University of Alberta

HYDROCARBON RECOVERY FROM WASTE STREAMS OF OIL SANDS PROCESSING

by

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Abstract

Bitumen recovery by the water-based extraction process produces waste streams known as tailings. When discharged into the tailing ponds, the coarse solids in the tailings stream settle out quickly, while the fine solids accumulate over years of settling to a solids content of 30-35% by weight. The formed fluid fine solids sludge, known as mature fine tailings (MFT), traps 1-3% by weight hydrocarbons within its stable slurry structure. The remediation of these mature fine tailings is one of the major challenges facing the oil sands industry. This study was intended to investigate the recovery of residual hydrocarbons in the MFT by froth flotation process. Using a laboratory Denver flotation cell operated in a batch mode, the effect of MFT dilution ratio by process water or tap water, the flotation hydrodynamics and aeration rate on hydrocarbon recovery kinetics was studied. It was found that at 1:2 dilution by weight of the MFT with process water, increasing aeration rate has a more favourable effect on recovering more than 85% of the hydrocarbons from the MFT. The hydrocarbon-rich froth produced was treated by naphtha and was found to produce a hydrocarbon product similar to diluted bitumen obtained in bitumen extraction process, suitable for upgrading. Similar approach was applied to the hydrocarbon-rich tailings from the Tailings Solvent Recovery Unit of paraffinic froth treatment. Satisfactory recovery of hydrocarbons from the MFT was obtained using a flotation column operated in a continuous mode, confirmed the results obtained from the batch tests. The tailings produced from the continuous flotation experiments were treated with polymer flocculants such as Magnafloc-1011 and Al-PAM to study the effect of hydrocarbon recovery on the remediation of the MFT. The results from initial tests showed that both flocculants were not as effective on flocculating MFT solids following the recovery of hydrocarbons by froth flotation.

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I dedicate this thesis to my parents, my sister, Tinu and **God**.

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Nomenclature

CLSM	Confocal Laser Scanning Microscopy
F	Froth product produced (kg/min)
HWEP	Hot Water Extraction Process
IPS	Inclined Plate Settler
k	Flotation rate constant
MFT	Mature Fine Tailings
NFT	Naphthenic Froth Treatment
OM	Optical Microscopy
OSTRF	Oil Sands Tailings Research Facility
PFT	Paraffinic Froth Treatment
R	Cumulative Recovery
R_m	Maximum possible recovery at infinite flotation time
S	Feed slurry to the flotation column (kg/min)
SEM	Scanning Electron Microscopy
T	Tailings or effluents produced (kg/min)
TSRU	Tailings Solvent Recovery Unit
x_{Hs}	Mass fraction of hydrocarbons in the continuous flotation feed
x_{Hf}	Mass fraction of hydrocarbons in froth
x_{Sf}	Mass fraction of solids in froth

1 Introduction

Oil sands are non-conventional form of crude oil, seen as unconsolidated deposits of sands impregnated with a high molar mass and viscous form of petroleum known as bitumen. Oil sands deposits are found all over the world with the largest of them being in the Athabasca region of Alberta, Canada. Over an underlying region of about 140,000 square kilometers of boreal forest, the Canadian oil sands entail a recoverable oil deposit of about 175 billion barrels, second only to Saudi Arabia's reserves of conventional oil [2]. In the past few years, the world has seen the rise of oil prices due to dwindling supplies of petroleum along with a host of other equally affecting factors. Hence the enormous oil sands deposits of Canada became suddenly relevant both economically and politically as a safe source of oil reserves for the United States. The total exports from this sector stand at 12% of the total U.S consumption. [3]

Oil sands are a mixture of sand (mineral solids constituting about 80%-85% by weight), water (3% to 7% by weight), mineral rich clays (15%-30% by weight of mineral solids of less than 44µm in diameter) and substantially heavier crude oil hydrocarbons known as bitumen (about 7%-16% by weight). Bitumen can be converted to synthetic crude oil through upgrading [1]. The current water based extraction method, known as the Hot Water Extraction Process (HWEP) [4] produces a bitumen product of high hydrocarbon recovery.

Bitumen recovery by the HWEP is promoted by the formation of bitumen-in-water emulsions (low bitumen–water interfacial forces) and dispersion of clays in water (low clay–water interfacial forces). Though resulting in higher efficiencies, the latter produces waste streams or tailing effluents that are difficult to handle. The effluent slurries containing sand particles, dispersed fines, water along with residual bitumen were hydraulically transported to and deposited in the tailings ponds. Coarse particles in tailings when discharged segregate to form a sloping beach that forms the dykes for the tailings ponds [6]. The remaining fine tails accumulate quickly to 20 weight percent solids. Over a few years they accumulate to about 30-35 weight percent solids of a stable slurry structure encapsulating about 1-3 weight percent hydrocarbons and the remaining water [7]. This fluid sludge is referred to as mature fine tails. Because of a slow consolidation rate, the matured fine tailings remain in a fluid state for decades [8]. The volume of the mature fine tailings increases at a rate of about 0.1 m^3 per tonne of processed oil sand ore. About 0.25 m^3 of mature fine tailings is produced per barrel of synthetic oil production [9].

MFT production causes the main controversy for oil sands development. An area of more than 130 square kilometres in northern Alberta contains this type of tailings sludge [5]. These ponds are separated by earth dykes from the Athabasca River which joins the Mackenzie River to form the main watershed of Northwest Canada. As part of the operating license agreements between the Alberta Provincial government and any oil sands operator, neither the tailings water nor the solids can be released to the environment [6]. This makes it obligatory to discharge all the tailings from the primary and secondary separation process vessels along with the froth treatment plants into these tailings ponds. The poor settling and consolidation features of the solids in effluent streams have resulted in the ever-expanding tailings ponds that form the largest visible environmental footprint of the oil sands extraction process. Dealing with oil sands extraction tailings is a serious issue that needs to be resolved by the industry, quickly if possible, if the main issues of sustainability and sound practices are to addressed.

The waste streams with time have been found to be a good source of hydrocarbons that are toxic in nature due to the presence of unrecovered bitumen which contains naphthenic acids and other toxins. If a technology is available to economically recover these 'lost' hydrocarbons, it could reduce the ever visible environmental footprint of the oil sands extraction processes. Despite its importance, there is very little to report in open literature on recovery of hydrocarbons from oil sands tailings. However for this study, various de-oiling techniques used for the removal of oil from oily water was reviewed.

Oily water has oil in the form of both dissolved and non-dissolved components [10]. The non-dissolved free oil in water is found to exist in 3 forms [11]:

- Oily drops sized greater than 150µm which can be separated by conventional gravity settling and other methods.
- Free oily droplets of sizes 15-50µm.

- Stabilised oil-in-water emulsion (helped by local anionic surfactants) with a droplet size of 3-20µm.

The dissolved form of oil-in-water can be removed by bio-remediation or ion exchange methods that have been described in detail elsewhere [12]. For lighter oils, where the density differences between the oil and the water phases are larger, the industry still prefers the conventional methods like gravity settlers, cyclones etc. to aid in oil removal [13]. However when the differences in density between the two phases decreases, there is less buoyancy between the phases, hence making these methods ineffective. Heavy oils like bitumen are found to have densities closer to water and are hard to process in de-oiling operations using the above mentioned conventional methods. Here a combination of high viscosities, densities and foaming properties, causes heavy oils like bitumen to form stable emulsions with water. They are aided by the asphaltene particles and other impurities present in bitumen. Therefore for de-oiling operations involving heavy oils like bitumen, gas flotation is mainly the preferred method to remove the non-dissolved oil droplets.

Gas flotation can be referred to as an 'accelerated gravitational separation' technique where fine gas bubbles are injected to oily water (where heavy oils like bitumen constitute the oil phase). The gas bubbles attach to the oil particles in the oily water system and increases the density difference between the oil and the water phases. Separation of the two phases is thus ensued in the process as the oil droplets now rise rapidly to the top resulting in an effective separation from the aqueous phase. Oily droplets in addition to the oil attached solids rises to the top, forms a hydrocarbon-rich froth, and are skimmed off [14], [15].

In de-oiling systems using gas flotation techniques, there are two major methods of introducing the gas bubbles. They are:

- Dissolved gas flotation, DGF
- Induced (also called dispersed) gas flotation, IGF

Dissolved flotation is where the water is saturated with gas under pressure (usually less than 4 atmospheres) and then fed into the flotation chamber. Pressure is reduced to atmospheric at the inlet to the flotation chamber. This causes the gas bubbles having diameters in the range of 20-100 µm (median ~ 60µm) to be released. It is a gentle process with a retention time of about 15-30 min. It is used as a secondary de-oil system in steam assisted gravity drainage, SAGD operations [5], [6].

Induced gas flotation is used in de-oil systems present in offshore oil production installations, etc. Here gas is drawn into the flotation chamber through a special type of disperser such as ejectors or by a vortex set up by mechanical rotor impeller [11], [14]. Gas bubbles are normally in the range of 1000µm and the retention time within a treatment unit is low as 4 min. IGF technique is used in this thesis for recovering hydrocarbons from oil sands tailings

Municipal waste water systems use more sophisticated and expensive methods of bubble generation such as electrolytic bubble generation. They are not however used in de-oiling gas flotation systems used by the oil industry [15].

Various gases have been used for gas flotation processes. In oil production installations, field gas (methane) is used, but methane gas also possesses an explosive and serious greenhouse effect hazard. Inert gas, sometimes air is commonly used [10]. For this thesis study, air is used in froth flotation.

The main objective of this thesis is to study the feasibility of recovering the 'lost' hydrocarbons from the tailings of oil sands processing. The study is initially performed using a laboratory Denver cell operated in a batch mode. The effect of dilution of the MFT, mixing and aeration on hydrocarbon recovery kinetics is investigated. Considering the tailings to be treated are volumetrically large, continuous flotation using a flotation column was also attempted to examine the recovery of hydrocarbons under steady state conditions. Furthermore, hydrocarbon froth hence produced is cleaned using diluents as used in the conventional oil sands extraction process. The hydrocarbons in the recovered froth are fractionated and studied. The effluents produced from the continuous flotation experiments are studied for their settling characteristics with the addition of various polymer aids.

2 Experimental Studies

2.1 *Waste streams used in this study*

Two different types of mature fine tailings (MFT) samples along with tailings from the tailings solvent recovery unit (TSRU) were used in the course of this study. For this thesis, it was initially decided to study the tailings from TSRU of Albian Sands. They are the waste tailings streams containing precipitated asphaltenes from the paraffinic froth treatment plant. Inherent difficulties in sampling led to the unavailability of TSRU tailings samples for this study. Hence the major portion of the work was done with Syncrude MFT provided by the Oil Sands Tailings Research Facility (OSTRF). A few tests were done with the MFT provided by Suncor Energy Inc. to test the generality of the approach.

2.2 *Froth flotation*

The process of separation and concentration of one kind of particulates from the other by their selective attachment onto the gas-liquid interface is called flotation [16]. Flotation is based on differences in buoyancy though the actual separation is by the differences in the surface wettabilities [17]. The best examples of flotation occurring at a gas-liquid interface are film flotation and froth flotation. In flotation, particles are brought to rich froth by the attachment of air bubbles onto hydrophobic particles that are rising in the pulp under buoyancy. The particle suspension is conditioned for some time to disperse the particles in the flotation cell. Air is fed into the cell near the impeller to allow for the creation of fine bubbles that aid in the collection of particles. Selective separation of the hydrophobic components from the hydrophilic components in the mixture is accomplished by selectively attaching the introduced air/ gas bubbles to the hydrophobic components and their flotation to the top of the slurry as froth. The produced froth consists of hydrophobic particles, some fractions of hydrophilic particles entrained in inter-bubble water. This froth is found to be rich in the hydrophobic component to be separated. The efficiency of flotation process is measured by the recovery of hydrophobic substance. Normally hydrophilic particles do not attach to the air and settle down to the bottom where they are discharged as tailings of the flotation process. Small gas bubbles are known to enhance the flotation process due to high (specific) bubble surface area (per unit volume of liquid) available for particle attachment.

2.3 Batch flotation using Denver cell

Recovery of hydrocarbons from the waste streams of oil sands processing was achieved by froth flotation of the hydrocarbons. Denver cell widely used in the study of oil sands processing [18] was used here. A schematic diagram of the modified laboratory Denver cell used for this study is shown in Figure 2.1.

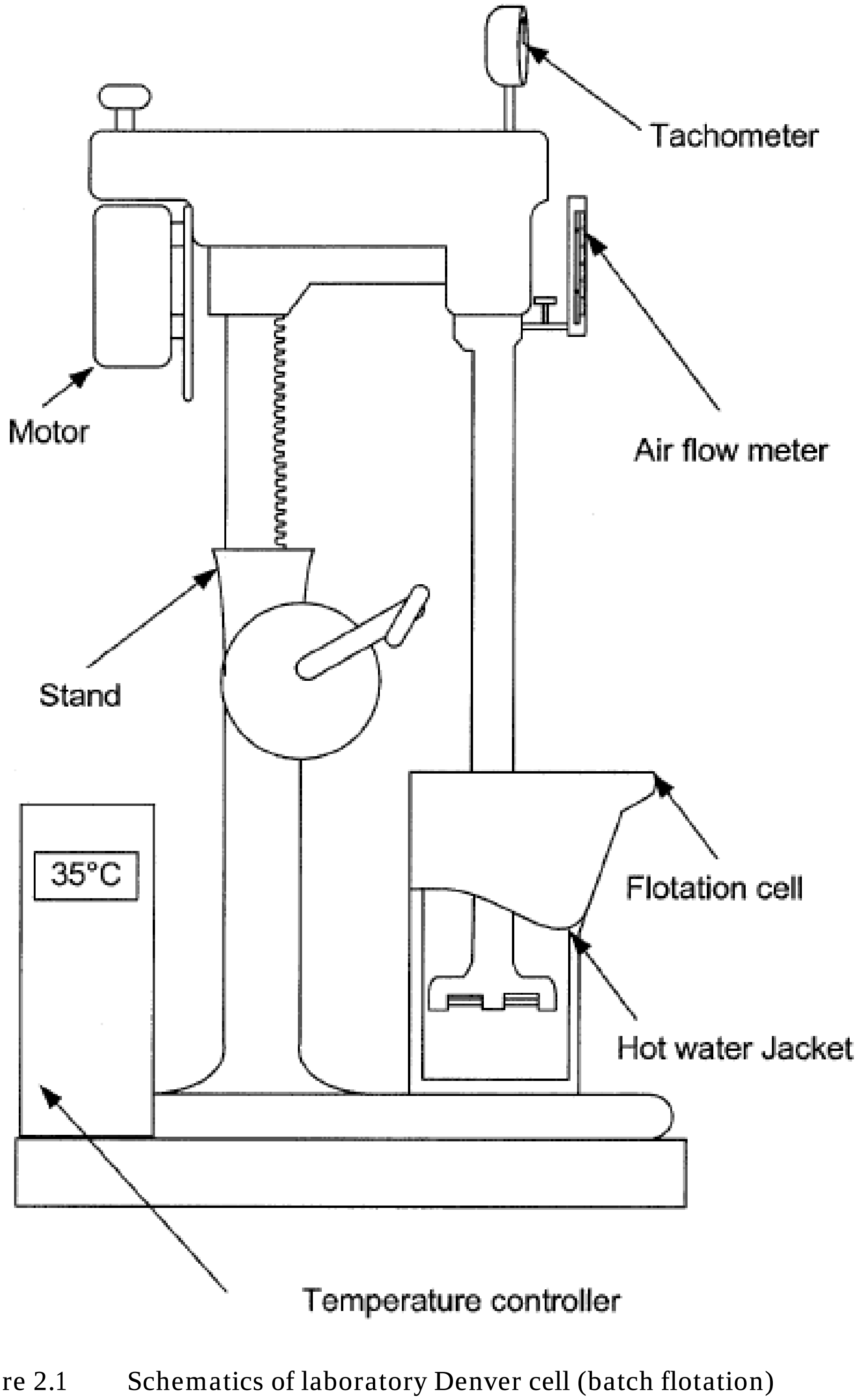

Figure 2.1 Schematics of laboratory Denver cell (batch flotation)

The cell manufactured by the Denver Company was modified to include a custom-made water jacket around a one-litre flotation cell made of 316 Stainless Steel. The water jacket was connected to a Neslab water bath from which water at a given temperature was circulated, to ensure a constant temperature within the cell. Aeration for froth flotation of the hydrocarbons was achieved by passing air through the impeller shaft. Air flow rate was measured using a pre-calibrated Matheson flow meter (No 7641 C/W602). The agitator (impeller) was driven by ½ HP Baldor Industrial Motor manufactured by the Baldor Electric Company. Agitation speed of the batch flotation tests was determined using a tachometer. The pH of feed slurry was measured using a portable pH meter from OAKTON Eutech Instruments, pH 110.

