The temperature of the lithium chloride at which this drop in conduction occurs can be correlated to the RH of the air.

One of the leading manufacturers of lithium chloride sensors advises that sensor should never be subjected to environments contaminated with reactive gases (Anon., 1983).

Although Mitchell (1985) has pointed out the possibility of cleaning lithium chloride sensors after they are contaminated, the cleaning procedure is time-consuming and requires good understanding of the sensors.

In addition to susceptibility to contamination, lithium chloride sensors also show long-term drift in the upper range of humidity and cannot measure very low moisture concentrations (Carr-Brion, 1986).

2.2.3 Electrolytic Sensors

This type of sensor is also referred to as an electrolysis sensor, because the water absorbed by a desiccant is electrolyzed into hydrogen and oxygen. The electrolysis current is a measure of the amount of water causing the current flow. The desiccant is usually phosphorous pentoxide placed between two noble metal electrodes which have a constant DC voltage difference maintained between them. These sensors are exposed to a constant flow of air so that Faraday's Law current provides a direct measure of moisture.

Electrolytic sensors have a precision better than 0.1% RH and are free of signal drift at high humidity levels. (Carr-Brion, 1986; Moore, 1976). However, the electrolyte can be washed away by direct contact with water or condensation. Also, the phosphorous pentoxide is highly reactive, which limits the use of the sensor to uncontaminated areas and, in practice, electrolytic sensors are preferred for laboratory use. The electrolysis cell of the sensor has to be renewed regularly, because the cells age with use.

2.2.4 Mechanical Sensors

The principle behind mechanical humidity sensors is the change in dimensions of organic materials as moisture is absorbed from or given to the air. The change is amplified mechanically and displayed by a pointer against a scale. The output of mechanical sensors is nonlinear; they exhibit considerable hysteresis; response is slow; electrical output is difficult to obtain and the sensors work poorly below -10°C (Carr-Brion, 1986). Mechanical sensors are inexpensive.

2.2.5 Wet and Dry-Bulb Sensors

Wet and dry-bulb psychrometers make use of the response of certain materials to, or the dependency of a physical phenomenon on, the degree of saturation of the air with water vapour. An artificially-created air flow takes moisture out of the wet wick covering a thermometer bulb or temperature sensor and causes the temperature to decrease to a new value (wet-bulb temperature). The wet and dry bulb temperatures are related to relative humidities in the air by basic energy balance equations (Treybal, 1968).

Industrial versions of these sensors use platinum resistance thermometers surrounded by a porous ceramic fed from a reservoir containing distilled water. Wet and dry bulb sensors have the advantage of simplicity in addition to being cheap and make accurate measurements provided that the wet wick or the ceramic surrounding the wet bulb is kept moist with distilled water; is subjected to air velocities greater than 3 m/s and is guarded against radiation. However, wick surfaces are easily contaminated with dust or other substances resulting in considerable errors (Wignall, 1984). Maintaining a clean wick in an animal housing environment is very difficult. Spraying water on the wet bulb sensor as a means of having a clean wick is reported to be promising in animal housing environments (Barber, 1987).

Wet and dry bulb thermometers can utilize thermistors or semiconductor temperature sensors which are easy to interface with microprocessors. Fisher et al. (1981) have demonstrated that this can be done without an analog-to-digital converter.

2.2.6 Optical Dew Point Sensors

The technique utilized by optical dew point sensors depends on establishing an equilibrium between condensate and the water molecules in the air at a certain temperature. A mirror is cooled until condensation takes place on its surface. The temperature at which condensation occurs is the equilibrium temperature (also called dew point temperature) and can be related easily to water vapour content of the air (ASHRAE 1981; Wood 1970; Dreisbach 1961).

In these sensors, the mirror is chilled thermoelectrically and an electro-optic detector senses the change in the surface reflectance of the mirror associated with the condensation of water. An output generated by the electro-optic detector, regulates the mirror temperature in order to maintain equilibrium between the water vapour in the air and the condensed dew or ice on the mirror.

Optical dew point sensors are precise, capable of good accuracy and have a wide range. However, filtered gas streams are required to minimize errors due to the presence of dissolved salts. Dew point hygrometers are also costly.

2.2.7 Electronic Sensors

Electronic humidity sensors can be divided into three major groups:

1. Ceramic Humidity sensors,
2. Thin film sensors, and
3. Semiconductor sensors.

Generally, if the sensing element is very thin hygroscopic substance acting as a dielectric between electrodes, the sensor is referred to as a thin film sensor. Ceramic humidity sensors utilize the change in the electrical resistance of porous ceramic with the water vapour pressure in the atmosphere. When the sensing element utilizes the principles of semiconductor physics it is referred to as semiconductor sensor. The three groups are now discussed in detail.

2.2.7.1 Ceramic Sensors

As the sensing elements of ceramic humidity sensors absorb moisture from the atmosphere, their electrical resistance changes over a range of 5 to 6 decades for a corresponding humidity change of 0 to 100% (Moore, 1976). The amount of water absorbed or desorbed is proportional to the water vapour pressure in the atmosphere. Hence, water vapour pressures may be related to the electrical resistance changes for each type of ceramic humidity sensor. The change in resistance is detected by an a.c. bridge circuit.

Ceramic humidity sensors can be classified into ionic and electronic types. The first class exhibits ionic conductivity in a humid atmosphere due to capillary condensation of water vapour. The second group makes use of the sensitivity of some semiconducting materials to moisture. Here, water vapour acts as an electron-donating gas (Seiyama et al. 1983).

The first practical ceramic humidity sensors introduced to the market were two multifunctional sensors (Nitta et al., 1980, 1981, 1982) which were described as humidity-gas and humidity-temperature ceramic sensors. These sensors featured automatic self cleaning cycles during which the ceramic element was subjected to temperatures around 500°C for a few seconds in order to burn off or vaporize any contaminants.

Another study, on titania (TiO_2) glass sensors (Speers, 1985), reported high sensitivity but indicated some potential problems such as the requirement for temperature compensation and slow dynamic response. However, the problems were not considered as being serious obstacles. The slow dynamic response was thought to be due to the fact that the water permeation through microscopic pores is time dependent.

Iwanaga and Ikagami (1981) described the characteristics of a manganese tungsten tetroxide ($MnWO_4$) humidity sensor. This sensor, withstood corrosive environments and, as the humidity increased, the resistance decreased as an inverse logarithmic function of RH.

2.2.7.2 Thin-Film Sensors

Thin-film sensors are based on carefully engineered, thin-film dielectrics which give linear responses (such as change in conductivity, capacitance, resistance) to the water vapour pressure in the atmosphere. The thin-film can be either aluminum oxide, which is the sensing part of aluminum oxide sensors, or various polymers which form the core of thin-film polymer sensors. Research in this area has started concentrating on the behaviour of thin films in various relative humidities in order to interpret the electrical signals better and to engineer a thin film possessing the required qualities for humidity detection.

2.2.7.2.1 Aluminum Oxide (Al_2O_3) Sensors

An aluminum oxide sensor is actually a capacitor. An aluminum strip and a thin, porous layer of gold form the electrodes of the capacitor. The dielectric is a thin, porous aluminum oxide layer. Water molecules pass through the porous gold layer and are absorbed or desorbed by the aluminum oxide dielectric material. The electrical impedance of an aluminum oxide capacitor depends on the amount of water absorbed and therefore on the moisture in the air (Mitchell, 1985).

Considerable research has been carried out on the alumina film growth mechanism for high and low moisture sensors with the aim of fabricating devices with desired response characteristics (Khanna and Nahar, 1987).

An aluminum oxide sensor which can withstand extremely cold and dry conditions has been fabricated directly on a silicon base (Chleck, 1985). The base had an integrated heater and a temperature sensor. The very thin oxide layer had improved absorption characteristics which decreased the response time.

Evaluation tests, conducted by Mehrhoff (1985) on five aluminum oxide sensors at low humidities indicated that all five aluminum oxide sensors showed a decline in sensitivity and gave lower than expected outputs during the entire experiment. By the end of the experiment which, lasted 53 days, all five sensors gave readings outside their specified accuracy limit.

A laboratory study carried out by Harding (1985) indicated that the characteristics which limit the performance of aluminum oxide sensors are repeatable, predictable and quantifiable. Thus, iteration and linearization techniques inherent in the capabilities of microprocessors make it possible for aluminum oxide sensors to give linear signals and to be calibrated automatically (Bryant and Scelzo, 1985).

Over two decades, aluminum oxide humidity sensors have become quite popular even though they have poor calibration stability and problems related to drift and aging. The main reasons for the popularity of aluminum oxide sensors are their fast response to rising humidities and their relatively low cost (Anon., 1983).

2.2.7.2.2 Thin-Film Polymer Sensors

Dissatisfaction of industrial users with the previously described sensors directed research activities to thin-film polymer humidity sensors. The sensing element of these sensors consists of a polymer foil which is sandwiched between two flat, porous electrodes. The thin polymer film absorbs moisture through the electrodes and, again, the degree of absorption depends on the water vapour pressure in the atmosphere. The water absorbed changes the electrical properties such as conductance, impedance, and capacitance of the thin polymer film, which can be correlated to the moisture content of the air.

The choice of the polymer and porous electrode materials are key factors in the design of thin polymer sensors. Also masking the sensor against contaminants is of major importance. Protective films with a good moisture permeability have proven to be effective in the shielding of polyelectrolyte polymers. Lafarie (1985) reported that the maximum tolerance of thin polymer sensors for ammonia was 850 ppm and also indicated that protection against heavy dust could be achieved by metal filters having 8 micron porosity.

A contamination-resistant, thin-film sensor was described in detail by Clayton et al. (1985). The sensor had a set of thin metal electrodes deposited on a solid substrate and the thin film. The water-absorbing film covered the electrodes and a conductive, water-permeable mesh covered the film. The manufacturers of the sensor claimed excellent accuracy in dirty environments and that the sensor was detergent-washable.

Visscher et al. (1985) carried out tests in a pig barn, a cheese storehouse and a greenhouse with five different thin polymer RH sensors. Except for one brand in the greenhouse, all sensors showed a drift towards higher humidity indications. Sensors in the greenhouse drifted considerably more than those in the pig barn and the cheese storehouse. Although comparative RH values were not given, the greater drift in the greenhouse probably was due to higher RH.

Smith et al. (1988) carried out tests in livestock environments with two different thin film humidity sensors for a Poultry Environmental Control Systems (PECS) program. The sensors performed differently. The first one stopped giving outputs at higher than 90% RH and recovery from this condition was very slow. The manufacturer of this sensor also warned of impeded performance if the sensor was exposed to moderate levels of ammonia for long periods. The other sensor handled a relative humidity range of 0-100% and recovered rapidly from exposure to condensed moisture.

Thin-film polymer sensors afford flexibility in optimizing sensitivity and response for applications in contaminated environments. However, all capacitive polymer-based sensors tend to suffer from inaccuracy and hysteresis effects near saturation (Muller, 1985). Also, there may be a tendency for the polymer to peel off the substrate (Krigman, 1982).

2.2.7.3 Semiconductor Sensors

This group includes sensors which are manufactured by conventional integrated circuit (IC) technology and are based on semiconductor physics. Generally these are miniature sensors and can be regarded as an extension of thin film polymer sensors. Semiconductor sensors offer promise, not only for moisture detection but, also, for detection of a variety of gases and chemicals.

These sensors are still at a developmental stage. Only one commercial manufacturer of semiconductor humidity sensor is known to the author and there is a very limited amount of performance data available, especially for industrial or agricultural environments.

Jachowicz (1985) and Jachowicz and Senturia (1981) reported a thin film capacitance humidity sensor fabricated by using planar metal oxide semiconductor (MOS) technology with an accuracy of 7% RH over the range of 17-65% RH and proposed a model based on sheet resistance to explain the moisture effects. Later, this model was modified to include the effects due to water penetration. Garverick et al. (1982) fabricated a moisture sensor using a metal-gate, n-channel, depletion mode MOS process. In this case a.c. measurement of surface impedance was needed for moisture detection. This research was carried out to illustrate the potential of surface impedance measurements for moisture monitoring. A gradual drift towards higher apparent sheet resistances (at lower dew points) was reported. An evaluation of the humidity sensor against conventional sensors was not reported in the paper.

Literature on the performance of semiconductor sensors in polluted environments has not been found.

2.3 Methods for Testing the Performance Characteristics of Sensors

The individual parameters describing the performance of humidity sensors can be grouped under four performance characteristics and evaluation methods (Norton,1982):

1. Static characteristics
2. Dynamic characteristics
3. Environmental characteristics

4. Reliability characteristics

The environmental characteristics describe the effects of external conditions such as shocks and vibration when the facilities are cleaned out or being subjected to condensing atmospheres. The sensor is expected to perform within specified tolerances after such exposures to nonoperating environmental conditions.

The reliability characteristics relate to the long term performance of sensors such as drift, operating life or cycling life.

Only the first two characteristics were addressed in this work and these are discussed in detail in the following sections.

2.3.1 Static Characteristics

The process by which the static characteristics of an instrument are measured is termed static calibration (Graham, 1975). A static calibration is a test during which known values of measurand (input) are applied to an instrument and corresponding outputs are recorded. The resulting test record, when in a tabular form, is called a calibration record. When it is in a graphical form it is referred to as a calibration curve (Norton, 1982). A single performance of this test once with increasing and once with decreasing values of the measurand is called a calibration cycle (Figure 2.2). Accuracy and hysteresis in addition to the least squares linear regression line are three important static

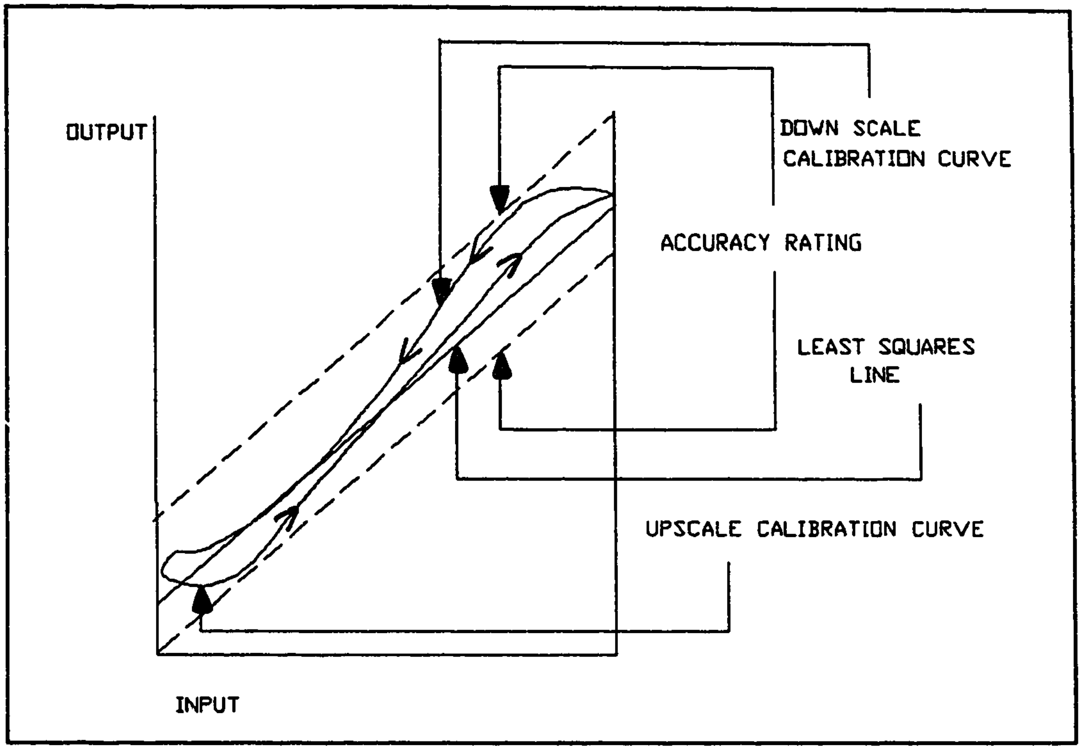

Figure 2.2 Accuracy rating and calibration curve

characteristics which are derived from calibration curves.

2.3.2 Dynamic Characteristics

The dynamic characteristics of sensors are usually described in terms of step response, ramp response and impulse response (Doeblin, 1983). These measure the response of sensors to the application of a change in the sensor input either in the form of a step, an impulse or a ramp.

Changes of RH in animal environments often take place as ramp inputs whereas the step and impulse changes happen seldom. However, creation of ramp inputs in the environmental chamber could not be achieved without major changes to the existing equipment. For this reason the step response of sensors were determined for estimating the reaction of the sensors to ramp responses.

When a step input is applied, the output will change toward the final value (100% output change) over a period of time and, usually, non linearly. The length of time required for the output to rise to a specified percentage of its final value (as a result of a step change in the measurand) is defined as the response time. The percentage is typically stated in the form of a prefix to 'response time'. A special term and symbol have been assigned to 63% (actually 63.2%) response time: time constant τ (Norton, 1982).

Chapter 7 concentrates on step response of humidity sensors.

3. SELECTION OF HUMIDITY SENSORS FOR ANIMAL ENVIRONMENTS

3.1 Requirements of Humidity Sensors in Animal Environments

If humidity sensors are to be used for control purposes in animal environments, they must be capable of operating with minimal maintenance for extended periods. This implies that they must be characterized by high reliability and low drift. They must be accurate or, at least, give repeatable readings for humidities ranging from 40% RH to condensation and they must do so in environments contaminated by airborne dust, ammonia (NH_3) and, to a lesser extent, methane (CH_4) and hydrogen sulfide (H_2S). The required accuracy is 5% RH, or better, in environments containing ammonia levels up to 40 ppm. When animal facilities are cleaned, humidity sensors are likely to be subjected to being hosed down and to mechanical shock of varying intensity. They must, therefore, be sufficiently robust to withstand such treatment.

Although regular checking and maintenance of sensors would be desirable, it should not be assumed. Nevertheless, should sensors become contaminated, or malfunction for some other reason, they should be easy to clean and recalibrate. If they are beyond recalibration, sensor elements should be cheap and easy to replace. Since an increasing number of environmental control systems are based on electronic and microprocessor technology, humidity sensors for environment control must be compatible with such systems. This implies that the sensors should provide an electrical output signal that is not easily contaminated by noise and that is easily conditioned to a voltage level appropriate to the host system.

3.2 Comparison of Sensors For Animal Environments

Table 3.1 makes a comparison of the humidity sensor types reviewed in chapter 2 and rates their satisfactory and

Table 3.1 COMPARISON OF VARIOUS SENSORS WHICH HAVE POTENTIAL FOR USE IN ANIMAL ENVIRONMENTS

Sensor	Requirement Categories						
	(A)	(B)	(C)	(D)	(E)	(F)	Total
Mechanical	3	3	3	3	1	3	16
Wet/dry bulb	3	1	1	3	2	2	12
Dew-point	3	1	1	3	3	2	13
Electrolytic	3	1	1	3	3	1	12
Lithium Chloride	3	1	1	1	1	1	8
Thin-film	1	2	2	1	1	1	8
Ceramic	1	1	1	3	3	1	10
Infrared	3	1	1	3	3	1	12

1=Satisfactory, 2=Not always satisfactory, 3=Unsatisfactory

(A): Contamination Resistance, (B): Reliability, (C): Low drift, (D): Ruggedness, (E): Low Cost, (F): Compatibility with Microprocessors and Electronic Technology

unsatisfactory qualities for animal environments. The scores were decided with the help of literature published on sensor types. 1 indicates that the authors of the publications surveyed found this sensor to be performing satisfactorily in the indicated requirement category. 2 implies that the performance of a sensor was found satisfactory only by some authors. Unsatisfactory rating (3) represents situations in which the sensor was reported to perform unsatisfactorily in the indicated category.

Table 3.1 shows that thin film and ceramic sensors are most likely to satisfy the requirements of humidity sensors for animal housing conditions. Even though lithium chloride sensors score highly, they fail to function satisfactorily in polluted environments and, therefore, can not be considered for animal environments.

Thin film polymer sensors are resistant to contamination and condensation. The signal drift is negligible and hysteresis is low. However these sensors are relatively unproven and performance among sensors varies considerably with manufacturers. Aluminum oxide sensors are widely used in the field of petrochemicals and have received acceptance. They can be good alternatives for thin film polymer sensors. Aluminum oxide sensors have a wide dynamic range and are relatively stable with low hysteresis and temperature coefficient. However, they have problems of slow drift and require periodic servicing.

The only commercial application of pollutant resistant ceramic sensors mentioned in the literature were detecting RH levels in microwave ovens (Nitta, 1981b). They feature self cleaning cycles and appear promising for use in animal environment control.

Information on the performance of semiconductor humidity sensors in polluted atmospheres has not been found in the literature. Since it was possible that they would perform satisfactorily in polluted environments and could offer a less expensive alternative to the existing sensors, testing a semiconductor humidity sensor was considered worthwhile.

3.3 Sensors Included in Performance Tests

In the light of the comparisons made above, the following sensors were included in preliminary sensor evaluation tests:

1. Two thin-film polymer sensors (Rotronic Instrument Corporation, Huntington, NY),
2. Aluminum oxide sensor (Ondyne Inc., Concord, CA),
3. Ceramic sensor (Matsushita Electronic Components Co., Ltd. System Products Bussiness Group, Osaka, Japan) and
4. Semiconductor sensor (Alberta Microelectronics Centre, Edmonton, Alberta).

3.3.1 Thin-Film Polymer Sensors

These sensors measure relative humidity with a hygroscopic polymer film capacitive sensor and temperature with a precision platinum RTD. The sensors had terminals for recording temperatures measured by RTD in addition to outputs for humidity measurements. The signals generated by sensors were converted into a linearized current (4 to 20 mA) which was transmitted to a remote recorder.

Two types of thin-film polymer sensors manufactured by the same company were tested and thin-film sensor #1 (model [illegible]0) was designed for fixed installations in [illegible].

applications, whereas thin-film sensor #2 (model HT46) was designed for clean environments. Temperature and humidity probes of both sensors were placed at the end of 200-mm long plastic cylinders which were attached to the circuit housing boxes. In both cases, a small plastic cage protected the sensors against minor shocks and the boxes containing the signal conditioning circuitry was hermetically sealed from the environment. Both HT220 and HT46 were capacitive sensors.

Table 3.2 gives a summary of the specifications (Appendix E).

Table 3.2 SPECIFICATIONS OF THE THIN-FILM SENSORS

	Thin-film sensor #1	Thin-film sensor #2
ACCURACY 0 to 100%RH at 77°F	2.0%RH	2.0%RH
HYSTERESIS 4-hour cycle 20-95-20%RH	0.3%RH	0.3%RH
TIME CONSTANT	10 seconds	10 seconds
POWER SUPPLY	115 VAC	24 VAC
OUTPUT	4-20 mA	4-20 mA
MAX. LOAD	500 ohms	500 ohms

3.3.2 Aluminum Oxide Sensor

The system consisted of a gold/aluminum oxide sensor probe and a microprocessor-controlled electronic module for signal conditioning. The signal conditioning circuitry of the sensor was set up to provide an output in terms of dew-point temperatures in °C.

The moisture probe was located at the end of 200-mm long stainless steel cylinder connected to the circuit housing box. Specifications for the aluminum oxide sensor were extracted from the manual supplied by the manufacturer (Appendix E) and are summarized in Table 3.3.

Table 3.3 SPECIFICATIONS OF ALUMINUM OXIDE SENSOR

ACCURACY	2°C (-65 to +20°C)
HYSTERESIS	N/A
TIME CONSTANT	N/A
POWER SUPPLY	115 VAC 50/60 Hz
OUTPUT	4 to 20 mA
MAX. LOAD	800 ohms

3.3.3 Ceramic Sensor

Two ceramic sensors (type EYH-H50C, EYH-H51C) were included in preliminary tests, both had a self cleaning circuit. The manufacturer claimed that the heat-cleaning cycle provided a long life, high stability and good protection from deterioration due to oils, dust etc.

The resistance of the sensor changes in proportion with the RH of the environment from mega ohms to kilo ohms in the range between 20% and 80%RH. Table 3.4 summarizes the specifications of both sensors. Product information sheets supplying further details are given in Appendix E.

3.3.4 Semiconductor Humidity Sensor

The semiconductor sensor included in the preliminary tests was not a commercial unit. It was supplied by Alberta Microelectronics Centre on a trial basis. For this reason

Table 3.4 SPECIFICATION OF CERAMIC SENSORS

	EYH-H50C	EYH-H51C
SUPPLY VOLTAGE	3.0 VAC MAX	3.0 VAC MAX.
HYSTERESIS (LESS THAN)	5%RH	5%RH HUMIDITY
RESPONSE TIME (s)	20	20
VOLTAGE (FOR HEAT CLEANING)	8.5 VAC MAX	10 VAC MAX

specifications were not available. The design of this humidity sensor is based on a lateral capacitance structure with interdigitated polysilicon electrodes. The attractive feature of this design is that it is compatible with CMOS fabrication technology. The moisture-absorbing film was magnesium fluoride (MgF_2) which has a varying dielectric constant with the humidity level in the air. The sensing probe generates a frequency proportional to the humidity in the air. This frequency was converted to voltage and amplified. The nominal sensor outputs were between 0 and 4 volts.

3.4 Preliminary Tests

The purpose of the preliminary tests was to assure that the sensors generated amplifiable, repeatable and continuous electrical signals over the humidity range that was to be used (30~90%RH).

The aluminum oxide and thin film polymer sensors performed satisfactorily during preliminary tests. The semiconductor and ceramic sensors did not perform satisfactorily and were not included in further tests. The reasons for excluding these sensors are explained in the following sections.

3.4.1 Preliminary Testing of the Semiconductor Humidity Sensor

Originally, the moisture absorbing layer was coated with a thin protective layer of epoxy to protect against dust and ammonia. After the epoxy layer had hardened the sensor stopped generating signals so the preliminary tests were continued without a protective layer.

Table 3.5 shows a range of typical signals generated by the semiconductor sensor. The signals fluctuated considerably making it difficult to attribute a single level of humidity to any given output.

The semiconductor sensor stopped responding to RH after eight cycles of increasing and decreasing humidity over the range 34%RH to 80%RH. This may be due to MgF_2 loosing its columnar porous structure by forming chemical bonds with water.

3.4.2 Preliminary Testing of Ceramic Sensor

The ceramic sensors were connected as recommended by the product information sheets (Figure 3.1). The desired input voltage level was obtained with the help of a voltage divider consisting of 1kΩ and 100kΩ resistors. The voltage difference across 10kΩ resistor measured at 33%RH was around 0.05 volts, this value increased to 0.10 volts at 85%RH for both type of sensors.

Table 3.5 THE SIGNALS GENERATED BY THE SEMICONDUCTOR SENSOR FOR VARIOUS RH LEVELS

RH	Signals (V)
0.83	3.528
0.8	3.474
0.74	3.492
0.69	3.51
0.65	3.51
0.61	3.492
0.59	3.51
0.58	3.474
0.56	3.51
0.55	3.474
0.52	3.492
0.49	3.456
0.48	3.438
0.47	3.456
0.47	3.456
0.34	3.438

After approximately 10 regeneration cycles, the self cleaning system stopped being effective and V_m (measured output voltage) dropped as low as 2 to 1.5 mV for both sensors around 80%RH levels.

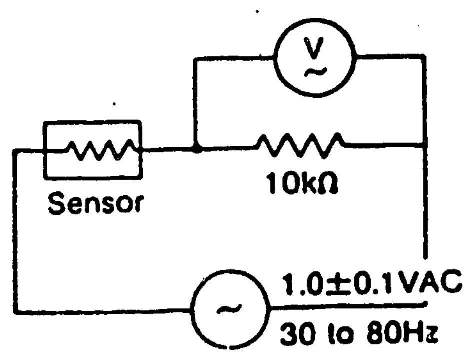

Figure 3.1 The electrical circuit recommended for measuring the effects of the humidity on the resistance of ceramic sensors

Both sensors were placed in an oven at 200°C for two hours for regeneration and were left to stabilize for 12 hours. For both sensors, V_a remained at 0.002 volts for both sensors over the range of 20 to 80%RH.

3.5 Establishing Humidity Levels for Calibration Cycles

As discussed earlier (2.3.1), calibration curves require known measured variables (input values) corresponding to each output generated by sensors under test. The measured variable, relative humidity levels in this case, were determined with the help of an optical dew-point hygrometer.

3.5.1 The Optical Dew Point Hygrometer

The dew point hygrometer used for the above purpose was an automatic, optically sensed thermoelectrically cooled, condensation Model 880 dew point hygrometer manufactured by Cambridge Systems (Division of EG & G, Watertown, MA).

The dew point hygrometer used in the measurement system was calibrated against an NBS traceable dew point hygrometer at the facilities of the Alberta Electronics Test Centre, Edmonton (Appendix A.4). The accuracy of the NBS hygrometer was 0.1°C dew point temperature. It was observed that the highest deviation between 880 dew point hygrometer and NBS traceable hygrometer was not greater than 0.2°C.

The operating principle of this dew point hygrometer was very close to the one described in the second chapter. A highly polished gold plated surface was used as a mirror.

The dew point hygrometer gave outputs between 0 to 50 mV in the range of -40 to +40°C dew point. The cooling rates of the gold plate was 2.2°C/s maximum.

The signals generated by the dew point hygrometer could be related to the dew point temperature only at equilibrium conditions. A lamp on the instrument's front panel served as an indicator of cooling of the gold plate. Light intensity was directly proportional to the activity of cooling the mirror surface.

Observation of the cooling indicator lamp showed that at times, the instrument took some time to come to equilibrium from seconds to minutes and sometimes prevented data recording at the desired frequency.

3.5.2 Factors Affecting Dew Point Accuracy

Optical dew point hygrometers are affected by the water insoluble contaminants, water soluble salts and gases which may be present in the air.

To remove dust particles, the air was filtered through a 0.5 micron steel filter before being directed into the hygrometer. Since insoluble contaminants would have the same effect as improper balancing of the hygrometer, the balance of the hygrometer was checked at regular intervals to ensure that it was not contaminated by insoluble particles in the air.

Water-soluble contaminants in the gas phase such as ammonia can change the equilibrium point at which the dew point

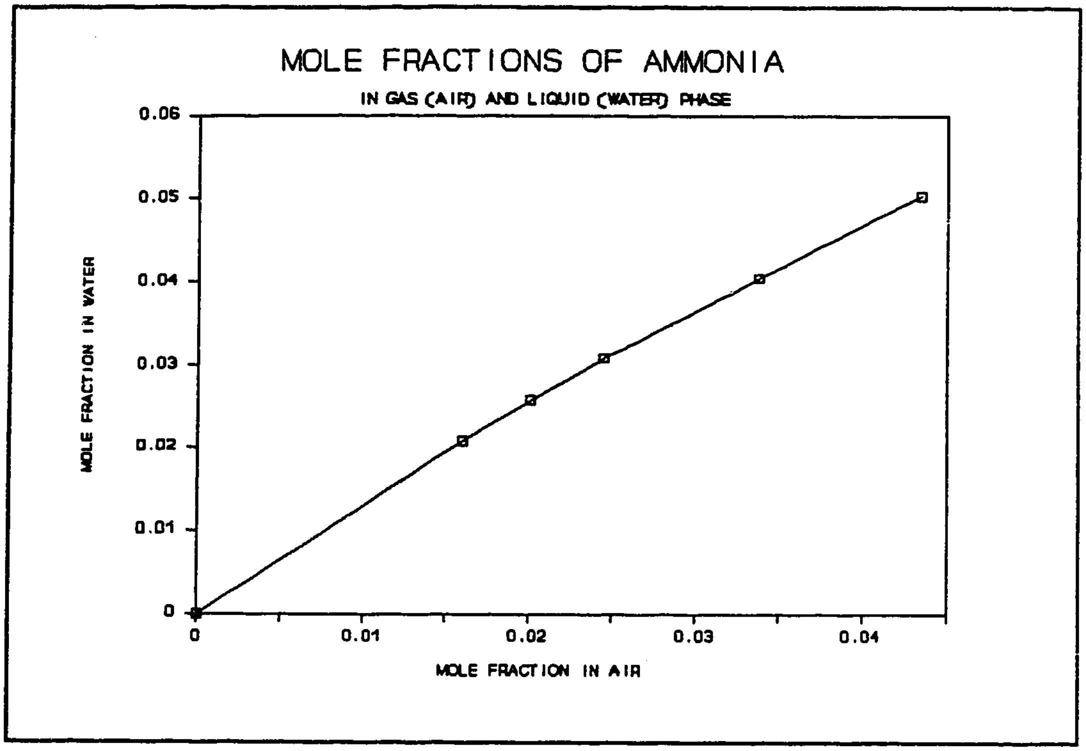

Figure 3.2 The mole fractions of ammonia in the air and water at equilibrium

occurs. This is due to the fact that the molar fraction of the water in the dew formed on the mirror becomes lower than 1 (Daniels and Alberty, 1970) and reduces the equilibrium pressure. The dew in the form of aqueous solution will be in equilibrium with the vapour in the air at a slightly higher dew point temperature which will lead to an upscale drift. However ammonia levels of 40 ppm (highest ammonia level generated in the environmental chamber) will not affect the dew point temperature. Based on the data given by Perry (1980) the molar fraction of ammonia dissolved in water (water on the gold plate of the dew point hygrometer) in the presence of 40 ppm ammonia will be around 0.00005. Daniels et al (1975) state that it is evident from the data that even for nonideal solutions Raoult's law always applies to a component (water in this case) as its mole fraction approaches 1. Roault's law can be written as follows:

$$p_w = X_w * p_s \qquad (3.1)$$

where: p_w=partial pressure of water,

X_w=mole fraction of water in liquid phase (0.99995) and

p_s=saturation vapour pressure of water.

According to Equation 3.1 the partial pressure of water on the gold plate of the dew point hygrometer will be very close to the saturation water vapour pressure at the temperature of the gold plate, hence, the deviation from the actaul dew point temperature can be considered negligible. Figure 3.2 shows the mole fractions of ammonia in water and air at equilibrium at 20°C.

3.6 Sensor Evaluation Environment

As mentioned earlier the performance characteristics of the sensors were evaluated in simulated animal environments in order to asses their suitability for use in environmental control systems. Since the concentrations of other contaminants were considerably less than dust and ammonia, the effects of only these two contaminants were examined. Clark and McQuitty (1985) reported that four of the six free-stall dairy barns they had monitored had average ammonia concentrations around 18 ppm (ranging from 0 to 54 ppm). The same authors reported dust levels ranging from 0.15 to 85 particles/mL. Feddes et al. (1982) reported daily average dust concentrations as low as 0.9 particles/mL and as high as 7.5 particles /mL.

For simulation purposes ammonia and dust levels used ranged from 20 ppm ammonia and 0.2 particles/mL dust to 40 ppm ammonia and 85 particles/mL dust.

3.7 Experimental design for Evaluation of Sensors

3.7.1 Static Chracteristics

The effects of ammonia and dust were considered simultaneously with the help of a randomized factorial design. Two treatment factors (ammonia and dust) each with 3 levels were grouped in 9 different possible combinations with two replicates. Each replicate combination of dust and ammonia formed a single test (18 tests) which were carried out in a random order. The levels of ammonia used were 20, 30 and 40 ppm and the dust levels were 0.2, 10 and 85 particles/mL. The performance characteristics such as accuracy and hysteresis, were determined from calibration curves.

3.7.2 Step Response Characteristics

Tests related to step response had another factor which indicated the direction of the step response. The direction of the step response is discussed in detail in chapter 7. For determining step response characteristics the mean square for the highest order interaction was used as an estimate of error

(Peterson, 1985). Again, tests (18) were carried out in a random order.

4. ANIMAL ENVIRONMENT SIMULATION

A system for simulating the atmospheric conditions prevailing in animal environments was designed and built. A measurement system for establishing actual humidity levels and which included components for recording the outputs of the sensors being evaluated constituted the testing apparatus. Descriptions of the systems for animal environment simulation and measurement are presented separately.

4.1 The Requirements of the Simulation System

The major requirement of the simulation system was to create an atmosphere, resembling animal environments, which could be changed in a controlled way to allow sensor testing. This implied the following features:

-Generating increasing and decreasing RH levels

-Generating and maintaining predetermined dust and ammonia levels in the atmosphere

-Creating step changes in the humidity levels at predetermined levels of ammonia and dust to test dynamic responses of sensors.

4.1.1 Preliminary Survey for Simulation of Animal Environment

Preliminary studies and tests had shown that simulation of barn environments with known pollutant levels would be more practical with an open environment chamber rather than with a closed system.

The literature search indicated that decreasing relative humidity levels were usually achieved either with the help of desiccants (or saturated salt solutions) or by dilution. Due to interaction of pollutants (either physical or chemical) with moisture absorbing material, the circulation of the air through a chamber containing dehumidifying material was not possible without disturbing pollutant levels in the atmosphere. This implies that each humidity level would have to be created in the chamber before the injection of pollutants, one at a time, which would give a very limited number of points on a calibration curve and consume considerable time. Dilution was only possible in vented (open) chambers.

The term open or vented chamber was used to refer to a chamber having exchange of mass with its environment, alternately, closed systems or chambers meant systems having no exchange of mass with the environment.

If the humidity in the closed systems was increased by recirculating the air through water the pollutants would, again, interact with water. Slow injection of steam was another possibility to increase the chamber moisture content which is the case with industrial humid atmosphere generation chambers. This would make the system considerably complicated and expensive. Generation of humidity levels stepwise, one level at a time, was rejected earlier. In addition, dust introduced into the atmosphere in a closed system tended to settle at certain spots unless random air flows were present in the system. Creating random air flows implied trial of various methods and was seen as a serious diversion from the topic.

4.2 Simulation System Overview

Figure 4.1 shows a block diagram of the simulation system. Air having a relative humidity in equilibrium with a selected saturated aqueous salt solution was fed into the chamber from the moisturizing unit. This unit was capable of providing relatively constant, increasing or decreasing RH levels in the chamber. The air inside the chamber was exhausted at the same rate as the inlet in order to reach a steady state. At steady state the moisture content of the incoming stream was equal to that of the chamber (Treybal, 1968). Dust and ammonia were injected into the chamber at two different locations. Each component of the system is described separately.

4.3 Environmental Chamber

The environmental chamber was a rectangular prism with average inside dimensions of $0.453 \times 0.451 \times 0.493$ m^3. This provided enough space to hold three humidity sensors with their transmitters. The walls of the chamber were made from 12.5 mm thick acrylic plastic sheet to allow for easy sealing, visibility of the test area and convenient fabrication.

4.4 Moisturizing Unit

The independent variables which describe a vapour-liquid equilibrium are temperature, pressure and composition (Perry

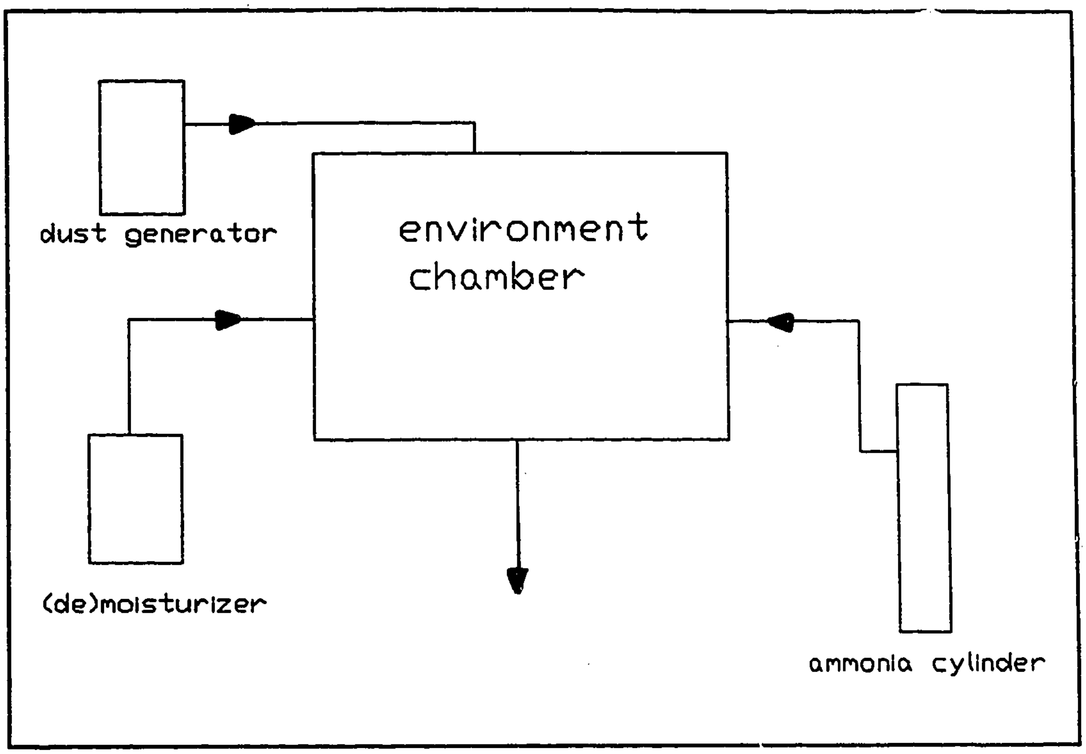

Figure 4.1 Block diagram of the system showing the main inlet and exhaust streams

and Chilton, 1985). Concentration of a saturated aqueous salt solution is fixed at any given temperature and does not have to be determined (Hildebrandt and Robert, 1962). This means that saturated salt solutions can be used for generation of known, increasing and decreasing humidity levels. Equilibrium relative humidity values for selected saturated salt solutions have been tabulated (ASTM, 1985).

Potassium chloride and magnesium chloride saturated salt solutions were chosen for generation of calibration cycles between approximately 33% and 85% RH levels. These salts were chosen because they would allow sensors to be tested over a sufficiently large range of relative humidity and would provide almost constant RH levels over the full range of expected room temperatures (15-25°C). However, due to the temperature differences between the solution, outside air, and the environmental chamber, deviations from 33% and 85% took place (up to 9% RH at high humidity levels, 3% RH at low humidity). The moisturizing system is shown in Figure 4.2.