Diluted MFT was preheated to a given temperature before being fed into the Denver flotation cell. The flotation cell was maintained at the same temperature throughout the flotation tests. Feed slurry in the Denver flotation cell was agitated using the impeller rotating at a given rpm for about 5 minutes without air addition. Flotation was carried out for about 20 minutes with continuous air addition at 150 mL/min, unless otherwise stated. Froth was collected into pre-weighed thimbles over different time intervals of 3, 5, 10 and 20 minutes. The composition of froth was analyzed using Dean Stark apparatus, which allowed determination of hydrocarbon recovery and froth quality. Flotation performance was evaluated by cumulative hydrocarbon recovery and froth quality defined as solids to hydrocarbon ratio.

Cumulative recovery, *R(t)* is defined as the percentage of hydrocarbon in the feed that is recovered over a given time period of flotation, i.e.,

$$R\ (t) = \frac{\text{Hydrocarbons recovered in froth (g)}}{\text{Hydrocarbons in feed (g)}} \times 100 \qquad (2.1)$$

Assuming the batch flotation process in the Denver cell follows a first order process, the recovery rate, *R (t)* can be calculated by:

$$R(t) = R_m(1 - e^{-kt}) \qquad (2.2)$$

R_m is the maximum possible recovery at infinite flotation time, k is the flotation rate constant and t is the cumulative flotation time. Solids to hydrocarbon ratio (SHR) is a measure of the solids that come along with the recovered hydrocarbons in the froth, and is given by

$$SHR = \frac{\text{Cumulative solids in froth (g)}}{\text{Cumulative hydrocarbons recovered in froth (g)}} \qquad (2.3)$$

Recovery of hydrocarbons from the mature fine tailings using a Denver cell in the batch mode was studied further by varying the parameters such as dilution ratio, dilution medium, aeration rates and mixing.

2.4 Dean Stark extraction method for assay of samples

Dean Stark extraction is the most common method used for the determination of hydrocarbons, water and solids content in oil sands. Assay of the waste streams was achieved here by this method. Schematic representation of the Dean Stark extraction system is shown in Figure 2.2. Properly homogenised and precisely weighed samples of the tailings were taken into a pre-weighed thimble that was hung inside the extraction flask filled with toluene. Feed was heated in the Dean

Stark extraction apparatus that separated the feed into hydrocarbons, water and solids. Toluene was repeatedly refluxed in the Dean Stark apparatus till the toluene dripping from the thimble was colourless. This indicated a complete dissolving of the hydrocarbons in the toluene that was then collected in the condenser flask. Water was separated and flowed into the collector trap. They were weighed separately and used to calculate the water content in the feed sample. Hydrocarbon-free solid collected in the thimble was dried under vacuum. They were weighed and used to calculate the solid content in the feed sample. Hydrocarbon-rich toluene sample in the flask was collected and was made up to 250 mL in a measuring flask. After complete mixing 5mL of solution was pipetted out into a pre-weighed 934-AH filter paper and dried under vacuum for about 20 minutes. The difference in weight was used to calculate the hydrocarbon content of sample in the entire volume (250mL) by multiplying with a factor of 50. This represented the hydrocarbons in the feed sample and the weight percent of the hydrocarbons in the sample were obtained. Since toluene was used as the extraction solvent, measured hydrocarbons would include bitumen and any asphaltenes present.

Fines are defined as mineral solids less than 44µm. The standard method used in the determination of fines in mineral solids is by wet sieving. The hydrocarbon-free solids collected in the thimble following the Dean Stark extraction operation were wet screened using a 44µm screen to separate the solids into two fractions. They were both dried and weighed to measure the percentage of fines in solids.

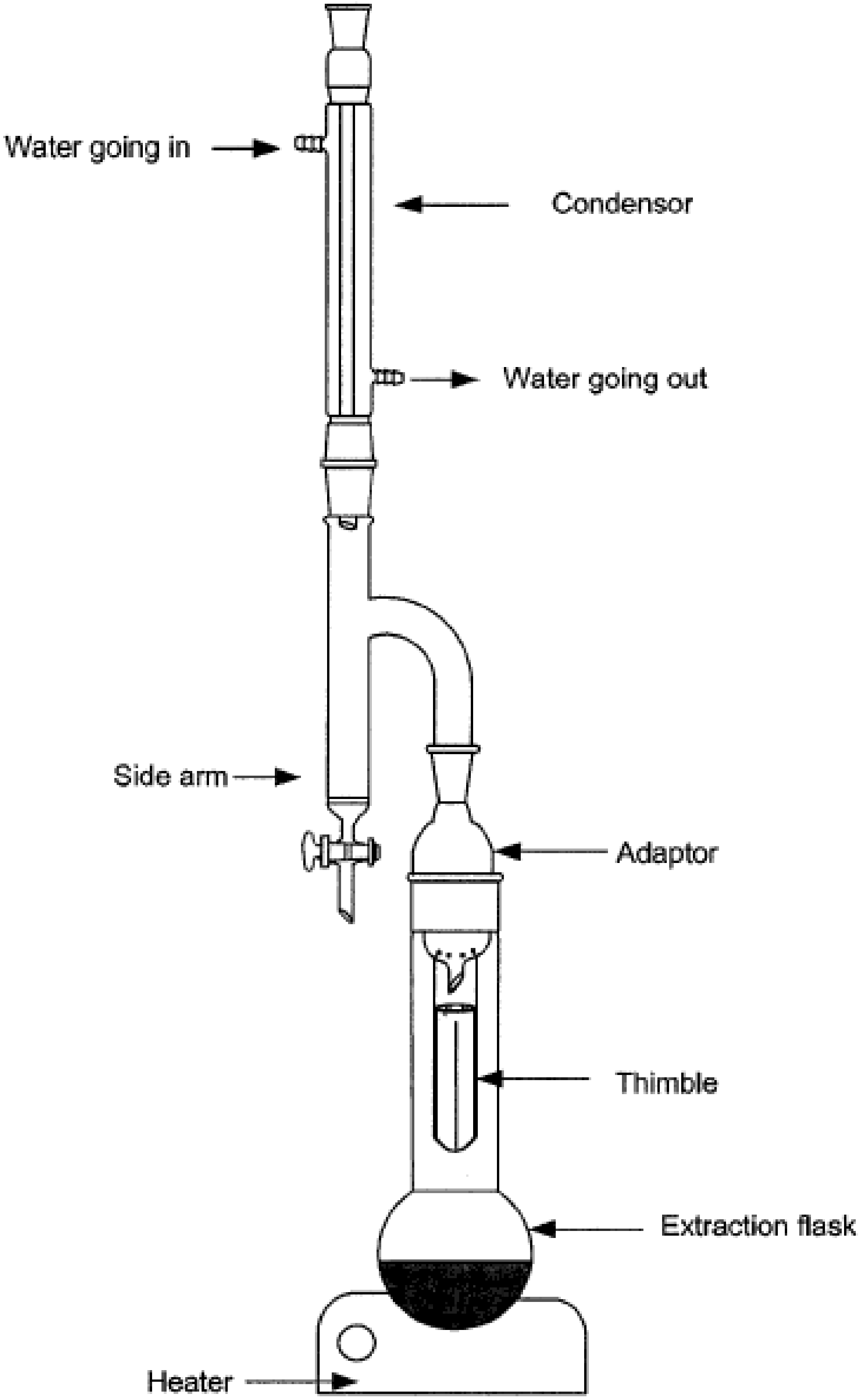

Figure 2.2 Schematics of Dean Stark extraction equipment

2.5 Two stage flotation using Denver cell

Multiple flotation schemes have also been used for a long time to produce a product rich in the desired component and reduce the undesired component in froth. In the flotation of the waste streams, undesired solids in the froth can be significantly decreased by a two stage froth flotation process. The feed slurry was prepared by mixing the froth produced from the single flotation operation with process water (300g of froth was mixed with 950mL of process water) and constantly heated to 35^{o}C. The mixed feed slurry was fed into Denver cell operated in batch mode and floated similarly as described earlier in Section 2.3. The recovered hydrocarbons were then assayed using Dean Stark extraction equipment and the various flotation parameters were studied.

2.6 Continuous process using a flotation column

For treating larger batches of feed, the dynamics derived from the batch flotation operations were employed in developing a methodology for continuous flotation operations. Flotation column was used for the purpose by employing a novel bubble generator assembly. In conventional column flotation, the feed is introduced below the interface between the bubbly and froth zones, while the gas is introduced at the bottom of the column via a gas sparger. Counter-current flow is produced by the bubbles that rise from the bottom of the column colliding with the downward travelling particles. The collision results in the attachment of the hydrophobic particles to the rising bubbles. The rising aggregates float to the top of the column where they are collected. The probability of contact between the hydrophobic particles and the gas bubbles is further enhanced by counter-current flow. Flotation column used for this thesis study adopts a recirculation line that aerates the feed in the bubble generator assembly just before it enters the column. Aerated slurry is introduced approximately 30 cm above the bottom into the column. The flotation column setup used in the continuous flotation experiments is shown in Figure 2.3. It consists of two main distinct zones.

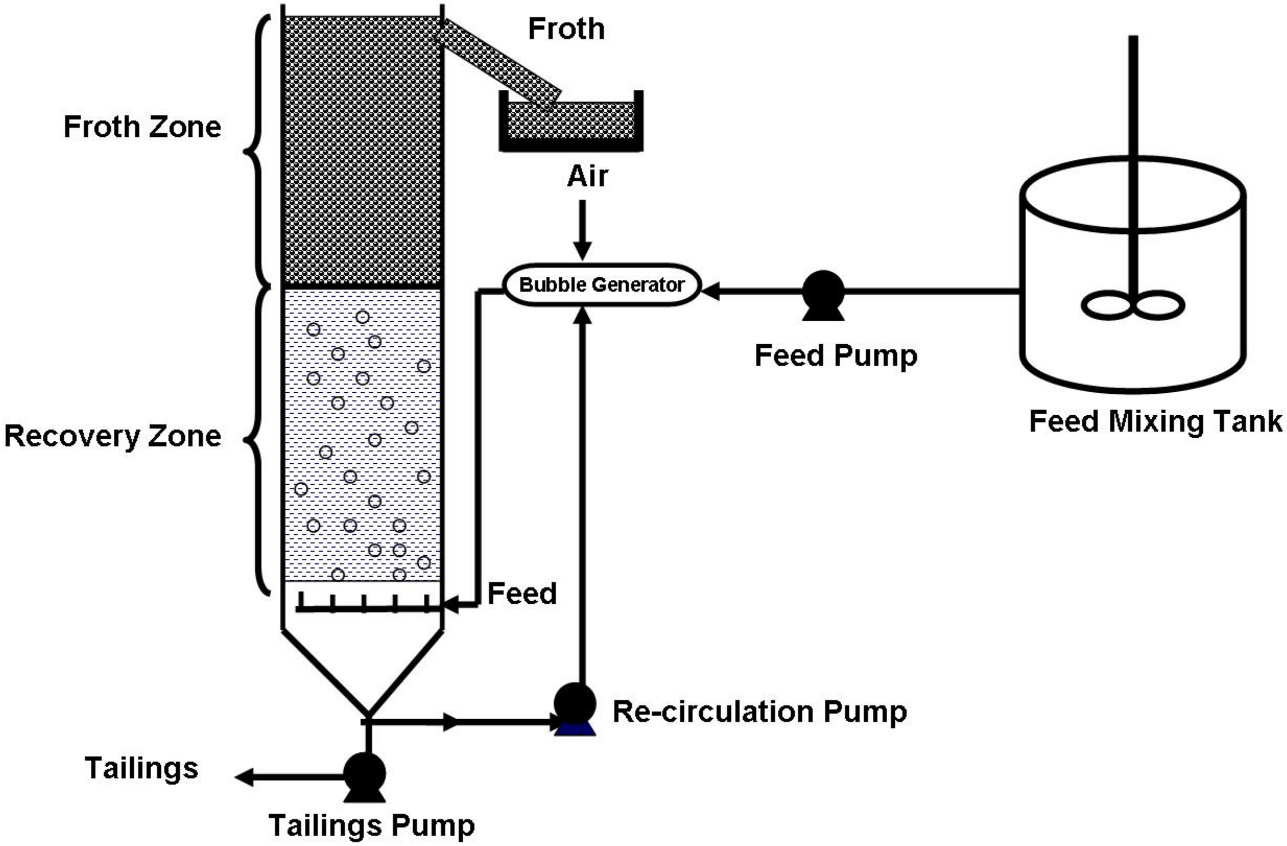

Figure 2.3 Schematics of flotation column (continuous flotation)

Recovery zone (Bubbly zone): The attachment of the gas bubbles to the hydrophobic particles occurs in the recovery (bubbly) zone. The bubble-particle aggregates rise and reach the froth zone after meeting the pulp-froth interface. The main means for the hydrophobic particles to enter the froth zone are by attachment to the gas bubbles, entrainment in the liquid behind the gas bubbles or the aggregates, mechanical entrapment in the aggregates due to partial slime coating or flocculation, and finally by the attachment of the fine particles to the coarser particles (carrier flotation), [23]. Deceleration of the bubble-particle aggregates and the resulting detachment of the particles from the gas bubbles occur at the interface of two zones. Bubble coalescence, particle detachment and liquid drainage are three main mechanisms through which the particles return to the recovery zone [19]. If the particles remain attached to the gas bubbles, they cross the interface and enter the froth zone.

Froth zone: The aggregates entering the froth zone continue to the top of the froth bed where they are removed as product. Possible detachment can occur from liquid drainage, bias wash water, and slippage or oscillation factors. The froth zone mainly consists of hydrophobic particles. The quality of froth is also affected by froth depth, bubble residence time and drop-back of solids that enter the froth zone as attached to the gas bubbles but eventually returns to the bubbly (recovery) zone [20]. In addition to main flotation column, the flotation column arrangement has the following parts.

Feed mixing tank: The dynamics of the flotation process determined using the batch flotation experiments is used in the preparation of the feed slurry. Here Aurora recycle water is used in feed preparation. A 20 litre baffled feed tank consists of an agitator by which the feed is mixed thoroughly prior to its introduction into the column/ bubble generator assembly. Masterflex I/P peristaltic pump is used to pump the feed to the bubble generator assembly at feed rates between 0.4~0.5 kg/min.

Bubble generator: The bubble generator as shown in Figure 2.4 is a reminiscent of the air sparger assembly used in mineral processing. The cross flow sectional area within the generator is reduced; hence the slurry velocity at the narrowest point becomes very high, causing a large decrease in the corresponding slurry pressure [22]. If the resulting pressure drop is below the pressure of water vapour or that of air saturation, cavities of water will form possibly in-situ on hydrophobic particles which may cause the migration of air into them. This gas nucleation mechanism leads to a more effective aeration on the hydrophobic hydrocarbon particles. The limitation to this methodology is the need to recirculate the slurry at fairly high velocity to reduce the pressure below the water vapour pressure. The super saturation of the slurry allows a certain amount of air to be dissolved, which may reduce the flow velocity for gas nucleation. The bubble generator fortunately generates a larger number of small bubbles as the air is fed at a smaller rate (as in the case of sparger, [23]) thereby increasing the probability of bubble-particle attachment and hence the particles collection rate.

The particle collection rate is also affected by the increase in the superficial gas velocity to an upper limit. Gas rate limitation can be identified by the loss of bubbly flow or the loss of the froth-recovery zone interface [24]. At the throat region of the orifice, the Reynolds number is sufficiently high such that the slurry is in the turbulent region. This turbulence and resulting shear forces avoid the formation of large bubbles. Smaller bubbles help in improving the froth stability and grade by entraining fewer particles in their wake owing to smaller drag forces. They also allow better froth drainage due to the availability of water pathways between the froth bubbles. The probability of gas bubble coalescence is also decreased by smaller diameter bubbles. The coalescence of bubbles if occurs, reduces the amount of surface area produced, probability of collision and ultimately recovery.

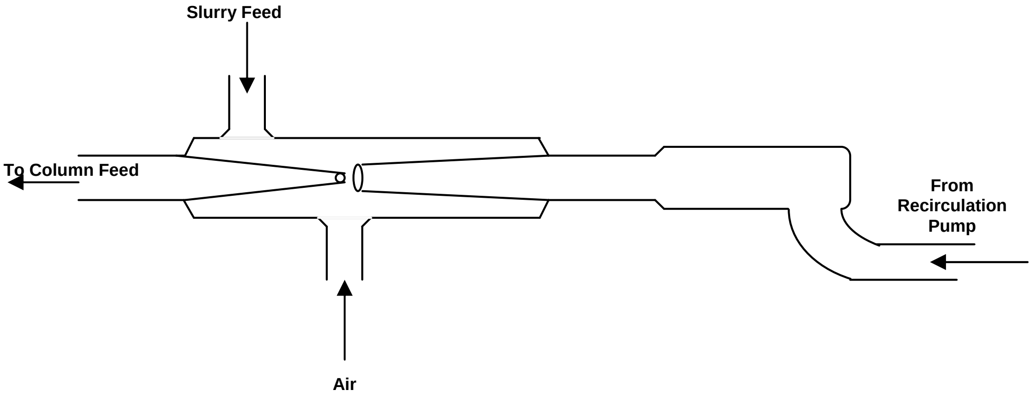

Figure 2.4 Bubble generator used in this study

Recirculation pump: The recirculation pump is vital for any column flotation experiment. Circulation of the feed within the column is necessary as the hydrophobic particles that fall to the recovery zone after having lost a chance to be generated as froth in the froth zone owing to bubble coalescence, particle detachment or liquid drainage, get another chance to be re-circulated and aerated within the system. Re-circulation pump rate affects the recovery of hydrocarbons greatly and is always kept in the maximum pumping rate. This is maintained in order to optimise recovery of hydrophobic particles. Masterflex I/P peristaltic pump was used in pumping the feed to the bubble generator assembly. Tygon tubing was used as the connecting tubing.

Tailings pump: The tailings pump is used in pumping the tailings or the effluent produced from the column flotation experiments. Production of froth and froth quality (measured as a ratio of the undesired solids in froth to recovered hydrocarbons in froth) can be varied by judicious operation of the tailings pump. Masterflex I/P peristaltic pump was used in pumping out the effluents at flow rates of 0.3~0.5 kg/min. Tygon tubing was used as the connecting tubing.

Experimental procedure: For each test, the feed slurry to the flotation column was prepared in the feed mixing tank. The dilution of MFT was accomplished using the same process water as used in the batch operations, to ensure similar system chemistry. The feed temperature was kept constant at 35°C. Process water was heated to the required temperature prior to mixing with MFT in the feed mixing tank. The column was first filled with process water at 35 ºC. The recirculation pump was started to establish the continuous flow condition. The feed slurry was then introduced into the flotation column. Once froth zone was established and the initial froth was produced, the tailings pump was started. The feed, tailings and froth samples were taken after an initial operation of 30 minutes at each condition to ensure the steady state operation of the flotation. Proper mixing takes place within the flotation column as the hydrocarbons were carried to the top with the air bubbles. Solids are pulled down by the water. The hydrocarbons still attached to the solids fall down and get immersed in this zone where the detachment of the hydrocarbons occurs. Establishing a stable and steady froth zone is very important for the success of the operation. Steady state was achieved once the froth and tailings flow rates measured for three consecutive samples were constant. The collected samples were analysed for their hydrocarbon, solids and water content using Dean Stark apparatus.

Recovery of hydrocarbons, R was calculated as a measure of the hydrocarbons recovered from the feed sample by the flotation process.

$$\text{Recovery of hydrocarbons, R\%} = \left[\frac{F \times x_{Hf}}{S \times x_{Hs}}\right] \times 100 \qquad (2.4)$$

F and S are the mass flow rate of froth product and feed streams, and x_{Hf} and x_{Hs} are the mass fraction of hydrocarbons in froth and feed streams, respectively.

Froth quality was measured as a ratio of the undesired solids recovered along with the hydrocarbons in the flotation process and is calculated as the solids to hydrocarbon ratio, SHR.

$$SHR = \left[\frac{x_{Sf}}{x_{Hf}}\right] \tag{2.5}$$

x_{Sf} and x_{Hf} are defined as the mass fraction of solids and hydrocarbons in the froth.

3 Results and Discussions

3.1 Composition of the waste streams used in this study

The average values of the weight percentage of hydrocarbons, solids and water obtained using the Dean Stark extraction method for the various types of waste streams used in this study are given in Table 3.1. Errors shown in the table represent the standard deviation obtained from five representative samples.

Table 3.1 Composition of the feed used for the study

Feed	**Hydrocarbons (% by wt.)**	**Solids (% by wt.)**	**Fines (% by wt.)**	**Water (% by wt.)**
Syncrude MFT from Oil Sands Tailings Research Facility.	3(±0.3)	35(±0.1)	97(±0.5)	62(±0.1)
TSRU tailings of Albian Sands.	5(±0.7)	23(±0.3)		72(±0.1)
Suncor Mature Fine Tailings from Ponds 1A and 1B.	2(±0.1)	54(±0.1)	87(±0.4)	44(±0.1)

The composition data in Table 3.1 show that MFT is a suspension composed of water, hydrocarbons and solids. The majority of solids are considered as fines. The average particle size of fine solids is determined to be d_{50}= 17.7 µm. The raw MFT is extremely viscous and difficult to process without dilution. The tailings from the TSRU contain more hydrocarbons due to the presence of precipitated asphaltenes. When compared to the viscous MFT, the more fluid TSRU tailings present no need for dilution prior to flotation. The amount of TSRU tailings and

MFT from Suncor was rather limited for the current study and hence the majority of the work was done on the MFT from Syncrude.

3.2 Effect of dilution ratio, N

Dilution of MFT prior to flotation is necessary because the raw MFT is extremely viscous, hindering the contact of hydrocarbons with air bubbles and hence their flotation. The effect of MFT dilution ratio, using Aurora recycle water (process water) on the recovery of hydrocarbons from the MFT was first studied. The MFT samples from Syncrude were diluted with process water to a mass ratio of 1:N by weight (where N = 0, 1 and 2). In this set of tests, the agitation speed and air flow rate were set at 1500 rpm and 150 mL/min, respectively. The feed slurry temperature was kept at 35ºC. The froth samples were collected into different pre-weighed thimbles over time intervals of 3, 5, 10 and 20 minutes. The hydrocarbon recovery in each time intervals was calculated using Equation (2.1). Figure 3.1 shows the recovery of hydrocarbons as a function of flotation time at different dilution ratios. It can be seen that increasing the dilution ratio for the mature fine tailings with process water enhances the recovery of hydrocarbons. At a dilution ratio of 2, for example, the hydrocarbon recovery could reach as high as 80%.

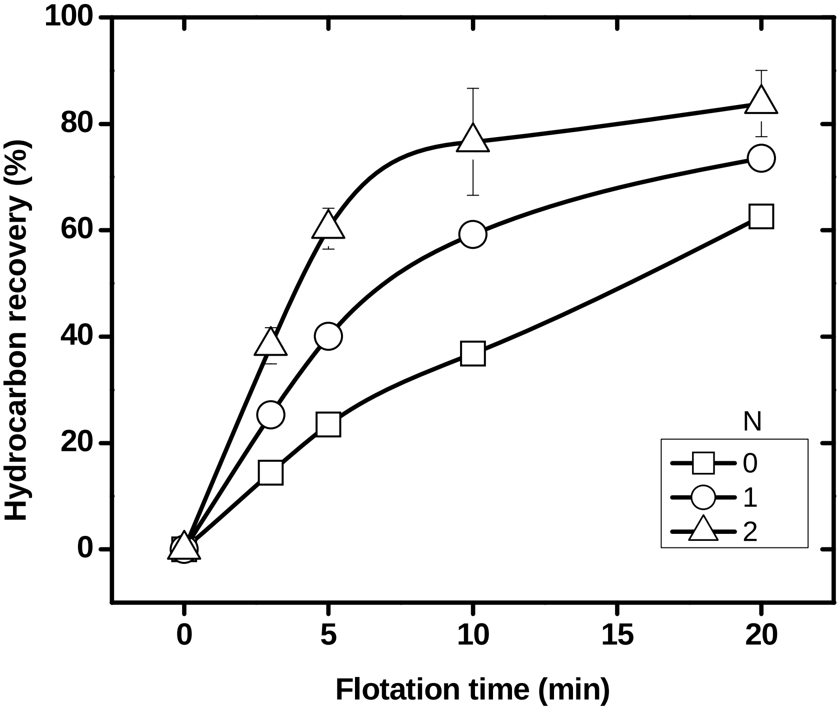

Figure 3.1 Effect of dilution ratio, N on hydrocarbon recovery from Syncrude MFT at different dilution ratios

Figure 3.2 compares hydrocarbon recovery and solids to hydrocarbon ratio (SHR) at different dilution ratios. Increasing the dilution ratio is shown to decrease the amount of solids recovered in the froth product, i.e., drastically improve the quality of hydrocarbon froth. An increase in dilution ratio decreases the solids content in the feed slurry and hence solid carry over into the froth, even though the water recovery is shown to increase with dilution ratio, as shown in Table 3.2. It is clear that increasing dilution ratio of MFT is highly beneficial for improving both MFT recovery and froth quality.

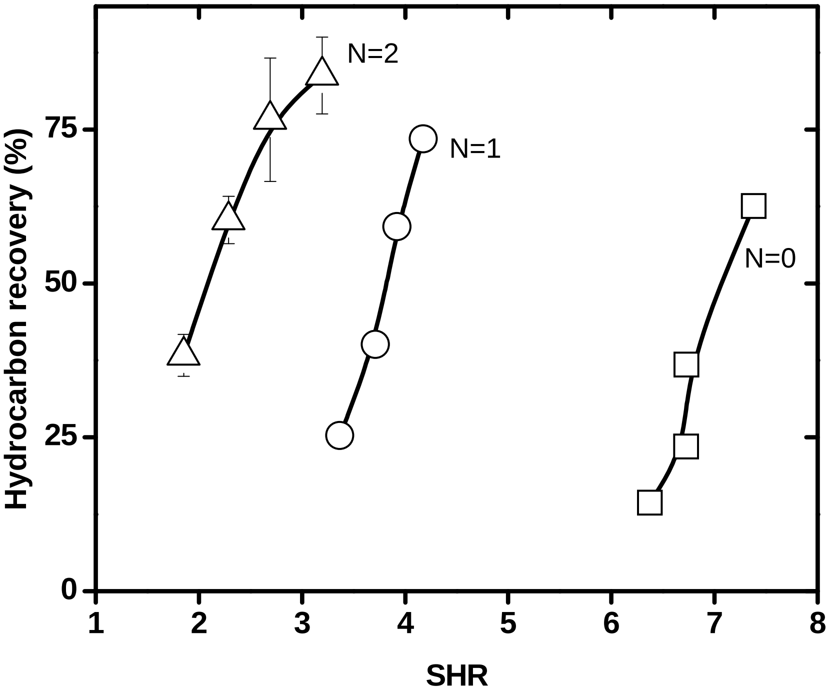

Figure 3.2 Effect of dilution ratio, N on hydrocarbon recovery and froth quality measured by solids to hydrocarbon ratio (SHR)

Table 3.2 Hydrocarbon recovery parameters of MFT flotation at different dilution ratio, N with process water

N	**Cumulative hydrocarbon recovery (%)**	**R_m (%)**	***k*** **(s^{-1})**	**SHR (wt:wt)**	**W:HC (wt:wt)**
0	62.6	97.4	0.05	7.4	12.1
1	73.5	78.4	0.14	4.2	23.2
2	83.8	85.5	0.22	3.2	26.4

The flotation parameters, such as the ultimate recovery, R_m and flotation rate constant, k (min^{-1}) obtained by fitting the flotation data given in Figure 3.1 to

Equation (2.2) using non-linear regression wizard of the Origin 7.5 software, and are shown in Table 3.2. It can be seen that the ultimate recovery, R_m is higher for flotation of MFT with no dilution as compared with a dilution ratio of 2. However the corresponding flotation rate constant, k is four times smaller. It indicates that a much shorter flotation time is needed to achieve a desired hydrocarbon recovery at a higher dilution ratio. Further increase in dilution ratio of 3 and above of the feed is not attempted in this study, as higher dilution would lead to handling of excessive large volumes of slurry by flotation cells in practice, which would reduce the residence time for treating the same volume of raw MFT. The dilution ratio was kept at 1:2 for the remaining tests.