Air was bubbled through two columns of saturated salt solution to establish equilibrium between the solution and the air. Cylinders with internal diameters of approximately 62 mm were used for the water columns and provided good turbulence and, hence, air-water contact. Two water columns of the same volume were used to ensure that near-equilibrium levels were reached. Each water column was 200 mm in height excluding the salt deposited at the bottom. Standard procedures set out by ASTM (1985) for the preparation of saturated salt solutions were sitrictly followed.

As can be seen in Figure 4.2, ambient air was forced through the first column and entered a two-litre flask. Any saturated salt solution which overflowed from the first column was trapped in this flask and accumulated at the bottom. Inlet air for the second column was withdrawn from close to the top of the flask. This way, any of the solution from the first column, or impurities which may have entered with the inlet air, were prevented from being carried into the second column. Thus, the constituents of the solution in the second column were pure distilled water and salt. After the second column, another two-litre flask prevented small droplets of solution going into the chamber. The size of the second flask and the rate of air flow was determined by trial and error. Smaller flasks caused condensation on the surface of the chamber at high relative humidity (around 80% RH). This was interpreted as presence of very small droplets of solution in the atmosphere of the environmental chamber carried by air loaded with moisture. Larger flasks prevented dew formation on the surfaces of the chamber.

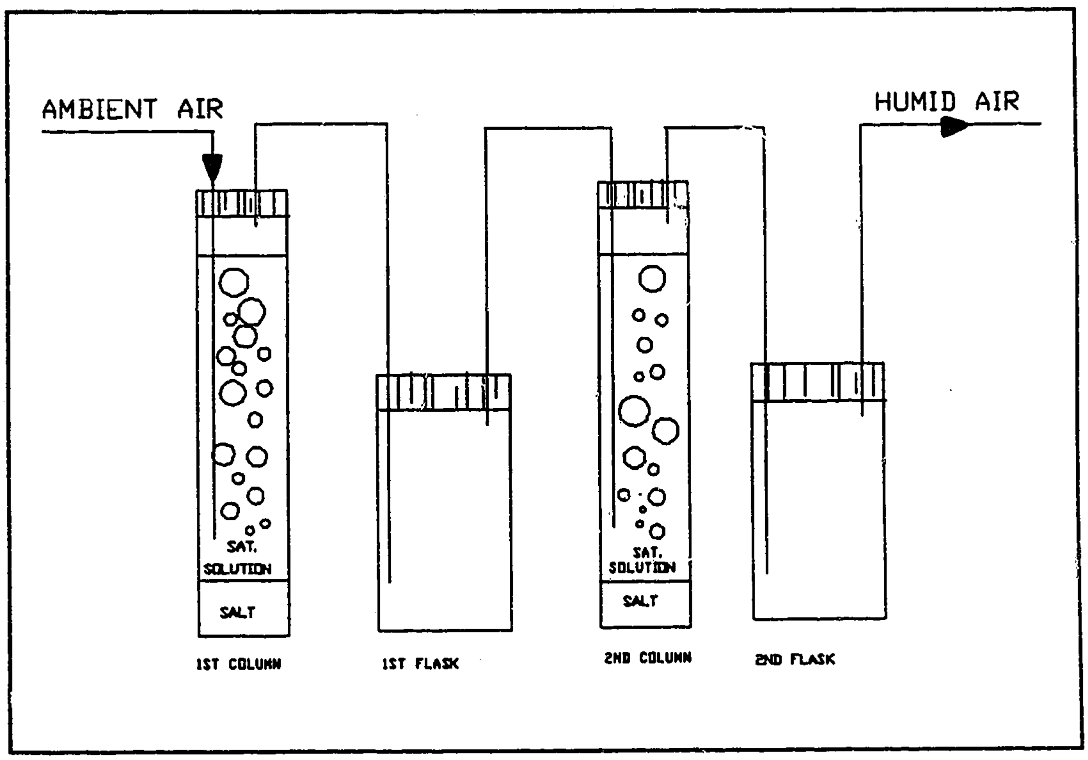

Figure 4.2 Moisturizing unit for one salt, the set-up is the same for each salt

The moisturizing units for potassium chloride and magnesium chloride were connected to the same injection inlet to the chamber. This way, simply opening and closing the valves located before the water saturation cylinders could shift the system from moisturizing to drying (Figure 4.5 valves 8 and 9). The check valves located at the entrance to the chamber inlet (valves 7 and 6) for each moisture saturation unit prevented air flowing in the reverse direction.

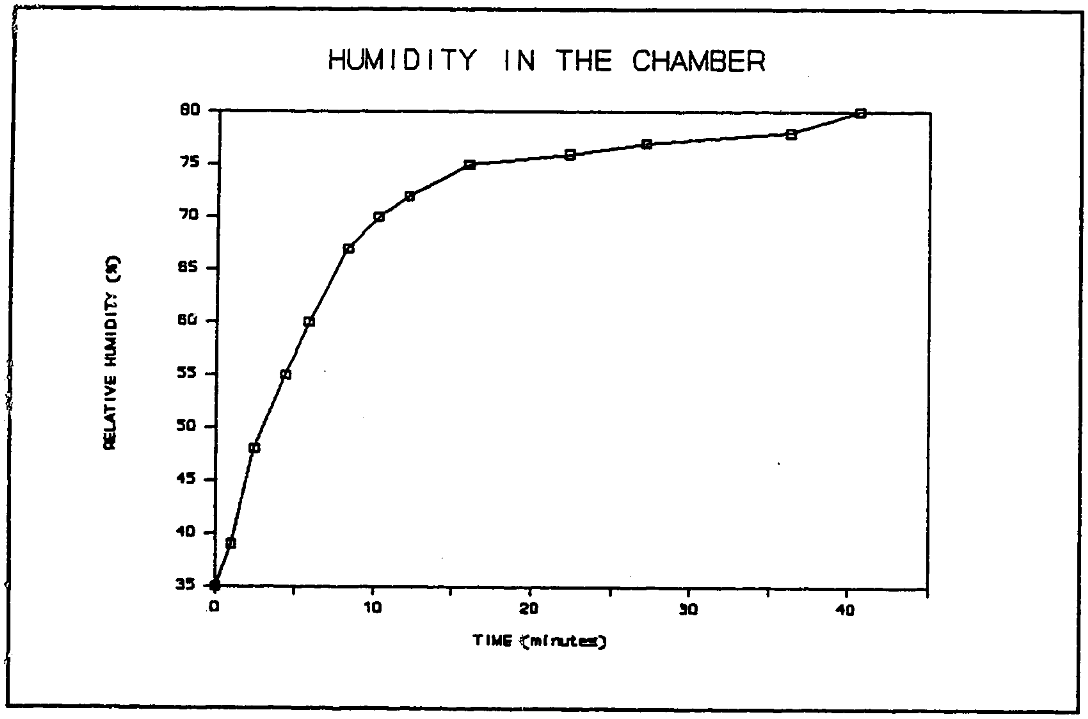

Figure 4.3 Relative humidity inside the chamber versus time

The air going through the moisturizing system picked up the moisture defined by the equilibrium state at the prevailing temperature. This air mixed with the air in the chamber to change its moisture content and a value was reached where the moisture contents of the incoming stream, the chamber and the outgoing streams were almost the same so long as changes in the temperature of inlet air stream were not frequent, fast or large.

Figure 4.3 shows a plot of the relative humidity inside the chamber versus time during a trial run. As can be seen, the response approximated that of a first order system which is what would be expected from a perfectly stirred tank. The time constant of the system was approximately ten minutes.

4.5 Air and Moisture Flow

Figure 4.5 shows how the air flowed in and out of the system. Air for the environmental chamber was injected into the system with a diaphragm pump (P3) through moisturizing unit (5 or 6).

The air flow into the chamber was measured just before the entrance of conditioned air into the chamber with a gas meter (Canadian Meter Company Limited, Model AL 225) during two separate trial runs (both runs at t_{dp} =4.4°C). The volumetric flows were converted to kg of dry air at the temperatures and RH at which they were measured. Since the air temperatures were relatively close (20.6 and 20.4°C), the two flow rates 0.022 and 0.020 kg dry air/ min. were averaged for subsequent calculations of the RH levels in the chamber (Section 4.6).

The air was injected in the centre of one of the sides of the chamber and exhausted through three outlets on the side facing the inlet surface. Two of the exhaust pipes carried samples to the ammonia analyzer (2), and dust particle counter (1).

The dew point hygrometer (3) and ammonia analyzer were protected from the dust particles in the air with 0.5 micron filters (F) (Edmonton Valve and Fitting Ltd., Edmonton, AB).

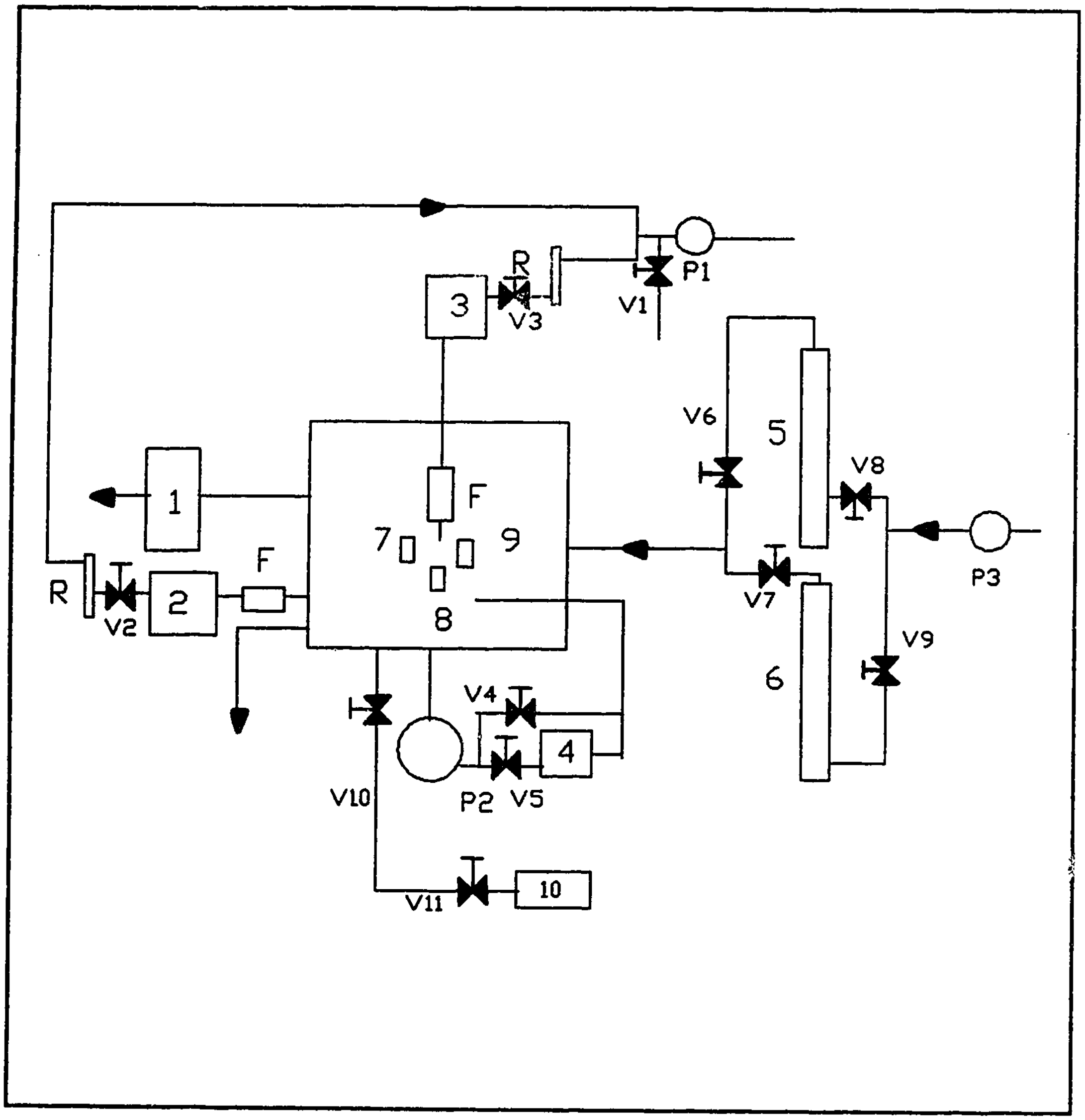

Figure 4.5 Plan views showing air flows in and out of the chamber

The tube sampling air for the dew-point hygrometer started at a location, inside the chamber, close to the centre and in the vicinity of sensor probes under test (7, 8, 9). The air outlets to the ammonia analyzer and the hygrometer were connected through rotameters (R) (Sho-Rate, Brooks Instrument Division of Emerson Electric Company, USA) to another diaphragm pump inlet (P1). The flows through rotameters were kept at desired rates (0.012 L/second for both dew-point hygrometer and ammonia analyzer) with the help of valves V2 and V3 which were supplied with the rotameters and by valve V1 located before the pump (P1). An additional stream was drawn by a second diaphragm pump (P2) from the face of the chamber between the injection and exhaust sides. Pump P2 recirculated air through a dust-generating cyclone (4) and its by-pass line. This stream supplied dust and helped promote air mixing inside by pushing the air from the upper part of the chamber.

The tubing used for the system was 6mm PVC tubing and the valves were brass, 6.4-mm ball valves.

4.5.1 Pressure Difference Between the Sampling Point and the Moisture Sensing Chamber of the Dew Point Hygrometer

Dew or frost point temperatures are pressure dependent (Carr-Brion, 1986) and, for this reason, the pressures in the vicinity of sensors being tested and the dew point hygrometer humidity sensing chamber were measured. Measurements were taken during eight separate runs, which were exact replicates of calibration tests, with a manometer containing a liquid hydrocarbon having the specific gravity of 0.872. During these tests the vacuum in the sensing chamber of the dew point hygrometer averaged 62 mm water column with the highest 72 and lowest 45 mm of water column. The air flow was kept constant at 0.012 L/second during measurements and calibration cycles.

The change in water vapour pressure is proportional to the total pressure change and can be calculated with the help of Dalton's law accordingly,

$$p_{w1}=p_{w2}*(P2/P1) \qquad (4.1)$$

where: p_{w2}=the partial pressure of water at total pressure P2 and

p_{w1}=the partial pressure of water at the total P1.

The following approximation was suggested by the manufacturers of the dew point hygrometer (Cambridge Systems)

$$\Delta td=14*\Delta(P/P) \qquad (4.2)$$

where: Δtd=the change in the dew-point temperature in °C due to the change in the original sample pressure P and

ΔP=the pressure change of the sample.

According to Equation 4.2, the pressure differences between the sampling and detection points corresponded to 0.1°C dew point temperature difference for the highest (72 mm water) observed pressure difference. This difference was considered negligible but was included in the calculation of overall error for establishing input humidity levels (Appendix D).

4.6 Comparison of the Calculated and Measured RH in the Environmental Chamber

In order to calculate RH levels in the environmental chamber over time and to check their agreement with the RH measurements obtained with the dew point hygrometer, a moisture balance was carried out to calculate air moisture contents and, later, the moisture contents were converted to RH.

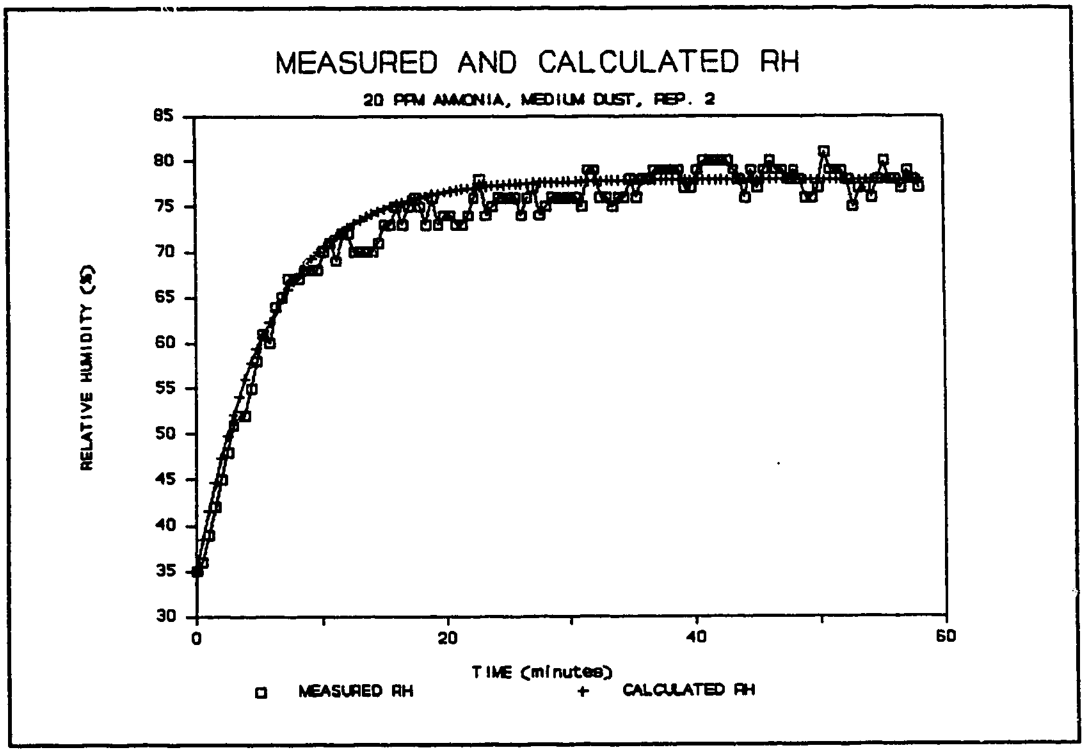

Figure 4.6 Measured and calculated relative humidity inside the chamber versus time

It was assumed that complete mixing of the air inside the chamber took place and the temperature of the saturated solution stayed constant. Also, it was assumed that streams were in near-equilibrium with the saturated solution at the solution temperature. According to the moisture balance, the time passed after the injection of air with a new moisture content can be related to the system variables by the following equation:

$$t'=(M/m)*\ln[(wf-wi)/(wf-w)] \quad (4.3)$$

where: m=air flow (kg/min.),

t'=time (min.),

M=mass of air the chamber holds (kg),

w=moisture content of air (kg/kg dry air) at time t,

wi=initial moisture content of the chamber and

wf=moisture content of the air in equilibrium with saturated salt solution.

The moisture content of the air corresponding to the humidity levels indicated by the dew point hygrometer at the start of the moisturizing cycle was taken as wi. The initial temperature of the moisturizing solution was 19°C and assumed constant.

RH was calculated according to Equation 2.4. The water vapour pressure (p_w) in equation 2.4 corresponding to each air moisture content was calculated according to the following equation (ASHRAE, 1981):

$$p_w=(w*P)/(0.6219+w) \quad (4.4)$$

where: P=Total pressure.

The total pressure was taken as the average local atmospheric pressure reported by Environment Canada for the day of the experiment.

Figure 4.6 and Appendix A.2 present the measured and calculated RH versus time for a typical calibration test for rising humidity levels (replicate 2, 20 ppm ammonia and medium dust).

Deviations averaged around 2%RH. The highest deviations occurred at points where the dew point hygrometer indications fell or stayed constant on an upscale calibration test.

Deviations at higher RH levels can be explained better by looking into the sensing mechanism of the dew point hygrometer. The temperature of the gold plate is kept at the dew point temperature by cooling slightly below the dew point temperature at which point cooling stops and gold plate temperature rises to the true dew point temperature. The time for this operation varies from seconds to 10 minutes at high dew point temperatures (Cambridge Systems, 1969). Cooling below dew point temperature will cause more than the usual amount of dew to form on the gold plate when the moisture content of the air being measured is increasing. The extra latent heat to be supplied by the gold plate for the dew to evaporate will make the temperature depressions more pronounced.

This tendency was noticed throughout this work and it was also observed that outputs from the humidity sensors under test kept on increasing on upscale calibration tests. The dew point temperatures showing a decline during the calibration cycles for rising humidity levels were not included in the calibration reports for the reasons given above.

4.7 Simulation of Dust Levels

4.7.1 Dust Generation Methods

The dust generation system was required to create dust inside the chamber continuously so that dust concentrations around either 10 or 85 particles/mL were maintained in the chamber for the duration of a complete calibration cycle.

Generation of dust inside the chamber and dust injection from an outside reservoir were the two modes which were included in preliminary tests for generation of durable dust concentrations in the chamber atmosphere.

The first approach was to place a preweighed amount of dust inside the chamber and create air flows with the help of fans. After initial high dust concentrations, the number of dust particles in the air dropped sharply from 1400 particles/L to 3 particles/L in less than 10 minutes. Introducing baffles and different flow patterns did not improve maintaining the required amount of dust in the air. At this stage the decision was made to carry out tests in open chambers.

The first trials of injecting dust consisted of entraining dust particles with the help of small air flows underneath a small cup in the shape of inverted cone. The cup (150 mL) was 2/3 full at the start of the tests. The air carried dust particles through a pipe into the chamber. This system required extremely small air flows or the dust content of the chamber became very high. A second approach to injecting dust was to make use of an air-floated dust feeder (Grassel, 1975). This aerosol generator consisted of a tube with dust at the bottom. Air flows were introduced through a pipe entering at the bottom and releasing air below the dust. The dusty air was withdrawn from the top of the tube which was 700 mm in length and 40 mm in diameter. Again, good control of the concentration of particles depended on controlling air flows precisely. The final approach attempted was creating dust with the help of small cyclones.

A cyclone subjects a mixture of gas and solids to a centrifugal force and exploits the higher inertia of solid particles to change their trajectories from the flow path of the gas (Storch et al, 1979). In this case, the solids which were carried with the air flow were introduced into the flow path of the air by generating desired air velocities on the surface of the dust (3 grams) which was placed at the bottom of the cyclone. The required parameters of the cyclone to get the desired dust concentrations in the chamber were found by trial and error.

The flow of the air above the dust at the bottom of the cyclone was the key element in controlling the dust concentrations. Flow adjustments were made with valves (V4 and V5 in Figure 4.5) placed on the cyclone inlet and by-pass lines. The pump size was determined by trial and error.

Dust levels inside the chamber were monitored continuously (1 in Figure 4.5) using a light-sensing particle counter (model CI-250, Climet Instruments, Redlands, CA) which was checked against an aerodynamic particle sizer (model TSI-APS-3300, TSI Inc. St.Paul, MIN).

Further adjustments of the air flow rates were also made in the course of the tests according to the readings indicated

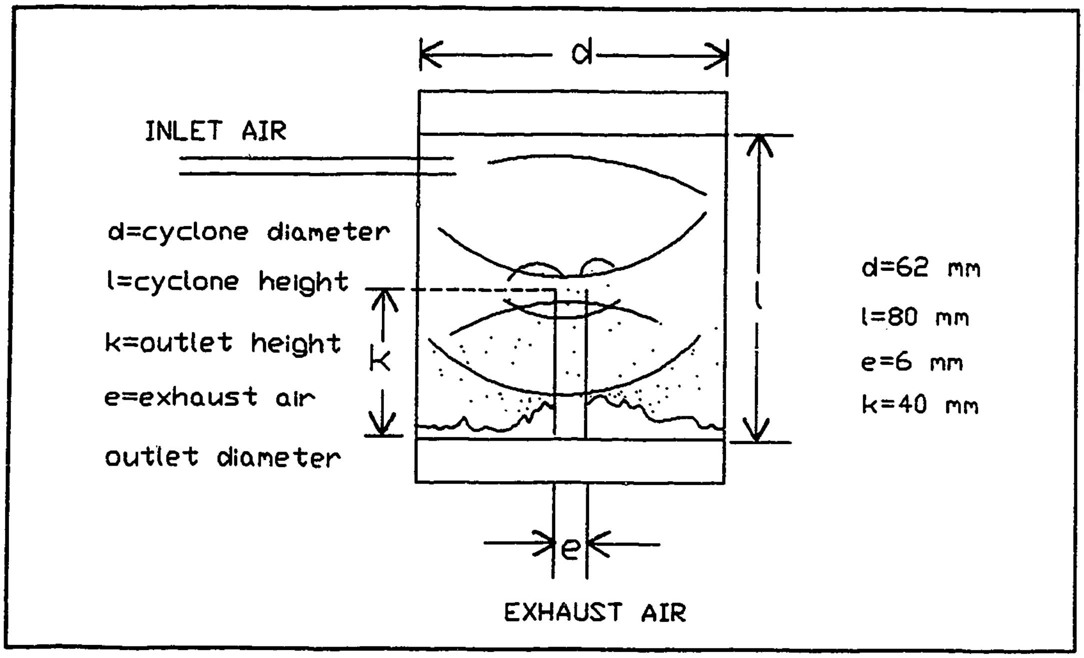

Figure 4.7 The cyclone used for dust generation

by the dust particle counter.

4.7.2 The Qualities of the Dust Generated

The dust injected into the environmental chamber was collected from a poultry brooder house at the University of Alberta's Edmonton Research Station. The brooder house usually housed chickens and turkeys. The dust sample was a mixture of the dust collected on the window sills, machinery, ducts and the roof of a small shack in the barn. The collected dust (2 kg) was sieved through a screen with 1.1mm (16 mesh) openings, in order to get rid of larger material. The screened dust was agitated in a rolling cylinder for three hours in order to obtain a homogeneous sample. Particle size distribution of the dust suspended in the air for low, high and medium dust levels measured during a trial run are presented in Table 4.1. The typical dust concentrations for three different dust levels are given in Appendix A.1. Initially, a low concentration of dust was generated inside the chamber and increased to the desired value by increasing the flow rate through the cyclone.

Table 4.1 PARTICLE SIZE DISTRIBUTION OF DUST SUSPENDED IN THE AIR FOR DIFFERENT DUST LEVELS

size	low	medium	high
micron	cumulative fractions		
<0.486	0.0232	0.0732	0.0418
<0.964	0.631	0.801	0.746
<1.48	0.862	0.914	0.908
<2.12	0.954	0.969	0.97
<5.04	0.992	0.998	0.998
<10.3	1	1	1
>10.3	0	0	0

4.8 Ammonia Injection

Ammonia was introduced into the chamber from an ammonia cylinder (10 in Figure 4.5) containing a mixture of 1.5 % ammonia in air. Ammonia concentrations were measured with an infrared analyzer (Rosemount Beckman Industrial Division, CA). Flow was controlled by needle valves placed after the cylinder pressure regulator (valves V10 and V11). The needle valve was opened manually by a small amount at 30-second intervals until the ammonia analyzer indicated the desired concentration. Once the intended ammonia levels were achieved further adjustments were seldom needed. Since the system was not sealed, ammonia concentrations could be reduced easily by disconnecting the cylinder from the chamber or by closing the needle valve.

4.9 Generation of Step Response

Figure 4.10 shows a schematic diagram of the system for generating a step input, that is, a sudden change in RH.

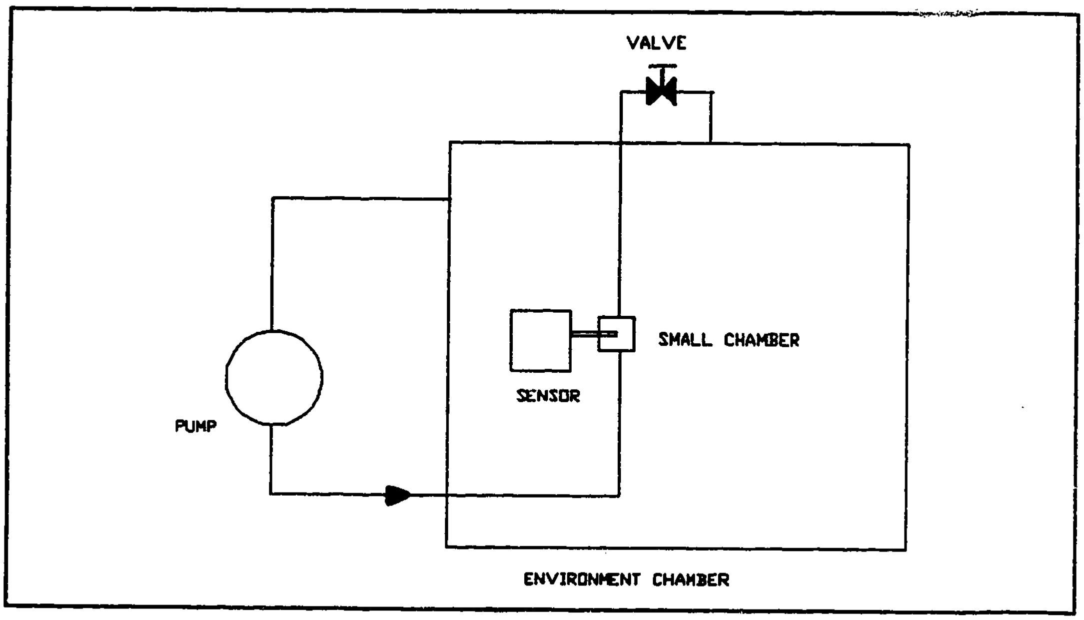

Figure 4.8 Schematic diagram of the system for generating step inputs

A number of alternatives were considered for generation of step inputs. The first approach was placing the sensors (as a whole) in a small container and introducing the conditioned air continuously from the environmental chamber. The required amount of pollutants and humidity levels was to be prepared in advance. Since the size of the second chamber would still be comparable to that of the environmental chamber introducing the new conditioned air would take time and the overall effect would not be of a step input. Additionally, the continuous air flows might create turbulence which would cause sensors to give misleading readings. Even if the air was not introduced continuously, filling the second box would take time comparable to sensor response times and it would be difficult to determine the time at which the step input was introduced.

The use of small cups encapsulating only the sensor probes was the second alternative considered. This eliminated the errors expected from having a relatively large step input chamber.

The environment chamber was used to create the desired levels of pollutants and RH as was proposed for the first alternative. The atmosphere generated in this way was recycled through a very small chamber (100 mL) enclosing the sensor thus exposing it to the same levels of dust and ammonia as in the environment chamber. The valve located on the outlet of the small chamber was used to isolate the small chamber from the rest of the system. The system is illustrated in Figure 4.9.

A diaphragm pump with a capacity of 200 mL/s suddenly introduced the air having a new level of moisture, but the same dust and ammonia concentrations, into the small chamber enclosing the probe of the moisture sensor.

Figure 4.10 shows a typical response curve obtained for thin-film sensor #2.

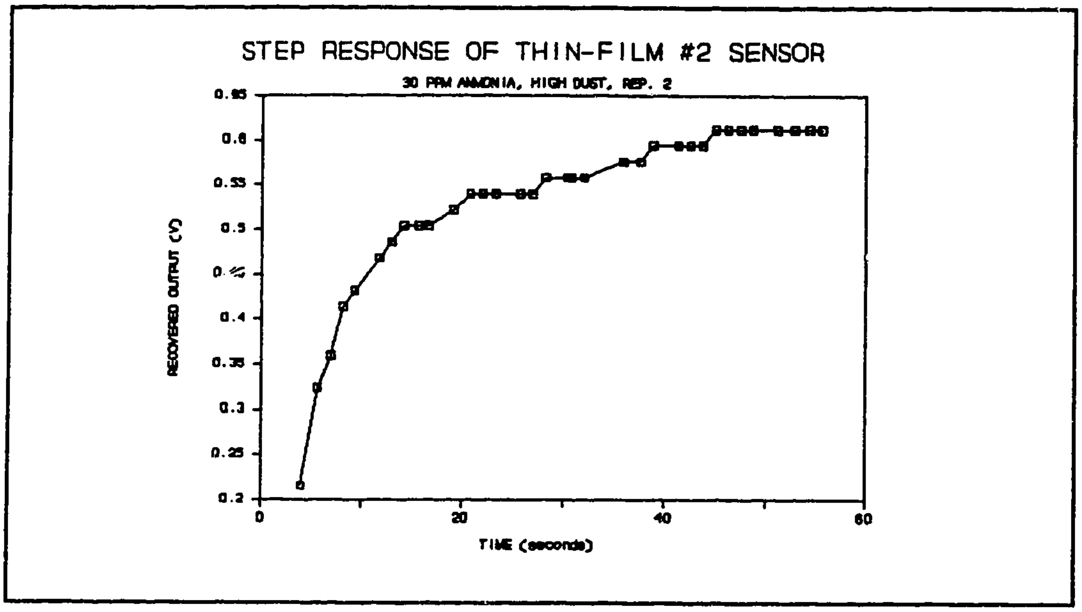

Figure 4.9 Step response, thin film sensor#2

4.10 Preparation of Sensors for Each Test

No adjustments were made on the sensors and they were tested as received.

After each test, sensors were cleaned with compressed air and subjected to a recovery period of 12 hours during which they were exposed to a clean atmosphere disconnected from the power supply. Before each test, sensors were subjected to a warm up period of at least two hours in a clean atmosphere connected to the power supply in addition to one warm-up cycle.

The environmental chamber and the small container in case of step response tests were cleaned with wet cloth and aerated for 12 hours in a clean room after each test.

5. MEASUREMENT SYSTEM

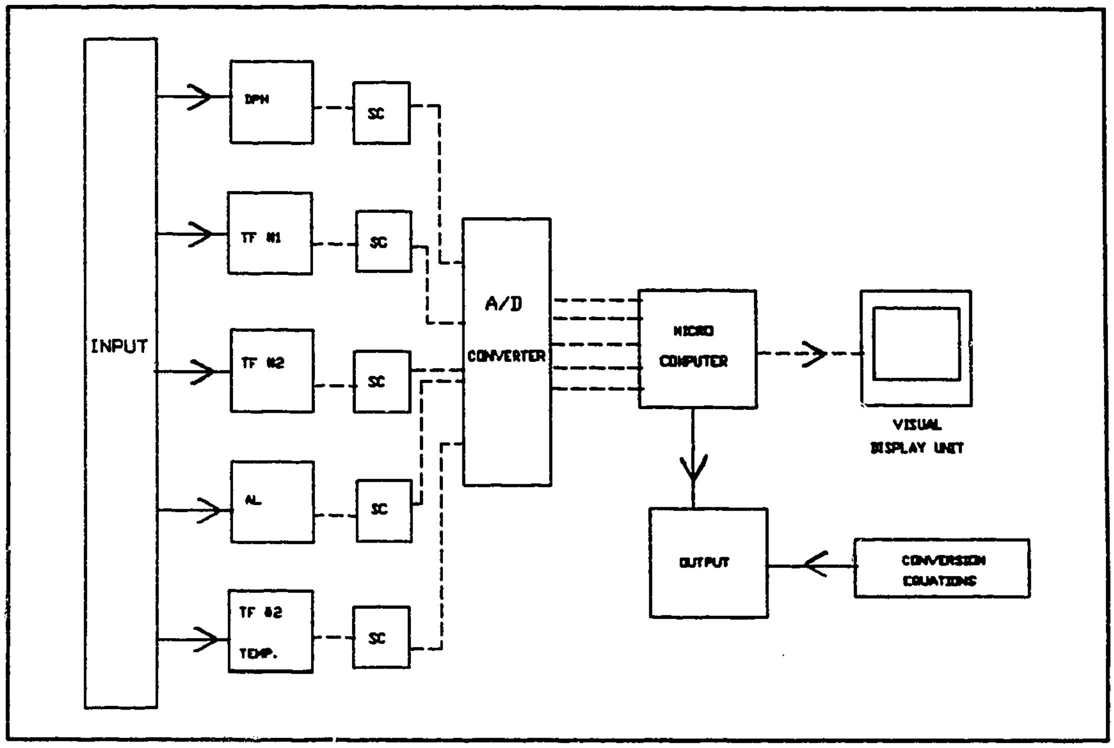

Figure 5.1 Measurement system for sensor performance evaluation

Figure 5.1 shows the structure of the measurement system for establishing sensor performance characteristics.

The reaction of the sensing probes to various levels of humidity (input) in simulated barn environments were transformed into electrical outputs by sensors (thin-film polymer sensor #1: TF#1, thin-film polymer sensor #2: TF#2, aluminum oxide sensor: AL, dew point hygrometer: DPH). Signal conditioning (SC) elements converted the electrical outputs coming from the sensors to the desired range (upper limit of 4.5 V for 85% RH) for the data processing stage.

The outputs from the signal conditioning elements were digitized by an analog-to-digital (A/D) converter and recorded on a magnetic disk with the help of a microcomputer. The analog input/output board (model DA/M-100, Dycor Industrial Research, Edmonton) featured 8 analog input channels and an 8-bit A/D converter. DA/M provided a resolution of 18 mV with an output range of 0.00 to 4.59 volts. The digitized voltage signals coming from various sensors were converted to meaningful units by means of equations detailed in Sections 5.2.3.2 and 5.2.3.3.

5.1 Measurement System Elements

5.1.1 Signal conditioning Elements

As already mentioned an additional signal conditioning component was required to convert the signals coming from sensors to voltages within the required voltage range (0 to 4.59 V).

With the exception of the signals for temperature measurements, the sensor outputs in mA were converted to voltage with the help of the circuit shown in Figure 5.2. Resistors (R) for the first four calibration cycles were 235Ω, 245Ω, 210Ω and 210Ω, 363Ω, 332Ω for the rest of the calibration cycles for AL, TF#1 and TF#2 respectively. The error due to the resolution were around 0.3 and 0.2 %RH for the first and second set of resistors.

TF#2 also provided outputs in mA for temperature

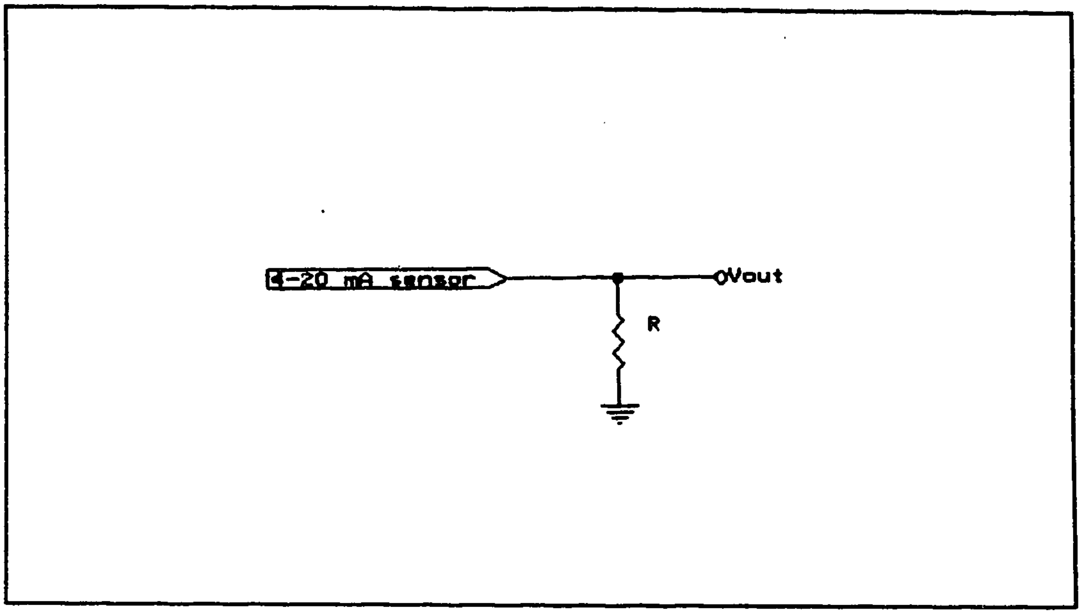

Figure 5.2 Signal conditioning circuit for 4 to 20 mA outputs

measurement. In this case the current was converted to voltage and amplified as shown in Figure 5.3 (R1=300Ω , R2=1kΩ, R3=2kΩ). This was necessary to bring the outputs within the desired range for the A/D converter.

In order to amplify the outputs from the dew-point hygrometer , two inverting amplifiers were used to provide an overall gain of approximately 190 (Figure 5.4). The first operational amplifier multiplied the signal 3.8 times with R1=100kΩ and R2=380kΩ , the second one amplified it 50 times with R3=1kΩ and R4=50kΩ.

5.1.2 Data Conversion

Data conversion was carried out with the help of a data manipulation software package (Lotus Development Co. MA, USA).

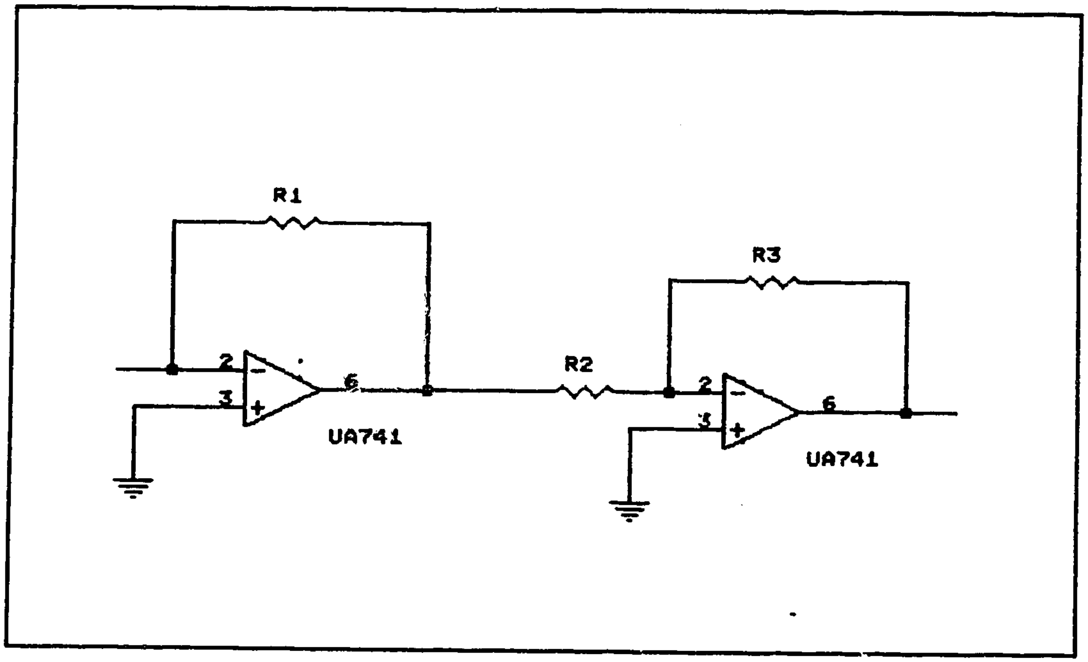

Figure 5.3 Signal conditioning circuit for temperature sensing

5.2. Temperature

The platinum RTD (supplied with TF#2) was calibrated over the range 19#C to 21#C against a mercury thermometer having divisions of 0.1°C. The resulting regression equation gave a linear relation between thermistor outputs (independent variable) and thermometer readings (dependent variable) with an R^2 of 0.917.