3.3 Effect of dilution medium

To determine the effect of dilution medium for MFT dilution prior to its flotation on hydrocarbon recovery, different types of water, including process water, de-ionized water and tap water were used. To eliminate the effect if any caused by the variation in pH of the three different sources of water, the pH of the other two sources of water was adjusted prior to dilution to the same pH value of 8.2 as the Aurora recycle water. Froth flotation was conducted under identical conditions of agitation at 1500 rpm, aeration rate at 150 mL/min and temperature at 35°C respectively. Table 3.3 shows a comparison of hydrocarbon recovery obtained with different dilution water. A negligible variation in hydrocarbon recovery was observed among the three sources of water, demonstrating that hydrocarbon recovery is independent of source of dilution water. Dilution is therefore thought to mainly reduce the viscosity of the feed slurry and entrainment of fine solids to hydrocarbon froth.

Table 3.3 Effect of dilution medium on hydrocarbon recovery from Syncrude MFT diluted at 1:2 mass ratios

Dilution media	**Cumulative hydrocarbon recovery (%)**
Process Water	83.8
Deionised Water	89.9
Tap Water	89.6

3.4 Effect of aeration rate

The effect of aeration rate on hydrocarbon recovery from diluted MFT was also studied. In this set of tests, the MFT from Syncrude was diluted with process water at a 1:2 mass ratio. The pH was maintained at 8.2, the solution temperature, at 35 °C, flotation time, at 20 minutes and agitation speed, at 1500 rpm. Air flow rate varied from 25, 150, 525 to 730 mL/min. Figure 3.3 shows the recovery of hydrocarbons as a function of flotation time when the flotation of the diluted mature fine tailings was conducted at various air flow rates using a Denver cell. It can be seen that hydrocarbon recovery increases with increasing air flow rates. Increasing the air flow rate is anticipated to produce more bubbles and hence larger bubble surface area flux, increasing the collisions of hydrocarbons with bubbles and resulting in higher hydrocarbon recovery rate as shown in Table 3.4. However the overall hydrocarbon recovery (R_m) for all air flow rates is essentially similar, although there is a slight trend of increasing hydrocarbon recovery with increasing aeration rates.

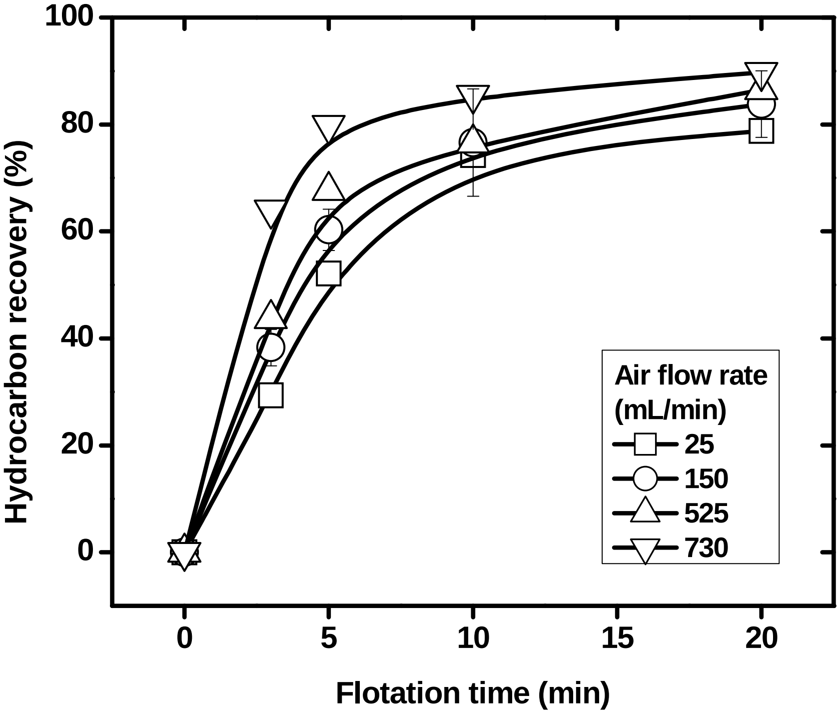

Figure 3.3 Effect of air flow rate on hydrocarbon recovery from Syncrude MFT diluted at 1:2 mass ratios

Table 3.4 Effect of air flow rate on recovery kinetics of hydrocarbons

Air flow rate (mL/min)	**Cumulative hydrocarbon recovery (%)**	**R_m (%)**	**k (s^{-1})**
25	78	83.5	0.18
150	83	85.5	0.22
525	86	85.8	0.26
730	89	88.5	0.43

Figure 3.4 shows the hydrocarbon recovery versus froth quality profile at different aeration rates. Increasing aeration rate shows a continuous increase in froth

quality, i.e., less solids were recovered in the froth at a given hydrocarbon recovery. It appears that increasing aeration rate caused a significant increase in collisions of mineralized (hydrocarbon-covered) bubbles, leading to an increased coalescence and hence increased hydrocarbon load per unit floated bubble surface area and reduced recovery of water per unit recovery of hydrocarbons. Both contribute to an improved hydrocarbon froth quality. Hence high air flow rates over the range studied are highly desirable for a higher hydrocarbon recovery and froth quality.

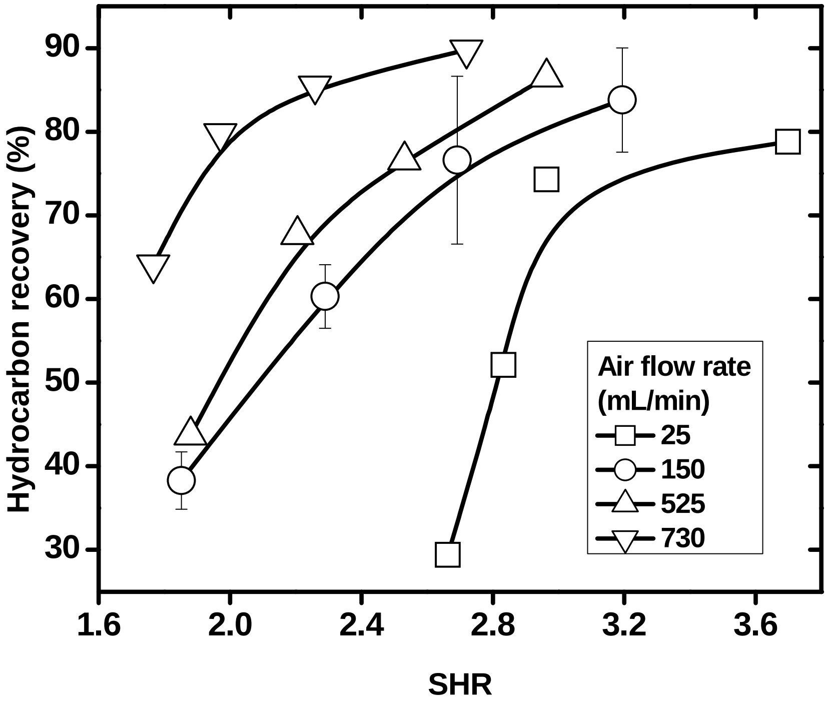

Figure 3.4 Effect of air flow rate on hydrocarbon recovery and froth quality measured by solids to hydrocarbon ratio (SHR)

Figure 3.5 shows that flotation rate constant increased only marginally with increasing aeration rate up to 550 mL/min. However a significant increase in flotation rate with further increase in aeration rate was observed. Although it is anticipated that flotation rate constant increases with increasing aeration rate due to increase in the number of bubbles or bubble surface area flux with increasing aeration rate, the reason for the sharp increase in flotation rate constant with increasing aeration rate above 550 mL/min remains to be established.

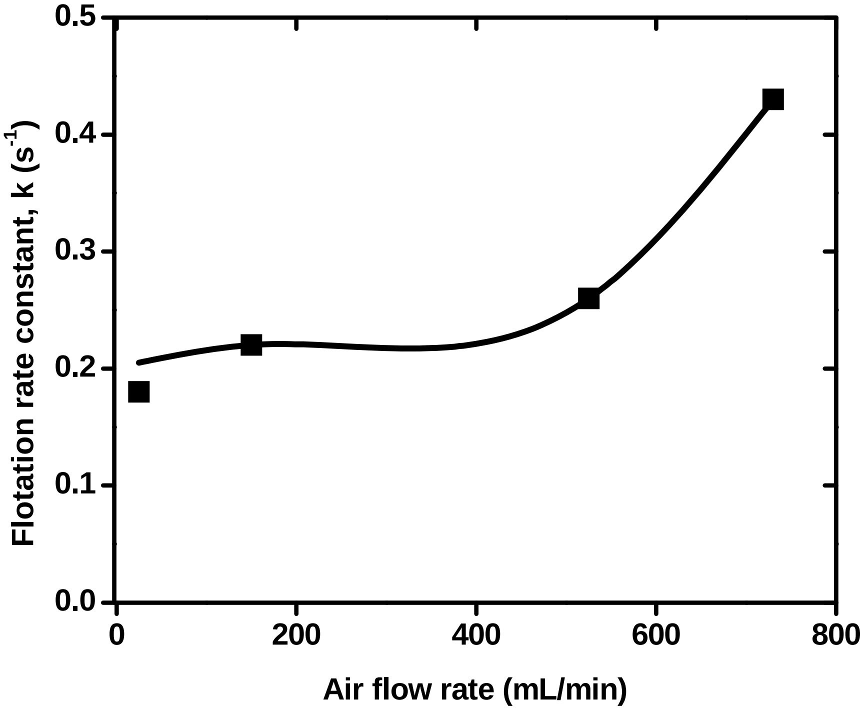

Figure 3.5 Effect of air flow rate on flotation rate constant of hydrocarbon recovery from Syncrude MFT diluted at 1:2 mass ratios

3.5 Effect of agitation speed

Effect of agitation speed on hydrocarbon recovery from MFT was also studied. In this set of tests, the feed slurry temperature and air flow rate were kept constant at 35°C and 150 mL/min, respectively. Three different agitation speeds of 900, 1500 and 2100 rpm were used. Figure 3.6 shows the recovery of hydrocarbons as a function of flotation time at different agitation speeds.

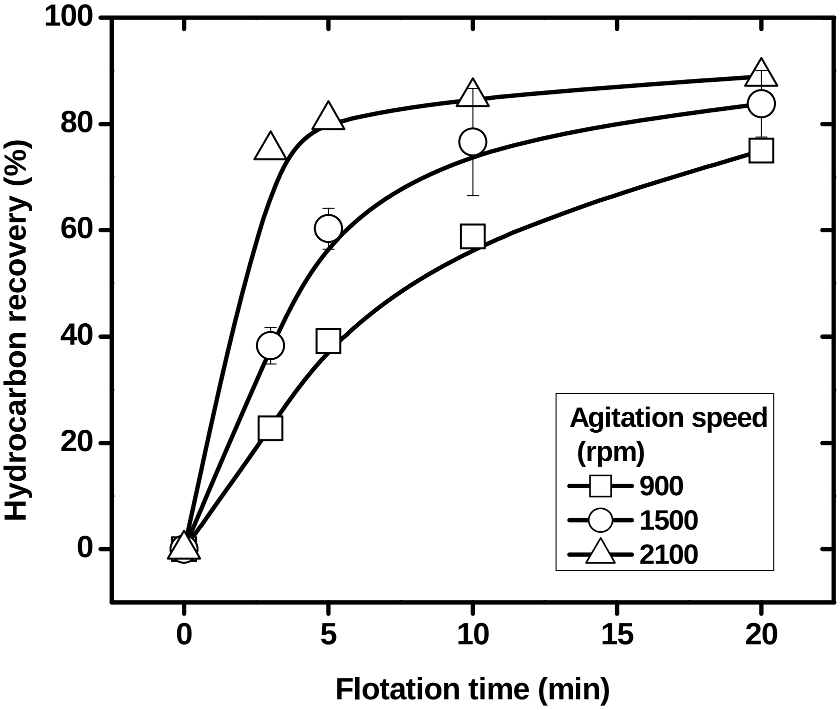

Figure 3.6 Effect of agitation speed on hydrocarbon recovery from Syncrude MFT diluted at 1:2 mass ratios

It can be noted that the hydrocarbon recovery increases with increasing agitation speed. Increasing agitation speed increases the shear of the feed slurry, possibly leading to an increased liberation of hydrocarbons from the solids. Increasing agitation speed also increases breakup of air bubbles, producing smaller air bubbles of higher total surface area for contacting hydrocarbons and hence, leading to a faster flotation rate and higher overall bitumen recovery. Furthermore, higher agitation speed increases the collision between air bubbles and liberated hydrocarbons, contributing to an increase in hydrocarbon recovery. Overall, increasing agitation speed increases ultimate hydrocarbon recovery and flotation rate constant as shown by the results in Table 3.5.

Table 3.5 Effect of agitation speed on hydrocarbon recovery parameters by flotation

Agitation speeds (rpm)	**Cumulative hydrocarbon recovery (%)**	**R_m (%)**	**k (s^{-1})**
900	75.0	82.6	0.12
1500	83.8	85.5	0.22
2100	88.9	86.4	0.64

It is interesting to note an exponential increase in flotation rate constant with increasing agitation speed, as shown in Figure 3.7. This finding further supports the fact that increasing agitation speed reduces the size of air bubbles and increases collision between the produced bubbles and liberated hydrocarbons, thereby collectively increasing flotation rate.