Appendix A.4 tabulates the sensor outputs and corresponding temperature readings and regression analysis outputs.

5.3 Dew Point Temperature

The relationship between the dew point temperature and

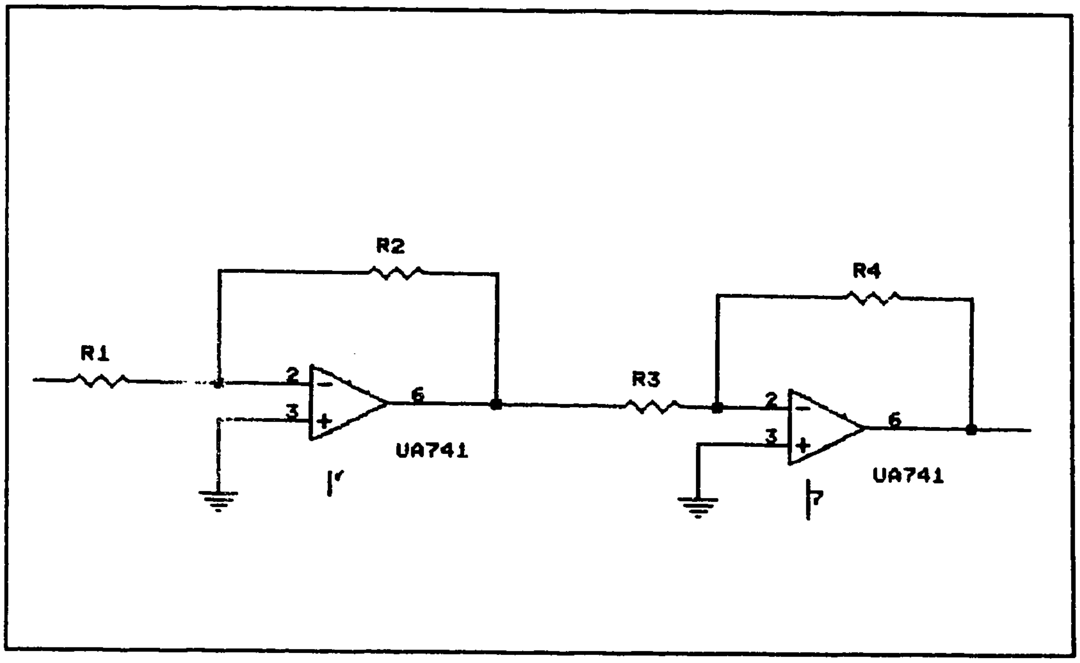

Figure 5.4 Signal conditioning circuit for dew-point hygrometer

dew point hygrometer output also was established with the help of a regression equation. The pointer on the front panel of the dew point hygrometer indicated dew point temperatures on a scale having 1°C divisions and was read and noted manually. In order to establish a relation between the indicated dew point temperature and recorded digital outputs, readings covering the range of the experiments were noted for ascending and descending humidity levels. A regression analysis was done on the data obtained using the manually-recorded dew point readings as the independent variable and the electrical outputs as the dependent variable.

This regression equation also was linear with an R^2 of 0.995. Related data and the regression analysis outputs are given in Appendix A.5.

5.4 Relative Humidity

Wood (1970) has shown that the Antoine Equation can be expressed as follows:

$$(t_{dp}+C)^{-1}=(t+C)^{-1}+L^{-1}\log(RH)^{-1} \qquad (5.1)$$

where: t_{dp}=dew point temperature in #C,

t=environment temperature in #C,

L=1750.286 (#C)$^{-1}$,

C=235.0 #C and

RH=relative humidity (decimals).

The constants were evaluated by Dreisbach (1961). Equation 5.1 was used for converting the outputs obtained by the dew point hygrometer in t_{dp} to %RH for establishing inputs for RH measuring instruments, namely: TF#1, TF#2.

6. STATIC PERFORMANCE CHARACTERISTICS

Static performance characteristics of the sensors were evaluated in terms of accuracy rating and hysteresis according to a factorial experimental design (Section 3.7) with three levels of ammonia and three levels of dust with two replicates.

The operating conditions for accuracy and hysteresis tests were defined as:

1. Temperatures between 20 and 22°C and relative humidity (RH) ranges between 33 and 85%,
2. Presence of dust and ammonia.

6.1 Test Procedures for Generating a Calibration Cycle

Preparation of the sensors and the environment chamber for each test were explained in Section 4.10. A single calibration cycle consisted of the following steps:

1. "Warming up" the sensors for two hours,
2. Putting the sensors and DPH through a calibration cycle (starting with the low humidity level (around 33% RH) going up to the high humidity level (around 85% RH) then back to the low humidity level in the absence of contaminants),
3. Introducing the contaminants, at low humidity, at the end of the first cycle,
4. Starting the upscale calibration cycle 30 minutes after the contaminants reached the desired values,
5. Allowing humidities to increase to the high humidity level and maintaining the system at this level for 30 minutes, and
6. Allowing humidities to decrease to the low humidity level.

Readings were taken at one minute intervals. Calibration tables are given in Appendix B.7.

6.2 Accuracy

Accuracy rating was chosen for expressing accuracy since the majority of the humidity sensor manufacturers use accuracy rating in their specifications.

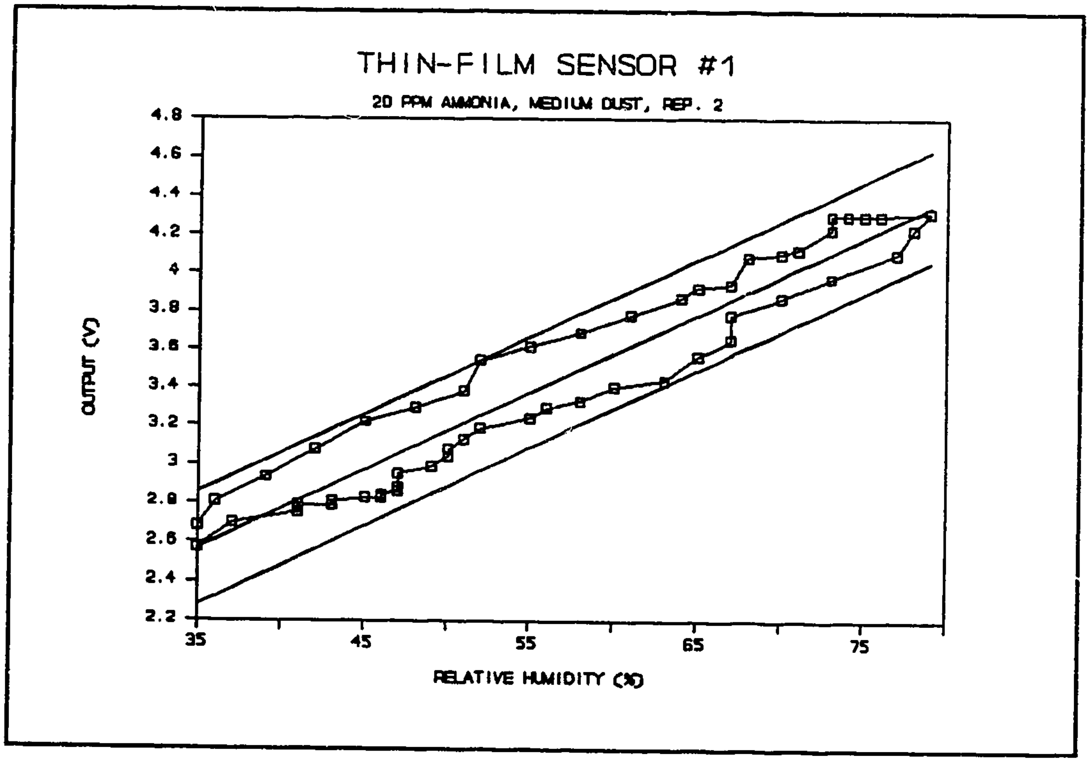

Figure 6.1 Calibration curve, least squares line and accuracy for a typical run with TF#1.

Accuracy ratings were determined by calculating the maximum deviation from input (error) for a calibration cycle. The error for each input was calculated to find the maximum error for sensor accuracy. In order to compute the error at each input a straight line of the following form was constructed for each test and sensor:

$$O_c = mX + b \qquad (6.1)$$

where m is the slope and b is the intercept for the straight line, X is the input determined by the dew-point hygrometer either in t_{dp} or its conversion to %RH and O_c stands for calculated output for the sensor in volts.

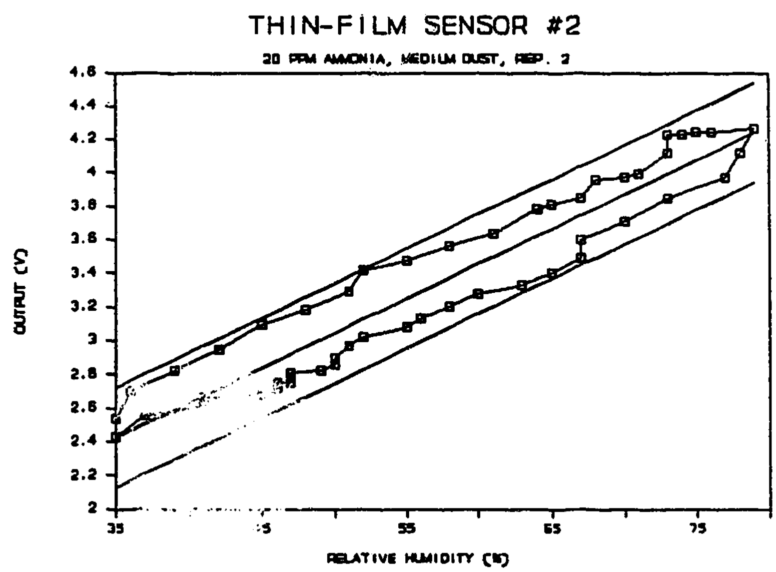

Figure 6.2 Calibration curve, least squares line and accuracy region for a typical run with TF#2.

The calibration curves used for determination of least squares straight line, errors for accuracy and hysteresis were established in the presence of the combinations of three ammonia concentrations (20, 30 and 40 ppm) and three dust levels (0.2, 10 and 85 particles/mL). There are a number of possible criteria for establishing the straight line from which accuracy rating is determined. These include terminal based, zero based and least squares criteria. The terminal based straight line is established in such a way that it will coincide with the calibration curve at upper and lower range-values (ISA, 1979). Zero based straight line can be defined as a straight line so positioned as to coincide with the calibration curve at the lower range-value and to minimize maximum deviation (ISA, 1979). The least squares straight lines were established using linear regression for the data points obtained during calibration cycles with input values as independent and sensor outputs in volts as dependent variables (ISA, 1979; Taylor, 1988).

The least squares straight line was selected for this project due to the fact that it makes use of all the data taken during a calibration cycle and reflects the average behaviour of the sensors.

All the linear regression equations gave coefficients of regression around 0.9. Equations for least squares straight lines are given together with the the regression parameters for all dust and ammonia combinations in Appendix B.7.

Error at each input was defined as the algebraic difference between the observed output and the output calculated with equation 6.1 (Taylor, 1988). Error can be expressed mathematically as follows:

$$E=O-O_c=O-(mX+b) \qquad (6.2)$$

where: O=observed sensor output in volts.

Figures 6.1, 6.2 and 6.3 show results from typical tests with data points, least squares regression lines and lines

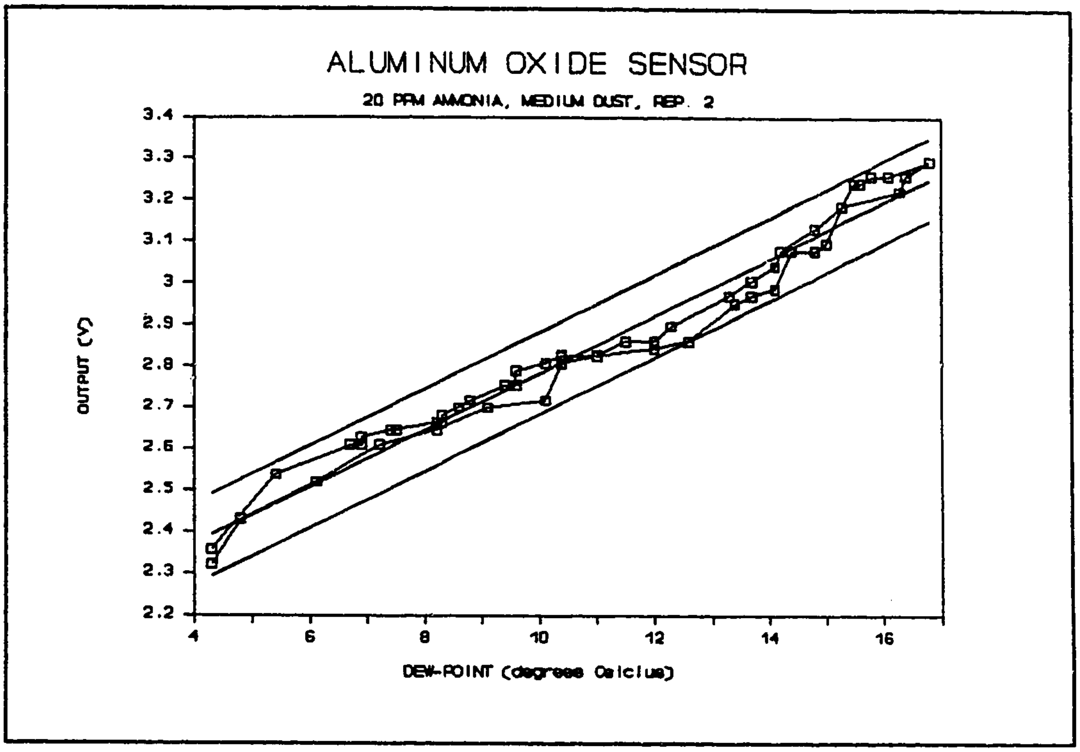

Figure 6.3 Calibration curve, least squares line and accuracy region for a typical run for aluminum oxide sensor

encompassing the accuracy rating region. These were obtained by drawing lines of identical slope to the least squares line through maximum error points. For comparison of sensors, average accuracies were calculated together with 95% confidence intervals from the pooled data of all runs.

6.3 Hysteresis

The hysteresis values for inputs at 50, 60 and 70 %RH were arbitrarily selected for sensor performance evaluation and calculated as follows:

$$H = O_u - O_d \qquad (6.3)$$

where: H=hysteresis,

O_u or O_d=observed sensor output on the upscale or downscale calibration curve, respectively at specified %RH levels (50, 60 and 70).

O_u and O_d were calculated, using linear interpolation from readings immediately before and after the specified RH.

6.4 Results

Table 6.1 shows the average accuracy and hysteresis values derived from all tests. Each average is based on eighteen tests and these are discussed in detail below.

Table 6.1 AVERAGE CALCULATED ACCURACY AND HYSTERESIS VALUES IN %RH FOR THE SENSORS TESTED

sensor	average accuracy	average hysteresis		
		50%	60%	70%
TF#1	6.28	5.94	6.72	5.94
TF#2	7.11	6.83	6.89	6.89
AL	6.83	4.44	4.72	4.00

6.4.1 Accuracy Ratings and Hysteresis Values for Thin-film Sensors

Tables 6.4 to 6.6 give the results of the static tests obtained for the two thin film sensors. The rated accuracy claimed by the manufacturer for these sensors was 2% RH from 0 to 100% at 20°C.

The average calculated accuracy was 6.28~1.12 and 7.11~1.10 %RH for TF#1 and TF#2, respectively. The difference between the two may be due to the fact that TF#2 was designed for laboratory use only, which implies cleaner atmospheres. The highest and lowest accuracy ratings obtained ranged from 2 to 12 %RH for TF#1 and 2 to 11 %RH for TF#2.

Average calculated hysteresis values for TF#1 at 50, 60 and 70% RH were 5.94±1.37, 6.72±1.70 and 5.94±1.44%RH, respectively; whereas the average hysteresis value for TF#2 were 6.83±1.52, 6.89±1.88 and 6.89±1.85 at 50, 60 and 70%RH, respectively. Again the hysteresis values showed a wide variation for both sensors from 0 (less than 0.5%RH) to 12 for TF#1 and 0 to 13 for TF#2.

As can be seen from the summary of ANOVA tables (Tables 6.2 and 6.3), the effects of ammonia, dust and their interaction on the behaviour of thin-film sensors (both accuracy and hysteresis) are not significant. The ANOVA tables for static characteristics of sensors tested were obtained in APL on the mainframe and are given in Appendix B.4 and Appendix B.5.

6.4.2 Accuracy Ratings and Hysteresis Values for Aluminum Oxide Sensor

The accuracy rating and hysteresis values for the aluminum oxide sensor are presented in Tables 6.4 and 6.7.

The average accuracy rating was 6.83±1.42. The summary of results of the ANOVA tables given in Table 6.2 indicate that the effects of dust, ammonia and ammonia-dust interaction on the accuracy rating of the aluminum oxide sensor are significant at 0.05 level.

A multiple regression analysis with ammonia , dust and their interaction together with the squares of ammonia and dust concentrations as independent variables and accuracy rating

Table 6.2 SUMMARY OF THE ANOVA TABLES FOR ACCURACY FOR THE SENSORS TESTED

sensor	source of variation	df	F'	F
TF#1	ammonia	2	0.79	4.26
	dust	2	0.09	4.26
	ammonia × dust	4	2.34	3.63
	error	9		
TF#2	ammonia	2	0.75	4.26
	dust	2	0.20	4.26
	ammonia × dust	4	2.22	3.63
	error	9		
TF#1	ammonia	2	11.15 *	4.26
	dust	2	9.82 *	4.26
	ammonia × dust	4	5.95 *	3.63
	error	9		

F'=calculated F value, F=tabulated F value at 5% level of significance
*=significant at 5% level

as dependent variable were carried out in order to predict the behaviour of the aluminum oxide sensor in the presence of ammonia and dust (Appendix B.6). The following regression equation was obtained with variables having significant t_s values:

$$Y_a=1.01395+0.15833C_1+0.34776C_2-0.00408C_2^2 \qquad (6.3)$$

where: Y_a=accuracy, %RH.

C_1=ammonia concentration ppm and

C_2=dust concentration particles per mL.

The above equation was obtained with an R value of 0.7 which is reported to be significant (at 0.05 level) by Steel and Torie (1982) with 14 degrees of freedom and three independent variables.

The above equation also indicates that the aluminum oxide sensor does not have zero accuracy (or inaccuracy in the literary sense) in clean atmospheres. This is in accordance with the behaviour of sensors in general.

The effects of dust, ammonia and their interaction on hysteresis were not significant at 0.05 level according to the Table 6.3. The average hysteresis values at 50, 60% and 70% RH were 4.44±1.39, 4.72±1.81 and 4.00±1.83. However, at 50% RH the effect of dust and at 70% RH the effect of ammonia were significant at 10% level of significance (Table 6.3). The following relations between the pollutants and the hysteresis values were established with the help of multiple regression analysis:

$$Y_h=5.76069-0.07950C_1-0.11238C_2+0.00487C_1C_2 \quad (50\%RH) \qquad (6.4)$$

$$Y_h=0.275C_1-4.2500 \quad (70\%RH) \qquad (6.5)$$

where: Y_h=hysteresis in %RH

The calculated R values (Appendix B.6) for both cases were greater than the tabulated significant R values (Steel and Torie, 1982).

Table 6.3 SUMMARY OF THE ANOVA TABLES FOR HYSTERESIS FOR THE SENSORS TESTED

sensor	%RH	source of variation	df	F'	F
TF#1	50	ammonia	2	1.79	3.01
		dust	2	1.46	3.01
		ammonia × dust	4	2.50	2.69
		error	9		
	60	ammonia	2	1.63	3.01
		dust	2	0.75	3.01
		ammonia × dust	4	1.58	2.69
		error	9		
	70	ammonia	2	0.14	3.01
		dust	2	0.37	3.01
		ammonia × dust	4	0.49	2.69
		error	9		
TF#2	50	ammonia	2	2.89	3.01
		dust	2	0.72	3.01
		ammonia × dust	4	2.26	2.69
		error	9		
	60	ammonia	2	1.20	3.01
		dust	2	1.15	3.01
		ammonia × dust	4	1.14	2.69
		error	9		
	70	ammonia	2	0.49	3.01
		dust	2	0.22	3.01
		ammonia × dust	4	0.81	2.69
		error	9		
AL	50	ammonia	2	0.83	3.01
		dust	2	3.42*	3.01
		ammonia × dust	4	2.40	2.69
		error	9		
	60	ammonia	2	0.75	3.01
		dust	2	0.20	3.01
		ammonia × dust	4	2.22	2.69
		error	9		
	70	ammonia	2	3.95*	3.01
		dust	2	0.74	3.01
		ammonia × dust	4	0.29	2.69
		error	9		

F'=calculated F value, F=tabulated F value at 10% level of significance
*=significant at 10% level

Table 6.4 ACCURACY RATINGS IN %RH FOR SENSORS TESTED

sensor	replicate	ammonia ppm	dust levels low	medium	high
aluminum oxide sensor	1	20	5	8	5
		30	5	5	6
		40	7	12	8
	2	20	6	6	5
		30	6	6	6
		40	6	16	5
thin film sensor #1	1	20	6	6	10
		30	5	7	7
		40	12	7	2
	2	20	5	7	8
		30	5	5	4
		40	5	7	5
thin-film sensor #2	1	20	8	8	11
		30	5	8	8
		40	11	8	2
	2	20	4	7	9
		30	6	7	5
		40	7	7	7

Table 6.5 HYSTERESIS VALUES FOR TF#1 (%RH)

%RH	replicate	ammonia ppm	dust levels low	medium	high
		20	7	4	12
	1	30	7	3	5
		40	12	5	2
50%					
		20	6	7	8
	2	30	5	7	3
		40	6	4	4
		20	8	8	11
	1	30	8	6	11
		40	4	11	1
60%					
		20	0	8	11
	2	30	6	7	8
		40	7	2	4
		20	7	7	6
	1	30	8	9	7
		40	5	9	0
70%					
		20	0	6	11
	2	30	5	5	4
		40	5	4	9

Table 6.6 HYSTERESIS VALUES FOR TF#2 (%RH)

%RH	replicate	ammonia ppm	dust levels low	medium	high
50%	1	20	8	6	13
		30	9	4	6
		40	12	5	2
	2	20	5	9	12
		30	6	6	5
		40	4	5	6
60%	1	20	8	8	12
		30	7	8	12
		40	5	12	0
	2	20	0	8	11
		30	5	6	9
		40	6	1	6
70%	1	20	9	10	6
		30	9	9	7
		40	5	8	1
	2	20	0	7	14
		30	7	9	4
		40	10	0	9

Table 6.7 HYSTERESIS VALUES FOR ALUMINUM OXIDE (%RH)

%RH	replicate	ammonia ppm	dust levels low	medium	high
50%	1	20	3	5	3
		30	2	8	6
		40	0	5	12
	2	20	5	2	3
		30	5	2	6
		40	2	4	7
60%	1	20	1	3	1
		30	5	2	2
		40	9	2	12
	2	20	10	3	3
		30	4	3	3
		40	3	12	7
70%	1	20	1	3	0
		30	1	2	1
		40	5	3	9
	2	20	2	3	0
		30	5	6	6
		40	4	15	6

7. STEP RESPONSE

Step response tests determined the behaviour of the sensor outputs to abrupt or step changes in the humidity levels of the air. The operating conditions and the experimental design were the same as those for accuracy and hysteresis.

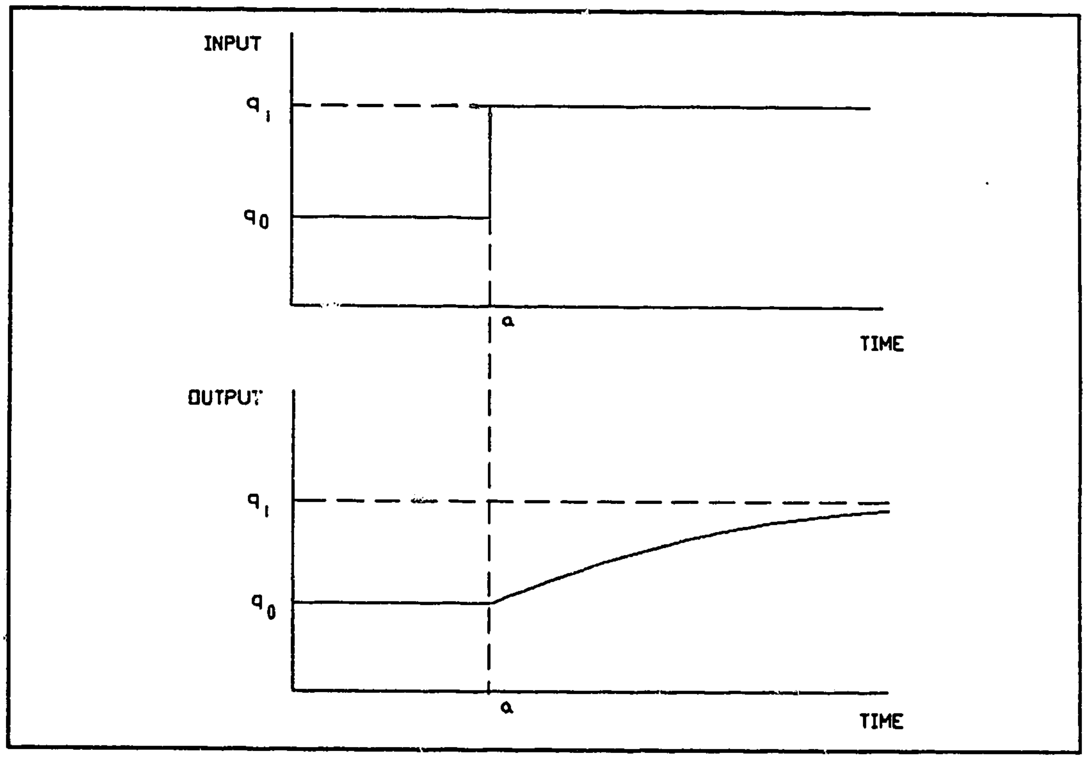

Figure 7.1 Step function (above) and the response of the sensor (below)

Mathematically, a step function can be expressed as follows (Figure 7.1):

$$\text{input}=q_0 \quad \text{if} \quad \text{time}<a$$

$$\text{input}=q_1 \quad \text{if} \quad \text{time}>a$$

It is common practice to equate the initial value of input

(q_0) to zero (Graham, 1975) for convenience. Then, the new output (recovered output) O_r can be expressed as follows:

$$O_r = q - q_0 \qquad (7.1)$$

where: q=output of sensor after time a.

The step input shown in Figure 7.1 increased the sensor outputs (positive step input). If q_1 is smaller than q_0 sensor outputs decrease after a step input (negative step input). Positive and negative step inputs were considered as replicates. However they were examined statistically for any significant difference (at 0.05% level).

The apparatus for generating step inputs was described in Chapter 4.

7.1 Test procedure

A single test consisted of the following steps:

1. Generation of desired pollutant levels in the environment chamber
2. Recirculation of polluted air through the second chamber for five minutes with the help of the pump
3. Sealing the second chamber by closing the valve on the line connecting two chambers
4. Creating a relative humidity increment inside the environment chamber
5. Opening the valve on the connecting line and starting the pump for approximately three seconds
6. Termination of the test after 95% of the step input was recovered.

In order to prevent turbulent air flows inside the small chamber, the pump was stopped after approximately three seconds for each test. If the pump was kept running, the total pressure and hence vapour pressure would be different at each point inside the small chamber due to turbulence.

Data recording (at approximately 1 second intervals) was started immediately before step 5 and the time was noted after the pump was stopped in order to mark the point after which the air inside the small container was not moving.

7.2 Data Handling

The data were recorded on magnetic disks and were arranged using a data handling package (Lotus 123, Lotus Development Corporation MA) before transferring to the mainframe for statistical analysis.

during the first few seconds the sensors were :o turbulent flows due to the introduction of air :elative humidity levels, the output values in this ict included in the analysis.

viour of the sensor outputs, when subjected to inputs were characterized by nondimensionalized step-function response curves (Doeblin, 1983) that were developed in two steps:

1. Regressing of recovered output values against time
2. Determination of the equation best fitting the data and nondimensionalizing this equation.

The recovered output values as a function of time are given in Appendix C.2. A plot of the recovered output values versus time for one of the thin film sensor at 20 ppm ammonia and medium dust is shown in Figure 4.10. Similar curves could be drawn for the other sensors tested.

Table 7.1 REGRESSION EQUATIONS FOR TF#1 AT 20 PPM AMMONIA AND MEDIUM DUST

	A	B	R^2
(1) Y=AX	.0137767975	.0000000000	.267
(2) Y=A+BX	.1223577207	.0078250352	.928
(3) Y=A EXP(BX)	.1361653970	.0346445342	.834
(4) Y=1/(A+BX)	7.1086313197	-.1058830123	.696
(5) Y=A+B/X	.3363068226	-.9799478916	.879
(6) Y=A+B LOG(X)	-.0368099866	.1087356444	.984
(7) Y=AX*B	.0631836086	.5050959686	.973
(8) Y=X/(A+BX)	25.4758345895	2.1736879126	.991
(9) Y=A+BX+CX*2	.0694861195	.0157515135	.980
	-.0002315895	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.0465404247	.0216305696	.982
	-.0006248739	.0000075314	

7.3 Results

Ten regression equations in different forms with varying coefficients of regression were obtained to describe the sensor response for each of the nine combinations of dust and ammonia and for positive and negative step inputs. Table 7.1 shows one such set of regression equations for one pollutant combination and one type of sensor. A complete listing of all regression equations are given in Appendix C.3.

The coefficient of regression was not the only criterion behaviour. However the regression equations having an average coefficient of regression less than 0.9 were not taken into consideration.

Equation types #9 and #10 in Table 7.1 had very high R^2's, but it was difficult attributing any physical significance to those equations and they failed to define the sensor outputs at high t' (time) values. Equations #5 and #8 had R^2 values higher than 0.9. But equation #8 had parameters which changed signs on one occasion. Parameters for equations #5 exhibited the same signs and were the simplest.

The following form of the regression equation with an average R^2 of 0.911 and consistent equation parameter signs for all the pollutant combinations and their replicates for three sensors was selected:

$$Y=A-B/t' \qquad (7.2)$$

where: Y=output recovered in V,

t'=time since the beginning of step input in seconds, and

A, B= regression constants (positive in sign).

In equation 7.1 "A" represented the final value of the sensor output when t' goes to large values. The comparison of the regression equations and the data for sensor outputs (Table 7.1, Appendix C.2 and C.3) showed that this was true. B/t' is the resistance preventing the sensor from responding to changes instantaneously; it is very high at the beginning and becomes smaller in time.

The above equation was established for the values of t' after the air flow into the sensor chamber was stopped. They all give values of B/t' less than A, thus making Y positive all the time.

Equation 7.1 can be nondimensionalized as:

$$Y'=1-T'/t' \quad (7.3)$$

where: T'=B/A.

T' has the dimensions of time and values for T' are tabulated in Table 7.2 together with relevant pollutant values.

7.4 Discussion

The response constants (T') were taken as dependent variables for the statistical analysis of the sensor responses. The F values derived from ANOVA tables in Table 7.3 show that none of the T' values for any of the sensors were affected significantly (at 5% significance level) by the pollutant levels (Appendix C.1 gives the mainframe APL outputs for ANOVA).

Since the T' values were not affected by the pollutants, all T' values for a sensor can be considered to be from the same population statistically. Therefore, values for each sensor can be averaged and used for prediction purposes. Table 7.4 the shows the response of nondimensionilized equations describing each sensor and can be used in approximating the response of each sensor to ramp inputs.

This table shows that the Aluminum oxide sensor displayed a slower response than the thin film sensor which had very similar dynamic response characteristics.

Table 7.2 T' VALUES FOR VARIOUS POLLUTANT LEVELS, THEIR REPLICATES AND SENSORS

sensor	replicate	ammonia ppm	dust levels low	dust levels medium	dust levels high
aluminum oxide sensor	1	20	4.3	4.4	3.6
		30	4.6	3.6	3.0
		40	3.0	3.5	4.7
	2	20	4.4	2.4	2.5
		30	4.5	3.0	2.9
		40	3.4	3.2	2.8
thin-film sensor #1	1	20	3.0	3.1	2.5
		30	2.3	3.6	3.3
		40	2.4	3.2	3.1
	2	20	2.8	2.6	2.5
		30	2.3	2.8	1.9
		40	3.0	3.4	2.1
thin-film sensor #2	1	20	3.6	2.2	2.4
		30	1.8	3.1	2.3
		40	3.7	2.2	1.8
	2	20	3.4	3.4	2.0
		30	2.9	2.8	2.7
		40	3.0	4.4	1.7

Table 7.3 SUMMARY OF THE ANOVA TABLES FOR STEP INPUTS FOR THE SENSORS TESTED

sensor	source of variation	df	F'	F
TF#1	replicate	1	3.59	7.71
	ammonia	2	0.29	6.94
	dust	2	3.63	6.94
	replicate × dust	2	2.19	6.94
	ammonia × dust	4	0.88	6.39
	replicate × ammonia	2	1.21	6.94
	error	9		
TF#2	replicate	1	0.61	7.71
	ammonia	2	0.10	6.94
	dust	2	0.69	6.94
	replicate × dust	2	0.83	6.94
	ammonia × dust	4	0.66	6.39
	replicate × ammonia	2	0.03	6.94
	error	9		
AL	replicate	1	3.04	7.71
	ammonia	2	0.32	6.94
	dust	2	2.11	6.94
	replicate × dust	2	0.21	6.94
	ammonia × dust	4	1.49	6.39
	replicate × ammonia	2	1.22	6.94
	error	9		

F'=lated F value, F=tabulated F value at 5% level of significance

Table 7.4 NONDIMENSIONALIZED RESPONSE EQUATIONS FOR EACH SENSOR

sensor	response curve (nondim.)
ALUMINUM OXIDE SENSOR	Y'=1-3.6/t'
THIN FILM SENSOR #1	Y'=1-2.8/t'
THIN FILM SENSOR #2	Y'=1-2.7/t'

8. CONCLUSIONS

The following conclusions can be drawn from this work:

1. According to the literature survey thin-film polymer sensors and aluminum oxide sensors offered the greater promise for use in animal environments.

2. The effects of dust, ammonia and their interaction on the performance of the thin-film sensors were statistically insignificant. Their accuracy ratings were considerably wider than the manufacturer's specification with average accuracy values of 6 and 7 %RH as opposed to 2 %RH claimed.

3. Hysteresis values for thin-film sensors ranged from 0 to 13% RH which were also higher than the manufacturer's specifications.

4. The effects of dust, ammonia and their interaction on the performance of the aluminum oxide sensor were statistically significant. The aluminum oxide sensor also exhibited wide accuracy rating and high hysteresis. However, its behaviour could be predicted within statistically acceptable limits if dust and ammonia concentrations were known.

5. Step response characteristics of neither thin film sensors nor aluminum oxide sensor were affected by varying ammonia and dust levels. However thin-film sensors showed faster response.

6. The aluminum oxide sensor is recommended for use in animal environments only if ammonia and dust levels are also being measured. In this case, output from the aluminum oxide sensor

can be be adjusted to give better estimates of relative humidity than those from thin-film sensors.

7. When dust and ammonia data are not available, thin-film sensors are recommended. Their average accuracy rating of 6%RH is considered adequate for most applications in animal environment control.

9. RECOMMENDATIONS

The data obtained in this work were limited by the error originating from RH determinations derived from dew point temperature and temperature measurements. The uncertainty related to RH measurements was around 3 and 6%RH for measurements at 35 and 80% RH respectively (Appendix D). The uncertainity band shows maximum possible deviations, but is still an indication of the range of errors related to the system. A system which works on the principle of gravimetric hygrometry would give a narrower uncertainity band (Cole and Reger, 1970). The high cost of these systems and limited time prevented such an approach, but this should be considered in future work.

Considerable variations of the dust concentrations could be eliminated with a more sophisticated aerosol generator.

Additionally, only short term influences of dust and ammonia on static and dynamic properties of sensors were examined in this study. For future studies the following are recommended:

-Determination of the effects of repeated humidity cycles on the sensors by increasing the number of cycles progressively.

-Determination of the long term affects of ammonia and dust on the static and dynamic behaviour of sensors for progressively increasing peroids of time. Such tests should be carried at both in the laboratory and in actual animal barns.

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APPENDIX A.1: DUST CONCENTRATIONS IN THE ENVIRONMENTAL CHAMBER FOR VARIOUS LEVELS OF DUST

time	dust levels (particles/mL)		
(min.)	Low	medium	high
5	0.02	11.31	44.33
10	0.04	11.92	62.75
15	0.06	11.34	82.17
20	0.07	8.9	90.42
25	0.09	7.78	99.67
30	0.11	6.71	108.08
35	0.13	7.61	105.91
40	0.15	8.8	101.33
45	0.17	8.95	98.83
50	0.19	8.29	96.67
55	0.2	8.03	92.57
60	0.22	7.31	79.21
65	0.24	7.05	81.25
70	0.26	6.81	74.81
75	0.28	11.64	75.84
80	0.3	10.12	61.89
85	0.31	14.77	86.71
90	0.33	13.54	102.52
95	0.35	13.35	104.12
100	0.37	12.59	95.46
105	0.39	10.7	93.17
110	0.41	9.91	91.38
115	0.43	9.37	88.21
120	0.44	12.75	71.2

APPENDIX A.2: MEASURED AND CALCULATED RH VALUES UPSCALE CALIBRATION CYCLE FOR 20 PPM AMMONIA, MEDIUM DUST AND REPLICATE 2, (1): MEASURED RH, (2): CALCULATED RH, (3): DIFFERENCE BETWEEN CALCULATED AND MEASURED RH

TIME (min.)	%RH (1)	%RH (2)	%RH (3)
0	35	35	0
0.48	36	38.4	-2.4
0.96	39	41.6	-2.6
1.45	42	44.6	-2.6
1.94	45	47.4	-2.4
2.42	48	49.8	-1.8
2.9	51	52.1	-1.1
3.38	52	54.1	-2.1
3.86	52	56	-4
4.34	55	57.8	-2.8
4.81	58	59.4	-1.4
5.29	61	60.9	0.1
5.79	60	62.3	-2.3
6.31	64	63.6	0.4
6.81	65	64.8	0.2
7.28	67	65.8	1.2
7.75	67	66.8	0.2
8.23	67	67.7	-0.7
8.71	68	68.5	-0.5
9.19	68	69.3	-1.3
9.67	68	70	-2
10.17	70	70.6	-0.6
10.64	71	71.2	-0.2
11.17	69	71.8	-2.8
11.65	72	72.3	-0.3
12.13	72	72.7	-0.7
12.61	70	73.1	-3.1
13.09	70	73.5	-3.5
13.57	70	73.9	-3.9
14.04	70	74.2	-4.2
14.54	71	74.5	-3.5
15.02	73	74.8	-1.8
15.5	73	75	-2
15.99	75	75.3	-0.3
16.48	73	75.5	-2.5
16.96	75	75.7	-0.7
17.44	76	75.9	0.1
17.92	75	76	-1
18.39	73	76.2	-3.2
18.89	76	76.3	-0.3
19.37	73	76.4	-3.4
19.85	74	76.6	-2.6
20.33	74	76.7	-2.7

20.84	73	76.8	-3.8
21.33	73	76.9	-3.9
21.81	74	77	-3
22.29	76	77	-1
22.77	78	77.1	0.9
23.28	74	77.2	-3.2
23.74	75	77.2	-2.2
24.22	76	77.3	-1.3
24.7	76	77.3	-1.3
25.18	76	77.4	-1.4
25.67	76	77.4	-1.4
26.16	74	77.5	-3.5
26.64	76	77.5	-1.5
27.12	77	77.5	-0.5
27.62	74	77.6	-3.6
28.09	75	77.6	-2.6
28.57	76	77.6	-1.6
29.05	76	77.7	-1.7
29.53	76	77.7	-1.7
30.01	76	77.7	-1.7
30.53	76	77.7	-1.7
31.02	75	77.7	-2.7
31.52	79	77.7	1.3
31.99	79	77.8	1.2
32.47	76	77.8	-1.8
32.95	76	77.8	-1.8
33.43	75	77.8	-2.8
33.91	76	77.8	-1.8
34.39	76	77.8	-1.8
34.86	78	77.8	0.2
35.36	76	77.8	-1.8
35.85	78	77.8	0.2
36.33	78	77.9	0.1
36.81	79	77.9	1.1
37.28	79	77.9	1.1
37.76	79	77.9	1.1
38.24	79	77.9	1.1
38.72	79	77.9	1.1
39.2	77	77.9	-0.9
39.68	77	77.9	-0.9
40.21	79	77.9	1.1
40.69	80	77.9	2.1
41.17	80	77.9	2.1
41.64	80	77.9	2.1

APPENDIX A.3: DEW POINT TEMPERATURES INDICATED BY AN NBS TRACEABLE DEW POINT HYGROMETER AND THE HYGROMETER USED FOR CALIBRATION CYCLES (FOR THE SAME INPUTS)

NBS traceable hygrometer	hygrometer used for tests
°C	°C
0.1	0.0
3.4	3.4
5.3	5.2
7.0	7.1
8.2	8.1
8.8	8.9
11.0	11.2
12.0	12.2
13.0	13.2
15.1	15.2
16.8	16.9
13.1	13.0
11.3	11.4
7.1	7.0
3.6	3.8
1.6	1.7
0.3	0.3

APPENDIX A.4: PLATINUM RTD OUTPUTS AND TEMPERATURE READINGS

Pt RTD outputs V	thermometer readings C
3.654	20.3
3.654	20.2
3.636	20.2
3.654	20.4
3.654	20.4
3.672	20.4
3.708	20.7
3.6	19.8
3.6	19.9
3.636	20.3
3.6	19.9
3.6	19.8
3.636	20.2
3.672	20.5
3.744	21
3.6	20.2
3.51	19.8
3.564	19.6
3.42	19.1
3.42	19.2
3.78	21
3.726	20.5
3.69	20.5
3.744	21
3.726	20.7
3.636	20.2
3.582	20
3.546	19.6
3.51	19.5
3.582	20.2

Regression Output:

Constant	0.672386
Std Err of Y Est	0.143441
R Squared	0.916783
No. of Observations	30
Degrees of Freedom	28
X Coefficient(s)	5.378355
Std Err of Coef.	0.306226

APPENDIX A.5: DEW POINT HYGROMETER OUTPUTS CORRESPONDING TO READINGS INDICATED BY THE DEW POINT HYGROMETER FOR PREDICTING DEW POINT TEMPERATURES AND THE REGRESSION OUTPUT

hygrometer output V	dew point temp. C
2.682	3.7
2.718	4.1
2.754	3.9
2.754	4.2
2.79	4.4
2.862	5.1
2.88	6.1
2.952	6.2
3.024	6.7
3.042	7
3.114	7.8
3.132	7.9
3.15	8
3.258	8.7
3.258	8.9
3.348	9.3
3.366	9.5
3.384	9.9
3.42	10.3
3.438	10.9
3.51	10.9
3.528	11.3
3.654	11.7
3.78	12.9
3.924	14.7
3.942	14.8
4.014	15.5
4.086	16.2
4.104	16.2
4.14	17.1

Regression Output:

Constant	-20.0460
Std Err of Y Est	0.284728
R Squared	0.995230
No. of Observations	30
Degrees of Freedom	28
X Coefficient(s)	8.852115
Std Err of Coef.	0.115814

APPENDIX B.1: SAMPLE CALCULAT IONS FOR ERROR DETERMINATIONS FOR ACCURACY RATING

The steps involved in the calculation of the error for a single point are as follows:

Input (RH determined by the dew point hygrometer)=35 % RH,

Least squares line: O=0.040471RH+1.151839,

Observed sensor output at 35 % RH=2.682 V,

The calculated RH based on the observed sensor output:

$RH_{calculated}=(O_{observed}-b)/m=(2.682-1.151839)/0.040471=38\%RH$,

Error=35-38=3%RH.