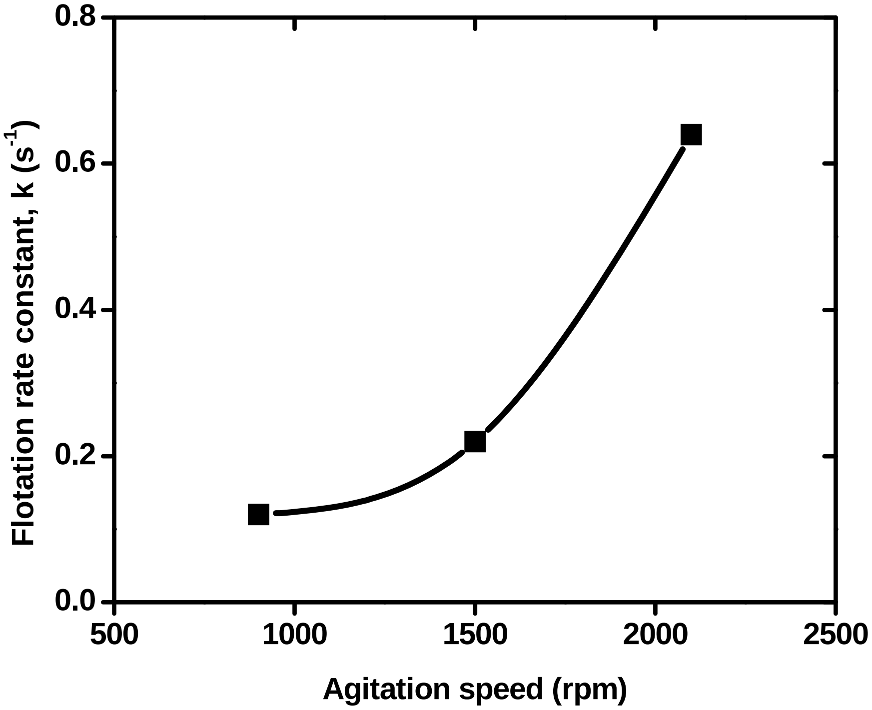

Figure 3.7 Effect of agitation speed on flotation rate constant of hydrocarbon recovery from MFT

Figure 3.8 shows the hydrocarbon recovery versus froth quality profile at different agitation speeds. A negligible effect of agitation speed on froth quality is seen as all the data points collapse essentially on a single hydrocarbon recovery versus froth quality curve. Overall, high agitation speed is beneficial for recovery of hydrocarbons from MFT by a mechanical flotation cell as it leads to a faster flotation rate as shown in Figure 3.7 without sacrificing froth quality as shown in Figure 3.8.

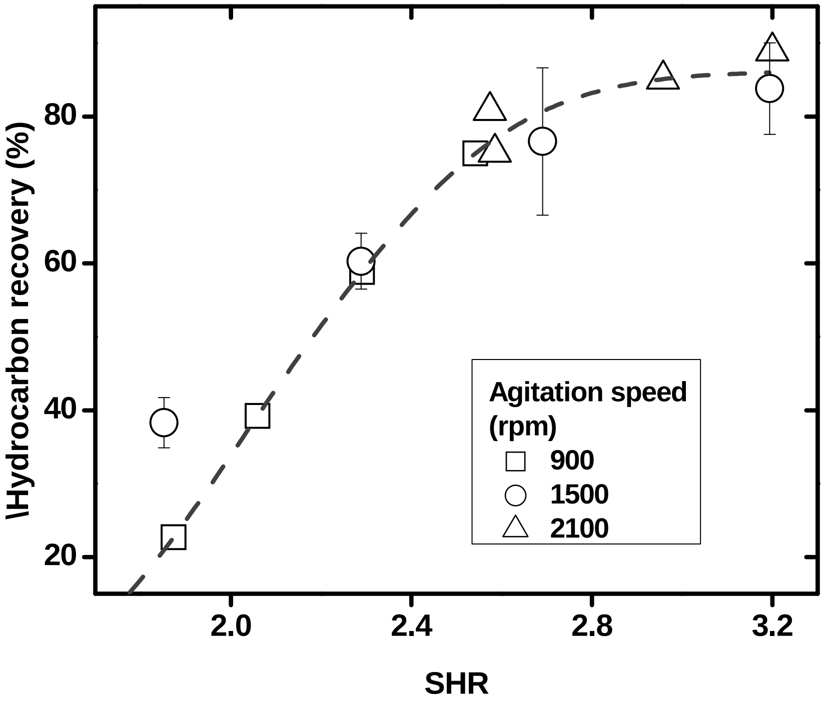

Figure 3.8 Effect of agitation speed on hydrocarbon recovery and froth quality measured by solids to hydrocarbon ratio (SHR)

3.6 Effect of air flow rates and agitation speeds on hydrocarbon recovery from MFT

It is necessary to understand which of the flotation parameter has more pronounced effect on hydrocarbon recovery from a given sample of MFT. It was already shown that aeration rate and agitation speed aid in hydrocarbon recovery from Syncrude MFT. To study these effects further, the MFT from Syncrude was diluted with process water to 1:2 MFT: dilution water by weight prior to flotation in a Denver cell. The pH was maintained at 8.2, flotation temperature at 35^{o}C, and flotation time period at 20 minutes. Four different runs were conducted at air flow rates of 150 mL/min and 730 mL/min at two agitation speeds of 900 rpm and 1500 rpm. The hydrocarbon recovery at these conditions was determined and the results are shown in Table 3.6. It can be seen that when the agitation is kept at lower speed, an increase in the air flow rate leads to an increase in hydrocarbon recovery that is more pronounced than for the case at higher agitation speeds. It appears that larger bubble surface area flux of small bubbles produced at higher agitation speed overshadows the effect of increased aeration rate. The froth quality, denoted by SHR improves with increasing aeration rate for lower agitation speeds, as also shown in Table 3.6. Hence at lower agitation speeds, increasing air flow rate improves both hydrocarbon recovery and froth quality. At higher agitation speeds, increasing aeration rate shows minimal benefits. Overall, increasing aeration rate improves the hydrocarbon recovery from diluted MFT.

Table 3.6 Recovery data for the flotation of MFT at different agitation speeds and different air flow rates

Flotation conditions		**Cumulative hydrocarbon recovery (%)**	**SHR**
Agitation speed (rpm)	**Air flow rate (mL/min)**		
900	150	75.0	2.54
900	730	85.1	1.98
1500	150	83.8	3.19
1500	730	89.8	2.72

3.7 Recovery of hydrocarbons from the MFT of Suncor Energy

The recovery of hydrocarbons by flotation was also conducted using MFT from Suncor Energy Inc. The solids content in the Suncor MFT was 54% by weight due to a more consolidated nature of MFT from Suncor. This extremely viscous MFT makes it necessary to dilute the mature fine tailings prior to any flotation experiments. The flotation temperature was kept at 35°C, the agitation speed at 1500 rpm and the air flow rate at 150 mL/min. Figure 3.9 shows the recovery of hydrocarbons from Suncor MFT by batch flotation as a function of flotation time up to 20 minutes for two different dilution ratios. Dilution is seen to reduce the viscosity of the MFT, thereby allowing the contact of the hydrocarbons with the air bubbles and hence their flotation. It can be seen that more than 80% of the hydrocarbons were recovered from the Suncor MFT by flotation of 20 minutes after dilution. Further tests using Suncor MFT were not conducted due to lack of samples.

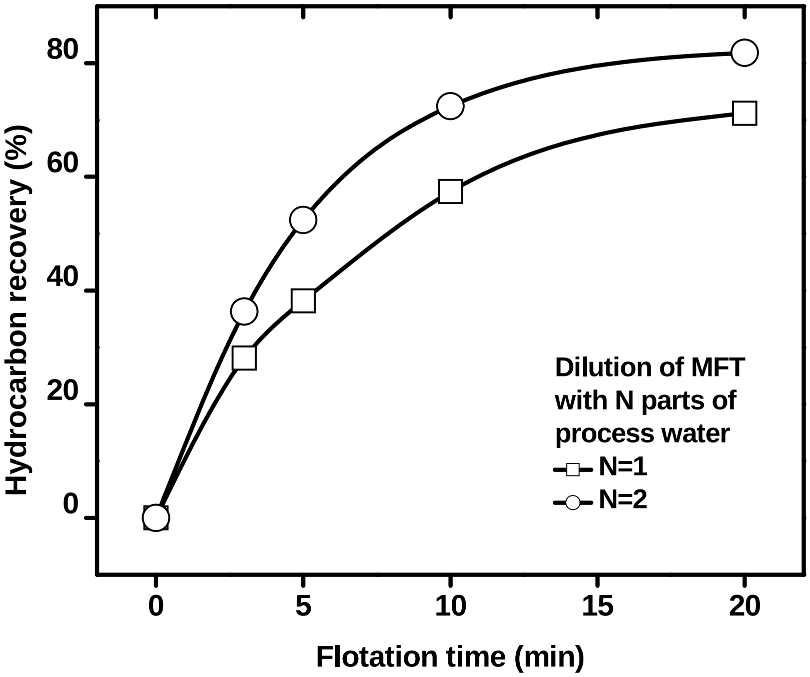

Figure 3.9 Effect of dilution ratio, N on hydrocarbon recovery from diluted Suncor MFT

3.8 Recovery of hydrocarbons from the tailings of TSRU

The hydrocarbons were recovered from the tailings of the TSRU using Denver flotation cell. The agitator speed and the air flow rate were maintained at 1500 rpm and 150 mL/min, respectively. The temperature of the flotation was kept at 35°C, 50°C and 65°C. These set of temperatures was selected because the TSRU was operated at higher temperatures and cooling down to various temperatures prior to flotation was anticipated in practice. The feed was preheated to these temperatures prior to batch flotation. The remaining procedures were similar to those used in the hydrocarbon recovery tests discussed earlier. Figure 3.10 shows the recovery of hydrocarbons from the TSRU tailings as a function of flotation time at different temperatures.

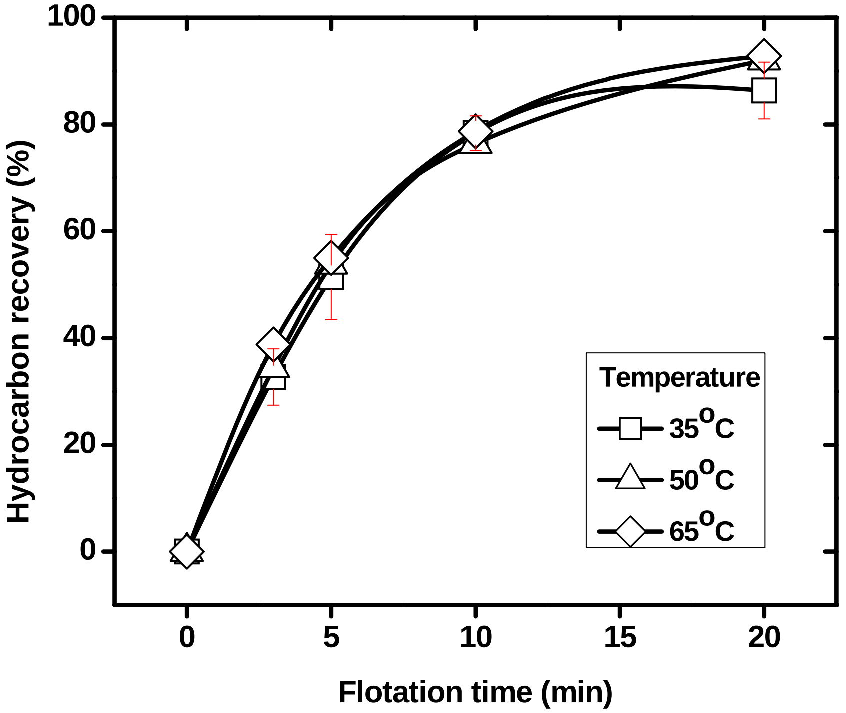

Figure 3.10 Effect of temperature on hydrocarbon recovery from TSRU tailings

The results in Figure 3.10 show that within the experimental error, the temperature had a negligible effect on hydrocarbon recovery from the TSRU tailings. Table 3.7 shows the cumulative hydrocarbon recovery and the solids to hydrocarbon ratio (SHR) for the froth product obtained by 20 minute flotation at different temperatures. It can be seen that froth quality decreases with increasing flotation temperature. It is known that the hydrocarbons in TSRU tailings are predominantly asphaltenes. It is these asphaltenes that were recovered by froth flotation. Asphaltenes are suspected to coat the solids and floated with them to the top of pulp. The froth quality decreases with increasing temperature due to this nature of asphaltenes. This finding has not been fully proven. An attempt is made to address this issue in the later sections.

Table 3.7 Characteristics of batch flotation experiments on the TSRU tailings

Flotation temperature (^oC)	**Cumulative hydrocarbon recovery (%)**	**SHR**
35	86.3	1.21
50	92	1.52
65	92.8	1.65

3.9 Effect of two stage flotation on the froth quality

Generally in the batch flotation experiments the ideal scenario would be to have hydrocarbon-rich froth. The reality as seen from the earlier section is different. However the solids recovered in the froth can be removed or the froth quality can be improved by a two-stage froth flotation process. To prove this, hydrocarbon froth floated from the TSRU tailings was used as the feed. About 300 g of the froth was diluted with 950 mL of water separated from the TSRU tailings by gravity separation. The same water was used to avoid any changes in the water chemistry that may occur. The second stage froth flotation was then conducted at an agitation speed of 1500 rpm, air flow rate at 150 mL/min and temperature at 35^{o}C. This temperature was selected as it leads to a lower SHR at this temperature as seen in the earlier section. Table 3.8 shows the performance of the single and two stage flotation processes. It can be seen that about 40% of the solids in the recovered froth are reduced in the second stage flotation process. The dilution of the froth reduced its viscosity, thereby enabling the air bubbles to attach to and float the hydrocarbons. About 98% of the hydrocarbons were recovered in the second stage flotation leading to an overall recovery of 84.6% at a much improved SHR of 0.75.

Table 3.8 Characteristics of two stage flotation experiments on TSRU tailings

Staged flotation	**Cumulative hydrocarbon recovery (%)**	**SHR**
Single Stage	86.3	1.20
Two Stage	84.6	0.75

Increasing dilution reduces the solids content in the feed and hence the carry over to the froth, thereby improving froth quality. The success of the two stage flotation gave us the onus to recover hydrocarbons using continuous flotation process.

3.10 Recovery of hydrocarbons from Syncrude MFT using continuous flotation

Following the recovery of hydrocarbons from MFT using batch flotation techniques, recovery of hydrocarbons was studied using a continuous flotation column. Feed slurry was prepared in the feed mixing tank by diluting MFT from Syncrude with Aurora recycle process water to a 1:2 MFT: process water mass ratio. The prepared feed slurry was found to have a hydrocarbon concentration of 1% by weight and a solid concentration of about 12% by weight. Continuous flotation was carried out at 35^{o}C. Feed slurry was fed into the column and the froth was collected after 30 minutes of initial run to ensure the steady state. The froth collected was analyzed for its hydrocarbon and solids content using the Dean Stark method. The results in Figure 3.10 show that after 30 minutes, the hydrocarbon recovery is constant at about 80%, indicating a steady state. The solids content in both froth and tailings remained at about 12% by weight, indicating entrainment of solids to the froth. Flotation column is seen to be suitable for recovering hydrocarbons from the diluted MFT.

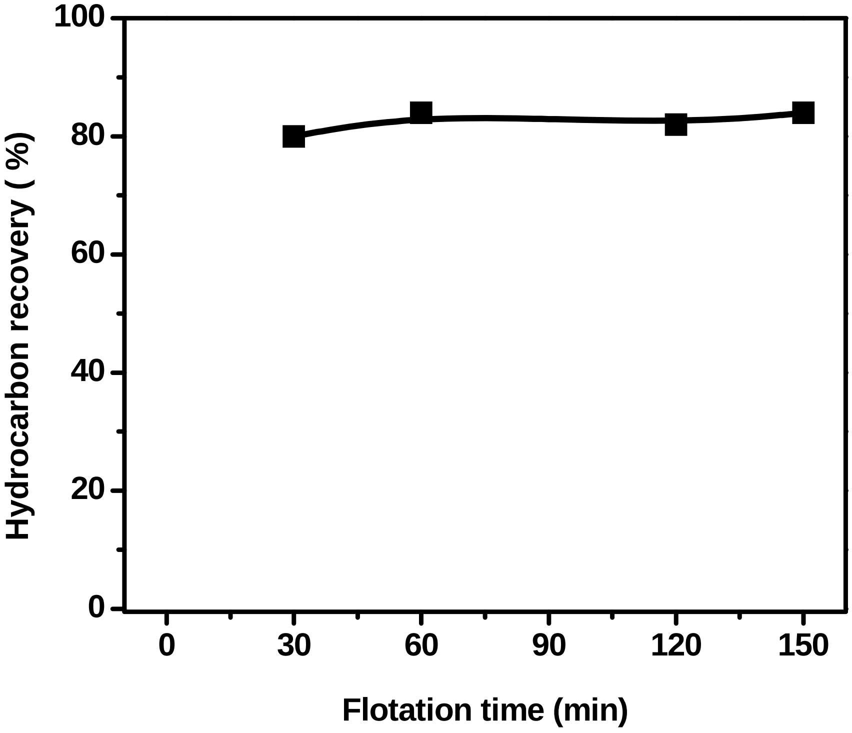

Figure 3.11 Hydrocarbon recovery from diluted MFT by a continuous flotation column

Continuous flotation techniques were also employed in the recovery of hydrocarbons from the tailings of TSRU. The TSRU tailings were used without dilution and floated continuously using a flotation column. For this feed about 85% of the hydrocarbons were recovered using flotation column.

3.11 Froth cleaning

Cleaning of the froth with diluents is essential prior to the upgrading of recovered hydrocarbons. To meet the downstream upgrading process conditions the water and the solids have to be removed from the recovered hydrocarbons. This is required to meet the specifications of less than 0.5 mass percent of total mineral solids and water. Centrifugation, inclined plate settler (IPS), hydrocyclone, and thickening are four major methods used in gravity separation in Athabasca bitumen froth treatment. [25].

The two commercial bitumen froth treatment processes used in Alberta are the naphthenic froth treatment (NFT) process (used by Syncrude Canada Ltd., CNRL and Suncor Energy Inc.) and the paraffinic froth treatment (PFT) process (used by Albian Sands Energy). In the NFT, naphtha is used as the diluent at a naphtha-to-bitumen mass ratio of 0.6–0.75, while in the PFT paraffinic solvent of C_5-C_6 mixtures is used at solvent-to-bitumen mass ratio of 2.1–2.5. Both processes facilitate the bitumen/water/solids separation by reducing the viscosity of the oil phase and, at the same time, increasing the density difference between the oil and water phases with added solvent. About 98% of the bitumen/ hydrocarbons are recovered by the naphthenic froth treatment process. It needs IPS and/or centrifugal equipment, such as a centrifuge and hydro cyclone to facilitate the bitumen/water/ solids separation for a product containing 1.0–2.5% residual water and 0.3–0.8% solids. In the case of the paraffinic froth treatment process, the residual water and solids can be reduced to less than 0.1% by weight of the bitumen/hydrocarbon at the cost of a 10% reduction in bitumen recovery as rejection of asphaltenes in the form of precipitates [25]. The residual water that remains in the diluted hydrocarbon-rich froth exists in the form of emulsified water droplets which carry chloride to downstream upgrading and/or refining operations. The presence of chlorine causes corrosion problems for the downstream process units and is highly undesirable.

In this study naphtha was used as the diluent in the froth cleaning to reject the water and solids. It was added to the hydrocarbon froth at a naphtha-to-hydrocarbon ratio of about 0.65. Diluted hydrocarbon froth was then centrifuged at low centrifugal speeds of 3500 rpm for 30 minutes and was allowed to stand. Three distinct layers of hydrocarbon, water and solids were formed. The hydrocarbon layer was removed carefully and was dried under vacuum to evaporate the diluent. The water content in the hydrocarbon layer is then analysed using a Karl Fischer titration apparatus.

The hydrocarbon-rich froth obtained from the continuous flotation experiments using the flotation column was found to contain about 15-20% hydrocarbons and 12-14% solids. Naphtha was used to clean this froth using the procedure mentioned above. The water content in the diluted froth was analysed and the results are shown in Table 3.9 for two different runs of the flotation experiments using flotation column and Syncrude MFT. It can be seen that despite a large amount of water in the froth, the addition of naphtha is capable of rejecting water from the froth from 73.7% to 0.2% at more than 98% of hydrocarbon recovery with least amount of solids. The effective removal of water from the recovered froth signifies that the hydrocarbons recovered from MFT by continuous flotation are valuable product suitable for downstream upgrading.

Table 3.9 Feed, hydrocarbon froth and water content in cleaned froth

No	**MFT (% by wt.)**			**Hydrocarbon froth (% by wt.)**			**Naphtha : HC (wt:wt)**	**Water in cleaned hydrocarbon froth (% by wt.)**
	HC	**Solids**	**Water**	**HC**	**Solids**	**Water**		
1	2.12	30	67.88	14.17	12.07	73.76	0.65	0.28
2	2.78	29.41	67.81	16.5	11.33	72.12	0.65	0.23

3.12 Morphology of froth from column flotation

Confocal laser scanning microscopy (CLSM) technique was widely used for studying morphology of bitumen froth produced from different oil sands ores [27]. The technique used for the analysis combines some features of the optical microscopy (OM) and scanning electron microscopy (SEM) wherein the froth sample is scanned point-by-point with a finely focused laser beam. Microscopic characterization of froth samples showed distinctive microscopic features. They included distinctly different fluorescence of hydrocarbons in froth of a good ore and totally different morphology for poor and degraded ores. The reason for the difference was due to the change resulting from the oxidation of the bitumen phase. These fluorescent micro features reveal the chemical complexities of the hydrocarbon component in oil sands [26].

The microscopic images of the mature fine tailings samples from Syncrude are shown in Figure 3.12 and those of the hydrocarbon froth from the column flotation experiments and the cleaned hydrocarbon froth are shown in Figure 3.13 and 3.14. These confocal images indicate a complex structure of water, solids and hydrocarbons. The dark areas in the images represent water or continuous phase present in the samples. The variation in the fluorescence contrast indicates the difference in the chemical composition of the samples. Figure 3.13 shows a hydrocarbon-rich type of fluorescence image along with relatively high percentage of fine solids which modifies the fluorescent image of the froth. The image of the cleaned froth (diluted with diluents) shown in Figure 3.14 shows a much clearer fluorescence, indicating a relatively higher quality of hydrocarbon containing much less solids or water, when compared to the fluorescent imaging of the un-cleaned froth as seen in Figure 3.12. The froth morphology results support the earlier statement that the hydrocarbons recovered from the mature fine tailings are valuable and can be used for upgrading to synthetic crude.

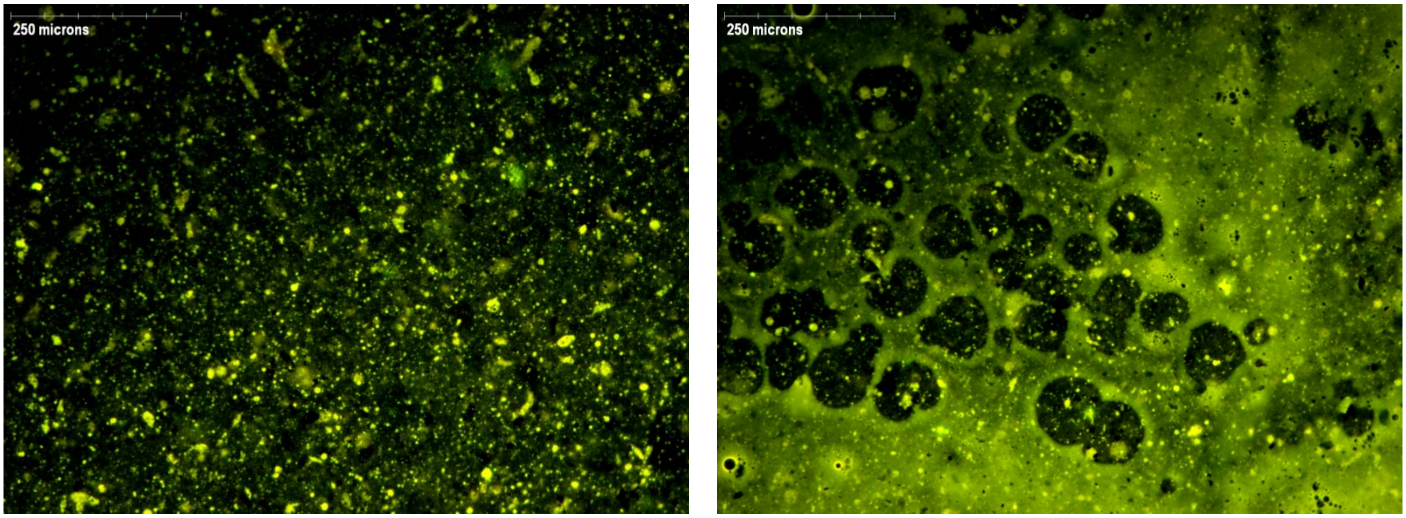

Figure 3.12 Microscopic images of the Syncrude MFT

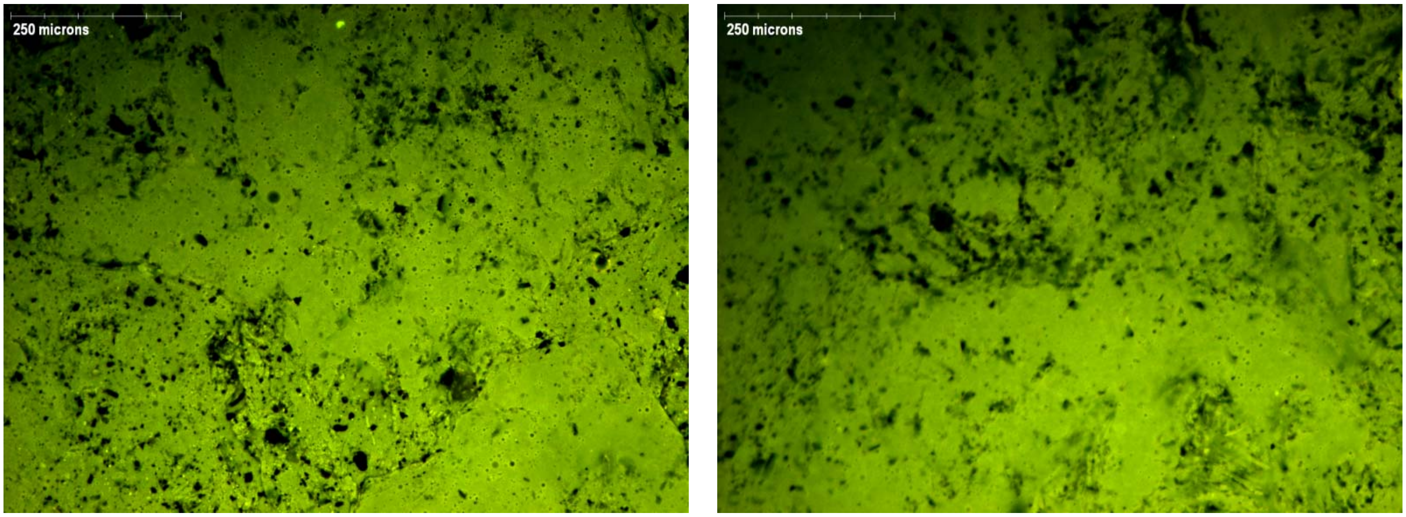

Figure 3.13 Microscopic images of the hydrocarbon froth

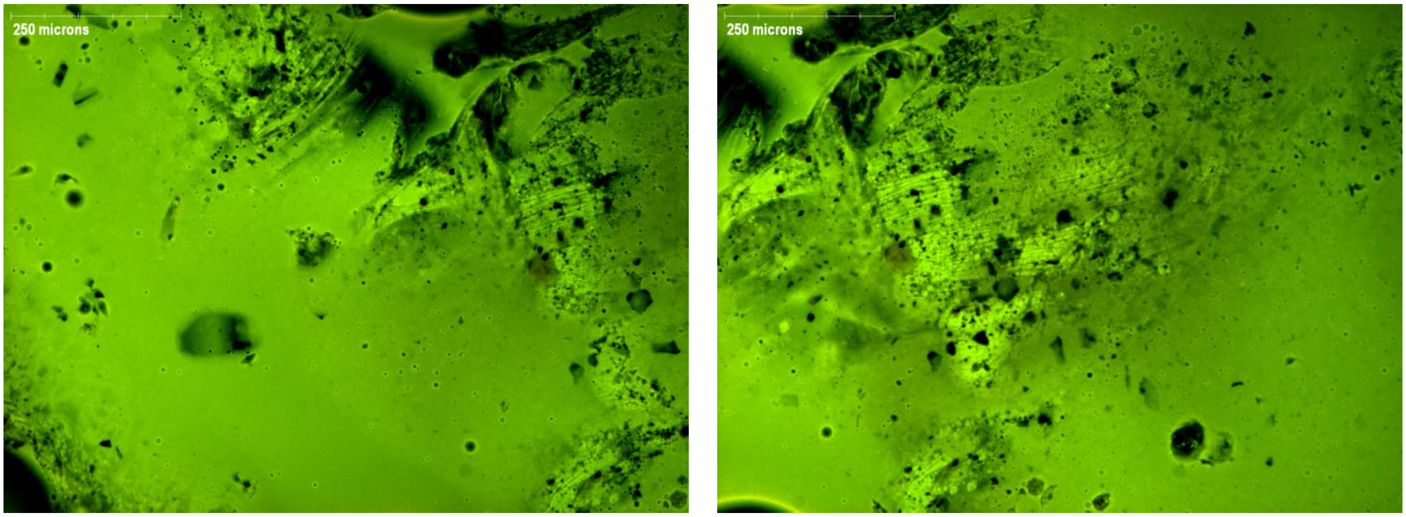

Figure 3.14 Microscopic images of cleaned hydrocarbon froth

3.13 Asphaltenes in recovered hydrocarbons

Asphaltenes (the word "asphaltene" was coined by Boussingault in 1837 on noticing that the distillation residue of some bitumen had asphalt-like properties) are high molecular weight, n-heptane (C_7H_{16})-insoluble and toluene ($C_6H_5CH_3$)-soluble component of heavy crude oil or bitumen. They are present with resins, aromatic hydrocarbons, and alkanes or saturated hydrocarbons. Asphaltenes consist primarily of carbon, hydrogen, nitrogen, oxygen, and sulphur, as well as trace amounts of structural vanadium and nickel with a C: H ratio of approximately 1:1.2, depending on the source of asphaltenes. Bitumen in oil sands contains much higher asphaltene content than medium-API oils or light oils. The high viscosities of crude oils are imparted by the presence of asphaltenes, hence negatively impacting oil production. The variable asphaltene concentration in crude oils within individual reservoirs creates a myriad of production problems [28].