The steps for calculating the error for the dew point temperature measuring sensor (aluminum oxide sensor) can be outlined in a similar manner:

Input: $t_{dp}=4.3°C$, t=20.4°C (35 % RH).

If the least squares line is $O=0.068615t_{dp}+2.097051$ V,

Observed sensor output at 35 % RH=2.338 V,

$tdp_{calculated}=(O_{observed}-b/)/m=(2.338-2.097051)/0.068615=3.5116°C$The dew point determined above was calculated to be 32.7151 % RH according to the Antoine equation at t=20.4°C, this is rounded to 33 % RH,

Error=35-33=2%RH.

APPENDIX B.2: SAMPLE CALCULATIONS FOR HYSTERESIS DETERMINATIONS

The following information represents typical values given in calibration tables:

Upscale		Downscale	
input (%RH)	output V	input (%RH)	output V
48	3.294	49	2.988
51	3.384	51	3.132

According to equation 6.5 Ou and Od are calculated below:

$O_{u \text{ at input } 50\ \%\ RH}$:

(3.294-3.384)/(51-48)*(50-48)+3.294=3.354 V

$O_{d \text{ at input } 50\ \%RH}$:

(3.132-2.988)/(51-49)*(50-49)+2.988=3.060 V

In order to have a common comparison base these outputs can be converted to RH using the least squares line established for this sensor:

If the least squares line was given as O=0.040471RH+1.151839 V earlier, therefore RH_u=54.413 % RH and RH_d=47.149 % RH, therefore hysteresis=54-47=7%RH.

If the following data were to be used for hysteresis determinations for aluminum oxide sensor:

Upscale			Downscale		
Input		Output	Input		Output
%RH	t_{dp}°C	volts	%RH	t_{dp}°C	volts
48	9.1	2.7	49	9.4	2.751
51	10.1	2.718	51	10.1	2.808

50 % RH at 20.4 C corresponds to 9.653 °C;

O_u at input t_{dp}=9.653°C:

(2.718-2.7-)/(10.1-9.1)*(9.653-9.1)+2.700= 2.709 V

Least Squares line: $O=0.06815t_{dp}+2.097051$

$t_{dp(output)}$=(2.709-2.09751)/0.06815=8.993°C, the Antoine equation gives the above dew point temperature at 20.4°C as 47.812 % RH which is rounded to 48 % RH.

$O_{d\ at\ input\ tdp}$=9.653°C:

(2.808-2.751)/(10.1-9.4)*(9.653-9.4)+2.751=2.772 V

$t_{dp(output)}$=(2.772-2.09751)/0.06815=9.890°C, the Antoine equation gives the above dew point temperature as 50.830 % RH which is rounded to 51 % RH, therefore, hysteresis=51-48=3%RH

# APPENDIX B.3: ANALYSIS OF VARIANCE TABLES FOR ACCURACY RATINGS
A=REPLICATE, B=AMMONIA, C=DUST

THIN FILM SENSOR#1:
APL OUTPUT:

'Y=M+B+C+BC+ϵ' AOV5 F1

B	2	6.77778	3.38889
C	2	0.77778	0.38889
BC	4	39.55556	9.88889
ERROR	9	38.5	4.27778
TOTAL	17	85.61111	

THIN FILM SENSOR#2:
APL OUTPUT:

'Y=M+B+C+BC+ϵ' AOV5 F2

B	2	5.44444	2.72222
C	2	1.44444	0.72222
BC	4	39.88889	9.97222
ERROR	9	37	4.11111
TOTAL	17	83.77778	

ALUMINUM OXIDE SENSOR:
APL OUTPUT:

'Y=M+B+C+BC+ϵ' AOV5 A

B	2	42.33333	21.16667
C	2	36	18
BC	4	43.66667	10.91667
ERROR	9	16.5	1.83333
TOTAL	17	138.5	

APPENDIX B.4: ANALYSIS OF VARIANCE TABLES FOR HYSTERESIS THIN FILM SENSOR#1:

APL OUTPUT:

50%

'Y=M+B+C+BC+ϵ' AOV5 A5

B	2	8.11111	4.05556
C	2	33.44444	16.72222
BC	4	46.88889	11.72222
ERROR	9	44	4.88889
TOTAL	17	132.44444	

60%

'Y=M+B+C+BC+ϵ' AOV5 A6

B	2	69.77778	34.88889
C	2	4.11111	2.05556
BC	4	27.22222	6.80556
ERROR	9	124.5	13.83333
TOTAL	17	225.61111	

70%

'Y=M+B+C+BC+ϵ' AOV5 A7

B	2	93	46.5
C	2	17.33333	8.66667
BC	4	13.66667	3.41667
ERROR	9	106	11.77778
TOTAL	17	230	

THIN FILM SENSOR#2:
APL OUTPUT:

```
50%
                 'Y=M+B+C+BC+ε' AOV5 T15
         B           2      18.11111      9.05556
         C           2      14.77778      7.38889
         BC          4      50.55556      12.63889
         ERROR       9      45.5      5.05556
         TOTAL       17      128.94444
60%              'Y=M+B+C+BC+ε' AOV5 T16
         B           2      32.11111      16.05556
         C           2      14.77778      7.38889
         BC          4      62.22222      15.55556
         ERROR       9      88.5      9.83333
         TOTAL       17      197.61111
                 'Y=M+B+C+BC+ε' AOV5 T17
70%      B           2      3.44444      1.72222
         C           2      8.77778      4.38889
         BC          4      23.22222      5.80556
         ERROR       9      107.5      11.94444
         TOTAL       17      142.94444
```

ALUMINUM OXIDE SENSOR:
APL OUTPUT:

```
50%            'Y=M+B+C+BC+ϵ' AOV5 T25
       B           2     36.33333     18.16667
       C           2     9    4.5
       BC          4     56.66667     14.16667
       ERROR       9     56.5     6.27778
       TOTAL       17     158.5
               'Y=M+B+C+BC+ϵ' AOV5 T26
60%    B           2     32.11111     16.05556
       C           2     30.77778     15.38889
       BC          4     50.88889     15.22222
       ERROR       9     120     13.33333
       TOTAL       17     243.77778
               'Y=M+B+C+BC+ϵ' AOV5 T27
       B           2     17.44444     8.72222
70%    C           2     0.77778     0.38889
       BC          4     57.55556     14.38889
       ERROR       9     160     17.77778
       TOTAL       17     235.77778
```

APPENDIX B.5: MULTIPLE REGRESSION OUTPUTS

Columns represent accuracy (%RH) ammonia concentration (ppm), dust (particles particle/mL), multiplication of dust and ammonia concentrations, square of ammonia concentration, square of dust concentration

ACCURACY, ALUMINUM OXIDE SENSOR:
APL OUTPUTS:

AA

5	20	0.2	4	400	0.04
8	20	10	200	400	100
5	20	85	1700	400	7225
5	30	0.2	6	900	0.04
5	30	10	300	900	100
6	30	85	2550	900	7225
7	40	0.2	8	1600	0.04
12	40	10	400	1600	100
8	40	85	3400	1600	7225
6	20	0.2	4	400	0.04
6	20	10	200	400	100
5	20	85	1700	400	7225
6	30	0.2	6	900	0.04
6	30	10	300	900	100
6	30	85	2550	900	7225
6	40	0.2	8	1600	0.04
16	40	10	400	1600	100
5	40	85	3400	1600	7225

(2 3 6 1) *REG AA*

REGRESSION COEFFICIENTS

	COEFF.	*S.E.*	*T*
0	1.01395	2.18674	.46
2	.15833	.06565	2.41
3	.34776	.15117	2.30
6	¯.00408	.00169	¯2.41

ANALYSIS OF VARIANCE

	D.F.	*S.S.*	*M.S.*	*F*
REGRESSION	3	66.08333	22.02778	4.26
ERROR	14	72.41667	5.17262	
TOTAL	17	138.50000		
S. E. OF ESTIMATE		2.27434		
R-SQUARED		.47714		

HYSTERESIS, ALUMINUM OXIDE SENSOR
APL OUTPUTS:

50% RH

A

3	20	0.2	4	400	1
5	20	10	200	400	1
3	20	85	1700	400	4
2	30	0.2	6	900	2
8	30	10	300	900	5
6	30	85	2550	900	5
0	40	0.2	8	1600	0.04
5	40	10	400	1600	100
12	40	85	3400	1600	7225
5	20	0.2	4	400	0.04
2	20	10	200	400	100
3	20	85	1700	400	7225
5	30	0.2	6	900	0.04
2	30	10	300	900	100
6	30	85	2550	900	7225
2	40	0.2	8	1600	0.04
4	40	10	400	1600	100
7	40	85	3400	1600	7225

(3 4 2 1) *REG A*

REGRESSION COEFFICIENTS

	COEFF.	*S.E.*	*T*
0	5.76069	2.33326	2.47
3	¯.11238	.04722	¯2.38
4	.00487	.00152	3.21
2	¯.07950	.07505	¯1.06

ANALYSIS OF VARIANCE

	D.F.	*S.S.*	*M.S.*	*F*
REGRESSION	3	76.85121	25.61707	6.45
ERROR	14	55.59323	3.97095	
TOTAL	17	132.44444		
S. E. OF ESTIMATE		1.99272		

R-SQUARED .58025

70% RH

A					
1	20	0.2	4	400	1
3	20	10	200	400	1
0	20	85	1700	400	4
1	30	0.2	6	900	2
2	30	10	300	900	5
1	30	85	2550	900	5
5	40	0.2	8	1600	0.04
3	40	10	400	1600	100
9	40	85	3400	1600	7225
2	20	0.2	4	400	0.04
3	20	10	200	400	100
0	20	85	1700	400	7225
5	30	0.2	6	900	0.04
6	30	10	300	900	100
6	30	85	2550	900	7225
4	40	0.2	8	1600	0.04
15	40	10	400	1600	100
6	40	85	3400	1600	7225

REGRESSION COEFFICIENTS

	COEFF.	S.E.	T
0	¯4.25000	2.64780	¯1.61
2	.27500	.08516	3.23

ANALYSIS OF VARIANCE

	D.F.	S.S.	M.S.	F
REGRESSION	1	90.75000	90.75000	10.43
ERROR	16	139.25000	8.70312	
TOTAL	17	230.00000		

APPENDIX B.6: CALIBRATION REPORTS
(1) INPUT, % RELATIVE HUMIDITY
(2) INPUT, Dew point TEMPERATURE C, DETERMINED BY Dew point HYGROMETER
(3) OUTPUT FROM THIN-FILM SENSOR # 1, VOLTS
(4) OUTPUT FROM THIN-FILM SENSOR #2, VOLTS
(5) OUTPUT FROM ALUMINUM OXIDE SENSOR, VOLTS
(6, 7, 8) ERROR IN % RH FOR EACH INPUT FOR THIN-FILM SENSOR #1, #2 AND ALUMINUM OXIDE SENSOR RESPECTIVELY

CALIBRATION TABLE FOR 20 PPM AMMONIA, LOW DUST AND REPLICATE#1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
34	4	20.3	2.538	2.358	2.232	0	1	2
36	4.8	20.3	2.718	2.61	2.286	-3	-4	2
40	6.2	20.3	2.826	2.736	2.394	-1	-3	2
43	7.5	20.3	2.988	2.862	2.484	-2	-3	2
47	8.5	20.3	3.114	3.024	2.556	-2	-2	3
48	9.1	20.3	3.258	3.15	2.61	-4	-5	2
51	9.9	20.3	3.366	3.258	2.682	-4	-4	1
53	10.4	20.3	3.42	3.348	2.718	-3	-4	2
56	11.2	20.3	3.528	3.42	2.754	-3	-3	3
56	11.3	20.3	3.618	3.474	2.79	-5	-4	1
59	12	20.3	3.672	3.546	2.808	-3	-3	3
61	12.6	20.3	3.816	3.69	2.844	-5	-4	3
62	12.9	20.3	3.87	3.762	2.862	-5	-5	3
68	14.1	20.3	4.014	3.942	2.988	-3	-4	2
68	14.2	20.3	4.05	3.96	3.006	-4	-4	1
69	14.4	20.3	4.104	3.978	3.006	-4	-3	2
69	14.5	20.3	4.14	4.014	3.042	-5	-4	0
72	15.2	20.3	4.194	4.086	3.078	-3	-3	1
73	15.3	20.3	4.248	4.14	3.114	-4	-3	-1
75	15.8	20.3	4.284	4.212	3.15	-2	-3	-1
78	16.3	20.3	4.302	4.23	3.186	0	0	-1
80	16.9	20.4	4.32	4.266	3.24	2	1	-2
81	17.1	20.4	4.32	4.284	3.258	3	1	-2
80	16.9	20.4	4.32	4.284	3.276	2	0	-5
77	16.1	20.3	4.284	4.176	3.24	0	0	-5
74	15.6	20.3	4.158	4.014	3.186	0	1	-5
74	15.5	20.3	3.996	3.888	3.114	4	4	0
71	14.8	20.3	3.906	3.78	3.078	3	3	0
69	14.4	20.3	3.78	3.6	3.006	4	6	2
68	14.1	20.3	3.654	3.474	2.988	6	8	2
65	13.6	20.3	3.564	3.402	2.934	5	6	2
62	12.8	20.3	3.438	3.33	2.862	5	5	3
59	12	20.3	3.384	3.258	2.844	4	4	1
56	11.2	20.3	3.33	3.222	2.826	2	2	-1
53	10.4	20.3	3.276	3.114	2.808	0	1	-3
52	10.2	20.3	3.15	3.006	2.754	3	3	-1
51	9.9	20.3	3.114	2.952	2.718	2	3	0
50	9.6	20.3	3.06	2.862	2.718	3	4	-1
49	9.3	20.3	3.006	2.844	2.7	3	4	-1
47	8.8	20.3	2.97	2.826	2.682	2	2	-3
46	8.2	20.3	2.862	2.772	2.646	4	3	-2
44	7.7	20.3	2.844	2.754	2.646	2	1	-4
43	7.5	20.3	2.826	2.736	2.61	2	0	-3
41	6.7	20.3	2.718	2.61	2.52	2	1	-2
41	6.6	20.3	2.718	2.574	2.502	2	2	-1
39	5.9	20.3	2.718	2.574	2.502	0	0	-3
38	5.4	20.3	2.682	2.538	2.466	0	0	-2
37	5.3	20.3	2.682	2.538	2.43	-1	-1	-2
37	5.1	20.3	2.664	2.52	2.43	0	0	-2
37	5	20.3	2.664	2.52	2.43	0	0	-2
36	4.8	20.3	2.592	2.43	2.304	0	1	1
36	4.7	20.3	2.556	2.394	2.286	1	2	2
35	4.5	20.3	2.556	2.394	2.268	0	1	2

TF#1:

Regression Output:

Constant	1.148196
Std Err of Y Est	0.123772
R Squared	0.958900
No. of Observations	53
Degrees of Freedom	51

X Coefficient(s)	0.040504
Std Err of Coef.	0.001174

TF#2:

Regression Output:

Constant	0.964711
Std Err of Y Est	0.136119
R Squared	0.953195
No. of Observations	53
Degrees of Freedom	51
X Coefficient(s)	0.041617
Std Err of Coef.	0.001291

AL:

Regression Output:

Constant	2.002924
Std Err of Y Est	0.048049
R Squared	0.973849
No. of Observations	53
Degrees of Freedom	51
X Coefficient(s)	0.071818
Std Err of Coef.	0.001647

CALIBRATION TABLE FOR 20 PPM AMMONIA, MEDIUM DUST AND REPLICATE#1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
34	4.7	21	2.574	2.412	2.214	0	0	1
35	4.8	21	2.574	2.412	2.214	1	[illegible]	2
35	5	21.1	2.574	2.412	2.214	1	1	2
36	5.4	21.1	2.7	2.592	2.25	-2	-3	2
40	6.9	21.1	2.826	2.754	2.322	-1	-3	3
42	7.8	21.1	3.042	2.88	2.448	-5	-4	0
47	9.4	21.1	3.204	3.078	2.538	-4	-5	0
49	10.1	21.1	3.33	3.258	2.61	-6	-8	-1
52	11	21.1	3.42	3.348	2.682	-5	-7	-2
58	12.5	21.1	3.546	3.42	2.718	-3	-3	2
59	12.9	21.1	3.636	3.528	2.754	-4	-5	1
61	13.3	21.1	3.726	3.618	2.79	-5	-5	1
63	13.9	21.1	3.834	3.708	2.826	-6	-6	1
68	15	21.1	3.888	3.798	2.844	-2	-3	5
69	15.2	21.1	3.978	3.888	2.862	-4	-5	5
74	16.3	21.1	4.014	3.942	2.916	0	-1	6
78	17.1	21.1	4.122	3.996	2.97	1	2	6
79	17.4	21.2	4.194	4.068	3.006	0	1	5
81	17.9	21.2	4.32	4.302	3.204	-1	-4	-8
77	17.1	21.2	3.978	3.834	3.06	4	5	-1
72	16	21.2	3.87	3.69	3.006	2	4	-2
71	15.8	21.2	3.78	3.582	2.952	4	6	1
67	14.8	21.2	3.654	3.438	2.88	3	6	2
65	14.4	21.2	3.528	3.366	2.862	5	6	1
61	13.3	21.2	3.42	3.312	2.826	4	3	-1
57	12.3	21.2	3.384	3.24	2.808	1	1	-4
55	11.8	21.2	3.312	3.15	2.79	1	1	-5
52	11	21.2	3.258	3.114	2.754	-1	-1	-6
50	10.4	21.2	3.222	3.042	2.718	-2	-1	-6
49	10.1	21.2	3.15	2.988	2.7	-1	0	-6
48	9.8	21.2	3.006	2.844	2.646	2	3	-4
47	9.4	21.2	2.898	2.79	2.61	4	3	-3
46	9.3	21.2	2.862	2.754	2.592	4	3	-3
44	8.6	21.2	2.844	2.754	2.574	3	1	-4
44	8.5	21.2	2.826	2.718	2.556	3	2	-3
38	6.2	21.2	2.646	2.502	2.304	2	2	2
37	6.1	21.2	2.646	2.502	2.304	1	1	1
37	5.9	21.2	2.646	2.502	2.286	1	1	1
35	5.3	21.2	2.646	2.484	2.286	-1	-1	-1
37	6.1	21.2	2.646	2.484	2.286	1	1	1
37	5.9	21.2	2.628	2.466	2.286	1	2	1
37	5.8	21.2	2.628	2.466	2.286	1	2	1
37	5.8	21.2	2.628	2.466	2.286	1	2	1
36	5.4	21.2	2.61	2.466	2.286	1	1	0
35	5.3	21.2	2.61	2.448	2.268	0	0	0
35	5.1	21.2	2.61	2.448	2.268	0	0	0
35	5.1	21.2	2.61	2.448	2.268	0	0	0
35	5.1	21.2	2.592	2.43	2.25	0	1	1

TF#1:

Regression Output:

Constant	1.337009
Std Err of Y Est	0.103317
R Squared	0.965056
No. of Observations	48
Degrees of Freedom	46

X Coefficient(s) 0.036315
Std Err of Coef. 0.001018

TF#2:

Regression Output:

Constant 1.163901

Std Err of Y Est	0.122238
R Squared	0.953587
No. of Observations	48
Degrees of Freedom	46

X Coefficient(s)	0.037058
Std Err of Coef.	0.001205

AL:

Regression Output:

Constant	1.929104
Std Err of Y Est	0.052424
R Squared	0.967121
No. of Observations	48
Degrees of Freedom	46

X Coefficient(s)	0.065898
Std Err of Coef.	0.001791

CALIBRATION TABLE FOR 20 PPM AMMONIA, HIGH DUST AND REPLICATE#1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
36	4.7	20.2	2.79	2.682	2.43	-2	-3	-2
40	6.2	20.2	2.916	2.808	2.52	-1	-2	-1
43	7.4	20.2	3.078	2.934	2.61	-2	-2	-2
46	8.2	20.2	3.204	3.078	2.646	-2	-2	0
47	8.6	20.2	3.294	3.186	2.7	-3	-4	-2
50	9.4	20.2	3.366	3.276	2.718	-2	-3	0
51	9.9	20.2	3.438	3.348	2.772	-3	-4	-1
53	10.2	20.2	3.528	3.402	2.808	-3	-3	-1
55	11	20.2	3.6	3.438	2.826	-3	-2	1
57	11.3	20.2	3.726	3.618	2.862	-4	-4	1
64	13.3	20.2	3.906	3.816	2.97	-1	-2	2
65	13.4	20.2	4.014	3.906	3.042	-3	-3	-1
66	13.6	20.2	4.014	3.942	3.06	-2	-3	-1
66	13.7	20.2	4.086	3.96	3.078	-4	-3	-2
68	14.2	20.2	4.104	3.978	3.096	-2	-1	-1
70	14.5	20.2	4.176	4.05	3.132	-2	-1	-1
80	16.6	20.2	4.284	4.212	3.276	6	5	0
69	14.4	20.2	3.906	3.762	3.132	4	5	-2
56	11.2	20.2	3.114	2.952	2.79	10	11	3
47	8.5	20.2	2.718	2.592	2.574	10	10	3
42	6.9	20.2	2.61	2.448	2.394	8	8	5
35	4.3	20.2	2.574	2.394	2.358	2	3	-1

TF#1:

Regression Output:

Constant	1.193593
Std Err of Y Est	0.192038
R Squared	0.882383
No. of Observations	22
Degrees of Freedom	20
X Coefficient(s)	0.041614
Std Err of Coef.	0.003397

TF#2:

Regression Output:

Constant	1.022756
Std Err of Y Est	0.203777
R Squared	0.874315
No. of Observations	22
Degrees of Freedom	20
X Coefficient(s)	0.042521
Std Err of Coef.	0.003604

AL:

Regression Output:

Constant	2.009311
Std Err of Y Est	0.048149
R Squared	0.968539
No. of Observations	22
Degrees of Freedom	20
X Coefficient(s)	0.075979
Std Err of Coef.	0.003061

CALIBRATION TABLE FOR 30 PPM AMMONIA, LOW DUST AND REPLICATE#1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
35	4.2	20.2	2.61	2.466	2.394	1	1	2
37	5	20.3	2.79	2.682	2.502	-2	-2	1
40	6.2	20.3	2.916	2.826	2.61	-2	-3	0
46	8.2	20.3	3.096	2.97	2.682	0	0	3
48	9.1	20.3	3.258	3.114	2.718	-2	-2	4
49	9.4	20.3	3.348	3.258	2.79	-4	-5	1
51	9.9	20.3	3.438	3.348	2.826	-4	-5	2
56	11.2	20.3	3.582	3.438	2.862	-2	-2	5
58	11.7	20.3	3.672	3.546	2.916	-3	-3	4
60	12.3	20.3	3.78	3.636	2.97	-3	-3	4
61	12.6	20.3	3.834	3.708	3.006	-4	-4	3
66	13.7	20.3	3.96	3.852	3.078	-2	-2	4
67	13.9	20.3	3.996	3.906	3.114	-2	-2	3
67	13.9	20.3	4.032	3.942	3.132	-3	-3	2
68	14.4	20.4	4.086	3.978	3.15	-3	-3	2
69	14.5	20.4	4.158	4.032	3.204	-4	-4	0
70	14.8	20.4	4.194	4.086	3.222	-4	-4	0
79	16.6	20.4	4.32	4.32	3.366	2	-1	-1
76	16.1	20.4	4.302	4.212	3.384	0	-1	-5
74	15.6	20.4	4.194	4.032	3.33	0	1	-3
73	15.5	20.4	4.068	3.924	3.294	2	3	-2
72	15.2	20.4	3.96	3.834	3.258	4	4	-1
69	14.5	20.4	3.852	3.69	3.222	4	5	-1
65	13.7	20.4	3.726	3.546	3.15	3	4	-1
61	12.6	20.4	3.582	3.42	3.114	3	3	-3
60	12.5	20.4	3.456	3.348	3.078	5	4	-2
56	11.3	20.4	3.402	3.294	3.042	2	2	-4
53	10.5	20.4	3.366	3.24	3.006	0	0	-5
53	10.4	20.4	3.294	3.186	2.97	2	1	-3
52	10.1	20.4	3.258	3.096	2.934	2	2	-2
51	9.9	20.4	3.204	3.042	2.88	2	3	0
50	9.8	20.4	3.132	2.97	2.862	3	4	-1
49	9.4	20.4	3.078	2.898	2.844	3	4	-1
47	8.8	20.4	3.042	2.862	2.826	2	3	-2
37	5.4	20.4	2.7	2.538	2.628	1	1	-4
36	4.8	20.4	2.646	2.502	2.574	1	1	-3

TF#1:

Regression Output:

Constant	1.253515
Std Err of Y Est	0.107872
R Squared	0.954447
No. of Observations	36
Degrees of Freedom	34
X Coefficient(s)	0.039836
Std Err of Coef.	0.001494

TF#2:

Regression Output:

Constant	1.075437
Std Err of Y Est	0.124817
R Squared	0.942366
No. of Observations	36
Degrees of Freedom	34
X Coefficient(s)	0.040769
Std Err of Coef.	0.001729

AL:

Regression Output:

Constant	2.152837
Std Err of Y Est	0.054474
R Squared	0.954493
No. of Observations	36
Degrees of Freedom	34

X Coefficient(s)	0.072199
Std Err of Coef.	0.002703

CALIBRATION TABLE FOR 30 PPM AMMONIA, MEDIUM DUST AND REPLICATE#1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
32	4.7	21.9	1.692	1.494	2.574	-1	-1	2
34	5.4	21.9	1.8	1.602	2.646	-3	-3	2
41	8.1	21.9	1.98	1.782	2.826	-2	-3	3
47	10.1	21.9	2.124	1.926	2.97	-2	-3	4
52	11.6	21.9	2.232	2.016	3.078	-1	-1	5
53	11.8	21.9	2.34	2.106	3.168	-3	-4	2
57	13.1	21.9	2.412	2.178	3.24	-2	-3	3
60	13.8	21.9	2.52	2.286	3.348	-3	-4	1
62	14.3	21.9	2.574	2.322	3.384	-3	-3	1
63	14.8	22.1	2.61	2.358	3.42	-3	-4	1
67	15.5	21.9	2.628	2.394	3.438	0	-1	4
66	15.5	22.1	2.664	2.412	3.474	-2	-3	2
68	16	22.1	2.754	2.502	3.564	-4	-4	-1
69	16.2	22.1	2.754	2.502	3.582	-3	-3	-1
71	16.5	22.1	2.772	2.52	3.582	-1	-2	1
71	16.7	22.1	2.772	2.52	3.6	-1	-2	0
73	17	22.1	2.826	2.556	3.672	-1	-1	-2
73	17.2	22.3	2.844	2.574	3.708	-2	-2	-4
75	17.7	22.3	2.844	2.574	3.708	0	0	-2
77	18	22.3	2.844	2.574	3.708	2	2	0
74	17.5	22.3	2.772	2.484	3.69	2	3	-2
73	17.2	22.3	2.592	2.322	3.6	7	8	3
67	15.8	22.3	2.466	2.196	3.528	6	7	1
60	14.3	22.3	2.358	2.088	3.438	3	4	-2
56	13.1	22.3	2.268	2.016	3.366	2	3	-2
53	12.3	22.3	2.196	1.944	3.312	2	3	-3
51	11.6	22.3	2.124	1.89	3.258	2	3	-2
47	10.6	22.3	2.052	1.818	3.204	1	2	-4
47	10.6	22.3	2.016	1.782	3.15	2	3	-2
43	9.1	22.3	1.908	1.692	3.042	2	2	1
42	8.9	22.3	1.89	1.674	3.024	2	2	[illegible]
41	8.4	22.3	1.854	1.638	2.97	2	3	-1
39	7.6	22.3	1.836	1.62	2.952	1	1	-2
37	6.9	22.3	1.8	1.584	2.898	0	1	-2
36	6.4	22.3	1.782	1.566	2.862	0	0	-2
34	5.7	22.3	1.71	1.512	2.736	1	0	0
33	5.4	22.3	1.71	1.512	2.718	0	-1	-1

TF#1:

Regression Output:	
Constant	0.796615
Std Err of Y Est	0.071122
R Squared	0.969085
No. of Observations	37
Degrees of Freedom	35

X Coefficient(s) 0.027321
Std Err of Coef. 0.000824

TF#2:

Regression Output:	
Constant	0.649929
Std Err of Y Est	0.077383
R Squared	0.959003
No. of Observations	37
Degrees of Freedom	35

X Coefficient(s) 0.025679
Std Err of Coef. 0.000897

AL:

Regression Output:

Constant	2.277583
Std Err of Y Est	0.056060
R Squared	0.972824
No. of Observations	37
Degrees of Freedom	35

X Coefficient(s)	0.079418
Std Err of Coef.	0.002243

CALIBRATION TABLE FOR 30 PPM AMMONIA, HIGH DUST AND REPLICATE#1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
31	3.7	21.3	1.71	1.512	2.52	-3	-3	0
33	4.4	21.3	1.71	1.512	2.52	-1	-1	2
35	5.4	21.3	1.71	1.512	2.52	1	1	4
41	7.6	21.3	2.034	1.836	2.808	-4	-5	1
48	9.9	21.3	2.178	1.98	2.952	-3	-4	3
55	11.8	21.3	2.286	2.07	3.042	0	0	6
60	13.5	21.5	2.628	2.394	3.348	-7	-8	-2
64	14.5	21.5	2.664	2.412	3.384	-5	-4	0
66	14.8	21.3	2.682	2.448	3.402	-3	-4	0
67	15	21.3	2.718	2.466	3.42	-4	-4	0
69	15.5	21.5	2.736	2.484	3.438	-2	-2	2
70	15.8	21.5	2.754	2.502	3.474	-2	-2	1
71	16	21.5	2.79	2.538	3.528	-2	-2	-1
73	16.5	21.5	2.808	2.538	3.528	-1	0	1
74	16.7	21.5	2.826	2.574	3.564	0	-1	0
76	17	21.5	2.826	2.574	3.582	2	1	1
73	16.5	21.5	2.826	2.574	3.618	-1	-2	-4
74	16.7	21.5	2.826	2.574	3.618	0	-1	-3
72	16.2	21.5	2.664	2.412	3.546	3	4	-1
69	15.5	21.5	2.52	2.268	3.438	6	6	2
62	14	21.5	2.394	2.142	3.366	3	4	-1
59	13.1	21.5	2.286	2.052	3.276	4	4	1
57	12.6	21.5	2.214	1.962	3.222	5	6	1
53	11.6	21.5	2.142	1.908	3.168	4	4	0
49	10.3	21.5	2.07	1.854	3.114	2	2	-2
48	9.9	21.5	2.016	1.8	3.06	3	3	-1
46	9.4	21.5	1.98	1.764	3.024	3	3	-1
44	8.9	21.5	1.944	1.728	2.988	2	2	-2
44	8.6	21.5	1.908	1.692	2.952	3	3	0
41	7.6	21.5	1.854	1.638	2.862	2	2	0
37	6.2	21.5	1.836	1.62	2.844	-1	-1	-3
36	5.7	21.5	1.818	1.602	2.826	-2	-1	-4
33	4.7	21.5	1.728	1.53	2.664	-1	-1	-1
33	4.4	21.5	1.728	1.512	2.646	-1	-1	-1

TF#1:

Regression Output:	
Constant	0.792937
Std Err of Y Est	0.084767
R Squared	0.959851
No. of Observations	34
Degrees of Freedom	32
X Coefficient(s)	0.027296
Std Err of Coef.	0.000986

TF#2:

Regression Output:	
Constant	0.636513
Std Err of Y Est	0.087008
R Squared	0.953500
No. of Observations	34
Degrees of Freedom	32
X Coefficient(s)	0.025948
Std Err of Coef.	0.001012

AL:

Regression Output:

Constant	2.254890
Std Err of Y Est	0.058376
R Squared	0.972928
No. of Observations	34
Degrees of Freedom	32
X Coefficient(s)	0.078450
Std Err of Coef.	0.002313

CALIBRATION TABLE FOR 40 PPM AMMONIA, LOW DUST AND REPLIICATE#1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
34	4	20.2	2.538	2.376	2.268	-1	-1	4
35	4.5	20.3	2.556	2.376	2.268	0	0	5
47	8.8	20.3	3.564	3.438	2.79	-12	-11	-4
61	12.5	20.3	3.78	3.672	2.862	-3	-3	7
61	12.5	20.3	3.852	3.762	2.862	-4	-5	7
62	12.8	20.3	3.906	3.816	2.934	-5	-5	4
64	13.3	20.3	3.96	3.87	2.97	-4	-4	4
67	14.1	20.4	3.996	3.906	3.006	-2	-2	5
69	14.5	20.4	4.05	3.96	3.042	-1	-1	5
70	14.8	20.4	4.158	4.014	3.078	-2	-1	4
72	15.2	20.4	4.176	4.086	3.096	-1	-1	5
73	15.5	20.4	4.284	4.212	3.186	-2	-3	0
76	16	20.4	4.302	4.248	3.222	0	-1	0
80	16.8	20.4	4.338	4.32	3.366	3	2	-6
73	15.5	20.4	4.176	4.032	3.258	0	1	-5
71	15	20.4	4.014	3.906	3.204	2	2	-4
70	14.8	20.4	3.924	3.798	3.15	3	4	-1
68	14.2	20.4	3.798	3.636	3.114	4	5	-1
64	13.4	20.4	3.69	3.546	3.078	2	3	-2
60	12.3	20.4	3.582	3.42	3.006	1	2	-2
58	12	20.4	3.456	3.348	2.97	2	2	-2
55	11.2	20.4	3.402	3.294	2.934	0	0	-3
53	10.4	20.4	3.348	3.24	2.88	-1	-1	-2
53	10.4	20.4	3.294	3.15	2.862	1	1	-1
52	10.1	20.4	3.24	3.096	2.844	1	1	-1
50	9.6	20.4	3.114	2.97	2.808	2	2	-1
48	9	20.4	3.006	2.844	2.754	2	3	-1
47	8.6	20.4	2.97	2.826	2.754	2	2	-2
46	8.3	20.4	2.916	2.79	2.718	3	2	-1
45	8.2	20.4	2.862	2.754	2.7	3	2	-1
45	8.2	20.4	2.844	2.718	2.682	3	3	0
43	7.5	20.4	2.808	2.682	2.664	2	2	-2
41	6.9	20.4	2.79	2.664	2.646	0	0	-3
40	6.4	20.4	2.754	2.61	2.61	0	0	-2
39	5.9	20.4	2.718	2.574	2.574	0	0	-2
37	5.3	20.4	2.664	2.502	2.502	-1	0	-1
[illegible]	4.8	20.4	2.61	2.448	2.43	0	0	1
[illegible]	4.5	20.4	2.592	2.43	2.412	-1	-1	0

TF#1:

Regression Output:

Constant	1.049424
Std Err of Y Est	0.125580
R Squared	0.956536
No. of Observations	38
Degrees of Freedom	36
X Coefficient(s)	0.04293J
Std Err of Coef.	0.001525

TF#2:

Regression Output:

Constant	0.833252
Std Err of Y Est	0.133238
R Squared	0.954762
No. of Observations	38
Degrees of Freedom	36
X Coefficient(s)	0.044604

Std Err of Coef. 0.001618

AL:

Regression Output:	
Constant	2.108295
Std Err of Y Est	0.062764
R Squared	0.948069
No. of Observations	38
Degrees of Freedom	36

X Coefficient(s) 0.069614
Std Err of Coef. 0.002715

CALIBRATION TABLE FOR 40 PPM AMMONIA, MEDIUM DUST AND REPLICATE#1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
31	3.7	21.3	1.746	1.53	2.592	-3	-3	-2
32	4.2	21.3	1.728	1.512	2.574	-2	-1	0
33	4.4	21.3	1.71	1.512	2.52	0	0	2
35	5.4	21.3	1.872	1.674	2.646	-4	-4	1
41	7.6	21.3	2.034	1.836	2.808	-4	-5	1
48	9.9	21.3	2.178	1.98	2.952	-2	-3	3
55	11.8	21.3	2.286	2.07	3.042	1	0	7
60	13.5	21.5	2.628	2.394	3.348	-7	-8	-1
64	14.5	21.5	2.664	2.412	3.384	-5	-5	1
66	14.8	21.3	2.682	2.448	3.402	-3	-4	1
67	15	21.3	2.718	2.466	3.42	-4	-4	1
69	15.5	21.5	2.736	2.484	3.438	-2	-2	3
70	15.8	21.5	2.808	2.538	3.528	-4	-3	-1
73	16.5	21.5	2.808	2.538	3.528	-1	0	2
74	16.7	21.5	2.826	2.574	3.564	-1	-1	1
76	17	21.5	2.826	2.574	3.618	1	1	0
81	18.2	21.5	2.952	2.7	3.87	2	1	-12
73	16.5	21.5	2.826	2.574	3.618	-2	-2	-3
73	16.5	21.5	2.826	2.574	3.618	-2	-2	-3
74	16.7	21.5	2.826	2.574	3.618	-1	-1	-2
72	16.2	21.5	2.664	2.412	3.546	3	3	0
69	15.5	21.5	2.52	2.268	3.438	6	6	3
62	14	21.5	2.394	2.142	3.366	3	4	0
59	13.1	21.5	2.286	2.052	3.276	5	5	1
57	12.6	21.5	2.214	1.962	3.222	5	6	2
53	11.6	21.5	2.142	1.908	3.168	4	4	0
49	10.3	21.5	2.07	1.854	3.114	3	2	-2
48	9.9	21.5	2.016	1.8	3.06	4	4	0
46	9.4	21.5	1.98	1.764	3.024	3	3	-1
44	8.9	21.5	1.944	1.728	2.988	2	2	-2
44	8.6	21.5	1.908	1.692	2.952	4	4	0
41	7.6	21.5	1.854	1.638	2.862	3	3	0
36	5.7	21.5	1.782	1.584	2.772	0	0	-2
33	4.4	21.5	1.746	1.548	2.7	-1	-1	-3

TF#1:

Regression Output:	
Constant	0.832224
Std Err of Y Est	0.089613
R Squared	0.955769
No. of Observations	34
Degrees of Freedom	32
X Coefficient(s)	0.026679
Std Err of Coef.	0.001014

TF#2:

Regression Output:	
Constant	0.675370
Std Err of Y Est	0.090790
R Squared	0.949988
No. of Observations	34
Degrees of Freedom	32
X Coefficient(s)	0.025342
Std Err of Coef.	0.001027

AL:

Regression Output:

Constant	2.242234
Std Err of Y Est	0.057598
R Squared	0.975814
No. of Observations	34
Degrees of Freedom	32
X Coefficient(s)	0.080447
Std Err of Coef.	0.002238