Asphaltenes cause the formation of water-in-crude oil emulsions that are known to be very stable and resist coalescence under centrifugation. They impart a problem to the upgrading of the Canadian oil sands industry as these water droplets carry a large amount of salts which remain in the hydrocarbon phase as the water is driven off prior to upgrading. Asphaltenes are undesirable components as far as hydrocarbon extraction process is concerned.

In this study, the asphaltenes were extracted from the hydrocarbons recovered from the mature fine tailings and the TSRU tailings. The recovered hydrocarbon froth was analyzed using the Dean Stark extraction equipment. Certified ACS grade toluene was used in the Dean Stark extraction process to dissolve the recovered hydrocarbons. The hydrocarbon-rich toluene sample was then allowed to stand in a well vented fume hood for a week during which the toluene was evaporated off and hydrocarbons were left behind. The remaining hydrocarbon samples were weighed and used for extraction of asphaltenes using n-heptane as the solvent. HLPC grade heptane was added to the hydrocarbons at a weight ratio of 40:1 and was well mixed using a shaker for 2 hours. The mixture was then allowed to stand overnight to precipitate the asphaltenes. The hydrocarbon/heptane suspension was then filtered under vacuum with one layer of filter paper having a pore size of 0.22 μm. The nC_7-insoluble asphaltenes retained on the filter paper were repeatedly washed n-heptane until colorless. The asphaltenes were then collected and dried under ambient conditions until there was no further change in the weight [29].

Generally bitumen has about 17% of asphaltenes. Table 3.10 shows the asphaltene content in the hydrocarbons recovered from Syncrude MFT and the TSRU tailings by flotation. It can be seen that hydrocarbons recovered from Syncrude MFT by flotation contained a relatively small amount of asphaltenes as compared to the hydrocarbons recovered from the TSRU tailings.

Table 3.10 Asphaltene content in the recovered hydrocarbons

Sl. No	**Material**	**Cumulative hydrocarbon recovery (%)**	**nC_7 asphaltenes (% by wt.)**
1.	Flotation of TSRU tailings at 35°C	86.34	51.5
2.	Flotation of TSRU tailings at 50°C	92.07	60.68
3.	Flotation of TSRU tailings at 65°C	92.82	68.03
4.	Flotation of dil. Syncrude MFT at 35°C	83.8	5.63

TSRU tailings are effluents from the paraffinic froth treatment process which rejects about 50% of the asphaltenes in the bitumen. This accounts for a higher value of the asphaltenes in the tailings of the solvent recovery unit of froth treatment tailings. It is interesting to note a slight increase in asphaltene content in hydrocarbons recovered from TSRU tailings at higher temperatures and hence an increased hydrocarbon recovery.

In the case of mature fine tailings, the asphaltene content of 5.6% by weight in the recovered hydrocarbon content is lower than the values of 15% for typical bitumen. Therefore, the hydrocarbons recovered from MFT could be easily upgraded owing to their lower asphaltene content.

4 Settling of Tailings

4.1 Introduction

Flocculation is the process by which large agglomerates or flocs are produced in a suspension by the addition of high molecular weight polymeric chemicals. Liquid-solid separation can be enhanced by flocculation. In this chapter, we will discuss settling of the tailings produced from the continuous flotation experiments, i.e., from mature fine tailings of Syncrude after removal of hydrocarbons. Two different polymers, Al-PAM and Magnafloc-1011, were used in the flocculation tests in this study. This chapter introduces these two polymers, the experimental procedure of tailings settling and presents some initial results obtained.

4.2 Flocculants used

Polymer flocculants have been widely used in the solid-liquid and solid-solid separation in municipal waste treatment, industry process effluent clarification, etc. Synthetic polymers are highly efficient flocculants and can be tailored in terms of functional groups, structure and molecular weight to suit a particular application [31, 33 & 34]. The most commonly used polymer is polyacrylamide and its derivatives. Polyacrylamide is non-ionic in nature and the ionic character is varied by copolymerization with other monomers. Yang et.al., (2004) synthesized an $Al\ (OH)_3$–polyacrylamide hybrid flocculant (Al-PAM) where the ionic bonds between $Al(OH)_3$ colloidal particles and polyacrylamide (PAM) chains were recognized. The efficiency of flocculation by Al-PAM used in treating kaolinite suspensions was found to be much higher than by a commercial PAM or a blend of PAM and $AlCl_3$ [32]. Al-PAM-induced floccules were denser, larger, and of a spherical shape. In the present study, Al-PAM was synthesized through in-situ polymerization of acrylamide monomers with $Al(OH)_3$ colloids using $NaHSO_3$ and $(NH4)_2S_2O_8$ as initiator using the same procedures detailed elsewhere [32]. Commercial Magnafloc-1011 was also used in this study for comparison. Cymerman et al., have shown that high molecular weight, medium charge anionic copolymers of acrylamide and acrylates such as Magnafloc-1011 caused flocculation of fine tailings at low dosages normal operating pH of the feed slurry (pH~ 8.5). Their results showed fast settling of flocs and a turbid supernatant water layer containing 1.5% solids by weight by Magnafloc-1011 addition. Further tests were conducted to study the effect of Magnafloc-1011 flocculant, pH and divalent cations concentration on settling rate and turbidity of Syncrude fine tailings [35].

4.3 Experimental procedure

Flocculation and the settling tests were carried out using the experimental setup shown in Figure 4.1. For each test, 90 mL of feed slurry or flotation column tailings were used. Feed slurry here refers to the diluted MFT in the ratio of 1:2 by weight and the flotation column tailings refer to the resulting effluent of MFT after removal of hydrocarbons by continuous flotation. Feed or flotation column tailings samples were mixed in a 250 mL four-baffled beaker with a flat blade impeller for about 2 minutes prior to flocculant addition. Different dosages of the flocculant were added into the slurry. The concentration of ppm in this thesis is with reference to final volume of slurry. For example, 25 ppm means 25 mg of polymer per litre of feed slurry or flotation tailings. The feed stock solution of flocculant used here was 5000 ppm prepared in Aurora recycle water as used in the dilution of the mature fine tailings and hydrocarbon recovery tests. Once the flocculant was added, the resultant mixed feed slurry or tailings were immediately transferred to a 100mL graduated cylinder for settling test. Downward movement of the mudline (supernatant-sediment interface) was recorded as a function of time. A typical settling curve plotted as normalised mudline height (h/H) versus settling time (t) is shown in Figure 4.2. The initial settling rate was determined by finding the slope of the initial settling curve.

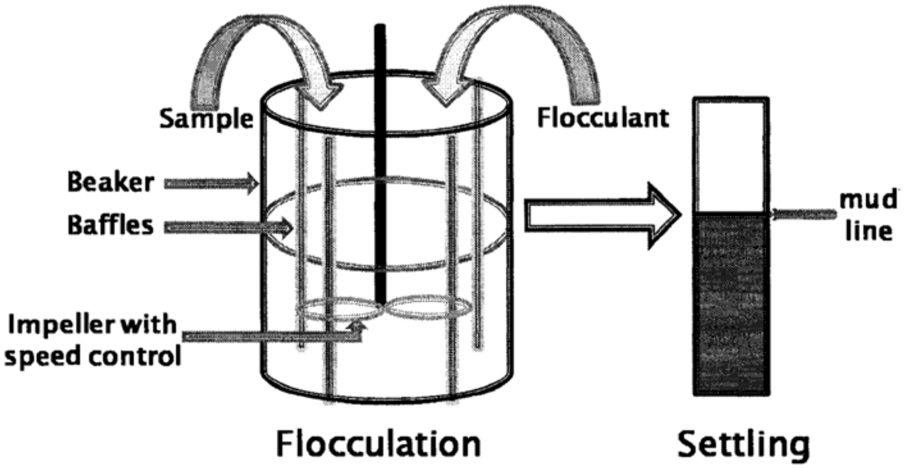

Figure 4.1 Apparatus for the flocculation and settling tests [31].

4.4 Effect of Al-PAM addition as a flocculant

Figure 4.2 shows the settling data as a function of settling time for the feed slurry with different amounts of Al-PAM addition, while Figure 4.3 shows similar data for the flotation column tailings after the removal of hydrocarbons.

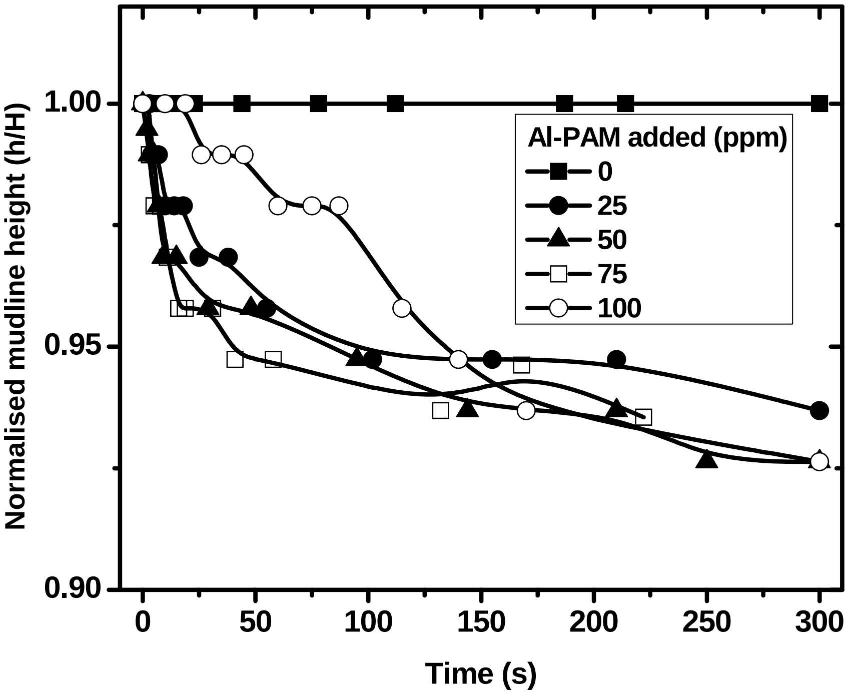

Figure 4.2 Settling data using Al-PAM as a flocculant on feed slurry (diluted MFT)

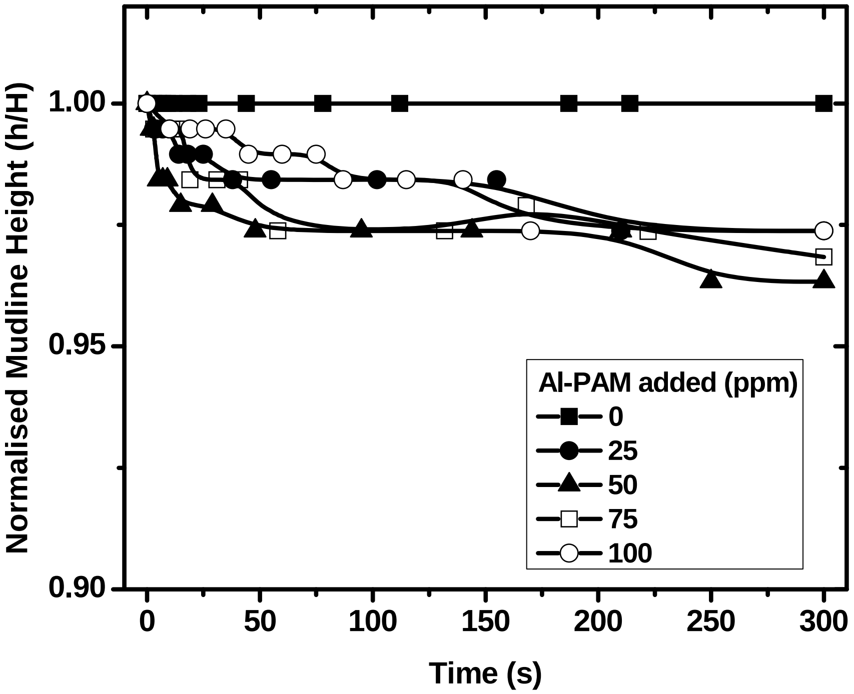

Figure 4.3 Settling data from using Al-PAM as a flocculant on flotation column tailings

The initial slopes of the settling curves were calculated as the initial settling rate and the results are shown in Figure 4.4. It can be seen that the addition of Al-PAM helps the settling of both diluted MFT and flotation column tailings. The initial settling increases with increasing polymer dosage for both the cases. For example, at 75 ppm of Al-PAM addition, the initial settling rate of feed slurry is 0.33 s^{-1}, in comparison to 0.15 s^{-1} for flotation column tailings where the hydrocarbons are removed. However the settling of the diluted mature fine tailings using Al-PAM as a flocculant is more effective than the flotation column tailings. One reason is that the flotation column tailings have less solids when compared to the diluted MFT. The poor settling characteristics could be due to the presence of a large number of fines. It is also to be noted that despite hydrocarbon removal, the flotation column tailings do not perform well with the addition of Al-PAM leading us to speculate that hydrocarbon removal has no effect on flocculation of the suspension using Al-PAM as a flocculant.