CALIBRATION TABLE FOR 40 PPM AMMONIA, HIGH DUST AND REPLICATE#1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
34	5.4	22.1	1.728	1.512	2.214	1	1	3
34	5.7	22.1	1.764	1.566	2.214	-1	-1	3
38	7.1	22.1	1.836	1.638	2.268	1	0	5
41	8.1	22.1	1.926	1.728	2.358	1	0	6
49	10.8	22.1	2.142	1.926	2.574	1	0	7
50	11.3	22.1	2.214	1.98	2.628	-1	-1	6
53	12.1	22.1	2.268	2.052	2.682	0	0	7
55	12.6	22.1	2.322	2.088	2.736	1	0	6
57	13.1	22.1	2.376	2.142	2.772	1	0	7
57	13.3	22.1	2.412	2.178	2.808	-1	-1	6
58	13.5	22.1	2.466	2.214	2.844	-2	-2	5
60	14	22.1	2.502	2.25	2.88	-1	-1	5
62	14.5	22.1	2.52	2.268	2.916	0	0	6
64	15	22.1	2.556	2.304	2.934	1	1	7
66	15.5	22.1	2.592	2.34	2.97	2	2	7
67	15.8	22.1	2.61	2.358	2.988	2	2	7
68	16	22.1	2.754	2.484	3.114	-2	-2	2
71	16.5	22.1	2.772	2.502	3.132	1	0	4
71	16.7	22.1	2.772	2.502	3.132	1	0	4
73	17	22.1	2.79	2.52	3.15	2	2	5
74	17.2	22.1	2.898	2.61	3.258	-1	-1	0
76	17.7	22.1	2.898	2.628	3.258	1	1	2
77	18	22.3	2.988	2.718	3.402	-1	-2	-4
78	18.2	22.3	2.988	2.718	3.402	0	-1	-3
75	17.7	22.3	2.898	2.61	3.384	0	0	-5
71	16.7	22.3	2.826	2.538	3.348	-1	-1	-7
70	16.5	22.3	2.754	2.466	3.294	0	1	-5
68	16.2	22.3	2.682	2.412	3.258	1	1	-5
65	15.5	22.3	2.628	2.34	3.222	0	1	-6
61	14.5	22.3	2.574	2.286	3.186	-2	-1	-8
60	14.3	22.3	2.52	2.25	3.15	-2	-1	-7
59	14	22.3	2.466	2.214	3.132	-1	-1	-7
57	13.3	22.3	2.43	2.16	3.096	-1	-1	-7
54	12.6	22.3	2.268	2.016	2.97	1	2	-4
51	11.8	22.3	2.232	1.998	2.952	0	0	-6
50	11.3	22.3	2.178	1.944	2.916	1	1	-6
49	11.1	22.3	2.16	1.926	2.88	0	0	-5
47	10.6	22.3	2.142	1.89	2.862	-1	0	-6
46	10.1	22.3	2.106	1.872	2.844	-1	-1	-6
45	9.6	22.1	2.016	1.782	2.754	1	2	-4
43	9.1	22.1	1.998	1.782	2.736	0	0	-6
41	8.6	22.3	1.962	1.746	2.718	-1	-1	-6
41	8.1	22.1	1.944	1.71	2.682	0	0	-5
36	6.7	22.3	1.8	1.584	2.466	0	0	-2
35	5.9	22.1	1.782	1.566	2.448	0	0	-3
34	5.4	22.1	1.728	1.512	2.196	1	1	3

TF#1:

Regression Output:

Constant	0.786396
Std Err of Y Est	0.029807
R Squared	0.993807
No. of Observations	46
Degrees of Freedom	44
X Coefficient(s)	0.028179
Std Err of Coef.	0.000335

TF#2:

Regression Output:	
Constant	0.638717
Std Err of Y Est	0.026136
R Squared	0.994578
No. of Observations	46
Degrees of Freedom	44
X Coefficient(s)	0.026417
Std Err of Coef.	0.000294

AL:

Regression Output:	
Constant	1.860043
Std Err of Y Est	0.126132
R Squared	0.859849
No. of Observations	46
Degrees of Freedom	44
X Coefficient(s)	0.081351
Std Err of Coef.	0.004951

CALIBRATION TABLE FOR 20 PPM AMMONIA, LOW DUST AND REPLICATE#2

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
32	4.7	22.2	2.61	2.466	2.304	1	1	3
33	5.3	22.2	2.628	2.466	2.322	1	2	4
35	6.2	22.2	2.718	2.646	2.412	1	0	3
38	7.2	22.2	2.862	2.79	2.502	1	0	4
44	9.4	22.2	3.33	3.24	2.718	-3	-3	2
46	10.2	22.2	3.42	3.33	2.772	-2	-3	2
48	10.7	22.2	3.51	3.42	2.808	-2	-3	3
49	11	22.2	3.654	3.546	2.862	-4	-4	2
50	11.3	22.2	3.708	3.6	2.862	-5	-4	3
60	14.1	22.2	3.96	3.87	3.006	0	0	6
61	14.4	22.2	4.014	3.942	3.078	0	0	4
62	14.5	22.2	4.086	3.978	3.096	-1	0	4
64	15	22.2	4.194	4.104	3.186	-1	-1	1
65	15.2	22.2	4.248	4.158	3.204	-1	-1	1
65	15.5	22.4	4.266	4.194	3.222	-2	-2	1
65	15.5	22.4	4.284	4.194	3.24	-2	-2	0
65	15.5	22.4	4.302	4.23	3.258	-2	-2	-1
71	16.9	22.4	4.32	4.32	3.348	3	2	0
72	17.1	22.4	4.32	4.32	3.366	4	3	0
69	16.4	22.4	4.32	4.32	3.348	1	0	-2
65	15.6	22.4	4.122	3.978	3.258	2	3	-1
60	14.5	22.6	3.978	3.87	3.222	0	0	-3
59	14.2	22.6	3.888	3.726	3.186	1	2	-2
59	14.1	22.6	3.798	3.618	3.114	2	4	1
53	12.6	22.6	3.654	3.492	3.078	0	1	-3
50	11.8	22.6	3.456	3.348	3.006	1	1	-3
48	10.9	22.6	3.402	3.294	2.97	0	0	-3
47	10.7	22.6	3.348	3.222	2.934	0	0	-2
45	10.1	22.6	3.294	3.186	2.88	-1	-1	-2
43	9.4	22.6	3.186	3.006	2.826	0	1	-2
42	9.1	22.6	3.078	2.88	2.808	1	2	-2
42	9	22.6	3.006	2.862	2.79	2	3	-1
40	8.2	22.6	2.88	2.79	2.718	3	2	-1
38	7.5	22.6	2.862	2.754	2.718	1	1	-3
37	7.4	22.6	2.844	2.736	2.7	1	0	-3
36	6.9	22.6	2.826	2.718	2.682	0	0	-3
35	6.2	22.6	2.79	2.664	2.646	0	0	-3
33	5.4	22.6	2.718	2.592	2.574	-1	-1	-3

TF#1:

Regression Output:	
Constant	1.145201
Std Err of Y Est	0.092820
R Squared	0.975467
No. of Observations	38
Degrees of Freedom	36
X Coefficient(s)	0.046919
Std Err of Coef.	0.001240

TF#2:

Regression Output:	
Constant	0.952839
Std Err of Y Est	0.096987
R Squared	0.975077
No. of Observations	38
Degrees of Freedom	36
X Coefficient(s)	0.048630
Std Err of Coef.	0.001295

AL:

Regression Output:	
Constant	2.065391
Std Err of Y Est	0.071495
R Squared	0.940826
No. of Observations	38
Degrees of Freedom	36

X Coefficient(s)	0.075725
Std Err of Coef.	0.003165

CALIBRATION FOR TABLE 20 PPM AMMONIA, MEDIUM DUST AND REPLICATE#2

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
35	4.3	20.4	2.682	2.538	2.322	-3	-3	3
36	4.8	20.4	2.808	2.7	2.43	-5	-6	0
39	6.1	20.4	2.934	2.826	2.52	-5	-6	0
42	7.2	20.4	3.078	2.952	2.61	-6	-6	-1
45	8.2	20.4	3.222	3.096	2.646	-6	-6	0
48	9.1	20.4	3.294	3.186	2.7	-5	-6	1
52	10.1	20.4	3.384	3.294	2.718	-3	-4	4
53	10.4	20.4	3.546	3.42	2.808	-6	-6	1
55	11	20.4	3.618	3.474	2.826	-6	-6	2
58	12	20.4	3.69	3.564	2.844	-5	-5	4
61	12.6	20.4	3.78	3.636	2.862	-4	-3	6
64	13.4	20.4	3.87	3.78	2.952	-3	-4	4
65	13.7	20.4	3.924	3.816	2.97	-4	-4	4
67	14.1	20.4	3.942	3.852	2.988	-2	-3	5
68	14.4	20.4	4.086	3.96	3.078	-5	-4	0
70	14.8	20.4	4.104	3.978	3.078	-3	-3	2
71	15	20.4	4.122	3.996	3.096	-3	-2	2
73	15.3	20.4	4.23	4.122	3.186	-3	-3	-2
73	15.5	20.4	4.302	4.23	3.24	-5	-6	-6
74	15.6	20.4	4.302	4.23	3.24	-4	-5	-5
75	15.8	20.4	4.302	4.248	3.258	-3	-4	-5
76	16.1	20.4	4.302	4.248	3.258	-2	-3	-4
80	16.8	20.4	4.32	4.266	3.294	1	0	-3
78	16.4	20.4	4.23	4.122	3.258	2	2	-2
77	16.3	20.4	4.104	3.978	3.222	4	4	-1
73	15.3	20.4	3.978	3.852	3.186	3	3	-2
70	14.8	20.4	3.87	3.708	3.132	3	4	-1
68	14.2	20.4	3.78	3.6	3.078	3	4	0
67	14.1	20.4	3.654	3.492	3.042	5	6	1
65	13.7	20.4	3.564	3.402	3.006	5	6	2
64	13.3	20.4	3.438	3.33	2.97	7	7	3
60	12.3	20.4	3.402	3.276	2.898	4	4	3
58	12	20.4	3.33	3.204	2.862	4	4	3
57	11.5	20.4	3.294	3.132	2.862	4	5	2
55	11	20.4	3.24	3.078	2.826	3	4	2
53	10.4	20.4	3.186	3.024	2.826	3	3	0
52	10.1	20.4	3.132	2.97	2.808	3	4	0
50	9.6	20.4	3.078	2.898	2.79	2	3	-2
50	9.6	20.4	3.042	2.862	2.754	3	4	0
49	9.4	20.4	2.988	2.826	2.754	4	4	-1
47	8.8	20.4	2.952	2.808	2.718	2	3	-1
47	8.8	20.4	2.88	2.79	2.718	4	3	-1
47	8.6	20.4	2.862	2.754	2.7	5	4	0
46	8.3	20.4	2.844	2.754	2.682	4	3	0
46	8.3	20.4	2.826	2.718	2.664	5	4	0
45	8.2	20.4	2.826	2.682	2.664	4	4	-1
43	7.5	20.4	2.808	2.682	2.646	2	2	-2
43	7.4	20.4	2.79	2.664	2.646	2	2	-2
41	6.9	20.4	2.79	2.664	2.628	0	0	-3
41	6.9	20.4	2.772	2.646	2.61	1	1	-2
41	6.7	20.4	2.754	2.61	2.61	1	1	-2
37	5.4	20.4	2.7	2.556	2.538	-1	-1	-3
35	4.3	20.4	2.574	2.43	2.358	0	0	2

TF#1:

Regression Output:

Constant	1.154164
Std Err of Y Est	0.158242
R Squared	0.919707
No. of Observations	53
Degrees of Freedom	51

X Coefficient(s)	0.040321
Std Err of Coef.	0.001668

Regression Output:

Constant	0.985387
Std Err of Y Est	0.171635
R Squared	0.910062
No. of Observations	53
Degrees of Freedom	51

X Coefficient(s)	0.041105
Std Err of Coef.	0.001809

Regression Output:

Constant	2.097051
Std Err of Y Est	0.044456
R Squared	0.969018
No. of Observations	53
Degrees of Freedom	51

X Coefficient(s)	0.068615
Std Err of Coef.	0.001718

CALIBRATION TABLE FOR 20 PPM AMMONIA, HIGH DUST AND REPLICATE#2

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
34	5	21.4	2.574	2.43	2.25	2	3	2
34	5.1	21.4	2.61	2.466	2.25	1	2	2
35	5.3	21.4	2.718	2.628	2.286	-1	-2	2
40	7.2	21.4	2.844	2.772	2.412	0	-2	2
43	8.5	21.4	3.06	2.934	2.502	-4	-4	1
48	9.9	21.4	3.222	3.114	2.61	-4	-4	0
48	10.1	21.4	3.33	3.258	2.664	-7	-9	-2
51	11	21.4	3.438	3.348	2.718	-8	-9	-3
55	12	21.4	3.546	3.42	2.754	-7	-7	-1
61	13.7	21.4	3.654	3.528	2.79	-4	-4	3
62	13.9	21.4	3.726	3.618	2.826	-5	-6	2
63	14.2	21.4	3.834	3.69	2.844	-8	-7	2
67	15	21.4	3.87	3.78	2.862	-5	-6	5
70	15.6	21.4	3.978	3.888	2.952	-5	-6	1
73	16.4	21.4	4.068	3.96	3.006	-5	-6	0
75	16.9	21.5	4.122	3.996	3.042	-5	-5	0
76	17.1	21.5	3.852	3.69	3.078	5	6	-2
73	16.4	21.5	3.726	3.564	3.006	6	7	1
70	15.8	21.5	3.618	3.438	2.97	6	8	0
67	15.2	21.5	3.51	3.384	2.916	6	6	1
64	14.5	21.5	3.42	3.312	2.862	6	5	2
63	14.2	21.5	3.366	3.24	2.844	7	7	2
61	13.6	21.5	3.312	3.186	2.826	6	6	1
55	12.1	21.5	3.258	3.114	2.808	2	3	-4
54	11.8	21.5	3.204	3.042	2.79	3	4	-3
51	11	21.5	3.15	2.988	2.754	1	2	-4
49	10.4	21.5	3.096	2.916	2.736	1	3	-5
48	10.1	21.5	3.042	2.862	2.718	2	3	-5
47	9.8	21.5	2.862	2.772	2.646	6	5	-2
40	7.5	21.5	2.736	2.61	2.502	3	3	-2
40	7.2	21.5	2.718	2.61	2.502	4	3	-2
34	5.1	21.5	2.61	2.448	2.286	1	2	1

TF#1:

Regression Output:

Constant	1.535739
Std Err of Y Est	0.159402
R Squared	0.881739
No. of Observations	32
Degrees of Freedom	30

X Coefficient(s)	0.032913
Std Err of Coef.	0.002173

TF#2:

Regression Output:

Constant	1.420075
Std Err of Y Est	0.174778
R Squared	0.859591
No. of Observations	32
Degrees of Freedom	30

X Coefficient(s)	0.032303
Std Err of Coef.	0.002383

AL:

Regression Output:

Constant	2.006070
Std Err of Y Est	0.046598
R Squared	0.962571
No. of Observations	32
Degrees of Freedom	30

X Coefficient(s)	0.061404
Std Err of Coef.	0.002210

CALIBRATION TABLE FOR 30 PPM AMMONIA, LOW DUST AND REPLICATE#2

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
36	5.6	21.4	2.646	2.52	2.286	0	0	4
39	6.9	21.4	2.79	2.682	2.394	-1	-1	3
44	8.8	21.4	2.97	2.826	2.502	-1	0	4
46	9.4	21.4	3.132	3.024	2.574	-3	-4	2
49	10.4	21.4	3.294	3.186	2.664	-5	-5	1
52	11.2	21.4	3.402	3.312	2.718	-5	-6	1
58	12.9	21.4	3.492	3.384	2.754	-1	-2	5
60	13.4	21.4	3.618	3.474	2.808	-3	-2	4
61	13.7	21.4	3.726	3.6	2.826	-5	-5	4
65	14.5	21.4	3.816	3.672	2.862	-3	-3	6
69	15.5	21.4	3.978	3.888	2.97	-4	-5	3
73	16.4	21.4	4.086	3.978	3.042	-3	-3	2
78	17.6	21.5	4.212	4.104	3.096	-1	-2	3
79	17.7	21.5	4.284	4.194	3.15	-2	-3	0
80	18	21.5	4.32	4.248	3.222	-2	-3	-5
84	18.7	21.5	4.302	4.194	3.276	2	2	-6
76	17.2	21.5	4.014	3.87	3.15	2	3	-3
75	16.8	21.4	3.906	3.762	3.114	4	5	-2
69	15.5	21.4	3.798	3.618	3.042	1	3	-2
68	15.3	21.4	3.672	3.492	3.006	4	5	-1
66	14.8	21.4	3.582	3.402	2.952	4	6	1
61	13.7	21.4	3.456	3.33	2.898	3	3	-1
58	12.9	21.4	3.348	3.222	2.844	3	3	0
54	11.7	21.4	3.294	3.132	2.826	0	1	-3
54	11.7	21.4	3.24	3.078	2.808	2	3	-2
51	11	21.4	3.186	3.006	2.79	0	2	-4
49	10.4	21.4	3.114	2.952	2.754	0	1	-4
43	8.5	21.4	2.844	2.736	2.646	2	1	-4
41	7.8	21.4	2.808	2.682	2.61	1	1	-4
41	7.8	21.4	2.79	2.682	2.61	1	1	-4
40	7.4	21.4	2.79	2.664	2.574	0	0	-4
40	7.2	21.4	2.718	2.574	2.502	2	2	0
38	6.4	21.4	2.7	2.538	2.466	1	1	-1
39	6.9	21.4	2.682	2.538	2.466	2	2	0

TF#1:

Regression Output:

Constant	1.353133
Std Err of Y Est	0.096141
R Squared	0.968492
No. of Observations	34
Degrees of Freedom	32

X Coefficient(s)	0.036158
Std Err of Coef.	0.001152

TF#2:

Regression Output:

Constant	1.205791
Std Err of Y Est	0.114811
R Squared	0.956337
No. of Observations	34
Degrees of Freedom	32

X Coefficient(s)	0.036449
Std Err of Coef.	0.001376

AL:

Regression Output:	
Constant	2.036724
Std Err of Y Est	0.057643
R Squared	0.949883
No. of Observations	34
Degrees of Freedom	32
X Coefficient(s)	0.062734
Std Err of Coef.	0.002547

CALIBRATION TABLE FOR 30 PPM AMMONIA, MEDIUM DUST AND REPLICATE#2

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
38	5.1	19.8	2.628	2.286	2.268	-1	1	0
39	5.6	19.8	2.808	2.592	2.358	-4	-5	-2
46	8.2	20	2.97	2.754	2.466	-1	-2	2
48	8.6	19.8	3.15	2.862	2.556	-3	-2	-1
51	9.3	19.8	3.276	3.006	2.628	-3	-3	-1
54	10.4	20	3.384	3.186	2.682	-3	-4	1
55	10.4	19.8	3.456	3.258	2.718	-3	-4	-1
59	12	20.3	3.6	3.366	2.754	-3	-3	3
60	12	20	3.69	3.402	2.79	-4	-3	2
62	12.9	20.3	3.78	3.51	2.826	-4	-3	3
64	12.9	20	3.834	3.564	2.844	-4	-2	3
67	13.9	20.3	3.942	3.708	2.88	-3	-3	5
6[illegible]	14.4	20.3	3.978	3.762	2.934	-2	-2	4
70	14.7	20.3	4.014	3.834	2.97	-2	-2	4
71	14.8	20.3	4.14	3.906	3.024	-4	-3	2
72	15.2	20.3	4.158	3.942	3.042	-3	-3	1
74	16	20.7	4.32	4.194	3.204	-5	-7	-4
75	16.1	20.7	4.32	4.194	3.204	-4	-6	-3
76	16.3	20.7	4.32	4.194	3.222	-3	-5	-4
78	16.3	20.3	4.32	4.194	3.222	-1	-3	-3
78	16.4	20.3	4.32	4.212	3.222	-1	-3	-3
79	16.9	20.7	4.32	4.23	3.24	0	-2	-2
83	17.4	20.3	4.32	4.266	3.294	4	1	-3
82	17.1	20.3	4.284	4.032	3.222	4	5	1
79	16.6	20.3	4.158	3.924	3.15	4	5	2
74	15.6	20.3	4.014	3.78	3.114	2	3	-1
73	15	20	3.924	3.618	3.06	3	5	0
70	14.4	20	3.816	3.438	3.006	3	7	0
68	13.9	20	3.69	3.384	2.97	4	6	0
67	13.9	20.3	3.582	3.33	2.898	5	6	4
61	12.6	20.3	3.474	3.24	2.862	2	2	0
60	12	20	3.402	3.15	2.844	3	3	-1
59	11.8	20	3.366	3.096	2.826	3	3	-1
58	11.8	20.3	3.294	3.042	2.79	3	4	1
56	11.2	20.3	3.258	2.97	2.772	2	3	0
53	10.5	20.3	3.204	2.916	2.754	1	1	-3
53	10.1	20	3.15	2.844	2.736	2	3	-3
51	9.9	20.3	3.06	2.808	2.7	2	2	-2
51	9.8	20.3	3.006	2.772	2.682	3	3	-1
50	9.1	19.8	2.988	2.736	2.664	3	2	-3
50	9	19.8	2.952	2.7	2.664	4	3	-3
49	9.3	20.3	2.898	2.7	2.646	4	2	-2
42	8.2	21.6	2.664	2.538	2.34	2	-1	6

TF#1:

Regression Output:

Constant	1.012247
Std Err of Y Est	0.133636
R Squared	0.937396
No. of Observations	43
Degrees of Freedom	41
X Coefficient(s)	0.041774
Std Err of Coef.	0.001686

TF#2:

Regression Output:

Constant	0.643379
Std Err of Y Est	0.161043
R Squared	0.919753
No. of Observations	43
Degrees of Freedom	41

X Coefficient(s) 0.044044
Std Err of Coef. 0.002031

AL:

Regression Output:	
Constant	1.866865
Std Err of Y Est	0.054788
R Squared	0.956956
No. of Observations	43
Degrees of Freedom	41

X Coefficient(s) 0.079562
Std Err of Coef. 0.002635

CALIBRATION TABLE FOR 30 PPM AMMONIA, HIGH DUST AND REPLICATE#2

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
36	4.7	20.4	2.574	2.43	2.232	2	3	3
36	4.8	20.4	2.61	2.466	2.25	2	2	2
37	5.4	20.4	2.79	2.718	2.304	-2	-3	1
41	6.7	20.4	2.934	2.844	2.43	-1	-2	1
45	8.2	20.4	3.114	3.042	2.52	-2	-3	2
48	9	20.4	3.2[illegible]	3.186	2.61	-2	-3	1
50	9.8	20.4	3.366	3.312	2.664	-3	-4	0
54	10.7	20.4	3.438	3.384	2.7	-1	-2	3
58	12	20.4	3.654	3.564	2.772	-2	-2	3
59	12.1	20.4	3.726	3.654	2.808	-3	-3	3
60	12.5	20.4	3.816	3.708	2.826	-4	-4	3
64	13.3	20.4	3.924	3.834	2.862	-3	-3	5
66	13.9	20.4	3.96	3.888	2.88	-2	-2	6
68	14.2	20.4	4.032	3.96	2.952	-1	-2	4
69	14.5	20.4	4.086	3.978	2.988	-2	-1	3
70	14.8	20.4	4.122	4.014	3.006	-2	-1	3
71	15	20.4	4.158	4.086	3.006	-2	-2	4
73	15.3	20.4	4.23	4.158	3.078	-1	-2	2
73	15.5	20.4	4.248	4.194	3.096	-2	-3	1
81	17.2	20.6	4.32	4.32	3.294	4	2	-3
79	16.9	20.6	4.302	4.194	3.258	3	3	-3
73	15.5	20.6	4.194	4.032	3.222	0	1	-6
72	15.3	20.6	4.014	3.924	3.15	3	3	-3
69	14.7	20.6	3.924	3.816	3.114	2	3	-3
65	13.9	20.6	3.816	3.672	3.06	1	2	-4
60	12.6	20.6	3.474	3.366	2.898	4	5	0
57	11.7	20.6	3.402	3.312	2.862	3	3	-1
54	10.9	20.6	3.294	3.186	2.826	3	3	-2
51	10.2	20.6	3.258	3.114	2.808	1	2	-5
49	9.6	20.6	3.204	3.06	2.79	0	1	-6
47	8.8	20.6	3.042	2.88	2.718	2	3	-4
45	8.3	20.6	2.862	2.772	2.664	4	4	-4
42	7.4	20.6	2.844	2.754	2.646	2	1	-6

TF#1:

Regression Output:	
Constant	1.210847
Std Err of Y Est	0.101524
R Squared	0.965296
No. of Observations	33
Degrees of Freedom	31

X Coefficient(s) 0.040599
Std Err of Coef. 0.001382

TF#2:

Regression Output:	
Constant	1.073110
Std Err of Y Est	0.113869
R Squared	0.958156
No. of Observations	33
Degrees of Freedom	31

X Coefficient(s) 0.041315
Std Err of Coef. 0.001550

AL:

Regression Output:

Constant	1.947940
Std Err of Y Est	0.071686
R Squared	0.934457
No. of Observations	33
Degrees of Freedom	31

X Coefficient(s)	0.075277
Std Err of Coef.	0.003580

CALIBRATION TABLE FOR 40 PPM AMMONIA, LOW DUST AND REPLICATE#2

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
38	5.1	19.8	2.628	2.286	2.268	-1	1	0
39	5.6	19.8	2.808	2.592	2.358	-4	-5	-2
46	8.2	20	2.97	2.754	2.466	-1	-2	2
48	8.6	19.8	3.15	2.862	2.556	-3	-2	-1
51	9.3	19.8	3.276	3.006	2.628	-3	-3	-1
54	10.4	20	3.384	3.186	2.682	-3	-4	1
55	10.4	19.8	3.456	3.258	2.718	-3	-4	-1
59	12	20.3	3.6	3.366	2.754	-3	-3	3
60	12	20	3.69	3.402	2.79	-4	-3	2
62	12.9	20.3	3.78	3.51	2.826	-4	-3	3
64	12.9	20	3.834	3.564	2.844	-4	-2	3
67	13.9	20.3	3.942	3.708	2.88	-3	-3	5
69	14.4	20.3	3.978	3.762	2.934	-2	-2	4
70	14.7	20.3	4.014	3.834	2.97	-2	-2	4
71	14.8	20.3	4.14	3.906	3.024	-4	-3	2
72	15.2	20.3	4.158	3.942	3.042	-3	-3	1
74	16	20.7	4.32	4.194	3.204	-5	-7	-4
75	16.1	20.7	4.32	4.194	3.204	-4	-6	-3
76	16.3	20.7	4.32	4.194	3.222	-3	-5	-4
78	16.3	20.3	4.32	4.194	3.222	-1	-3	-3
78	16.4	20.3	4.32	4.212	3.222	-1	-3	-3
79	16.9	20.7	4.32	4.23	3.24	0	-2	-2
83	17.4	20.3	4.32	4.266	3.294	4	1	-3
82	17.1	20.3	4.284	4.032	3.222	4	5	1
79	16.6	20.3	4.158	3.924	3.15	4	5	2
74	15.6	20.3	4.014	3.78	3.114	2	3	-1
73	15	20	3.924	3.618	3.06	3	5	0
70	14.4	20	3.816	3.438	3.006	3	7	0
68	13.9	20	3.69	3.384	2.97	4	6	0
67	13.9	20.3	3.582	3.33	2.898	5	6	4
61	12.6	20.3	3.474	3.24	2.862	2	2	0
60	12	20	3.402	3.15	2.844	3	3	-1
59	11.8	20	3.366	3.096	2.826	3	3	-1
58	11.8	20.3	3.294	3.042	2.79	3	4	1
56	11.2	20.3	3.258	2.97	2.772	2	3	0
53	10.5	20.3	3.204	2.916	2.754	1	1	-3
53	10.1	20	3.15	2.844	2.736	2	3	-3
51	9.9	20.3	3.06	2.808	2.7	2	2	-2
51	9.8	20.3	3.006	2.772	2.682	3	3	-1
50	9.1	19.8	2.988	2.736	2.664	3	2	-3
50	9	19.8	2.952	2.7	2.664	4	3	-3
49	9.3	20.3	2.898	2.7	2.646	4	2	-2
42	8.2	21.6	2.664	2.538	2.34	2	-1	6

TF#1:

Regression Output:	
Constant	1.012247
Std Err of Y Est	0.133636
R Squared	0.937396
No. of Observations	43
Degrees of Freedom	41
X Coefficient(s)	0.041774
Std Err of Coef.	0.001686

TF#2:

Regression Output:	
Constant	0.643379
Std Err of Y Est	0.161043
R Squared	0.919753
No. of Observations	43
Degrees of Freedom	41

X Coefficient(s)	0.044044
Std Err of Coef.	0.002031

AL:

Regression Output:

Constant	1.866865
Std Err of Y Est	0.054788
R Squared	0.956956
No. of Observations	43
Degrees of Freedom	41

X Coefficient(s)	0.079562
Std Err of Coef.	0.002635

CALIBRATION TABLE FOR 40 PPM AMMONIA, MEDIUM DUST AND REPLICATE#2

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
35	5.3	21.4	2.592	2.43	2.358	-1	-1	3
35	5.4	21.4	2.628	2.466	2.376	-2	-2	3
38	6.6	21.4	2.754	2.646	2.466	-2	-4	2
41	7.8	21.4	2.88	2.79	2.556	-3	-5	1
47	9.6	21.4	3.096	2.934	2.646	-3	-3	2
48	10.1	21.4	3.24	3.096	2.718	-6	-7	0
60	13.3	21.4	3.348	3.24	2.754	2	1	10
63	14.2	21.4	3.438	3.33	2.808	3	2	9
69	15.5	21.4	3.546	3.42	2.844	6	5	13
73	16.4	21.4	3.654	3.528	2.862	7	6	16
76	16.9	21.4	3.888	3.762	3.006	3	3	9
77	17.2	21.4	4.14	3.996	3.186	-3	-3	-4
79	17.7	21.4	4.266	4.158	3.24	-5	-6	-7
80	17.9	21.4	4.302	4.212	3.276	-5	-6	-10
83	18.5	21.6	4.32	4.248	3.294	-3	-4	-7
81	18.2	21.6	4.266	4.122	3.294	-3	-3	-9
73	16.4	21.4	3.78	3.564	3.096	3	5	-1
68	15.3	21.4	3.654	3.42	3.042	2	4	-2
64	14.4	21.4	3.546	3.366	3.006	1	2	-3
61	13.6	21.4	3.438	3.294	2.97	1	1	-3
58	12.9	21.4	3.384	3.24	2.898	-1	-1	-1
57	12.6	21.4	3.312	3.15	2.862	0	1	0
56	12.3	21.4	3.258	3.096	2.844	1	1	0
54	11.8	21.4	3.204	3.024	2.826	1	2	-1
51	11	21.4	3.15	2.97	2.808	-1	0	-3
48	10.1	21.4	3.078	2.88	2.79	-2	0	-5
47	9.8	21.4	3.042	2.844	2.754	-2	0	-3
47	9.6	21.4	2.988	2.826	2.754	0	0	-3
46	9.4	21.4	2.952	2.79	2.736	0	0	-3
46	9.3	21.4	2.88	2.772	2.718	2	1	-2
46	9.3	21.4	2.862	2.754	2.7	2	1	-1
45	9	21.4	2.844	2.718	2.682	2	1	-1
44	8.8	21.4	2.826	2.7	2.664	1	1	-1
44	8.6	21.4	2.808	2.682	2.664	2	1	-1
43	8.3	21.4	2.79	2.664	2.646	2	1	-2
43	8.3	21.4	2.79	2.646	2.628	2	1	-1
41	7.8	21.4	2.772	2.628	2.61	0	0	-2
41	7.5	21.4	2.754	2.61	2.61	1	0	-2
40	7.2	21.4	2.754	2.61	2.592	0	-1	-2
40	7.2	21.4	2.736	2.592	2.574	0	0	-1
39	6.9	21.4	2.718	2.574	2.574	0	-1	-2
39	6.9	21.4	2.718	2.574	2.556	0	-1	-1
39	7	21.4	2.718	2.556	2.556	0	0	-1
40	7.2	21.4	2.7	2.538	2.538	1	1	1
39	7	21.4	2.7	2.538	2.52	0	0	1
39	6.9	21.4	2.682	2.538	2.52	1	0	1
38	6.4	21.4	2.682	2.52	2.52	0	0	0
39	6.9	21.4	2.682	2.52	2.502	1	1	1
38	6.6	21.4	2.664	2.502	2.502	0	0	0
38	6.6	21.4	2.664	2.502	2.484	0	0	1
38	6.6	21.4	2.664	2.502	2.484	0	0	1
37	6.2	21.4	2.646	2.484	2.466	0	0	1

TF#1:

Regression Output:

Constant	1.350368
Std Err of Y Est	0.084741
R Squared	0.972447
No. of Observations	52
Degrees of Freedom	50

X Coefficient(s) 0.034695

Std Err of Coef. 0.000825

TF#2:

Regression Output:	
Constant	1.182952
Std Err of Y Est	0.092176
R Squared	0.968284
No. of Observations	52
Degrees of Freedom	50

X Coefficient(s) 0.035100
Std Err of Coef. 0.000898

AL:

Regression Output:	
Constant	2.128262
Std Err of Y Est	0.068793
R Squared	0.920523
No. of Observations	52
Degrees of Freedom	50

X Coefficient(s) 0.058473
Std Err of Coef. 0.002429

APPENDIX C.1: APL OUTPUTS FOR STEP INPUTS

THIN FILM SENSOR#1:

'Y=M+A+B+C+AC+BC+AB+ε' AOV5 B

A	1	0.53389	0.53389
B	2	0.08778	0.04389
C	2	1.08111	0.54056
AC	2	0.65444	0.32722
BC	4	0.52222	0.13056
AB	2	0.36111	0.18056
ERROR	4	0.59556	0.14889
TOTAL	17	3.83611	

THIN FILM SENSOR#2:

'Y=M+A+B+C+AC+BC+AB+ε' AOV5 A

A	1	0.56889	0.56889
B	2	0.19111	0.09556
C	2	1.27444	0.63722
AC	2	1.55444	0.77722
BC	4	2.43889	0.60972
AB	2	0.05778	0.02889
ERROR	4	3.71889	0.92972
TOTAL	17	9.80444	

ALUMINUM OXIDE SENSOR:

'Y=M+A+B+C+AB+BC+AC+ε' AOV5 C

A	1	1.28	1.28
B	2	0.27111	0.13556
C	2	1.78111	0.89056
AB	2	0.17333	0.08667
BC	4	2.51556	0.62889
AC	2	1.03	0.515
ERROR	4	1.68667	0.42167
TOTAL	17	8.73778	

APPENDIX C.2: DATA RELATED TO STEP RESPONSE
TIME (SECONDS) AND (RECOVERED) OUTPUT (V)

TF#1, LOW DUST, REPLICATE#1

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
6.54	0.594	4.29	0.504	3.64	0.378
8.19	0.63	5.5	0.54	5.17	0.45
9.45	0.666	6.76	0.576	6.37	0.504
10.66	0.702	8.02	0.612	7.64	0.54
11.92	0.738	9.29	0.648	8.9	0.576
13.18	0.756	10.5	0.684	10.16	0.612
15.55	0.81	11.76	0.702	13.34	0.648
16.75	0.828	13.02	0.72	13.73	0.684
18.02	0.846	14.23	0.756	15	0.702
19.55	0.846	18.46	0.81	16.26	0.72
21.75	0.882	20.22	0.828	19.14	0.738
23.46	0.882	21.48	0.828	20.22	0.756
24.72	0.9	22.69	0.846	21.42	0.774
25.98	0.9	24.76	0.846	22.69	0.774
27.19	0.918	25.22	0.864	23.95	0.792
29.61	0.918	26.42	0.864	26.31	0.792
30.82	0.918	27.69	0.864	27.58	0.792
32.08	0.918	29.76	0.864	28.78	0.81
34.15	0.918	31.31	0.882	30.05	0.81
34.61	0.936	34.28	0.9	31.31	0.81
38.45	0.954	36.09	0.9	34.77	0.828
40.21	0.954	37.3	0.9	36.74	0.828
41.42	0.954	38.56	0.9	37.74	0.828
42.68	0.954	39.83	0.9	39	0.828
45.1	0.954	41.09	0.9	40.21	0.828
46.75	0.954	42.3	0.9	42.63	0.828
47.57	0.954	43.56	0.9	43.89	0.828
48.83	0.954	44.82	0.9	45.1	0.828
50.09	0.954	47.24	0.9	46.36	0.828
51.75	0.954	49.66	0.9	47.62	0.828
53.77	0.954	51.47	0.9	50.04	0.828

TF#1, LOW DUST, REPLICATE 2

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
3.79	0.216	3.25	0.234	4.11	0.234
5	0.252	5.01	0.252	5.27	0.27
6.26	0.27	6.22	0.27	6.71	0.306
7.53	0.306	7.48	0.288	8.95	0.378
8.74	0.306	8.74	0.306	10.21	0.414
10	0.36	10.01	0.324	11.42	0.432

12.74	0.414	11.22	C.36	12.69	0.45
14.45	0.432	13.63	0.396	13.95	0.468
15.71	0.45	14.9	0.414	15.16	0.486
16.97	0.45	16.7	0.432	16.42	0.504
18.18	0.468	18.58	0.45	19.72	0.522
19.45	0.486	20.33	0.45	21.42	0.54
20.71	0.486	21.54	0.468	22.79	0.54
21.92	0.486	22.8	0.468	24	0.558
23.18	0.504	24.07	0.486	25.26	0.558
25.25	0.504	25.28	0.486	26.71	0.558
28.34	0.522	27.69	0.486	27.74	0.558
30.21	0.522	28.96	0.486	29	0.558
31.47	0.522	30.22	0.486	30.26	0.576
32.74	0.54	31.48	0.504	31.71	0.576
33.95	0.54	35.44	0.504	34	0.576
35.21	0.54	37.2	0.504	35.81	0.576
36.47	0.54	38.46	0.504	37.07	0.576
37.74	0.54	39.72	0.504	38.34	0.576
38.94	0.54	40.99	0.504	39.81	0.594
40.21	0.54	43.35	0.522	40.81	0.594
44.33	0.54	44.61	0.522	42.07	0.594
46.08	0.54	45.87	0.522	43.33	0.594
47.29	0.54	47.08	0.522	44.81	0.594
48.56	0.558	48.35	0.522	45.81	0.594
49.82	0.558	50.71	0.522	50.41	0.594

TF#1, MEDIUM DUST, REPLICATE#1

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
3.73	0.108	4.06	0.162	4.29	0.288
4.99	0.144	6.1	0.342	5.99	0.378
7.41	0.18	7.3	0.432	7.25	0.414
8.67	0.198	8.57	0.486	8.46	0.45
9.88	0.216	9.83	0.558	9.73	0.486
12.35	0.234	11.04	0.594	12.09	0.558
14.06	0.252	12.3	0.63	13.62	0.594
15.32	0.252	13.57	0.666	14.61	0.612
16.58	0.252	14.77	0.684	15.82	0.63
17.79	0.27	16.04	0.702	17.09	0.648
19.05	0.27	20.43	0.738	19.56	0.666
21.47	0.306	22.13	0.756	21.32	0.684
22.68	0.306	23.4	0.774	22.52	0.702
23.94	0.324	24.66	0.774	23.79	0.702
25.48	0.324	25.87	0.774	25.05	0.702
29.58	0.324	27.13	0.774	28.22	0.72
30.97	0.342	28.4	0.792	28.68	0.738
32.78	0.342	29.66	0.792	29.94	0.738
33.5	0.342	30.87	0.792	31.15	0.738
34.71	0.342	33.28	0.81	33.22	0.738
37.13	0.342	35.87	0.828	36.48	0.756

38.33	0.342	37.62	0.828	38.18	0.756
39.6	0.342	38.83	0.828	39.44	0.756
40.86	0.342	40.1	0.846	40.7	0.756
42.07	0.342	41.36	0.846	43.07	0.774
44.54	0.342	42.62	0.846	44.42	0.774
46.3	0.36	43.83	0.846	45.59	0.774
47.51	0.36	45.09	0.846	46.8	0.774
48.77	0.36	47.46	0.846	48.06	0.774
51.13	0.36	48.72	0.846	49.42	0.774
52.39	0.36	52.73	0.846	51.91	0.774
53.66	0.36	54.49	0.846	53.67	0.774
55.25	0.36	55.75	0.864	54.93	0.774

TF#1, MEDIUM DUST, REPLICATE#2

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
3.24	0.18	3.24	0.126	4.61	0.27
4.51	0.252	5.05	0.342	6.54	0.324
5.72	0.306	6.32	0.414	7.08	0.36
6.98	0.36	7.58	0.486	8.35	0.378
8.24	0.396	8.79	0.558	9.61	0.396
9.51	0.432	10.05	0.576	11.54	0.414
10.71	0.432	11.31	0.594	13.24	0.45
11.98	0.468	12.58	0.612	14.5	0.504
16.43	0.54	14.94	0.63	15.94	0.522
18.13	0.558	16.2	0.648	20.05	0.576
19.39	0.576	18.89	0.666	21.91	0.576
20.66	0.576	20.76	0.666	23.18	0.594
21.95	0.576	22.02	0.684	24.39	0.612
23.13	0.576	23.29	0.702	25.65	0.612
24.39	0.576	24.5	0.702	26.91	0.612
25.65	0.576	25.76	0.702	28.12	0.612
26.95	0.576	27.02	0.702	30.54	0.63
29.28	0.594	29.38	0.702	31.84	0.63
32.3	0.594	30.65	0.702	33.01	0.648
34	0.594	31.86	0.702	35.7	0.648
35.27	0.594	37	0.702	37.4	0.648
36.53	0.594	38.06	0.72	38.67	0.648
37.74	0.594	39.33	0.72	39.93	0.648
39	0.594	40.53	0.72	41.14	0.648
40.26	0.594	41.8	0.72	42.4	0.648
41.47	0.594	43.06	0.72	44.94	0.648
44.25	0.594	45.42	0.72	46.03	0.648
45.15	0.594	46.69	0.72	47.29	0.648
47.57	0.594	47.95	0.72	48.5	0.666
49.33	0.594	49.7	0.72	52.56	0.666
50.59	0.594	51.85	0.72	54.32	0.666
51.8	0.594	53.61	0.72	55.53	0.666
53.06	0.594	54.81	0.72	57.24	0.666

TF#1, HIGH DUST, REPLICATE#1

20 AMMONIA TIME	OUTPUT	30 PPM AMMONIA TIME	OUTPUT	40 PPM AMMONIA TIME	OUTPUT
4.06	0.414	4.45	0.378	5.32	0.396
5.93	0.504	5.72	0.432	7.08	0.504
7.19	0.54	6.92	0.468	8.29	0.54
8.46	0.576	8.19	0.576	9.55	0.612
9.67	0.612	9.45	0.612	11.97	0.666
10.93	0.63	10.66	0.666	13.23	0.684
12.19	0.666	11.92	0.702	14.89	0.72
14.55	0.72	14.28	0.756	15.7	0.72
16.45	0.738	15.55	0.792	16.97	0.756
17.03	0.756	18.07	0.846	18.18	0.756
19.72	0.774	19.67	0.864	20.81	0.774
21.64	0.792	20.93	0.864	22.57	0.792
22.85	0.792	22.19	0.882	23.78	0.792
24.11	0.81	23.46	0.9	26.14	0.81
25.38	0.828	24.66	0.9	27.49	0.81
26.58	0.828	25.93	0.9	28.67	0.81
29	0.828	28.34	0.918	29.93	0.828
30.26	0.828	29.55	0.918	31.14	0.828
31.53	0.846	30.82	0.936	32.49	0.828
32.74	0.846	34.5	0.936	33.66	0.828
37.02	0.864	36.2	0.936	37.84	0.828
38.72	0.864	37.41	0.936	39.6	0.828
39.93	0.864	38.67	0.936	40.92	0.828
41.19	0.864	39.93	0.936	42.18	0.828
42.46	0.864	41.14	0.936	43.39	0.828
45.45	0.864	43.56	0.954	44.65	0.828
46.03	0.864	44.82	0.954	45.91	0.828
47.29	0.864	46.09	0.954	47.12	0.846
48.55	0.864	47.29	0.954	48.38	0.846

TF#1, HIGH DUST, REPLICATE#2

20 AMMONIA TIME	OUTPUT	30 PPM AMMONIA TIME	OUTPUT	40 PPM AMMONIA TIME	OUTPUT
	0		0		0
3.13	0.216	4.17	0.324	6.63	0.468
4.4	0.27	5.71	0.414	8.5	0.54
5.6	0.306	6.97	0.432	9.76	0.54
6.87	0.324	8.23	0.45	11.03	0.558
9.34	0.36	9.44	0.468	13.39	0.576
10.55	0.396	10.71	0.486	14.65	0.594
11.81	0.432	11.97	0.486	16.4	0.594
13.07	0.45	13.18	0.504	17.12	0.612
17.36	0.504	14.44	0.504	18.39	0.612
19.28	0.522	18.01	0.54	19.65	0.612
20.49	0.54	19.93	0.54	22.29	0.63
22.29	0.54	21.2	0.54	23.99	0.63
23.01	0.558	22.46	0.558	25.25	0.63

25.38	0.576	23.72	0.558	27.67	0.648
26.64	0.576	24.93	0.558	28.93	0.648
27.9	0.576	26.19	0.576	30.14	0.648
29.11	0.576	27.46	0.576	31.4	0.648
30.37	0.576	29.3	0.576	32.67	0.648
33.01	0.594	29.93	0.576	34.6	0.648
35.49	0.594	33.7	0.576	35.14	0.648
36.03	0.594	35.2	0.576	39.2	0.648
37.24	0.594	36.47	0.576	40.96	0.648
38.5	0.594	37.73	0.576	42.22	0.648
40.87	0.594	38.99	0.576	43.49	0.648
42.13	0.594	40.2	0.576	44.7	0.648
43.34	0.594	41.46	0.576	45.96	0.648
44.6	0.612	42.73	0.576	47.22	0.648
45.86	0.612	43.94	0.576	48.49	0.648
49.87	0.612	46.35	0.576	49.69	0.648

TF#2, LOW DUST, REPLICATE#1

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
4.32	0.072	5.33	0.468	6.15	0.396
6.15	0.306	7.2	0.558	7.36	0.468
7.42	0.396	8.46	0.576	8.62	0.504
9.78	0.468	9.72	0.594	10.51	0.558
11.04	0.504	12.09	0.612	12.41	0.63
13.02	0.504	13.35	0.63	14.28	0.684
13.57	0.522	14.61	0.63	15.54	0.702
14.78	0.54	15.88	0.63	16.75	0.738
16.04	0.54	17.14	0.648	18.01	0.774
18.02	0.558	18.35	0.666	20.54	0.792
19.99	0.576	21.04	0.666	21.75	0.792
21.92	0.576	23.25	0.666	23.01	0.792
23.92	0.576	24.01	0.666	24.27	0.792
24.55	0.594	26.42	0.666	25.54	0.792
25.82	0.594	27.69	0.666	29.6	0.81
27.02	0.594	28.95	0.666	31.52	0.81
28.92	0.594	30.16	0.684	32.79	0.81
29.55	0.594	31.42	0.684	34	0.828
30.81	0.594	32.68	0.684	36.41	0.828
32.08	0.594	33.95	0.684	37.68	0.828
36.47	0.594	38.18	0.684	38.94	0.828
38.39	0.594	39.88	0.684	40.2	0.828
39.66	0.594	41.31	0.684	41.41	0.828
40.92	0.594	42.57	0.684	44.02	0.828
42.18	0.594	44.05	0.684	45.29	0.828
43.45	0.594	45.48	0.684	46.5	0.828
44.66	0.594	46.74	0.684	48.91	0.828
45.92	0.594	48	0.684	50.18	0.828

TF#2, LOW DUST, REPLICATE#2

20 AMMONIA TIME	OUTPUT	30 PPM AMMONIA TIME	OUTPUT	40 PPM AMMONIA TIME	OUTPUT
3.73	0.324	5.05	0.234	7.19	0.252
4.99	0.396	6.31	0.288	8.46	0.27
6.26	0.432	7.58	0.324	9.66	0.288
10.6	0.522	8.79	0.36	10.93	0.306
12.46	0.558	10.05	0.378	12.19	0.324
13.73	0.558	11.31	0.396	13.45	0.324
14.99	0.576	12.58	0.396	14.72	0.342
16.25	0.576	14.94	0.432	18.73	0.36
17.46	0.576	16.2	0.45	20.65	0.36
18.73	0.594	18.89	0.468	21.91	0.36
19.99	0.594	20.76	0.468	23.18	0.36
21.25	0.612	22.02	0.468	24.44	0.378
23.61	0.612	23.23	0.468	25.65	0.378
26.96	0.612	24.49	0.468	26.78	0.378
28.89	0.612	25.76	0.468	28.04	0.378
30.15	0.612	27.02	0.486	29.25	0.378
31.36	0.612	30.07	0.486	30.51	0.378
32.62	0.63	30.7	0.486	33.04	0.396
33.89	0.63	31.91	0.486	34.25	0.396
35.15	0.63	36.19	0.504	35.51	0.396
36.41	0.63	38.12	0.504	36.77	0.396
39.04	0.63	39.47	0.504	38.04	0.396
39.98	0.63	40.59	0.504	42.1	0.396
42.84	0.63	41.85	0.504	43.07	0.396
44.94	0.63	43.11	0.504	44.27	0.396
46.02	0.63	42.67	0.504	45.33	0.396
47.29	0.63	45.2	0.504	46.7	0.396
48.55	0.63	47.07	0.504	48.02	0.396

TF#2, MEDIUM DUST, REPLICATE#1

20 AMMONIA TIME	OUTPUT	30 PPM AMMONIA TIME	OUTPUT	40 PPM AMMONIA TIME	OUTPUT
3.73	0.144	3.75	0.198	3.74	0.27
4.99	0.162	5.46	0.252	5	0.306
6.2	0.198	6.72	0.27	6.21	0.342
7.47	0.234	8.7	0.288	7.74	0.36
8.67	0.252	9.19	0.324	9.89	0.414
11.27	0.252	10.45	0.36	11.1	0.432
13.4	0.27	12.82	0.396	14.94	0.504
15.37	0.27	14.08	0.432	17.34	0.504
16.36	0.27	15.34	0.45	17.74	0.522
17.57	0.27	16.55	0.45	19.01	0.522
18.83	0.288	18.8	0.468	20.27	0.522
20.37	0.288	20.56	0.486	21.84	0.522
21.31	0.288	21.82	0.504	22.74	0.522
22.57	0.288	23.03	0.504	25.1	0.522
24.93	0.288	24.29	0.522	26.37	0.522
26.19	0.288	26.66	0.522	27.57	0.522

30.04	0.288	28.1	0.54	29.55	0.522
31.8	0.288	29.13	0.54	31.2	0.522
33.06	0.288	30.39	0.54	32.41	0.522
34.27	0.288	31.65	0.54	33.67	0.522
35.53	0.288	35.44	0.54	34.94	0.522
36.8	0.288	37.2	0.54	36.14	0.522
38	0.288	38.41	0.558	39.14	0.522
40.42	0.288	39.67	0.576	39.77	0.522
41.63	0.288	42.04	0.576	41.03	0.522
42.89	0.288	43.3	0.576	42.24	0.522
45.77	0.288	44.51	0.576	45.81	0.522

TF#2, MEDIUM DUST, REPLICATE#1

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
3.62	0.09	3.73	0.144	6.16	0.126
4.89	0.108	5	0.162	7.98	0.18
6.15	0.162	6.21	0.18	9.07	0.198
7.36	0.198	7.47	0.216	10.27	0.216
8.62	0.198	8.73	0.216	11.54	0.234
9.88	0.234	11.45	0.252	12.98	0.252
12.19	0.27	14.65	0.288	14.06	0.27
13.89	0.27	15.93	0.288	15.33	0.27
15.32	0.306	17.19	0.306	16.54	0.288
16.58	0.306	18.45	0.306	18.95	0.288
17.85	0.324	19.66	0.324	21.75	0.288
19.06	0.324	20.93	0.324	23.4	0.324
20.32	0.342	22.19	0.342	24.67	0.324
21.58	0.342	23.4	0.342	25.93	0.324
22.79	0.342	25.81	0.36	27.19	0.324
24.05	0.342	27.35	0.36	28.4	0.324
27.9	0.36	29.6	0.36	29.66	0.342
29.71	0.378	31.47	0.378	30.93	0.342
30.92	0.378	32.68	0.378	33.34	0.342
32.18	0.378	33.94	0.378	34.55	0.342
34.08	0.378	35.21	0.378	37.58	0.36
34.65	0.378	36.41	0.378	38.56	0.36
35.92	0.378	37.68	0.378	40.18	0.36
37.18	0.378	40.04	0.378	41.09	0.36
38.48	0.378	41.25	0.378	42.35	0.36
39.65	0.414	42.51	0.378	43.61	0.36
43.66	0.414	46.47	0.378	45.18	0.36

TF#2, HIGH DUST, REPLICATE#1

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
4.39	0.522	4.12	0.324	3.74	0.36
5.33	0.594	5.38	0.396	5	0.45
6.59	0.63	6.92	0.468	6.21	0.54

7.86	0.684	7.91	0.54	7.47	0.558
9.07	0.72	9.12	0.576	8.74	0.576
10.33	0.756	10.38	0.576	9.95	0.594
12.69	0.81	11.82	0.594	12.36	0.612
14.78	0.846	12.85	0.612	14.17	0.63
16.43	0.864	14.12	0.612	14.89	0.63
17.69	0.882	16.92	0.63	19.07	0.648
18.9	0.882	19.44	0.648	20.27	0.648
20.79	0.918	21.15	0.648	21.53	0.666
21.42	0.918	22.41	0.666	22.74	0.666
22.69	0.918	24.12	0.666	24.01	0.666
23.9	0.936	24.94	0.666	25.27	0.666
26.26	0.954	26.14	0.666	28.17	0.666
27.52	0.954	27.41	0.666	28.84	0.666
29.44	0.972	29.12	0.684	30.1	0.666
31.69	0.972	31.03	0.684	31.37	0.666
32.35	0.99	32.3	0.684	33.89	0.684
33.62	0.99	34.55	0.684	35.54	0.684
34.88	0.99	36.25	0.684	36.8	0.684
36.09	1.008	37.51	0.684	38.07	0.684
37.35	1.008	38.78	0.684	39.28	0.684
39.77	1.008	40.04	0.684	41.69	0.684
41.03	1.008	41.25	0.684	42.96	0.684
42.24	1.008	42.51	0.684	44.16	0.684
45.37	1.008	44.93	0.684	45.43	0.684
47.02	1.008	46.14	0.684	46.69	0.684
48.28	1.008	47.4	0.684	50.54	0.666
49.55	1.008	51.25	0.684	52.24	0.666
50.81	1.008	53	0.684	53.5	0.666
52.02	1.008	54.21	0.684	54.71	0.666
53.28	1.008	55.47	0.684	57.13	0.666

TF#2, HIGH DUST, REPLICATE#2

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
4.17	0.162	3.9	0.216	3.18	0.342
6.59	0.198	5.54	0.324	4.45	0.378
8.12	0.198	6.81	0.36	5.65	0.432
9.11	0.234	8.07	0.414	6.92	0.45
10.32	0.27	9.28	0.432	8.18	0.468
11.59	0.288	11.69	0.468	9.44	0.504
13.12	0.306	12.96	0.486	10.65	0.504
16.53	0.342	14.17	0.504	11.92	0.522
18.23	0.36	15.7	0.504	15.98	0.558
19.5	0.36	16.69	0.504	17.63	0.558
20.7	0.378	19.16	0.522	19.52	0.558
23.12	0.378	20.87	0.54	20.1	0.558
24.33	0.378	22.08	0.54	21.36	0.558
25.59	0.378	23.34	0.54	22.63	0.576
27.22	0.378	25.76	0.54	24.52	0.576
28.12	0.396	27.02	0.54	25.15	0.576

29.33	0.396	28.23	0.558	26.36	0.594
31.58	0.414	30.3	0.558	28.72	0.594
33.34	0.414	30.75	0.558	31.58	0.63
34.6	0.414	32.02	0.558	33.23	0.63
36.96	0.414	35.86	0.576	34.43	0.594
38.22	0.414	37.62	0.576	35.7	0.63
39.43	0.414	38.83	0.594	36.96	0.63
40.7	0.414	41.24	0.594	38.22	0.63
41.96	0.432	42.51	0.594	39.49	0.648
43.22	0.432	43.72	0.594	40.7	0.648
44.43	0.432	44.98	0.612	43.11	0.63
48.28	0.432	46.24	0.612	44.38	0.63
50.03	0.432	47.51	0.612	46.52	0.648
51.41	0.432	48.71	0.612	48.17	0.648
52.67	0.432	51.13	0.612	49.43	0.63
54.42	0.432	52.89	0.612	50.69	0.63
55.14	0.432	54.37	0.612	51.96	0.648
56.41	0.432	55.64	0.612	53.22	0.648

AL , LOW DUST, REPLICATE#1

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
4.62	0.432	4.34	0.036	3.32	0.126
5.88	0.432	6.21	0.126	4.53	0.162
7.09	0.648	7.42	0.126	5.79	0.162
8.35	0.648	[illegible].68	0.18	7.06	0.198
9.56	0.864	11.1	0.216	8.27	0.198
10.82	0.864	12.36	0.216	11.84	0.234
13.3	0.954	13.57	0.234	13.48	0.234
14.56	1.026	14.83	0.27	15.5	0.234
15.77	1.098	16.1	0.27	15.95	0.27
20.11	1.206	17.31	0.288	18.32	0.306
21.97	1.188	20	0.288	19.58	0.324
23.24	1.224	22.04	0.306	20.84	0.324
24.86	1.314	23.13	0.306	22.05	0.342
25.76	1.314	25.54	0.324	23.31	0.342
26.97	1.368	26.81	0.324	24.58	0.36
29.39	1.404	28.02	0.324	26.5	0.36
30.65	1.404	29.28	0.324	28.15	0.36
31.86	1.44	30.54	0.324	29.41	0.378
33.12	1.476	31.75	0.324	31.77	0.378
35.98	1.512	33.01	0.342	33.04	0.396
37.68	1.53	37.3	0.378	34.3	0.396
38.95	1.548	39.17	0.396	35.51	0.396
40.15	1.548	40.43	0.396	36.77	0.396
41.42	1.548	42.94	0.396	38.04	0.414
43.78	1.584	44.05	0.414	39.24	0.414
45.04	1.584	45.32	0.414	42.81	0.414
46.31	1.602	46.58	0.414	44.46	0.414
47.96	1.602	47.79	0.432	45.83	0.432
48.78	1.62	49.05	0.432	47.1	0.432
53.06	1.638	50.32	0.432	48.31	0.432

AL , LOW DUST, REPLICATE#2

20 AMMONIA TIME	OUTPUT	30 PPM AMMONIA TIME	OUTPUT	40 PPM AMMONIA TIME	OUTPUT
4.34	0.036	5.39	0.072	4.18	0.108
6.21	0.036	7.36	0.126	5.39	0.126
7.47	0.054	8.63	0.162	7.8	0.144
8.68	0.072	9.83	0.162	9.07	0.144
11.1	0.072	11.1	0.198	10.27	0.18
12.31	0.072	12.36	0.216	11.54	0.198
13.93	0.09	13.57	0.216	12.8	0.198
14.83	0.09	14.83	0.234	15.05	0.216
16.04	0.108	16.1	0.234	16.76	0.234
17.3	0.108	18.46	0.234	18.02	0.27
20	0.108	21.15	0.252	19.23	0.27
21.92	0.126	23.18	0.252	21.64	0.27
23.13	0.126	24.45	0.27	22.91	0.288
25.49	0.126	25.71	0.27	24.12	0.288
26.75	0.144	27.46	0.27	25.38	0.288
28.02	0.144	28.18	0.27	26.64	0.288
29.22	0.144	29.44	0.27	28.3	0.288
30.49	0.144	30.65	0.288	31.53	0.288
31.75	0.144	32.46	0.288	33.23	0.306
33.01	0.144	35.16	0.288	34.5	0.306
37.24	0.144	38.29	0.306	35.76	0.306
39.17	0.144	40.32	0.306	38.12	0.306
40.65	0.144	41.58	0.306	39.38	0.306
41.91	0.162	42.79	0.306	40.65	0.306
43.12	0.162	44.05	0.306	42.4	0.306
44.38	0.162	45.32	0.324	43.12	0.306
45.65	0.162	46.58	0.324	44.38	0.306
46.85	0.162	47.79	0.324	46.63	0.306
48.12	0.162	50.21	0.324	48.39	0.306
49.38	0.162	51.41	0.324	49.6	0.306

AL , MEDIUM DUST, REPLICATE#1

20 AMMONIA TIME	OUTPUT	30 PPM AMMONIA TIME	OUTPUT	40 PPM AMMONIA TIME	OUTPUT
3.79	0.09	3.68	0.108	3.74	0.036
6.1	0.126	4.94	0.108	7.91	0.036
6.64	0.198	6.2	0.144	9.37	0.036
7.91	0.306	7.41	0.144	10.49	0.036
10.27	0.396	8.68	0.18	11.76	0.054
11.53	0.396	9.94	0.18	13.02	0.054
12.79	0.45	13.62	0.216	14.37	0.072
14	0.45	15.63	0.216	15.49	0.072
15.27	0.522	16.64	0.216	16.75	0.072
16.53	0.558	17.9	0.216	18.02	0.072
18.84	0.594	19.11	0.234	20.71	0.072
20.48	0.594	20.37	0.234	23.45	0.072

21.75	0.63	21.64	0.288	25.21	0.09
24.11	0.648	22.85	0.288	26.48	0.09
26	0.666	24.11	0.306	27.74	0.09
26.63	0.666	25.37	0.324	28.95	0.09
27.84	0.702	27.84	0.324	30.21	0.09
29.11	0.702	29.66	0.324	31.47	0.09
31	0.702	30.92	0.342	32.68	0.09
31.63	0.702	32.18	0.342	35.1	0.09
35.53	0.738	33.45	0.342	37.17	0.09
37.18	0.738	34.66	0.36	38.72	0.09
38.55	0.756	35.92	0.36	40.77	0.09
39.76	0.756	37.18	0.36	41.58	0.09
41.03	0.756	38.39	0.36	42.84	0.09
42.29	0.756	39.65	0.36	44.05	0.09
43.5	0.774	43.88	0.36	45.67	0.09
44.76	0.774	45.59	0.378	46.58	0.108
46.02	0.774	46.85	0.378	48.94	0.108
47.29	0.774	48.06	0.378	50.2	0.108
49.7	0.774	50.13	0.396	51.47	0.108
51.57	0.792	50.58	0.396	55.37	0.108
52.78	0.792	51.85	0.396	57.01	0.108
54.04	0.792	53.06	0.396	58.37	0.108

AL , MEDIUM DUST, REPLICATE#2

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
3.73	0.108	3.23	0.09	4.12	0.126
4.94	0.162	4.34	0.09	5.38	0.162
6.2	0.162	5.61	0.126	6.91	0.162
7.46	0.162	6.82	0.126	7.85	0.18
9.48	0.162	8.08	0.162	10.27	0.198
9.94	0.18	9.34	0.216	11.53	0.198
14.48	0.198	10.55	0.216	12.8	0.216
15.32	0.198	11.81	0.234	16.75	0.252
16.53	0.198	14.23	0.234	18.56	0.27
18.89	0.216	16.33	0.234	19.77	0.27
20.15	0.216	17.36	0.234	21.03	0.306
21.42	0.216	18.62	0.252	22.3	0.306
22.68	0.234	19.83	0.252	23.51	0.306
23.89	0.234	21.1	0.252	25.92	0.324
25.15	0.234	22.36	0.252	27.19	0.324
26.41	0.234	23.57	0.27	28.45	0.324
28.89	0.234	24.83	0.27	30.11	0.324
30.68	0.252	26.04	0.27	32.07	0.324
31.91	0.252	30.43	0.288	34.21	0.324
33.12	0.252	31.92	0.288	34.93	0.324
34.38	0.252	33.63	0.288	36.19	0.324
36.18	0.252	34.39	0.288	37.4	0.324
36.85	0.252	35.65	0.288	39.82	0.324
38.11	0.252	36.86	0.288	41.08	0.324
39.38	0.252	38.12	0.306	42.35	0.324

40.58	0.27	39.39	0.306	43.55	0.342
44.48	0.27	40.59	0.306	44.82	0.342
46.3	0.27	43.01	0.306	48.55	0.342
47.51	0.27	45.87	0.306	50.2	0.342
48.77	0.27	47.46	0.306	51.46	0.342
50.03	0.27	48.72	0.306	53.21	0.342
51.3	0.27	49.93	0.306	55.03	0.342
52.5	0.27	51.83	0.324	56.3	0.342
53.77	0.27	52.46	0.324	57.56	0.342

AL , MEDIUM DUST, REPLICATE#1

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
3.73	0.252	3.73	0.162	4.23	0.162
4.99	0.252	4.99	0.162	5.98	0.162
6.2	0.342	7.41	0.198	6.71	0.234
7.47	0.414	8.67	0.234	7.97	0.234
8.73	0.414	12.79	0.27	9.23	0.306
12.63	0.558	14.44	0.306	10.98	0.342
14.55	0.63	15.7	0.306	12.86	0.414
15.81	0.63	16.97	0.306	14.12	0.414
17.02	0.684	18.9	0.306	15.38	0.486
18.29	0.684	19.44	0.324	19.34	0.558
19.55	0.72	20.7	0.324	21.15	0.576
20.76	0.774	23.06	0.342	22.36	0.612
22.02	0.774	24.33	0.342	23.62	0.648
23.28	0.792	25.59	0.36	24.89	0.648
24.49	0.792	28.3	0.36	26.09	0.666
27.07	0.828	29.76	0.378	28.51	0.702
28.89	0.846	31.03	0.378	29.77	0.702
30.15	0.882	32.29	0.378	31.04	0.72
31.81	0.882	33.5	0.378	32.25	0.72
32.62	0.882	34.76	0.378	34.83	0.756
33.88	0.918	36.03	0.378	36.64	0.756
35.15	0.918	38.44	0.396	37.9	0.774
36.81	0.918	39.65	0.396	39.11	0.774
37.62	0.918	40.91	0.396	40.37	0.774
38.88	0.936	44.98	0.414	42.74	0.774
43.06	0.954	46.68	0.414	44	0.792
44.76	0.954	47.95	0.432	45.26	0.792
45.97	0.954	49.6	0.432	47.28	0.81
47.23	0.972	50.42	0.45	47.73	0.81
48.49	0.972	51.68	0.45	51.69	0.828

AL , HIGH DUST, REPLICATE#2

20 AMMONIA		30 PPM AMMONIA		40 PPM AMMONIA	
TIME	OUTPUT	TIME	OUTPUT	TIME	OUTPUT
3.63	0.054	4.23	0.144	3.09	0.054
4.84	0.09	6.7	0.144	4.35	0.054

7.2	0.108	7.91	0.162	5.61	0.072
9.01	0.126	9.17	0.162	6.88	0.072
10.27	0.126	10.44	0.18	8.08	0.09
11.48	0.144	11.65	0.18	9.35	0.09
12.75	0.144	12.91	0.18	13.52	0.108
14.01	0.144	16.92	0.216	15.17	0.108
15.22	0.144	18.68	0.216	17.3	0.126
17.63	0.162	19.89	0.216	17.75	0.126
18.84	0.18	22.3	0.234	18.96	0.144
20.11	0.18	23.51	0.234	20.22	0.144
24.01	0.198	25.31	0.234	22.3	0.144
25.83	0.198	25.98	0.252	22.69	0.144
26.92	0.216	27.25	0.252	23.96	0.144
28.12	0.216	28.51	0.252	25.22	0.144
29.39	0.216	29.81	0.252	27.69	0.144
30.83	0.216	32.19	0.252	29.5	0.162
31.86	0.234	33.89	0.252	30.77	0.162
34.28	0.234	35.15	0.27	32.03	0.162
35.48	0.252	37.57	0.27	33.24	0.162
36.75	0.252	39.41	0.27	34.5	0.162
39.27	0.252	40.04	0.27	35.77	0.162
40.92	0.252	41.31	0.288	36.97	0.18
42.13	0.252	42.51	0.288	38.24	0.18
44.93	0.252	44.99	0.288	43.68	0.18
45.87	0.252	49	0.288	45.7	0.18
48.[illegible]8	0.252	51.11	0.288	46.64	0.18
49.49	0.252	52.13	0.288	47.9	0.18
43.39	0.252	44.41	0.288	39.5	0.18

APPENDIX C.3: APL OUTPUT FOR REGRESSION EQUATIONS FOR STEP RESPONSE OF THE SENSORS

THIN-FILM SENSOR #1

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      ⍝20 PPM AMMONIA, LOW DUST, REPLICATE 1
      SIMRE M19
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                          COEFFICIENTS              R*2

 (2) Y=A+BX              .6062404221    .0104477192     .861
 (3) Y=A EXP(BX)         .6195520956    .0132346523     .825
 (4) Y=1/(A+BX)         1.5913879578   ¯.0169789881     .785
 (5) Y=A+B/X            1.0156226774  ¯3.0921009657     .975
 (6) Y=A+B LOG(X)        .2210992417    .2064292198     .971
 (7) Y=AX*B              .3765718901    .2648799625     .955
 (8) Y=X/(A+BX)         5.3042988542    .9094530290     .991
 (9) Y=A+BX+CX*2         .4240911007    .0308793446     .984
                        ¯.0004672893    .0000000000
(10) Y=A+BX+CX*2+DX*3    .2964376776    .0535473785     .996
                        ¯.0016058432    .0000170203

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

EQUATION(S) (1) CANNOT BE FIT



      M20 M20[⍳20;1,2]

      ⍝30 PPM AMMONIA, LOW DUST, REPLICATE 1
      SIMRE M20
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                          COEFFICIENTS              R*2

 (2) Y=A+BX              .5246447399    .0127033452     .902
 (3) Y=A EXP(BX)         .5393165440    .0177514181     .863
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 (4)  Y=1/(A+BX)              1.8239361254  ¯.0252767193     .816
 (5)  Y=A+B/X                  .9258285568 ¯2.1581430390     .932
 (6)  Y=A+B LOG(X)             .2074814599   .2000216682     .990
 (7)  Y=AX*B                   .3415455555   .2844663532     .981
 (8)  Y=X/(A+BX)              4.6375228607   .9987999561     .983
 (9)  Y=A+BX+CX*2              .3886013716   .0320914112     .992
                              ¯.0005234122   .0000000000
(10)  Y=A+BX+CX*2+DX*3         .3188685138   .0477330302     .998
                              ¯.0014553915   .0000161299

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3


EQUATION(S) (1) CANNOT BE FIT

      M21 M21[⍳21;1,2]

      ⍝40 PPM AMMONIA, LOW DUST, REPLICATE 1
      SIMRE M21
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                         COEFFICIENTS                R*2

 (2)  Y=A+BX                   .4495804234   .0130652670     .864
 (3)  Y=A EXP(BX)              .4610214806   .0207870817     .798
 (4)  Y=1/(A+BX)              2.1470149106  ¯.0342464786     .716
 (5)  Y=A+B/X                  .8518212811 ¯2.0227945954     .936
 (6)  Y=A+B LOG(X)             .1293559281   .2040669783     .987
 (7)  Y=AX*B                   .2700547569   .3338965975     .964
 (8)  Y=X/(A+BX)              6.0080430747  1.0361941263     .997
 (9)  Y=A+BX+CX*2              .2951090618   .0350692137     .985
                              ¯.0005927005   .0000000000
(10)  Y=A+BX+CX*2+DX*3         .2134620851   .0544455071     .996
                              ¯.0017808355   .0000208545

BEST FIT EQUATION IS  (8) Y=X/(A+BX)

EQUATION(S) (1) CANNOT BE FIT
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      M22 M22[⍳20;1,2]

      ⍝20 PPM AMMONIA. LOW DUST. REPLICATE 2
      SIMRE  M22
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
 EQUATION                              COEFFICIENTS                    R*2

  (2) Y=A+BX                       .2393070003   .0105202473          .876
  (3) Y=A EXP(BX)                  .2526014926   .0275911599          .813
  (4) Y=1/(A+BX)                  3.8716508458  ¯.0759022290          .738
  (5) Y=A+B/X                      .5528852333 ¯1.5479782156          .908
  (6) Y=A+B LOG(X)               ¯.0053887765   .1589907592          .981
  (7) Y=AX*B                       .1285554640   .4294340882          .966
  (8) Y=X/(A+BX)                 12.6526835195  1.4864146259          .982
  (9) Y=A+BX+CX*2                  .1239501486   .0272559989          .990
                                  ¯.0004615104   .0000000000
 (10) Y=A+BX+CX*2+DX*3             .0852992906   .0368147105          .993
                                  ¯.0010723409   .0000111160

 BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

      M23 M23[⍳20;1,2]

      ⍝30 PPM AMMONIA LOW DUST. REPLICATE 2
      SIMRE 23
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW
DATA ERROR (⍴X≠⍴Y)
      SIMRE M23
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                              COEFFICIENTS                    R*2

  (2) Y=A+BX                       .2331316885   .0097192446          .914
  (3) Y=A EXP(BX)                  .2476073227   .0262688228          .875
  (4) Y=1/(A+BX)                  3.9189165939  ¯.0734905877          .825
  (5) Y=A+B/X                      .5032454294 ¯1.1768917884          .813
  (6) Y=A+B LOG(X)                 .0334935063   .1372686099          .969
  (7) Y=AX*B                       .1409060451   .3800028414          .973
  (8) Y=X/(A+BX)                  9.8978199011  1.7908113877          .908
  (9) Y=A+BX+CX*2                  .1464744534   .0230091523          .991
                                  ¯.0003811919   .0000000000
 (10) Y=A+BX+CX*2+DX*3             .1589095228   .0198146463          .992
                                  ¯.0001689715  ¯.0000040295

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3
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      M24 M24[⍳25;1,2]

      ⍝40 PPM AMMONIA, LOW DUST, REPLICATE 2
      SIMRE M24
   ⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW

ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                          COEFFICIENTS                 R*2

 (2) Y=A+BX                 .3122332244    .0083462516      .796
 (3) Y=A EXP(BX)            .3151696917    .0193815484      .712
 (4) Y=1/(A+BX)            3.1896798901   ¯.0474726454      .616
 (5) Y=A+B/X                .6194548812  ¯1.8386791588      .958
 (6) Y=A+B LOG(X)           .0350212167    .1574515647      .964
 (7) Y=AX*B                 .1596936627    .3779847150      .922
 (8) Y=X/(A+BX)           12.0962086125   1.3316840125      .991
 (9) Y=A+BX+CX*2            .1637805519    .0262991130      .973
                          ¯.0004103732    .0000000000
(10) Y=A+BX+CX*2+DX*3       .0667012954    .0462177092      .997
                          ¯.0014636779    .0000159111

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

EQUATION(S) (1) CANNOT BE FIT

      M25 M25[⍳17;1,2]

      ⍝20 PPM AMMONIA, MEDIUM DUST, REPLICATE 1
      SIMRE M25
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW

ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                          COEFFICIENTS                 R*2

 (1) Y=AX                   .0137767975    .0000000000      .267
 (2) Y=A+BX                 .1223577207    .0078250352      .928
 (3) Y=A EXP(BX)            .1361653970    .0346445342      .834
 (4) Y=1/(A+BX)            7.1086313197   ¯.1658830123      .696
 (5) Y=A+B/X                .3363068226   ¯.9799478916      .879
 (6) Y=A+B LOG(X)          ¯.0368099866    .1087356444      .984
 (7) Y=AX*B                 .0631836086    .5050959686      .973
 (8) Y=X/(A+BX)           25.4758345895   2.1736879126      .991
 (9) Y=A+BX+CX*2            .0694861195    .0157515135      .980
                          ¯.0002315895    .0000000000
(10) Y=A+BX+CX*2+DX*3       .0465404247    .0216305696      .982
                          ¯.0006248739    .0000075314
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M25 M25[⍳27;1,2]

⍝20 PPM AMMONIA, MEDIUM DUST, REPLICATE 1
SIMRE M25
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW

ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(2) Y=A+BX	.1653785811	.0048603801	.837
(3) Y=A EXP(BX)	.1687707044	.0197424995	.735
(4) Y=1/(A+BX)	5.9771260743	¯.0868910543	.593
(5) Y=A+B/X	.3572693408	¯1.1187635011	.887
(6) Y=A+B LOG(X)	¯.0144305669	.0992777304	.977
(7) Y=AX*B	.0765376619	.4231694235	.944
(8) Y=X/(A+BX)	25.1471246439	2.2218290294	.992
(9) Y=A+BX+CX*2	.0820151222	.0139233156	.981
	¯.0001816758	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.0554549503	.0189896194	.987
	¯.0004238036	.0000032582	

```
BEST FIT EQUATION IS  (8) Y=X/(A+BX)

⍝30 PPM AMMONIA, MEDIUM DUST, REPLICATE 1
SIMRE M26
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW

ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(2) Y=A+BX	.4713254120	.0088483472	.679
(3) Y=A EXP(BX)	.4450216769	.0155380123	.501
(4) Y=1/(A+BX)	2.4941174341	¯.0326022751	.305
(5) Y=A+B/X	.9085318705	¯3.2894969696	.989
(6) Y=A+B LOG(X)	.0076581082	.2268291727	.911
(7) Y=AX*B	.1816428017	.4241310895	.762
(8) Y=X/(A+BX)	16.6621356587	.6326894106	.839
(9) Y=A+BX+CX*2	.2438637774	.0300572996	.896
	¯.0003614168	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.0306366632	.0641388361	.963
	¯.0017043523	.0000148786	

```
BEST FIT EQUATION IS  (5) Y=A+B/X
```

```
      ⍝40 PPM AMMONIA, MEDIUM DUST, REPLICATE 1
      SIMRE M27
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(2) Y=A+BX	.4040341562	.0103164222	.799
(3) Y=A EXP(BX)	.4089004245	.0183768706	.711
(4) Y=1/(A+BX)	2.4561574680	¯.0345833914	.604
(5) Y=A+B/X	.8068663828	¯2.5813034895	.956
(6) Y=A+B LOG(X)	.0246267883	.2077325928	.968
(7) Y=AX*B	.2000477906	.3832408564	.923
(8) Y=X/(A+BX)	10.1395475394	1.0093054090	.992
(9) Y=A+BX+CX*2	.2134823786	.0318367340	.973
	¯.0004594366	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.0872455296	.0561612081	.997
	¯.0016695608	.0000171296	

```
BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

EQUATION(S) (1) CANNOT BE F[illegible]

      M28 M28[⍳18;1,2]

      ⍝20 PPM AMMONIA, MEDIUM DUST, REPLICATE 2
      SIMRE M28
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(1) Y=AX	.0265150269	.0000000000	.017
(2) Y=A+BX	.2502541351	.0141029303	.845
(3) Y=A EXP(BX)	.2600616790	.0348538639	.745
(4) Y=1/(A+BX)	3.8496348536	¯.0939584658	.607
(5) Y=A+B/X	.6342183034	¯1.6780894614	.952
(6) Y=A+B LOG(X)	¯.0188853240	.1907147381	.975
(7) Y=AX*B	.1275887064	.4894637124	.926
(8) Y=X/(A+BX)	13.3937524780	1.0814936877	.980
(9) Y=A+BX+CX*2	.0870032528	.0423254249	.985
	¯.0008916926	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.0050405001	.0648474572	.995
	¯.0024918175	.0000327057	

```
      M29 M29[⍳22;1,2]

      ⍝30 PPM AMMONIA, MEDIUM DUST, REPLICATE 2
      SIMRE M29
  ⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


  ENTER FOR:
  BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
  ⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(2) Y=A+BX	.3919294673	.0110888929	.621
(3) Y=A EXP(BX)	.3581585849	.0245658852	.438
(4) Y=1/(A+BX)	3.2608109934	¯.0686141510	.267
(5) Y=A+B/X	.7781306530	¯2.1432183326	.994
(6) Y=A+B LOG(X)	.0475321559	.2013073311	.869
(7) Y=AX*B	.1534873493	.4763741805	.699
(8) Y=X/(A+BX)	18.0595630980	.4863911754	.792
(9) Y=A+BX+CX*2	.1748432794	.0402726803	.866
	¯.0007251807	.0000000000	
(10) Y=A+BX+CX*2+DX*3	¯.0630564358	.0935649832	.960
	¯.0037232897	.0000476919	

```
  BEST FIT EQUATION IS  (5) Y=A+B/X

  EQUATION(S) (1) CANNOT BE FIT


      M30 M30[⍳29;1,2]

      ⍝40 PPM AMMONIA, MEDIUM DUST, REPLICATE 2
      SIMRE M30
  ⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


  ENTER FOR:
  BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
  ⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(2) Y=A+BX	.3532552437	.0076681916	.806
(3) Y=A EXP(BX)	.3579535683	.0156132787	.746
(4) Y=1/(A+BX)	2.7911644350	¯.0332058898	.670
(5) Y=A+B/X	.6947889228	¯2.3767771209	.933
(6) Y=A+B LOG(X)	.0231725139	.1722187441	.961
(7) Y=AX*B	.1776266538	.3598555127	.937
(8) Y=X/(A+BX)	11.6153085193	1.2367533107	.988
(9) Y=A+BX+CX*2	.1935635778	.0240116158	.984
	¯.0003085668	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.1248871354	.0360200896	.993
	¯.0008365829	.0000065821	

```
BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3
```

```
      ⍝20 PPM AMMONIA, HIGH DUST, REPLICATE 1
      SIMRE M31
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                         COEFFICIENTS                R*2

 (2) Y=A+BX                    .4835756838   .0123668900    .866
 (3) Y=A EXP(BX)               .4960277263   .0185327946    .805
 (4) Y=1/(A+BX)               1.9919675806  ¯.0286040044    .729
 (5) Y=A+B/X                   .8913977127 ¯2.2707477882    .937
 (6) Y=A+B LOG(X)              .1393968388   .2079698551    .986
 (7) Y=AX*B                    .2895358211   .3196977994    .965
 (8) Y=X/(A+BX)               5.8990866398  1.0008392795    .996
 (9) Y=A+BX+CX*2               .3255328143   .0332745650    .985
                              ¯.0005295490   .0000000000
(10) Y=A+BX+CX*2+DX*3          .2326181878   .0532428126    .997
                              ¯.0016594668   .0000184530

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

EQUATION(S) (1) CANNOT BE FIT
      M32 M32[⍳26;1,2]

      ⍝30 PPM AMMONIA, HIGH DUST, REPLICATE 1
      SIMRE M32

⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 A.  EQ NO.(1-11)
⎕:
      1 0


EQUATION                         COEFFICIENTS                R*2

 (2) Y=A+BX                    .5128151599   .0125326832    .757
 (3) Y=A EXP(BX)               .5138908548   .0180008611    .682
 (4) Y=1/(A+BX)               1.9637568672  ¯.0272508803    .598
 (5) Y=A+B/X                  1.0195695818 ¯3.3348827456    .964
 (6) Y=A+B LOG(X)              .0364904142   .2583719297    .943
 (7) Y=AX*B                    .2511137127   .3818727111    .901
 (8) Y=X/(A+BX)               8.2344738768   .7980535340    .982
 (9) Y=A+BX+CX*2               .2453350781   .0429243601    .973
                              ¯.0006432551   .0000000000
(10) Y=A+BX+CX*2+DX*3          .0902756834   .0749039625    .997
                              ¯.0022290395   .0000223094
```

```
      M33 M33[⍳28;1,2]

      ⍝40 PPM AMMONIA, HIGH DUST, REPLICATE 1
      SIMRE M33
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                           COEFFICIENTS              R*2

 (2) Y=A+BX                   .5637905689    .0071806349    .671
 (3) Y=A EXP(BX)              .5592768385    .0107530226    .600
 (4) Y=1/(A+BX)              1.8104817118   ¯.0166653093    .520
 (5) Y=A+B/X                  .9046330221  ¯2.7914497514    .991
 (6) Y=A+B LOG(X)             .2053039970    .1756925962    .889
 (7) Y=AX*B                   .3204380182    .2695496605    .834
 (8) Y=X/(A+BX)              7.2365485543    .9783747403    .958
 (9) Y=A+BX+CX*2              .3439153614    .0287068193    .936
                             ¯.0004046312    .0000000000
(10) Y=A+BX+CX*2+DX*3         .1591728763    .0595537520    .988
                             ¯.0017657759    .0000172408

BEST FIT EQUATION IS  (5) Y=A+B/X

EQUATION(S) (1) CANNOT BE FIT
      M34 M34[⍳27;1,2]

      ⍝20 PPM AMMONIA, HIGH DUST, REPLICATE 2
      SIMRE M34
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                           COEFFICIENTS              R*2

 (2) Y=A+BX                   .3087822646    .0080948585    .813
 (3) Y=A EXP(BX)              .3101531910    .0187021715    .740
 (4) Y=1/(A+BX)              3.2551160180   ¯.0458827443    .645
 (5) Y=A+B/X                  .6148306487  ¯1.5519800391    .891
 (6) Y=A+B LOG(X)             .0452516004    .1544571649    .974
 (7) Y=AX*B                   .1623017302    .3698458045    .952
 (8) Y=X/(A+BX)             10.4112343464   1.4071847067    .989
 (9) Y=A+BX+CX*2              .1748474224    .0240092965    .987
                             ¯.0003348042    .0000000000
(10) Y=A+BX+CX*2+DX*3         .1235188399    .0349580662    .996
                             ¯.0008830523    .0000076152

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3
```

```
      SIMRE M35
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                         COEFFICIENTS                R*2

 (2) Y=A+BX                    .3685538390   .0084603273    .853
 (3) Y=A EXP(BX)               .3745714412   .0179959045    .785
 (4) Y=1/(A+BX)               2.6464728030  ¯.0390301166    .704
 (5) Y=A+B/X                   .5996869288 ¯1.1622011789    .974
 (6) Y=A+B LOG(X)              .1974359776   .1158174149    .961
 (7) Y=AX*B                    .2568049446   .2515821456    .921
 (8) Y=X/(A+BX)               5.8868912740  1.5333757612    .969
 (9) Y=A+BX+CX*2               .2753372199   .0238690851    .945
                              ¯.0005012333   .0000000000
(10) Y=A+BX+CX*2+DX*3          .1715540750   .0518549286    .975
                              ¯.0026131466   .0000467813

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

EQUATION(S) (1) CANNOT BE FIT
      M36 M36[⍳14;1,2]

      ⍝40 PPM AMMONIA HIGH DUST, REPLICATE 2
      SIMRE M36
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                         COEFFICIENTS                R*2

 (2) Y=A+BX                    .4735034462   .0068803330    .853
 (3) Y=A EXP(BX)               .4794209717   .0120599399    .818
 (4) Y=1/(A+BX)               2.0668389775  ¯.0212720912    .779
 (5) Y=A+B/X                   .6903287030 ¯1.4328012420    .977
 (6) Y=A+B LOG(X)              .2892457892   .1093817292    .947
 (7) Y=AX*B                    .3453711126   .1935544481    .925
 (8) Y=X/(A+BX)               4.6084575162  1.3838243596    .966
 (9) Y=A+BX+CX*2               .3768307726   .0200281708    .949
                              ¯.0003859783   .0000000000
(10) Y=A+BX+CX*2+DX*3          .2446495445   .0485422341    .973
                              ¯.0022101478   .0000355532
```

THIN-FILM SENSOR #2

```
      ⍝20 PPM AMMONIA, LOW DUST, REPLICATE 1
      SIMRE M37
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW

ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(1) Y=AX	.0305575095	.0000000000	.256
(2) Y=A+BX	.2214922603	.0177542947	.665
(3) Y=A EXP(BX)	.1913218117	.0569150057	.453
(4) Y=1/(A+BX)	6.7708717643	¯.2674639209	.296
(5) Y=A+B/X	.7077900642	¯2.5707250985	.979
(6) Y=A+B LOG(X)	¯.1588123857	.2490509293	.856
(7) Y=AX*B	.0497898363	.8478304363	.657
(8) Y=X/(A+BX)	48.8659682557	¯1.4500784969	.692
(9) Y=A+BX+CX*2	¯.0989013411	.0708102332	.903
	¯.0017991051	.0000000000	
(10) Y=A+BX+CX*2+DX*3	¯.4909468703	.1803748625	.972
	¯.0103487521	.0001962697	

```
BEST FIT EQUATION IS  (5) Y=A+B/X


      M38 M38[⍳10;1,2]

      ⍝30 PPM AMMONIA, LOW DUST, REPLICATE 1
      SIMRE M38
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW

ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(2) Y=A+BX	.4562266128	.0118704157	.843
(3) Y=A EXP(BX)	.4650538182	.0206612215	.804
(4) Y=1/(A+BX)	2.1218966213	¯.0362718703	.761
(5) Y=A+B/X	.7265203542	¯1.3199021544	.974
(6) Y=A+B LOG(X)	.2732863233	.1347294789	.927
(7) Y=AX*B	.3363893797	.2367504880	.901
(8) Y=X/(A+BX)	4.1926018612	1.2808155679	.951
(9) Y=A+BX+CX*2	.3218207929	.0376323016	.931
	¯.0010812463	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.0056751936	.1319587758	.990
	¯.0096129235	.0002389557	

```
        ⍝40 PPM AMMONIA, LOW DUST, REPLICATE 1
        SIMRE M39
  ⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


  ENTER FOR:
  BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
  ⎕:

 EQUATION                          COEFFICIENTS                 R*2

  (2) Y=A+BX                 .4404872598    .0134502462      .777
  (3) Y=A EXP(BX)            .4544394329    .0212667059      .725
  (4) Y=1/(A+BX)            2.1688084948   ¯.0347510210      .665
  (5) Y=A+B/X                .9321254037  ¯3.4689717336      .977
  (6) Y=A+B LOG(X)          ¯.0108438567    .2499875834      .930
  (7) Y=AX*B                 .2180643728    .4024890810      .900
  (8) Y=X/(A+BX)            9.6749896528    .8517345169      .974
  (9) Y=A+BX+CX*2            .1537142169    .0484044880      .982
                            ¯.0008686915    .0000000000
 (10) Y=A+BX+CX*2+DX*3      ¯.0082148286    .0808441572      .994
                            ¯.0026963135    .0000303944

 BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

 EQUATION(S) (1) CANNOT BE FIT


       ⍝20 PPM AMMONIA, LOW DUST, REPLICATE 2
       SIMRE M40
 ⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


 ENTER FOR:
 BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
 ⎕:
       1 0


 EQUATION                          COEFFICIENTS                 R*2

  (2) Y=A+BX                 .4082859065    .0079599248      .717
  (3) Y=A EXP(BX)            .4065718271    .0161227225      .659
  (4) Y=1/(A+BX)            2.4786887271   ¯.0336000118      .598
  (5) Y=A+B/X                .6588766317  ¯1.3027478395      .989
  (6) Y=A+B LOG(X)           .1982578937    .1294232652      .931
  (7) Y=AX*B                 .2614150629    .2680211934      .896
  (8) Y=X/(A+BX)            6.0141740666   1.3802328181      .987
  (9) Y=A+BX+CX*2            .2648562479    .0280982560      .961
                            ¯.0005450345    .0000000000
 (10) Y=A+BX+CX*2+DX*3       .1755339230    .0515543597      .991
                            ¯.0020930504    .0000287193
```

```
      ⍝20 PPM AMMONIA, MEDIUM DUST, REPLICATE 1
      SIMRE M43
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION
                                 COEFFICIENTS                    R*2
 (2) Y=A+BX                   .1467592156    .0080385001        .800
 (3) Y=A EXP(BX)              .1524767746    .0372950841        .748
 (4) Y=1/(A+BX)              6.4344478778   ¯.1785410012        .693
 (5) Y=A+B/X                  .3163045223   ¯.6799427480        .959
 (6) Y=A+B LOG(X)             .0450204040    .0837022470        .916
 (7) Y=AX*B                   .0937140646    .3947592570        .885
 (8) Y=X/(A+BX)             16.1587895715   2.5458913876        .951
 (9) Y=A+BX+CX*2              .0553164002    .0283891315        .940
                             ¯.0009005933    .0000000000
(10) Y=A+BX+CX*2+DX*3        ¯.0477140729    .0642460037        .976
                             ¯.0044618548    .0001054624

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

EQUATION(S) (1) CANNOT BE FIT
      M44 M44[⍳24;1,2]

      ⍝30 PPM AMMONIA, MEDIUM DUST, REPLICATE 1
      SIMRE M44
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION
                                 COEFFICIENTS                    R*2
 (2) Y=A+BX                   .2544452380    .0092349900        .847
 (3) Y=A EXP(BX)              .2643624959    .0233832414        .768
 (4) Y=1/(A+BX)              3.7491075774   ¯.0629696657        .668
 (5) Y=A+B/X                  .5764812147  ¯1.7822285212        .886
 (6) Y=A+B LOG(X)            ¯.0301174263    .1666966923        .974
 (7) Y=AX*B                   .1228107571    .4381059630        .952
 (8) Y=X/(A+BX)             14.3958431259   1.3940543048        .981
 (9) Y=A+BX+CX*2              .1206200782    .0256209802        .983
                             ¯.0003771010    .0000000000
(10) Y=A+BX+CX*2+DX*3         .0643486432    .0374132139        .991
                             ¯.0010095386    .0000096235
```

```
      M45 M45[⍳9;1,2]

      ⍝40 PPM AMMONIA, MEDIUM DUST, REPLICATE 1
      SIMRE M45
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11): Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                          COEFFICIENTS                R*2

 (2) Y=A+BX                   .2261643132    .0172734384     .971
 (3) Y=A EXP(BX)              .2518847118    .0435356468     .942
 (4) Y=1/(A+BX)              3.7616453336   ¯.1127763023     .897
 (5) Y=A+B/X                  .5589723729  ¯1.2185949366     .907
 (6) Y=A+B LOG(X)             .0410708333    .1647747713     .986
 (7) Y=AX*B                   .1553008702    .4230167718     .993
 (8) Y=X/(A+BX)              8.5094042988   1.5067650045     .982
 (9) Y=A+BX+CX*2              .1573967795    .0329824352     .993
                             ¯.0007125953    .0000000000
(10) Y=A+BX+CX*2+DX*3         .1909320716    .0205897306     .994
                              .0005998751   ¯.0000410300

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

EQUATION(S) (1) CANNOT BE FIT

      M46 M46[⍳26;1,2]

      ⍝20 PPM AMMONIA, MEDIUM DUST, REPLICATE 2
      SIMRE M46
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11): Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                          COEFFICIENTS                R*2

 (1) Y=AX                     .0126127818    .0000000000     .197
 (2) Y=A+BX                   .1516993974    .0071028216     .829
 (3) Y=A EXP(BX)              .1543992992    .0286979312     .692
 (4) Y=1/(A+BX)              6.6990541941   ¯.1329420450     .525
 (5) Y=A+B/X                  .4054540574  ¯1.3882646250     .929
 (6) Y=A+B LOG(X)            ¯.0675915405    .1290926062     .975
 (7) Y=AX*B                   .0583941103    .5514053294     .910
 (8) Y=X/(A+BX)             33.3062416140   1.4250117890     .965
 (9) Y=A+BX+CX*2              .0434535107    .0206132797     .971
                             ¯.0003097374    .0000000000
(10) Y=A+BX+CX*2+DX*3        ¯.0225311774    .0351288925     .990
                             ¯.0011126018    .0000124803
```

```
      M47 M47[⍳18;1,2]

      ⍝30 PPM AMMONIA, MEDIUM DUST, REPLICATE 2
      SIMRE M47
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                          COEFFICIENTS                  R*2

 (1) Y=AX                      .0150216793    .0000000000     .159
 (2) Y=A+BX                    .1440901523    .0082607117     .942
 (3) Y=A EXP(BX)               .1585681779    .0321338682     .881
 (4) Y=1/(A+BX)               6.0653891524   ¯.1319339989     .800
 (5) Y=A+B/X                   .3759337403  ¯1.0541863409     .889
 (6) Y=A+B LOG(X)             ¯.0203046994    .1142735423     .991
 (7) Y=AX*B                    .0804720764    .4589892799     .989
 (8) Y=X/(A+BX)              19.2212491780   2.1591247554     .985
 (9) Y=A+BX+CX*2               .0897940431    .0166844684     .993
                              ¯.0002469553    .0000000000
(10) Y=A+BX+CX*2+DX*3          .0720279348    .0212576619     .994
                              ¯.0005476993    .0000056605

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3



      SIMRE M48
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                          COEFFICIENTS                  R*2

 (2) Y=A+BX                    .1556339731    .0061090364     .863
 (3) Y=A EXP(BX)               .1662895149    .0240846445     .761
 (4) Y=1/(A+BX)               5.8834436734   ¯.1008642311     .626
 (5) Y=A+B/X                   .3890608496  ¯1.7018131272     .979
 (6) Y=A+B LOG(X)             ¯.0583464566    .1169935271     .967
 (7) Y=AX*B                    .0685347313    .4758743857     .907
 (8) Y=X/(A+BX)              32.3618158848   1.7654742539     .943
 (9) Y=A+BX+CX*2               .0639982058    .0167656657     .958
                              ¯.0002502819    .0000000000
(10) Y=A+BX+CX*2+DX*3         ¯.0397753202    .0356025506     .984
                              ¯.0012145716    .0000146908
```

```
M49 M49[⍳23;1,2]

⍝20 PPM AMMONIA, HIGH DUST, REPLICATE 1
SIMRE M49
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                           COEFFICIENTS              R*2

 (2)  Y=A+BX                  .5959534856   .0129178839     .870
 (3)  Y=A EXP(BX)             .6076382367   .0162806471     .814
 (4)  Y=1/(A+BX)             1.6296366713  ¯.0210177424     .748
 (5)  Y=A+B/X                1.0386068386 ¯2.5231086182     .963
 (6)  Y=A+B LOG(X)            .2287776171   .2208145720     .988
 (7)  Y=AX*B                  .3758454534   .2844985151     .966
 (8)  Y=X/(A+BX)             4.5076261086   .8804528004     .997
 (9)  Y=A+BX+CX*2             .4313833392   .0344941712     .982
                             ¯.0005356513   .0000000000
(10)  Y=A+BX+CX*2+DX*3        .3102776576   .0613651776     .997
                             ¯.0020843001   .0000255478

BEST FIT EQUATION IS  (8) Y=X/(A+BX)

EQUATIO             NNOT BE FIT

                    1,2]
                    NIA, HIGH DUST, REPLICATE 1

⍝                   E FOUND IN THE VARIABLE SIMREHOW


EN
BE                 Q NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                           COEFFICIENTS              R*2

 (2)  Y=A+BX                  .4195470680   .0104874869     .725
 (3)  Y=A EXP(BX)             .4200701482   .0198289698     .644
 (4)  Y=1/(A+BX)             2.3950222567  ¯.0388867687     .560
 (5)  Y=A+B/X                 .7380775139 ¯1.7282484316     .986
 (6)  Y=A+B LOG(X)            .1682949730   .1597643571     .897
 (7)  Y=AX*B                  .2560505271   .3096290637     .838
 (8)  Y=X/(A+BX)             7.1274118485  1.1527309179     .943
 (9)  Y=A+BX+CX*2             .2355826166   .0393471080     .916
                             ¯.0008705503   .0000000000
(10)  Y=A+BX+CX*2+DX*3        .0386955064   .0892194768     .979
                             ¯.0043298730   .0000699879
```

```
      MS1 MS1[ι19;1,2]

      ⍝40 PPM AMMONIA, HIGH DUST, REPLICATE 1
      SIMRE MS1
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW

 ENTER FOR:
 BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(2) Y=A+BX	.4776145464	.0074852459	.668
(3) Y=A EXP(BX)	.4743838207	.0136035318	.597
(4) Y=1/(A+BX)	2.1288962991	¯.0253921188	.522
(5) Y=A+B/X	.7168975740	¯1.2758009512	.986
(6) Y=A+B LOG(X)	.2884483970	.1189978063	.866
(7) Y=AX*B	.3323142045	.2207720523	.806
(8) Y=X/(A+BX)	4.7481772491	1.2816860210	.926
(9) Y=A+BX+CX*2	.3414699043	.0285189078	.888
	¯.0006019826	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.1981406847	.0645864804	.952
	¯.0029646832	.0000444682	

```
BEST FIT EQUATION IS  (5) Y=A+B/X

EQUATION(S) (1) CANNOT BE FIT

      MS2 MS2[ι25;1,2]

      ⍝20 PPM AMMONIA, HIGH DUST, REPLICATE 2
      SIMRE MS2
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW

ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(2) Y=A+BX	.2022375593	.0062011562	.834
(3) Y=A EXP(BX)	.2084368720	.0204349836	.758
(4) Y=1/(A+BX)	4.7655719428	¯.0711711232	.669
(5) Y=A+B/X	.4409632486	¯1.4837002148	.893
(6) Y=A+B LOG(X)	¯.0202014433	.1228851171	.964
(7) Y=AX*B	.0962063445	.4182980000	.935
(8) Y=X/(A+BX)	19.7125730716	1.8596985731	.960
(9) Y=A+BX+CX*2	.0982827866	.0178922797	.972
	¯.0002499510	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.0392999800	.0292039710	.985
	¯.0008115278	.0000079796	

```
BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3
```

```
        M53 M53[ι2   1,2]

        ⍝30 PPM AMMONIA, HIGH DUST, REPLICATE 2

      SIMRE M53
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                          COEFFICIENTS              R*2

 (2) Y=A+BX                   .3615426413   .0062307020    .739
 (3) Y=A EXP(BX)              .3580195784   .0139460331    .614
 (4) Y=1/(A+BX)              2.8572877494  ¯.0332649504    .475
 (5) Y=A+B/X                  .6173589318 ¯1.6436508248    .982
 (6) Y=A+B LOG(X)             .1175635024   .1314314264    .933
 (7) Y=AX*B                   .1992626076   .3074880037    .846
 (8) Y=X/(A+BX)             10.7138367741  1.3664652613    .941
 (9) Y=A+BX+CX*2              .2477975215   .0187466400    .892
                             ¯.0002546877   .0000000000
(10) Y=A+BX+CX*2+DX*3         .1073956637   .0457123832    .971
                             ¯.0015571028   .0000177017

BEST FIT EQUATION IS  (5) Y=A+B/X

EQUATION(S) (1) CANNOT BE FIT

      M54 M54[ι25;1,2]

      ⍝40 PPM AMMONIA, HIGH DUST, REPLICATE 2
      SIMRE M54
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                          COEFFICIENTS              R*2

 (2) Y=A+BX                   .4099549435   .0064836859    .856
 (3) Y=A EXP(BX)              .4137023676   .0126383859    .795
 (4) Y=1/(A+BX)              2.4090335841  ¯.0251884105    .723
 (5) Y=A+B/X                  .6316437227 ¯1.0852919960    .914
 (6) Y=A+B LOG(X)             .2327239444   .1104350496    .974
 (7) Y=AX*B                   .2878518370   .2213040242    .956
 (8) Y=X/(A+BX)              4.7553955192  1.5062043921    .981
 (9) Y=A+BX+CX*2              .3436497768   .0152111483    .938
                             ¯.0002052757   .0000000000
(10) Y=A+BX+CX*2+DX*3         .2640693377   .0335490824    .975
                             ¯.0012276235   .0000159066
```

ALUMINUM OXIDE SENSOR

⍝20 *PPM AMMONIA, LOW DUST, REPLICATE* 1
*SIMRE M*1
⍝*DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW*

ENTER FOR:
BEST FIT 1 *AND EQ NO.*(0-11); Y(*EST*) 2 *AND EQ NO.*(1-11)
⎕:
1 0

EQUATION	*COEFFICIENTS*		*R**2
(1) Y=*AX*	.0404719825	.0000000000	.304
(2) Y=*A*+*BX*	.5976890309	.0235239717	.885
(3) Y=*A EXP*(*BX*)	.6311027568	.0225613839	.762
(4) Y=1/(*A*+*BX*)	1.5926298439	¯.0242358376	.604
(5) Y=*A*+*B*/*X*	1.6540872247	¯7.1015258143	.912
(6) Y=*A*+*B LOG*(*X*)	¯.3971981396	.5256007060	.990
(7) Y=*AX***B*	.2241644105	.5298488998	.942
(8) Y=*X*/(*A*+*BX*)	9.1029485703	.4036142618	.963
(9) Y=*A*+*BX*+*CX**2	.2569378279	.0572725211	.981
	¯.0006106471	.0000000000	
(10) Y=*A*+*BX*+*CX**2+*DX**3	.0876630215	.0859661586	.989
	¯.0018099259	.0000141388	

BEST FIT EQUATION IS (6) Y=*A*+*B LOG*(*X*)

⍝30 *PPM AMMONIA, LOW DUST, REPLICATE* 1
*SIMRE M*2
⍝*DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW*

ENTER FOR:
BEST FIT 1 *AND EQ NO.*(0-11); Y(*EST*) 2 *AND EQ NO.*(1-11)
⎕:
1 0

EQUATION	*COEFFICIENTS*		*R**2
(1) Y=*AX*	.0105776904	.0000000000	.552
(2) Y=*A*+*BX*	.1223529249	.0068384528	.886
(3) Y=*A EXP*(*BX*)	.1268873374	.0297082445	.612
(4) Y=1/(*A*+*BX*)	9.3175560144	¯.1874806498	.280
(5) Y=*A*+*B*/*X*	.4102238459	¯1.8887478151	.895
(6) Y=*A*+*B LOG*(*X*)	¯.1518660547	.1466200654	.97[illegible]
(7) Y=*AX***B*	.0313098695	.7045413300	.826
(8) Y=*X*/(*A*+*BX*)	84.5265732435	¯.4929999843	.753
(9) Y=*A*+*BX*+*CX**2	.0460051721	.0145722273	.942
	¯.0001463170	.0000000000	
(10) Y=*A*+*BX*+*CX**2+*DX**3	¯.0673232715	.0345528237	.981
	¯.0010451634	.0000114296	

```
      M3 M3[⍳28;1,2]

      ⍝40 PPM AMMONIA, LOW DUST, REPLICATE 1
      SIMRE M3
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                         COEFFICIENTS                 R*2

 (1) Y=AX                     .0118498503    .0000000000     .309
 (2) Y=A+BX                   .1532087567    .0068712309     .922
 (3) Y=A EXP(BX)              .1673276443    .0246586212     .849
 (4) Y=1/(A+BX)              5.8231591014   ¯.0957740175     .740
 (5) Y=A+B/X                  .4017822568  ¯1.2039806708     .773
 (6) Y=A+B LOG(X)            ¯.0525435161    .1244852631     .964
 (7) Y=AX*B                   .0748803197    .4686773057     .977
 (8) Y=X/(A+BX)             20.7727437719   2.0878074416     .951
 (9) Y=A+BX+CX*2              .0889655976    .0141561551     .984
                             ¯.0001507990    .0000000000
(10) Y=A+BX+CX*2+DX*3         .0904041878    .0138591597     .984
                             ¯.0001362059   ¯.0000001992

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

      M4 M4[⍳25;1,2]

      ⍝20 PPM AMMONIA, LOW DUST, REPLICATE 2
      SIMRE M4
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                         COEFFICIENTS                 R*2

 (1) Y=AX                     .0044974737    .0000000000     .613
 (2) Y=A+BX                   .0432937598    .0030161211     .878
 (3) Y=A EXP(BX)              .0498326566    .0320634644     .768
 (4) Y=1/(A+BX)             19.7474933854   ¯.3925684685     .605
 (5) Y=A+B/X                  .1579338921   ¯.7010771753     .839
 (6) Y=A+B LOG(X)            ¯.0624366158    .0590008088     .961
 (7) Y=AX*B                   .0145827060    .6623283931     .937
 (8) Y=X/(A+BX)            116.3255755216   3.2463259531     .939
 (9) Y=A+BX+CX*2              .0035307451    .0073969078     .970
                             ¯.0000916599    .0000000000
(10) Y=A+BX+CX*2+DX*3        ¯.0056613678    .0091277381     .972
                             ¯.0001760887    .0000011735
```

```
      M5 M5[⍳26;1,2]

      ⍝30 PPM AMMONIA, LOW DUST, REPLICATE 2
      SIMRE M5
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11): Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(2) Y=A+BX	.1356489893	.0044752034	.822
(3) Y=A EXP(BX)	.1385270842	.0214932141	.650
(4) Y=1/(A+BX)	7.4498184776	¯.1174646434	.442
(5) Y=A+B/X	.3324087749	¯1.4992698713	.971
(6) Y=A+B LOG(X)	¯.0573021584	.0994437298	.956
(7) Y=AX*B	.0505283799	.5043322420	.843
(8) Y=X/(A+BX)	50.7720887305	1.6359321682	.869
(9) Y=A+BX+CX*2	.0603425076	.0121494816	.929
	¯.0001501686	.0000000000	
(10) Y=A+BX+CX*2+DX*3	¯.0428724067	.0296187385	.975
	¯.0009384057	.0000102541	

```
BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

      M6 M6[⍳19;1,2]

      ⍝40 PPM AMMONIA, LOW DUST, REPLICATE 2
      SIMRE M6
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11): Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(1) Y=AX	.0117063593	.0000000000	.385
(2) Y=A+BX	.1051430252	.0069629574	.893
(3) Y=A EXP(BX)	.1195540078	.0339183037	.842
(4) Y=1/(A+BX)	7.9647813665	¯.1758682953	.767
(5) Y=A+B/X	.3132829819	¯1.0655525487	.838
(6) Y=A+B LOG(X)	¯.0618583478	.1064911165	.956
(7) Y=AX*B	.0506083166	.5355160226	.960
(8) Y=X/(A+BX)	31.0043877564	2.3923414058	.956
(9) Y=A+BX+CX*2	.0346082709	.0167716154	.977
	¯.0002666793	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.0503442364	.0131412248	.978
	¯.0000432896	¯.0000039775	

```
BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3
```

```
      M7 M7[⍳32;1,2]

      ⍝20 PPM AMMONIA, MEDIUM DUST, REPLICATE 1
      SIMRE M7
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                              COEFFICIENTS              R*2

  (1) Y=AX                       .0199227822   .0000000000    .452
  (2) Y=A+BX                     .2578900316   .0125170787    .812
  (3) Y=A EXP(BX)                .2472315816   .0288208263    .610
  (4) Y=1/(A+BX)                4.6933027481  ¯.0894867938    .380
  (5) Y=A+B/X                    .8077485724 ¯3.5689677719    .899
  (6) Y=A+B LOG(X)              ¯.2909557465   .2856300527    .972
  (7) Y=AX*B                     .0587488280   .7131185015    .859
  (8) Y=X/(A+BX)               37.4825274863   .0719387052    .907
  (9) Y=A+BX+CX*2                .0087998502   .0372413669    .970
                                ¯.0004497088   .0000000000
 (10) Y=A+BX+CX*2+DX*3          ¯.1342200457   .0619022445    .991
                                ¯.0015102417   .0000128429

 BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

      M8 M8[⍳32;1,2]


      ⍝30 PPM AMMONIA, MEDIUM DUST, REPLICATE 1
      SIMRE M8
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                              COEFFICIENTS              R*2

  (1) Y=AX                       .0098009271   .0000000000    .502
  (2) Y=A+BX                     .1219949210   .0061347252    .918
  (3) Y=A EXP(BX)                .1377296639   .0251293882    .842
  (4) Y=1/(A+BX)                7.0372531780  ¯.1134823908    .719
  (5) Y=A+B/X                    .3637096642 ¯1.3091561480    .757
  (6) Y=A+B LOG(X)              ¯.0922953428   .1220553539    .953
  (7) Y=AX*B                     .0526676078   .5271438913    .971
  (8) Y=X/(A+BX)               30.6154684082  2.1703707120    .947
  (9) Y=A+BX+CX*2                .0603777575   .0124710123    .977
                                ¯.0001197639   .0000000000
 (10) Y=A+BX+CX*2+DX*3           .0709734530   .0104980881    .978
                                ¯.0000312501  ¯.0000011043
```

```
      M9 M9[⍳28;1,2]

      ⍝40 PPM AMMONIA, MEDIUM DUST, REPLICATE 1
      SIMRE M9
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(1) Y=AX	.0026145228	.0000000000	.055
(2) Y=A+BX	.0395175411	.0013987692	.769
(3) Y=A EXP(BX)	.0412186235	.0216431066	.703
(4) Y=1/(A+BX)	24.0972750513	¯.3610918466	.623
(5) Y=A+B/X	.0951345601	¯.3343223592	.664
(6) Y=A+B LOG(X)	¯.0179095891	.0302753813	.861
(7) Y=AX*B	.0161804995	.4833665318	.837
(8) Y=X/(A+BX)	98.3243515642	9.0698323073	.698
(9) Y=A+BX+CX*2	.0123774252	.0040942127	.896
	¯.0000513447	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.0053041219	.0053072512	.899
	¯.0001058498	.0000007014	

```
BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

      M10 M10[⍳26;1,2]

      ⍝20 PPM AMMONIA, MEDIUM DUST, REPLICATE 2
      SIMRE 10
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW
DATA ERROR (ρX≠ρY)
      SIMRE M10
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:

BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(2) Y=A+BX	.1413698158	.0032817508	.896
(3) Y=A EXP(BX)	.1452073162	.0165803859	.818
(4) Y=1/(A+BX)	6.2227063887	¯.0871831293	.704
(5) Y=A+B/X	.2581392702	¯.6093450137	.854
(6) Y=A+B LOG(X)	.0465835868	.0575885520	.959
(7) Y=AX*B	.0873750764	.3007939125	.935
(8) Y=X/(A+BX)	18.9336840428	3.5338380171	.917
(9) Y=A+BX+CX*2	.1112424263	.0069687189	.953
	¯.0000830270	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.1004391639	.0093144679	.956
	¯.0002083855	.0000018851	

```
      M11 AA2M[;3,4]
      M11 M11[⍳33;1,2]
      SIMRE M11
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                         COEFFICIENTS                 R*2

 (2) Y=A+BX                   .1498777890    .0038240901     .776
 (3) Y=A EXP(BX)              .1470762504    .0184554704     .644
 (4) Y=1/(A+BX)              7.0949316143   ¯.0991726999     .506
 (5) Y=A+B/X                  .3115335305   ¯.9253239356     .898
 (6) Y=A+B LOG(X)            ¯.0032299864    .0832349667     .953
 (7) Y=AX*B                   .0653674324    .4252862203     .886
 (8) Y=X/(A+BX)             30.5436036049   2.4736939447     .949
 (9) Y=A+BX+CX*2              .0836686707    .0107615249     .922
                             ¯.0001282870    .0000000000
(10) Y=A+BX+CX*2+DX*3         .0327830744    .0202342621     .960
                             ¯.0005464500    .0000051024

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

EQUATION(S) (1) CANNOT BE FIT
      M12 M12[⍳27;1,2]

      ⍝40 PPM AMMONIA, MEDIUM DUST, REPLICATE 2
      SIMRE M12
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                         COEFFICIENTS                 R*2

 (2) Y=A+BX                   .1606652527    .0046931492     .823
 (3) Y=A EXP(BX)              .1650813934    .0194705502     .773
 (4) Y=1/(A+BX)              6.0153360837   ¯.0851136725     .701
 (5) Y=A+B/X                  .3480121854  ¯1.1228430565     .870
 (6) Y=A+B LOG(X)            ¯.0093860041    .0945643988     .951
 (7) Y=AX*B                   .0787647890    .4036396986     .945
 (8) Y=X/(A+BX)             23.2522767258   2.4392603028     .966
 (9) Y=A+BX+CX*2              .0794218569    .0136789897     .976
                             ¯.0001834760    .0000000000
(10) Y=A+BX+CX*2+DX*3         .0641628450    .0166469762     .978
                             ¯.0003264101    .0000019409

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3
```

```
      M13 M13[⍳29;1,2]

      ⍝20 PPM AMMONIA, HIGH DUST, REPLICATE 1
      SIMRE M13
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                              COEFFICIENTS              R*2

 (1) Y=AX                      .0265200521   .0000000000       .366
 (2) Y=A+BX                    .3414063940   .0157797914       .876
 (3) Y=A EXP(BX)               .3600088507   .0261088649       .760
 (4) Y=1/(A+BX)               2.8002787981  ¯.0487273447       .615
 (5) Y=A+B/X                   .9586904217 ¯3.4692122204       .867
 (6) Y=A+B LOG(X)             ¯.2187114348   .3149496109       .989
 (7) Y=AX*B                    .1300516311   .5511320841       .960
 (8) Y=X/(A+BX)              13.5259127904   .7171900897       .973
 (9) Y=A+BX+CX*2               .1205717571   .0393082330       .991
                              ¯.0004654802   .0000000000
(10) Y=A+BX+CX*2+DX*3          .0508326992   .0527922858       .996
                              ¯.0010980454   .0000082848

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

      M14 M14[⍳29;1,2]

      ⍝30 PPM AMMONIA, HIGH DUST, REPLICATE 1
       SIMRE M14
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0


EQUATION                              COEFFICIENTS              R*2

 (2) Y=A+BX                    .1980477588   .0051891526       .895
 (3) Y=A EXP(BX)               .2056604665   .0172351842       .797
 (4) Y=1/(A+BX)               4.8305383279  ¯.0610876540       .678
 (5) Y=A+B/X                   .4114757168 ¯1.2218186847       .825
 (6) Y=A+B LOG(X)             ¯.0055572237   .1104727265       .984
 (7) Y=AX*B                    .0983233883   .3865737753       .972
 (8) Y=X/(A+BX)              17.7936120793  2.1223838050       .956
 (9) Y=A+BX+CX*2               .1349416725   .0112732127       .967
                              ¯.0001104053   .0000000000
(10) Y=A+BX+CX*2+DX*3          .0812391261   .0209187116       .990
                              ¯.0005330091   .0000051644
```

EQUATION(S) (1) CANNOT BE FIT

⍝40 PPM AMMONIA, HIGH DUST, REPLICATE 1
SIMRE M15
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW

ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11): Y(EST) 2 AND EQ NO.(1-11)
⎕:
1 0

EQUATION	COEFFICIENTS		R*2
(1) Y=AX	.0203819407	.0000000000	.673
(2) Y=A+BX	.2138620348	.0141642678	.891
(3) Y=A EXP(BX)	.2405869416	.0301302647	.771
(4) Y=1/(A+BX)	4.1679303374	¯.0757616394	.609
(5) Y=A+B/X	.8225363116	¯3.8457871779	.861
(6) Y=A+B LOG(X)	¯.3538275127	.3059716770	.985
(7) Y=AX*B	.0640455327	.6881116668	.953
(8) Y=X/(A+BX)	26.2475099678	.5810927050	.959
(9) Y=A+BX+CX*2	.0091839175	.0349319929	.993
	¯.0003844821	.0000000000	
(10) Y=A+BX+CX*2+DX*3	¯.0513955470	.0455160866	.996
	¯.0008397517	.0000055131	

BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

M16 M16[⍳21;1,2]

⍝20 PPM AMMONIA, HIGH DUST, REPLICATE 2
SIMRE M16
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW

ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11): Y(EST) 2 AND EQ NO.(1-11)
⎕:
1 0

EQUATION	COEFFICIENTS		R*2
(1) Y=AX	.0079867902	.0000000000	.588
(2) Y=A+BX	.0699336532	.0051332085	.959
(3) Y=A EXP(BX)	.0825180884	.0341031382	.839
(4) Y=1/(A+BX)	11.7403238096	¯.2564629854	.621
(5) Y=A+B/X	.2272316811	¯.7437747275	.799
(6) Y=A+B LOG(X)	¯.0520805983	.0793075068	.965
(7) Y=AX*B	.0332378623	.5620498412	.961
(8) Y=X/(A+BX)	50.4187098346	2.8714429211	.954
(9) Y=A+BX+CX*2	.0468376635	.0082517303	.974
	¯.0000791792	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.0221595354	.0139835020	.981
	¯.0004248355	.0000059359	

```
      M1 M17 M17[⍳24;1,2]

      ⍝30 PPM AMMONIA, HIGH DUST, REPLICATE 2
      SIMRE M17
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(2) Y=A+BX	.1398252163	.0035861104	.949
(3) Y=A EXP(BX)	.1479150866	.0167251364	.912
(4) Y=1/(A+BX)	6.5631098119	¯.0802736255	.863
(5) Y=A+B/X	.2771322545	¯.8047670117	.778
(6) Y=A+B LOG(X)	.0179600245	.0692063497	.964
(7) Y=AX*B	.0816971302	.3310454818	.975
(8) Y=X/(A+BX)	20.0225330231	3.3698260636	.874
(9) Y=A+BX+CX*2	.1123722720	.0065605357	.980
	¯.0000608275	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.1002127465	.0088188360	.982
	¯.0001681756	.0000014557	

```
BEST FIT EQUATION IS (10) Y=A+BX+CX*2+DX*3

EQUATION(S) (1) CANNOT BE FIT

      M18 M18[⍳24;1,2]

      ⍝40 PPM AMMONIA, HIGH DUST, REPLICATE 2
      SIMRE M18
⍝DOCUMENTATION CAN BE FOUND IN THE VARIABLE SIMREHOW


ENTER FOR:
BEST FIT 1 AND EQ NO.(0-11); Y(EST) 2 AND EQ NO.(1-11)
⎕:
      1 0
```

EQUATION	COEFFICIENTS		R*2
(1) Y=AX	.0056084134	.0000000000	.414
(2) Y=A+BX	.0579365750	.0033733173	.923
(3) Y=A EXP(BX)	.0640138655	.0308263576	.852
(4) Y=1/(A+BX)	15.1782596415	¯.3064049872	.748
(5) Y=A+B/X	.1631143191	¯.4541290960	.805
(6) Y=A+B LOG(X)	¯.0191852382	.0517430997	.966
(7) Y=AX*B	.0297754156	.4942395445	.974
(8) Y=X/(A+BX)	49.6602611444	4.9651547348	.945
(9) Y=A+BX+CX*2	.0332713732	.0067802508	.974
	¯.0000852910	.0000000000	
(10) Y=A+BX+CX*2+DX*3	.0238495381	.0091119279	.976
	¯.0002235637	.0000022907	

APPENDIX D: ERROR DUE TO RH DETERMINATION

If N is the quantity to be attributed to an output and a function of n independent variables due to individual measured quantities u1, u2.....un, +/-ΔN the error for this output (uncertainty) and d1, d2......dn errors for individual measurements we can write the following equations (Doeblin, 1983): N=f(u1,u2......un)

ΔN+ΔN=f(u1+d1, u2+d2.........un+dn)

ΔN= Δu1(∂f/∂u1) + Δu2(∂f/∂u2) +..... Δun(∂f/∂un) (D.1)

A step-by-step procedure for computing the overall erorr given by Doeblin (1983) is summarized below:

1. Determine all the errors for each measured quantity
2. Compute the partial derivatives (∂f/∂un) for each u. Either calculus can be used to evaluate the partial derivatives or, alternatively, simple difference equations can be used to numerically approximate the partial derivatives as follows (Taylor, 1988):

∂f/∂u1=(Fo-F'1)/(uo-u'1) (D.2)

where: Fo=f(u1, u2, u3....) and

F'1=(u'1, u2, u3......),

u'1= 1.01*u1

u'1 can be determined in both directions if there is a directional change in the error. (Error expressed should be considered as values)

The errors discussed below reflect the worst situations where errors line up so as to create the largest deviation.

D.1 Errors Due to establishing RH in the Environment Chamber

RH is a function of dew point temperature and temperature of the environment:

$RH=f(t_{dp}, t)$

According to Equation D.1 the error due to t and t_{dp} measurements (ΔRH= overall error for RH determinations) can be expressed as follows:

$$\Delta RH=\Delta t_{dp}*\partial RH/\partial t_{dp}+\Delta t*\partial RH/\partial t. \qquad (D.3)$$

Errors coming from temperature and dew point temperature measurements (Δt and Δt_{dp}) are discussed in the next sections.

D.1.2 Errors in Prediction of Dew point

When outputs were converted to dew-point temperatures with the help of the fitted (Section 5.2.3.2) equation a new source of error was brought into the system.

The error for predicting DP with the help of a correlation equation for the outputs generated by the hygrometer is given as (Steel and Torie, 1982):

$$S_Y=(S^2_{Y.X}[1+1/n+(X_i-X_m)^2/E^2])^{1/2} \qquad (D.4)$$

where : n=number of observations,

$S_{Y.X}$=standard error of Y estimate,

E^2=(st.error of Y est)^2/(st.error of coefficient)^2,

X_i=ith measurement

X_m=mean of the measurements

For example,the following error related terms were calculated when establishing a relation between dew point hygrometer outputs and the dew point temperatures indicated on the front panel of the dew point hygrometer.

Fitted (regression) equation:$t_{dp}=8.852*O-20.0460$

where: O=observed sensor output (volts),

Standard error of estimate=0.284728

Standard error of coefficient=0.115814

$X_i=O_i=2.754$ V (4.2°C)

$X_m=O_i=3.3336$ V

n=30

$E^2=6.044192$

$S_Y=0.284728(1+1/30+(2.754-3.3336)^2/6.044192)^{1/2}=0.297$

error= $(t_s*S_Y)=0.6$°C dew-point temperature

where:t_s = student's t value at 0.05 significance level and 28 degrees of freedom=2.0480.

The errors obtained with this equation are dependent on the hygrometer output values. However,for $X_i=4.14$ V (highest output) rounded to 0.6°C.

D.1.3 Resolution Errors for the Hygrometer and the Platinum RTD

In assigning a digital value to an analog signal, the converter is limited to the number of bits it can assign. The error associated with the digital value is defined as 1/2 a least significant bit (LSB) according to Taylor (1983). The data acquisition system has an 8-bit analog-to-digital converter and the smallest signal that the converter can resolve was 0.018 V. Therefore, resolution error was 0.009V (0.0018/2). 0.009 V resolution error applies to TF#1, TF#2, AL and Pt RTD.

D.1.4 Errors coming from Environment Temperature Readings

The temperature readings were based on the Pt RTD outputs from TF#2.

The error due to the prediction of temperature was calculated in a similar way to those errors for dew point temperature determinations. During the determination of the regression line relating the Pt RTD outputs to the temperature readings indicated by a mercury thermometer the folllowing errors were also calculated:

Fitted (regression) equation:t=5.378355*O+0.672386

Standard error of estimate=0.143441

Standard error of coefficient=0.306226

O_i=3.654 V (20.4°C)

O_m=3.6252 V

E^2=0.219413

$S_y=0.143441*(1+1/30+(3.654-3.6252)^2/0.219490)^{1/2}=.146$

$error=t_s*S_y=0.3°C$

D.1.5 Calculation of the Overall Error for RH Determinations

Calculation of RH levels from dew point temperature and environment temperature measurements were carried out according to the Antoine equation:

$$RH=1/10\exp.\{[(t_{dp}+C)^{-1}-(t+C)^{-1}]*B\}$$

One typical low humidity level (t_{dp}=4.3 C, t=20.4 C) and one typical high humidity level (t_{dp}=16.6 C, t=20.4 C) were selected to find out the usual range of error introduced. Only samples for the low humidity levels are given here.

Equation D.3 gives the error due to t and t_{dp} measurements for ΔRH (overall error in RH determinations). The parameters constituting Equation D.3 were determined as follows:

$\partial RH/\partial t_{dp}$ can be approximated according to equation D.2 as:

$\partial RH/\partial t_{dp}=(RH-RH_1)/(t_{dp}-t_{dp1})=2.4$ %RH

where: RH=relative humidity at X_1=2.682 V (t_{dp}=4.3°C at t=20.4°C)=34.588 %RH

RH_1=(relative humidity at t_{dp1}=1.01*4.3 at t=20.4oC)=34.693 %RH.

Similarly,

$\partial RH/\partial t=(RH-RH_2)/(t-t_1)=2.1$ %RH

where: RH_2=(relative humidity at t_1=1.01*t and t_{dp}=4.3 C)=34.155 %RH

Δt_{dp} error due to dew point determinations is comprised of the 0.6°C prediction error and 0.1°C error due to pressure, giving a total of 0.7°C.

From Section D.1.4 the error due to temperature determination, Δt=0.3°C, and from equation D.3 ΔRH=3%RH.

The errors due to Antoine equation were calculated by considering the error range (0.025 mm Hg pressure difference) given by Wood (1970) and included in the overall error.

Since the dew point temperature measurements were taken up to one decimal values. One decimal in dew-point temperatures (°C) can give rise to changes around 0.4%RH for an average dew point temperature (for a typical calibration cycle) of 10.5°C . For this reason RH determinations were rounded to integers and 0.25 %RH error for rounding were included in the overall error calculations.

Table D.1 CALCULATION OF THE OVERALL ERROR (ΔRH) IN RH DETERMINATIONS FOR LOW DPH OUTPUT=2.754 V (t_{dp}=4.2°C, t=20.4°C) HIGH DPH OUTPUT=4.14 V (t_{dp}=16.6°C, t=20.4°C),

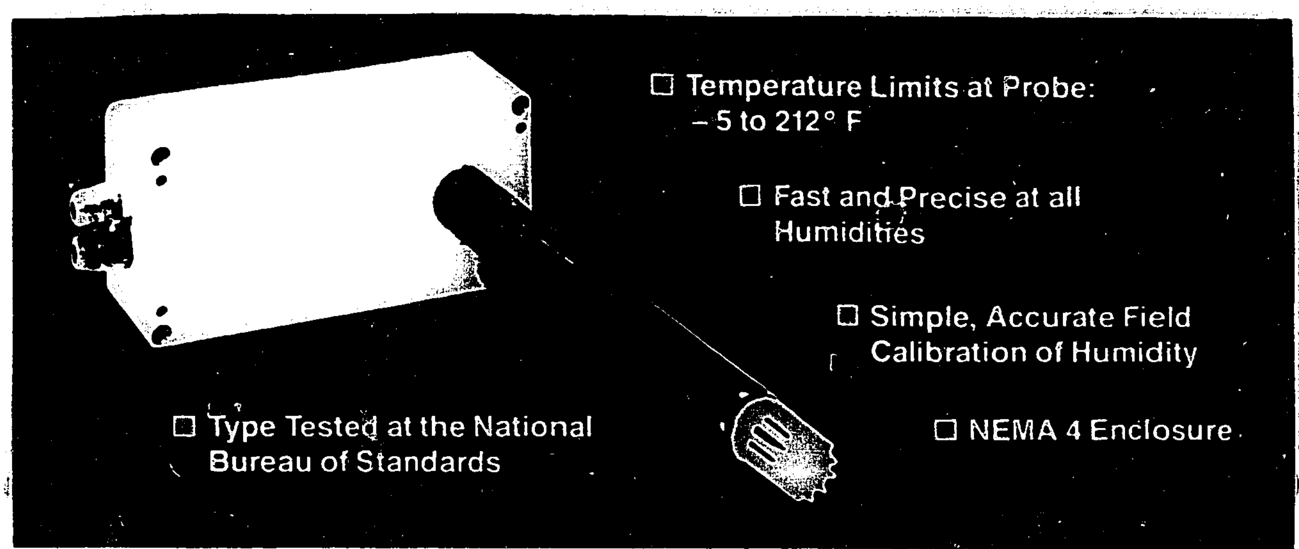
source	type of error	error	
		low	high
t_{dp} determinati on	Prediction	0.6	0.6
	Pressure	0.1	0.1
Total (dew-point °C)		0.8	0.8
Temperature Det.	Prediction	0.3	0.3
$(RH-RH1)/(0.01t_{dp})$, %RH		2.4	5.1
$(RH-RH2)/(0.1t)$, %RH		2.1	4.9
$(RH-RH1)/(0.01t_{dp})*\Delta t_{dp}$, %RH		1.7	3.6
$(RH-RH2)/(0.1t)*\Delta t$, %RH		0.6	1.5
Antoine equation, %RH		0.4	0.2
Rounding of %RH readings		0.25	0.25
Total (ΔRH), %RH		3.0	5.6

APPENDIX E: PRODUCT SHEETS FOR THE SENSORS EVALUATED

rotronic instrument corp

HUMIDITY-TEMPERATURE TRANSMITTER

HT220 SERIES



MANUFACTURING PROCESSES • MANUFACTURING AREAS • WAREHOUSES • RESEARCH LABORATORIES • DRYERS AND OVENS • ENVIRONMENTAL CHAMBERS, ETC.

GENERAL DESCRIPTION

The HT220 measures relative humidity with a HYGROMER™ capacitive sensor and temperature with a precision platinum RTD. Each paramenter is converted into a linearized output signal (DC current or voltage) that can be transmitted over a length of cable to a remote display, recorder, controller or data processing unit. The HT220 is designed for fixed installation in industrial applications that require precise monitoring of humidity and temperature conditions. Uses include warehouses, research laboratories, manufacturing areas and manufacturing processes, ovens and dryers, incubators, environmental chambers, etc.

PERFORMANCE AND RELIABILITY

The HT220 features fast sensor response and high repeatability, even when exposed to high humidity over long periods of time. Each HT220 is factory calibrated and adjusted both at 35 and 80 %RH. This provides an accuracy of +/− 2 %RH over the full range of measurement. Standard temperature calibration at the factory results in an accuracy of +/− 1.0°F. Unique HYGROCOMP™ electronic temperature compensation maintains the accuracy of humidity measurement to within a few %RH at high temperatures.

Sensor durability and resistance provide years of trouble-free operation with low maintenance requirements. Under most conditions, calibration is maintained to within 1 %RH and 0.4° F over a one-year period.

CONFIGURATIONS

Select from two basic configurations: model HT220W for wall mounting and measurement at temperatures up to 130° F, model HT220D for duct (through-wall) installation and for measurement at high temperature.

OPTIONS & ACCESSORIES

The HT220 is available for operation with various standard supply voltages. Standard unit wiring is by means of terminals. With the exception of units powered with 115 VAC, the HT220 can also be provided with a connector. On request, the transmitter case is modified to accept a conduit.

The HT220 can be equipped with two additional potentiometers and calibrated at 0, 10, 35 and 80 %RH. This improves accuracy in the range of 0 to 35 %RH to +/− 1.5 %RH or better. For field calibration of humidity measurement, a humidity standard is placed in a calibration device that fits over the probe. Humidity standards are available in boxes of 5 ampules of the same value ranging from 0 to 95 %RH.

For applications involving dust, or air velocity above 1000 feet/min., use the optional filter to protect the sensors. The quick mount adapter simplifies installation of duct mount models. This adapter is a mounting flange with compression fitting, which grips the probe of the transmitter, providing a sealing effect. Several probe lengths are available on model HT220D (duct mount).

HUMIDITY KNOWLEDGE...THAT WORKS

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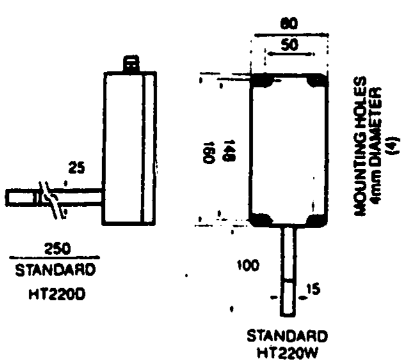
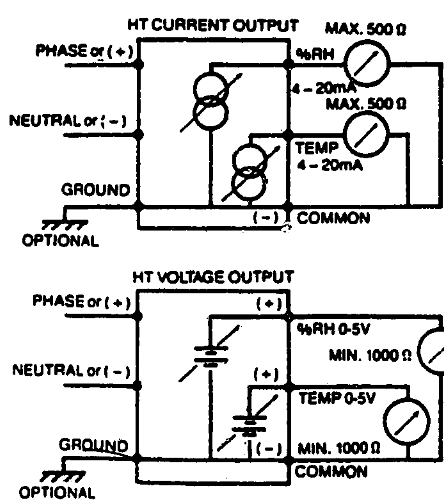
SPECIFICATIONS

Transmitter Model	HT220W for Wall Mounting HT220D for Through-Wall Installation
Humidity Sensor	ROTRONIC HYGROMER™
Temperature Sensor	Pt 100 RTD
Output Range	0-100 %RH 0-100° F, 0-100° C or −30 to +70° C
Accuracy:	+/− 2.0 %RH from 0 to 100 %RH @ 77° F +/− 1.0° F
Linearity:	0.7 %RH from 0 to 100 %RH 0.4° F over 200° F Span
Hysteresis (4-Hour Cycle 20-95-20 %RH)	Max. +/− 0.3 %RH
Repeatability (includes Hysteresis)	0.6 %RH or better
Typical Long Term Stability	1% RH or better over a year
Sensors Time Constant	10 seconds or better
Temperature Limits at Electronics	−5 to 130° F (−20 to 55° C)
Temperature Limits at Probe	−5 to 212° F (−20 to 100° C)
Electrical Connections	DC units: 4 or 5 Wires AC units: 5 Wires + Optional Ground
Wiring Type	Terminals 12 AWG Max. 1 or 2 Cable Grips (Standard)
Power Requirements	115VAC or 24VAC, 2.5VA or 8-35VDC, 100mA
Output Signals 0-100 %RH (Linear)	2 x 4-20mA or 0-20mA (Max. Load 500 ohms) 2 x 0-5V or 0-1V (Min. Load 1000 ohms)
Minimum Voltage Required by DC Operated Units with Current Outputs	4 VDC + 0.02 x Load, Min. 8VDC
Calibration Adjustment	35-80 %RH Potentiometers (Standard) 35-80-10-0 %RH Pots. (Optional) T min & T max Potentiometers
Calibration Device (Order Separately)	ER15 (HT220W) EM25 (HT220D)
Humidity Standards (Order Separately)	EA00-05-10-20-35-50-65-80-95 %RH
Probe Dimensions HT220W	100 x 15mm (Standard)
HT220D	250 x 25mm (Standard) 100 x 25mm (Optional) 500 x 25mm (Optional) 750 x 25mm (Optional)
Probe Material	Delrin (Pbe Length 500mm and above: PVDF)
Sensor Protection	Slotted Cap (Standard) Dust Filter (Optional)
Dimensions of Case	160mm (H) x 80mm (W) x 55mm (D) 6⅜" x 3⅛" x 2¼"
Weight	1.8 lbs.
Case Material	Macrolon
Case Protection	NEMA 4/ DIN IP 65
Quick-Mount Adaptor (Order Separately)	QMA-25 (for HT220D)

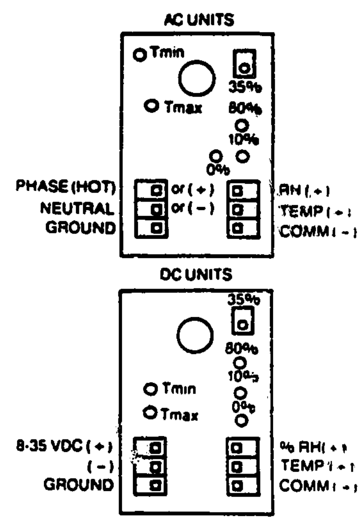


Dimensions in mm

WIRING DIAGRAMS



WIRING CONNECTIONS AND CALIBRATION POT.

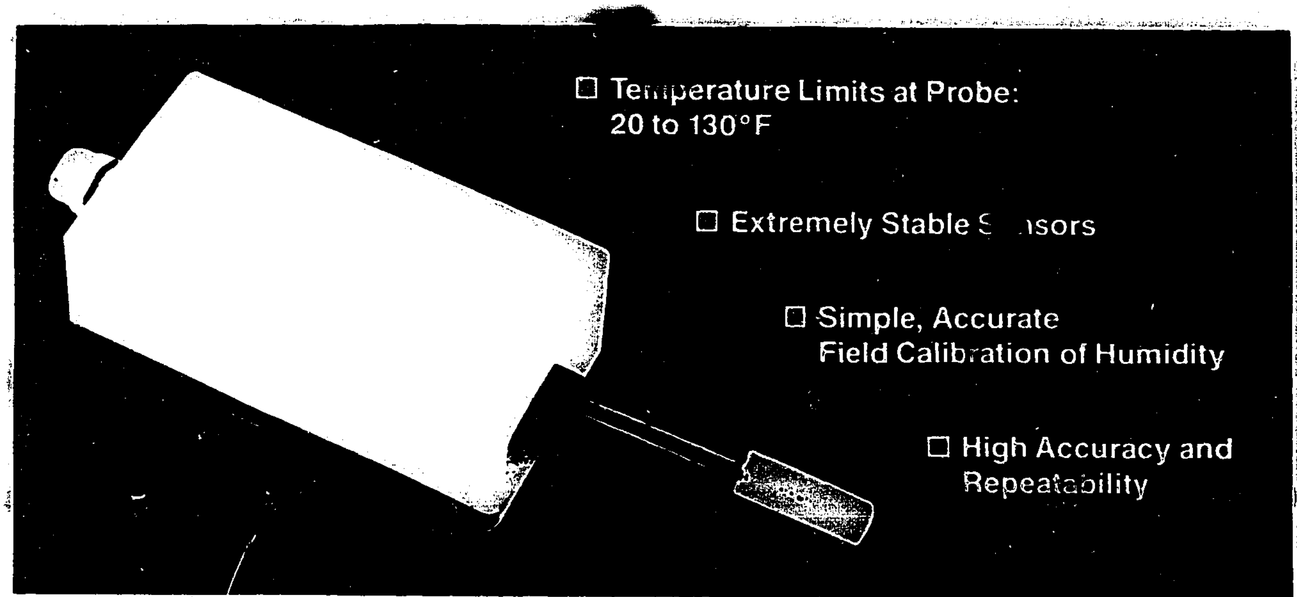


HOW TO SPECIFY: when ordering, please specify the following: temperature range, supply voltage, probe length (duct models only), sensor protection (slotted cap or filter), output signal, type of electrical wiring (terminals/cable grip, terminals/conduit or connector).

rotronic instrument corp

HUMIDITY-TEMPERATURE TRANSMITTER

HT46 SERIES



CLEAN ROOMS • MANUFACTURING AREAS • WAREHOUSES • RESEARCH LABORATORIES, ETC.

GENERAL DESCRIPTION

The HT46 measures relative humidity with a HYGROMER™ capacitive sensor and temperature with a precision platinum RTD. Both paramenters are converted into a linearized output signal (DC current or voltage) that can be transmitted over a length of cable to a remote display, recorder, controller or data processing unit. The HT46 is primarily designed for fixed installation in clean rooms used in the microelectronics industry and in the pharmaceutical industry, as well as for use in any clean environment in the range of 0 to 95 %RH and at temperatures between 20 and 130° F.

PERFORMANCE AND RELIABILITY

The HT46 features fast sensor response and high repeatability. Each HT46 is factory calibrated and adjusted both at 35 and 80 %RH. This provides an accuracy of +/− 2 %RH from 0 to 100 %RH. Standard temperature calibration at the factory provides an accuracy of +/− 1° F.

Sensor stability and durability provide years of trouble-free operation with low maintenance requirements. Typically, calibration is maintained within 1 %RH and 0.3° F over a one-year period.

CONFIGURATIONS

Select from two basic configurations: Model HT46W for wall mounting and Model HT46D for duct or through-wall installation.

OPTIONS & ACCESSORIES

The HT46 is designed for operation with a DC supply voltage between 8 and 35 V or with an AC voltage of either 12 V or 24 V. Standard unit wiring is by means of terminals. The HT46 can also be provided with a connector instead of terminals. On request, the transmitter case can be modified to accept a conduit.

The HT46 can be equipped with two additional potentiometers and calibrated at 0, 10, 35 and 80 %RH. This improves accuracy in the range of 0 to 35 %RH to +/− 1.5 %RH or better. Special temperature calibration is available that results in +/− 0.2° F accuracy between 67° F and 77° F. For field calibration of humidity measurement, a humidity standard is placed in a calibration device that fits over the probe. Humidity standards are available in boxes of 5 ampules of the same value ranging from 0 to 95 %RH.

For applications involving dust, or air velocity above 1000 feet/min., use the optional filter to protect the sensors. The quick mount adapter simplifies installation of duct mount models. This adapter is a mounting flange with compression fitting, which grips the probe of the transmitter, providing a sealing effect. Several probe lengths are available on model HT46D (duct).

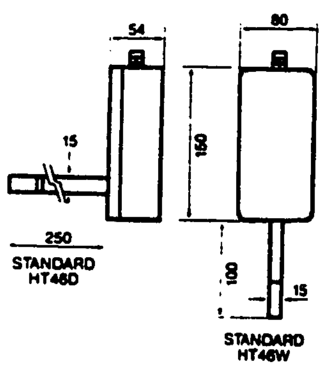
HUMIDITY KNOWLEDGE...THAT WORKS

ROTRONIC INSTRUMENT CORP. • 7 HIGH STREET, HUNTINGTON, NY 11743 • (516) 427-3994 • TWX 510 226-6995

SPECIFICATIONS

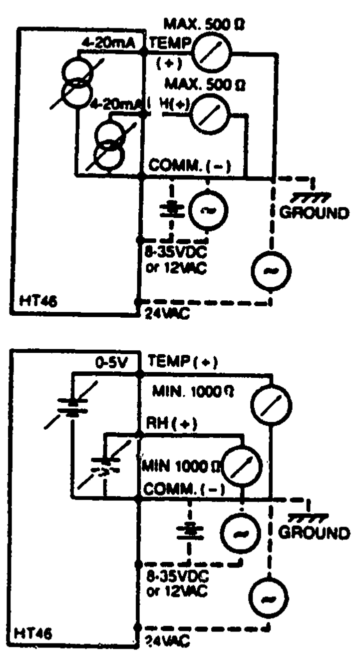
Transmitter Model	HT46W for Wall-Mounting HT46D for Through-Wall Installations
Humidity Sensor	ROTRONIC HYGROMER™
Temperature Sensor	Pt 100 RTD
Measuring Range	0-100 %RH 0-100° F
Accuracy: Humidity	+/− 2 %RH from 0-100 %RH @ 77° F
Temperature	+/− 1.0° F from 20 to 130° F
Linearity: Humidity	0.7 %RH from 0 to 100 %RH
Temperature	0.4° F over 100° F Span
Hysteresis (4-Hour Cycle 20-95-20 %RH)	+/− 0.3 %RH, Max.
Repeatability (includes Hysteresis)	0.6 %RH or better
Typical Long Term Stability	1 %RH or better over one year
Sensors Time Constant	10 seconds or better
Temperature Limits at Electronics	20 to 130° F (−5 to 55° C)
Temperature Limits at Probe	20 to 130° F (−5 to 55° C)
Electrical Connections	4 Wires
Wiring Type	Terminals 18 AWG Max. 1 Cable Grip (Standard)
Power Requirements	8-35VDC, 40mA 12 VAC, 2VA 24 VAC, 2VA
Output Signals (Linear)	2 x 4-20 mA, Max. Load 500 Ohms 2 x 0-5 V, Min. Load 1000 Ohms
Minimum Supply Voltage Required by DC Operated Units with Current Outputs	4 VDC + 0.02 x Load, Min. 8VDC
Calibration Adjustment	35-80 %RH Potentiometers (Standard) 35-80-10-0 %RH Pots. (Optional) T min & T max Potentiometers
Calibration Device (Order Separately)	EM15
Humidity Standards (Order Separately)	EA00-05-10-20-35-50-65-80-95 %RH
Probe Dimensions HT46W	100 x 15mm
HT46D	250 x 15mm (Standard) 100 x 15 mm (Optional)
Probe Material	Delrin
Sensor Protection	Slotted Cap (Standard) Dust Filter (Optional)
Dimensions of Case	150mm (H) x 80mm (W) x 54mm (D) 5⅞" x 3⅜" x 2⅛"
Weight	0.6 lbs.
Case Material	2 Tone Gray Plastic
Quick-Mount Adapter (Order Separately)	QMA-15 (for HT46D)

OUTLINE

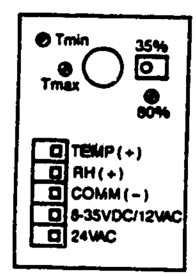


Dimensions in mm

WIRING DIAGRAM



WIRING CONNECTIONS AND CALIBRATION POT.



HOW TO SPECIFY: when ordering, please specify the following: configuration (wall or duct), supply voltage, probe length (duct models only), output signal, sensor protection (slotted cap or filter), type of electrical wiring (terminals/cable grip, terminals/conduit or connector).

DESCRIPTION:

The Hygroguard 2100 hygrometer consists of an Ondyne gold/aluminum oxide sensor probe and a microprocessor controlled electronics module. The microprocessor continuously calculates moisture dew/frost point temperatures; water concentration as Parts Per Million (PPM), sample temperature, and controls the alarm setpoints. The measured sample temperature is also used for sensor compensation.

A four character LCD display shows either dew/frost point. PPM, alarm setpoints, temperature or error codes.
A physical description of each analyzer follows:

RACK MOUNT:	Model 2130	5.25" High, 19" Wide, 11" Deep (See Drawing C2100-03)
PANEL MOUNT:	Model 2140	5.25" High, 10" Wide, 11" Deep (See Drawing C2100-04)
NEMA 4X:	Model 2150	7" High, 5" Wide, 3" Deep Polycarbonate Enclosure With a Clear Window (See Drawing C2100-08B)
PORTABLE CASE:	Model 2160	5" High, 9" Wide, 12" Deep (See Drawing C2100-05)

POWER: 115 VAC, 50/60 Hz, 5 Watts maximum. Optional Battery Pack, Eight hours running time, recharges from 115 VAC.

MOISTURE PROBE: DY-137-Z model; total length 7.8 inches, 1/2 inch diameter Stainless Steel tube, standard mounting adaptor is 1/2 inch tube compression fitting by 1/2 MNPT (Male National Pipe Thread), comes equipped with a multi-pin connector for connection to analyzer; Standard calibration range is -110 degrees C to +30 degrees C (-166 degrees F to +86 degrees F) Dew/Frost point. (See Drawing B100-62).

MOISTURE PROBE: (cont'd)

DY-135-Z model; total length 5.8 inches, 1/2 inch diameter Stainless Steel tube, standard mounting adaptor is 1/2 inch tube compression fitting by 1/2 MNPT (Male National Pipe Thread), comes equipped with a multi-pin connector mounted for connection to analyzer; Standard calibration range is -110 degrees C to +30 degrees C (-166 degrees F to +86 degrees F) Dew/Frost point. (See Drawing A100-63).

Operating Temperature: -70 to +70 degrees C. (-94 to +158 degrees F.)

Accuracy: ± 2 degrees C in the range -65 to +20 degrees C, ± 3 degrees C in the range of -80 to -66 degrees C.

Reproducibility: ± 1 degree C

Flow velocity, gases: 5000 cm/s., liquids: 50 cm/s max.

STANDARD CABLE: 5 ft. long with a multi-pin connector, maximum length 1,000 feet.

STANDARD INSTRUMENT RANGE & UNITS: Moisture; -110 to +30 degrees C, (-166 to +86 degrees F) dew/frost point temperature and 0.01 ppmv to 3300 ppmv concentration,

Sample Temperature; -70 to +70 degrees C (-94 to +158 degrees F).

SOFTWARE VERSIONS: The hygrometer's software is identified each time the analyzer is turned on. After the diagnostics check (see OPERATION) the version of software in use will be displayed as a number and the letter C or F. This letter designation indicates that the unit reads out in either degrees C or degrees F. The version number may change as new software becomes available, but the Centigrade (C) or Fahrenheit (F) designator will always be present. New or recalibrated probes will be supplied with the newest version available.

STANDARD OUTPUTS:

One alarm relay; energizes on high alarm, user assigned to one of eight setpoints for dew/frost point <u>or</u> one of eight setpoints for ppmv concentration.
Alarm condition is indicated by a LED
Alarm relay connections; NO/C/NC.
Contact rating 120 VAC @ 1 Amp.

One current output 4 to 20 mA corresponding to: -80 degrees C to +20 degrees C, (-112 F to +68 F) dew/frost point <u>or</u> 0 ppmv to 1000 ppmv. Maximum load of 800 OHMS.

CONNECTIONS: Screw terminal for outputs. Multi-pin connector for the probe.

INSTALLATION:

Connect the sensor to the readout module via the cable supplied and provide 115 VAC 50/60 Hz power. For models 2130, 2140, 2160; see Drawing C2100-11. For model 2150, see Drawing C2100-12. The instrument can be turned on at any time but it should be noted that stable readings will only occur after the sample has come to equilibrium; this can take several minutes to more than a couple of hours depending on the moisture content of the sample, flow rate, and materials. It is highly recommended that stainless steel be used when possible to give the fastest system response time.

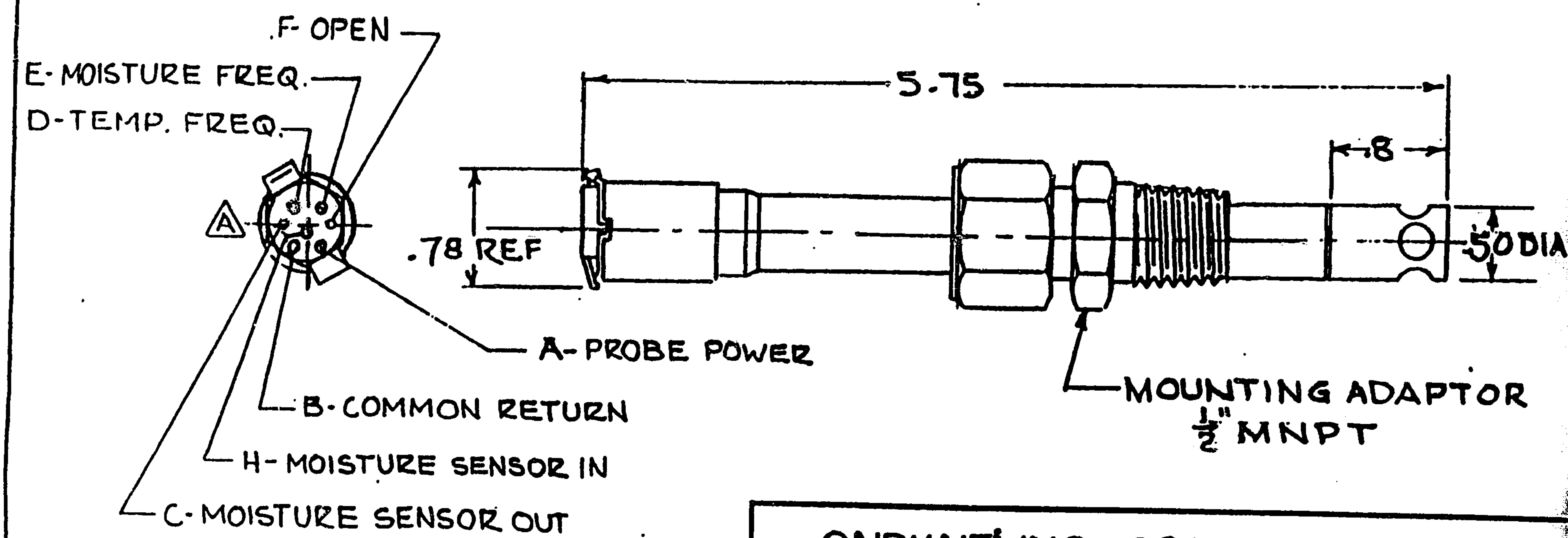
OPERATION:

Turn on the front panel power switch. (NOTE: No power switch is supplied on the Model 2150). Upon power-up, the analyzer does a program diagnostics check which includes a display and alarm function test. The diagnostics will turn on all of the display segments, will activate the alarm light and the relay will come on for approximately one second. Next, the software version will show for three (3) seconds and then the measured moisture value, in the selected units, will display continuously.

A. DEWPOINT/PPM MEASUREMENT SELECTION

The analyzer can measure moisture in either dew/frost point or ppm. This is selected via the front panel Dew point/PPM switch for Models 2130, 2140 and 2160. For Model 2150, use

LTR.	DESCRIPTION	DATE	APPROVED
A	CHANGED CONNECTOR TO 7 PIN	12/8/87 R.B.	[signature]



ONDYNE INC.- CONCORD, CA.		
SCALE: 1:1 DATE: 2-24-87	APPROVED BY: [signature] 2/87	DRAWN BY BERT FISHER REVISED
MOISTURE PROBE-MODEL 135Z		
MATERIAL - STN. STL.		DRAWING NUMBER A100-63 A

Humidity Sensor "Humiceram" Type EYH-H51C

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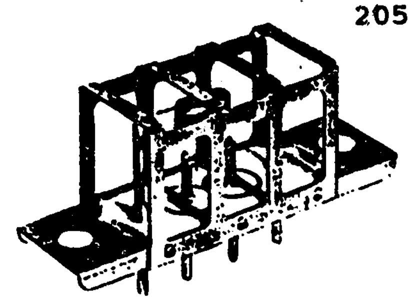


Detect humidity due to resistance change caused through hydration/dehydration processes in the pores of $MgCr_2O_4TiO_2$ ceramic.

Features

- Work at AC potentials.
- Wide humidity range 5 to 99%RH.
- High response speed 20sec. max.
- Aheat-cleaning construction provides a long life, high stability and good protection from deterioration due to oils, dust, etc.

Application

- Humidity controller.
- Humidity detector.

Part Number Code

E Y H — H 51 C

Common Code	Humidity	Design No.	Cleaning type
E Y H	H	51	C

Specifications

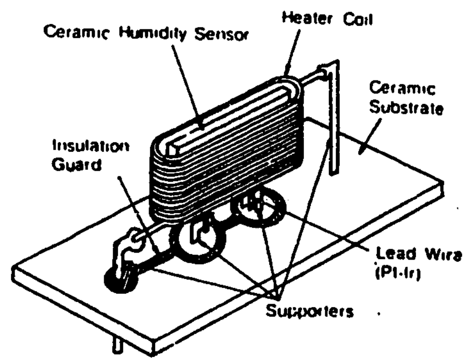
- Climatic
  - Operating Temperature Range : 1°C to 80°C
  - Storage Temperature Range : −40°C to 125°C
  - Operating Humidity Range : 5 to 99%RH
  - Storange Humidity Range : 1 to 99%RH
- Sensor
  - Supply Voltage : 3.0VAC max. including a voltage devider (a 10 kΩ resister)
- Heater
  - Supply Voltage for Heat Cleaning Duty: 10V max. (AC or DC)
  - Supply Voltage for a Continuous Operation: 1V max. (AC or DC)
  - Resistance of Heater : 6.1Ω±10%
- AC Resistance (Heat Cleaning Conditions)

When specimens are tested as specified in the following, the ac resistance shall be within the specified range in Table-1.

Prior to every ac resistance measurement, a heat cleaning as specified below must be conducted in an atmosphere specified respectively.

After the heat cleaning duty, a 10 to 30 minute conditioning at the specified atmosphere shall be allowed for stabilization, and then, ac resistance measurement shall be made at a temperature of 20±2°C and at each relative humidity listed in it using the test circuit specified in Table-1

Construction



Dimmension (mm)

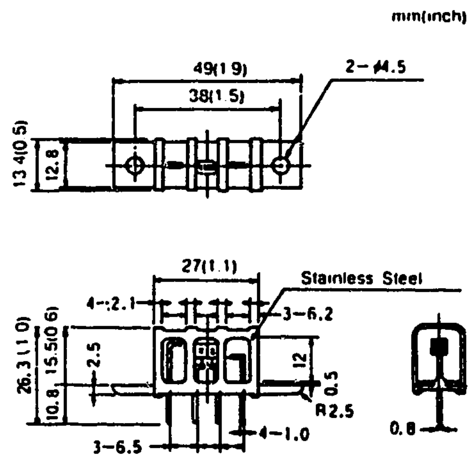
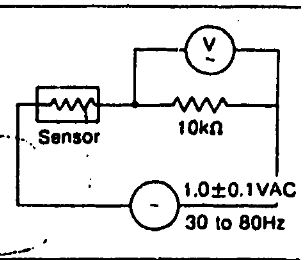
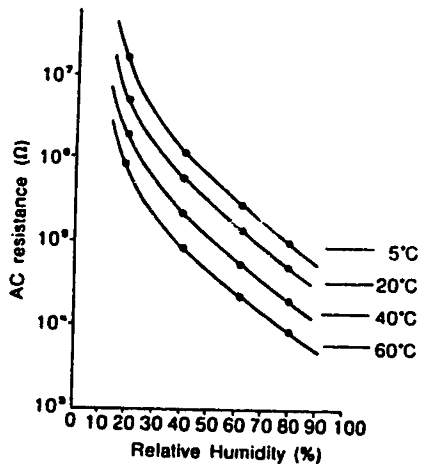


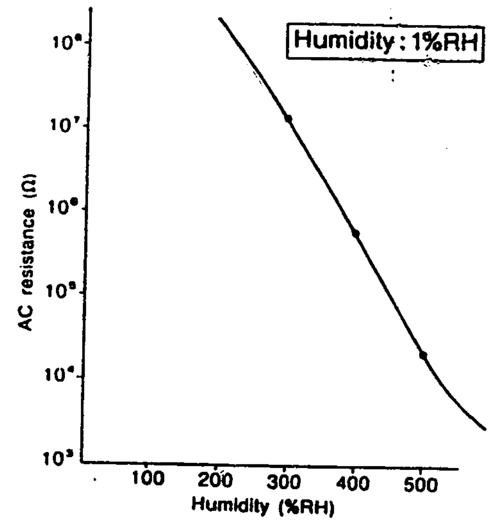
Table-1

Relative Humidity (at 20°C±2°C)	Resistance Value (Ω)	AC Resistance measurement circuit
20%	2.6M~24M	
40%	230k~21M	
60%	70k~600k	
80%	17k~150k	

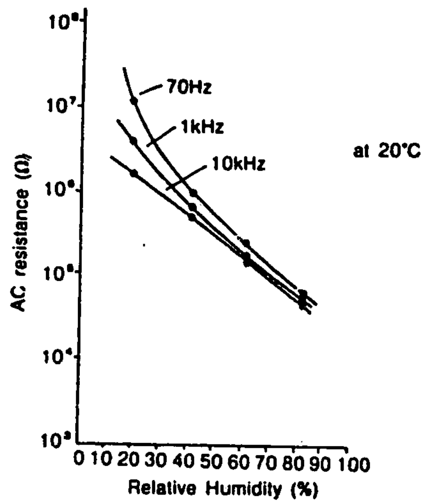
● Temperature dependency of humidity-resistance characteristics



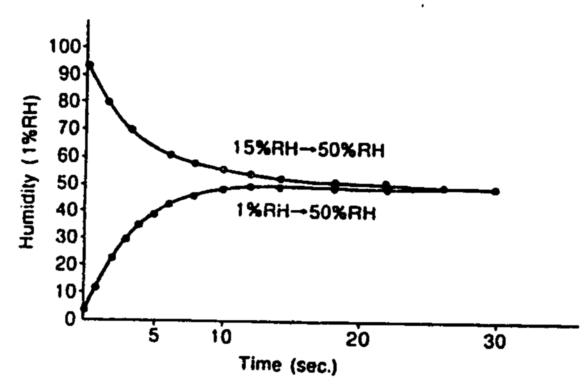
● Resistance temperature characteristics



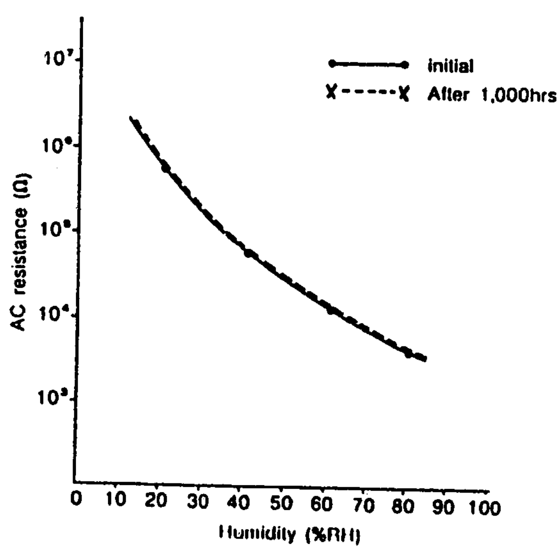
● Frequency dependency of humidity-resistance characteristics



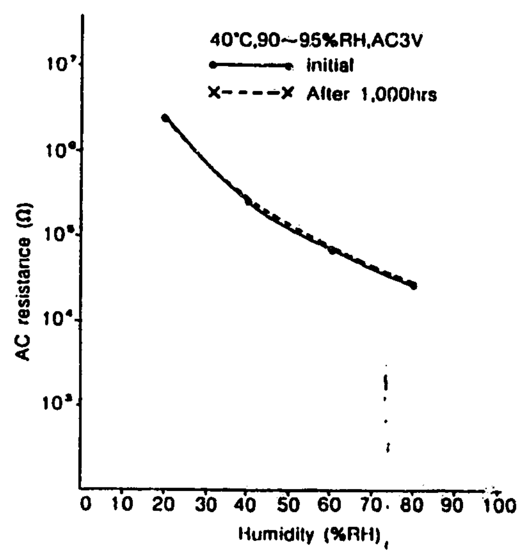
● Humidity responce time



● Load life



● Humidity load life



Characteristics

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Items	Conditions	Standard Values
Hysterisis	25°C 20%RH → 90%RH → 20%RH	Not exceed ±5%RH
Humidity response time	Humidity switching from 95%RH → 50%RH and from 5%RH → 50%RH	within 20 seconds
High Temperature Exposure	Store specimens for 1000 hrs at 85°C	Not exceed ±10%RH
Low Temperature Exposure	Store specimens for 1000 hrs at −40°C	
Temperature cycling	One cycle at step −25°C, 30min to 85°C, 30min shall be applied for 10 cycles.	
Humidity Steady state	Exposure specimens for 1,000hrs in a humidity test chamber controlled at 60°C, 90~95%RH.	
Load Life	Apply 3V AC including a 100kΩ over divider, for 1,000hrs continuous at room condition.	
Humidity Load life	Apply 3V AC including a 100kΩ over divider, for 1,000hrs continuously at 60°C, 90~95%RH.	
Dew cycle	100%RH, 3min→room conditions, 57min at room temp. One cycle of above slep shall be applied for 1,000cycles.	
Temperature coefficient of humidity sensitivity	AC resistance measurements shall be made at 10°C, 20°C, 40°C, 60°C.	~1%RH/°C
Vibration	Frequency 10~55Hz, Amplitude 1.52mm, cycle 1min. Above conditions in direction X,Y,Z, on speciments and each for 2 hrs.	Not exceed ±10%RH

Heat Cleaning Conditions

Parameters	Conditions	Duty Cycle of Heat Cleaning
Healter Supply Voltage	7.8V±5%	RI : Initial Resistance RE : RI X 1.36 RC : Cleaning Stop Resistance TR : Thermal Time Constant TC : Heal Cleaning Duration
Heat Cleaning Duration	15sec. max.	
Thermal Time Constant	120sec. max.	
Cleaning Stop Resistance (Respective Sensor Temp.)	6~10kΩ (540°C~560°C)