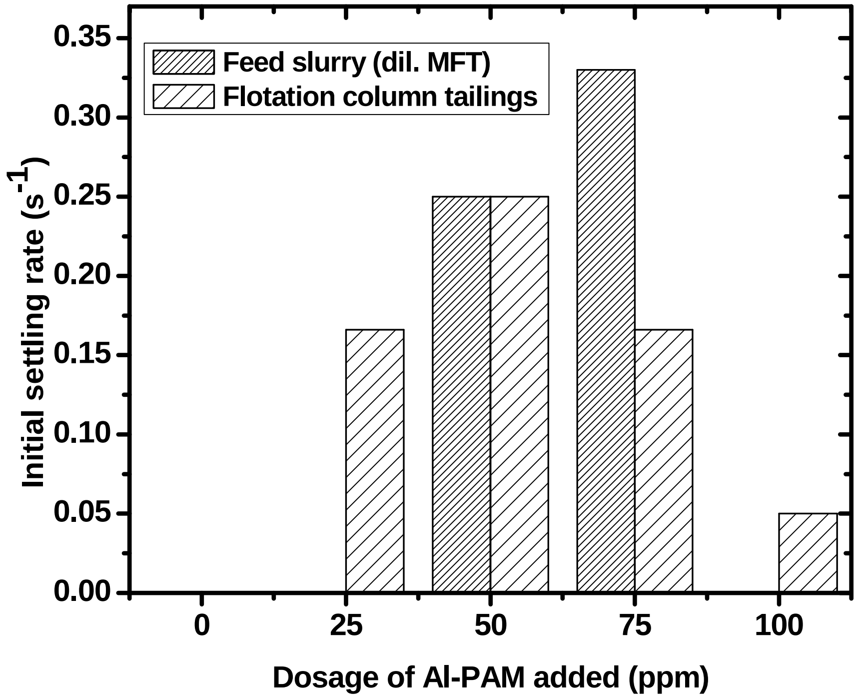

Figure 4.4 Initial settling rate as a function of Al-PAM dosage

Turbidity data for the different dosages of Al-PAM are shown in Figure 4.5. It is seen that increasing polymer dosage leads to a deterioration of supernatant quality. The reason can be due to the fact that with increase in concentration of polymer, the surface of the fine particles are covered by the adsorbed polymer which results in a steric barrier that prevents the fines from approaching each other and thereby leading to more fine particles in suspension as it becomes stabilized. We can conclude that Al-PAM has been a poor flocculant in the flocculation of both the feed slurry and the flotation column tailings based on the poor settling curves and initial settling rates.

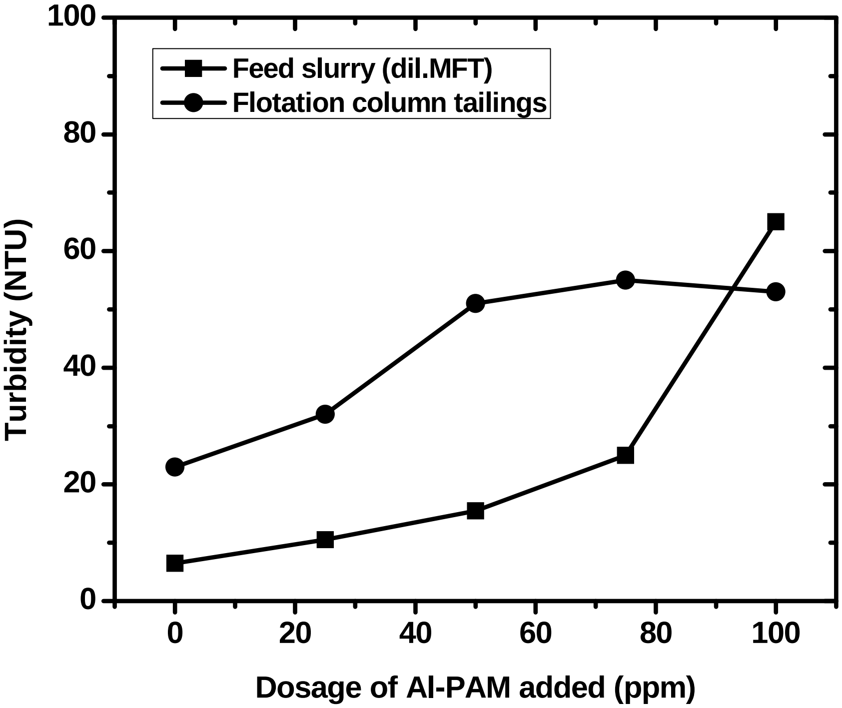

Figure 4.5 Turbidity as a function of Al-PAM usage

4.5 *Effect of Magnafloc-1011 addition as a flocculant*

Initial settling rate for the feed slurry and the flotation column tailings at different polymer concentrations of Magnafloc-1011 was evaluated from the results of the settling tests as seen in Figure 4.6 and Figure 4.7.

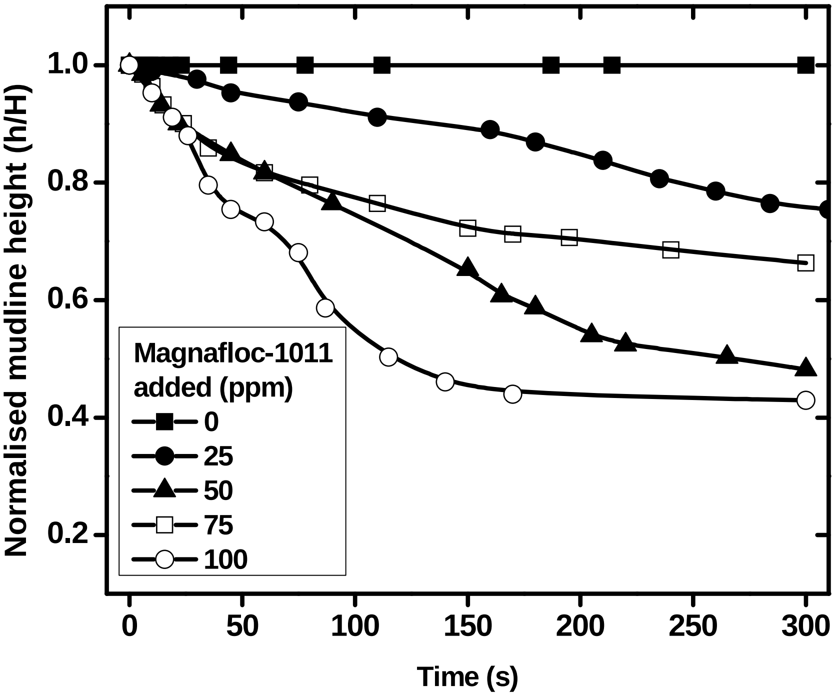

Figure 4.6 Settling data from using Magnafloc-1011 as flocculant on feed slurry (diluted MFT)

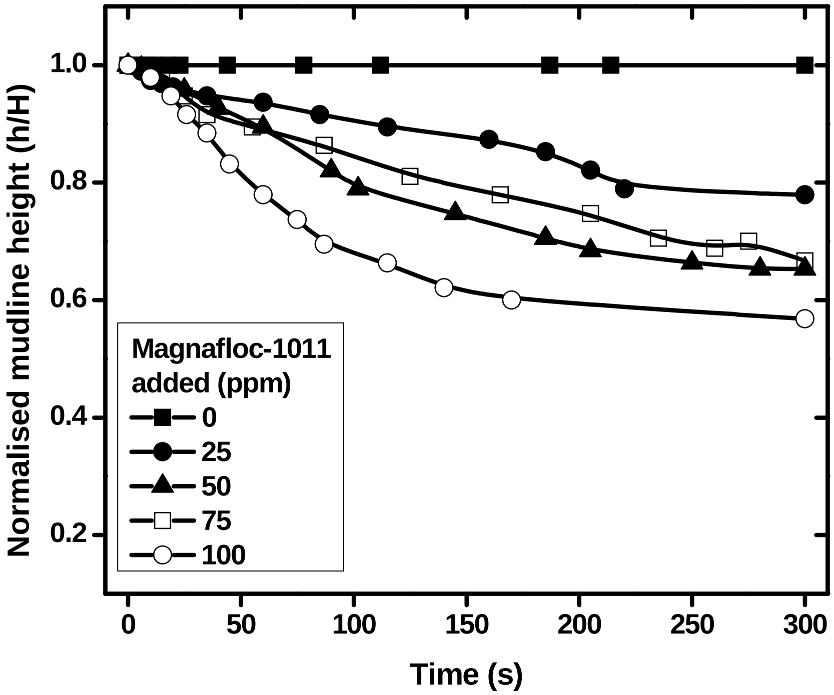

Figure 4.7 Settling data from using Magnafloc-1011 as flocculant on flotation column tailings

Figure 4.8 shows the initial settling rate derived from the slope of the settling curves of Figures 4.6 and 4.7. It can be seen that the addition of Magnafloc-1011 enhances settling for both diluted MFT and flotation column tailings. The initial settling increases with increasing polymer dosage for both the cases. For example, at 100 ppm of Magnafloc-1011 addition, the initial settling rate of feed slurry is 0.45 s^{-1}, in comparison to 0.2 s^{-1} for flotation column tailings where the hydrocarbons were removed. Compared to Al-PAM, Magnafloc-1011 shows a better performance on the settling of both the feed slurry and flotation column tailings. However, the effect of hydrocarbon removal on flocculation using

Magnafloc-1011 was similar to the case of using Al-PAM; i.e., removal of hydrocarbons from flotation column tailings leads to poorer flocculation results. It appears that the presence of hydrocarbons facilitates the binding of flocculant with fines.

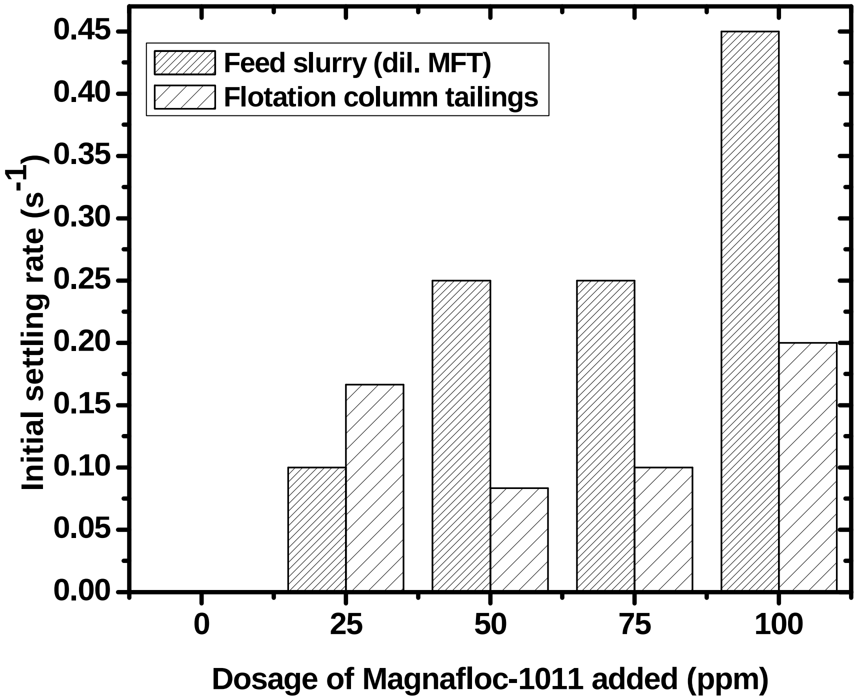

Figure 4.8 Initial settling rate as a function of Magnafloc-1011 usage

Turbidity data in Figure 4.9 shows that the supernatant of the feed slurry after flocculation has a much clearer supernatant when compared to that of the flotation column tailings. This could be explained from the fact that more fine solids are present in the flotation column tailings samples when compared to the feed slurry samples. The poor settling characteristics of the flotation column tailings when compared to the feed slurry reiterates the fact that the presence of more fine solids affects the polymer performance.

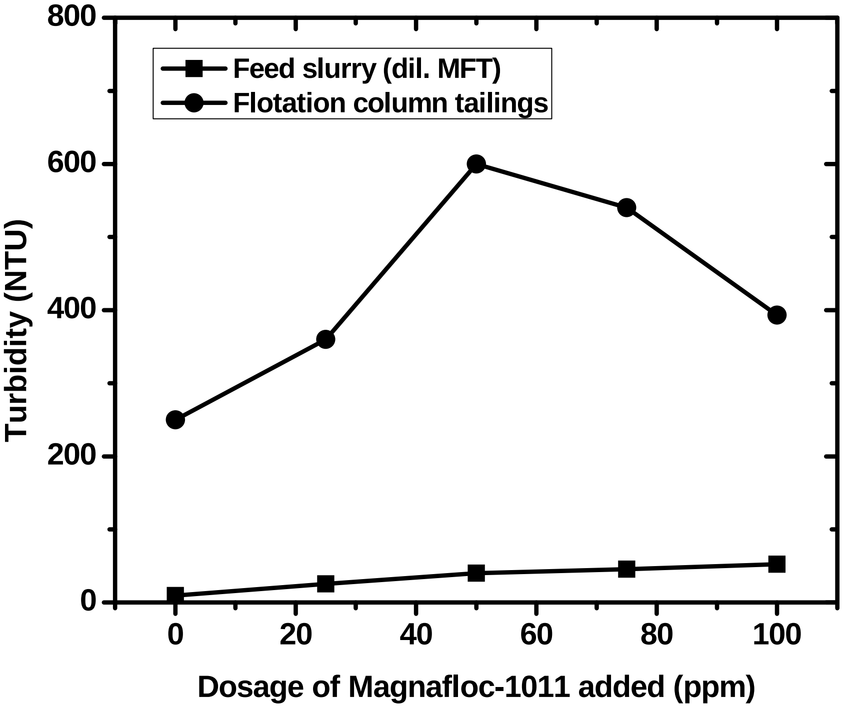

Figure 4.9 Turbidity as a function of Magnafloc-1011 usage

4.6 Effect of hydrocarbon recovery on settling of Denver cell flotation tailings by Magnafloc-1011 addition

It can be seen from Section 4.4 that addition of Al-PAM fails when compared to Magnafloc-1011 to settle the fine solids in the feed slurry and tailings. It can also be noted from Section 4.5 that the optimum concentration of Magnafloc-1011 to be used in flocculation is 100 ppm. The effect of hydrocarbon removal from feed slurry on flocculant addition was studied by treating the tailings obtained from the various batch flotation experiments with the optimum concentration of

Magnafloc-1011. Different hydrocarbon removal was achieved by varying the flotation parameters. Figure 4.10 shows the effect of hydrocarbon removal on the Denver cell flotation tailings settling at 100ppm of Magnafloc-1011 addition, evaluated using the same experimental procedures mentioned in Section 4.3. It can be seen that the removal of hydrocarbons inversely affects the performance of the settling of Denver cell flotation tailings.

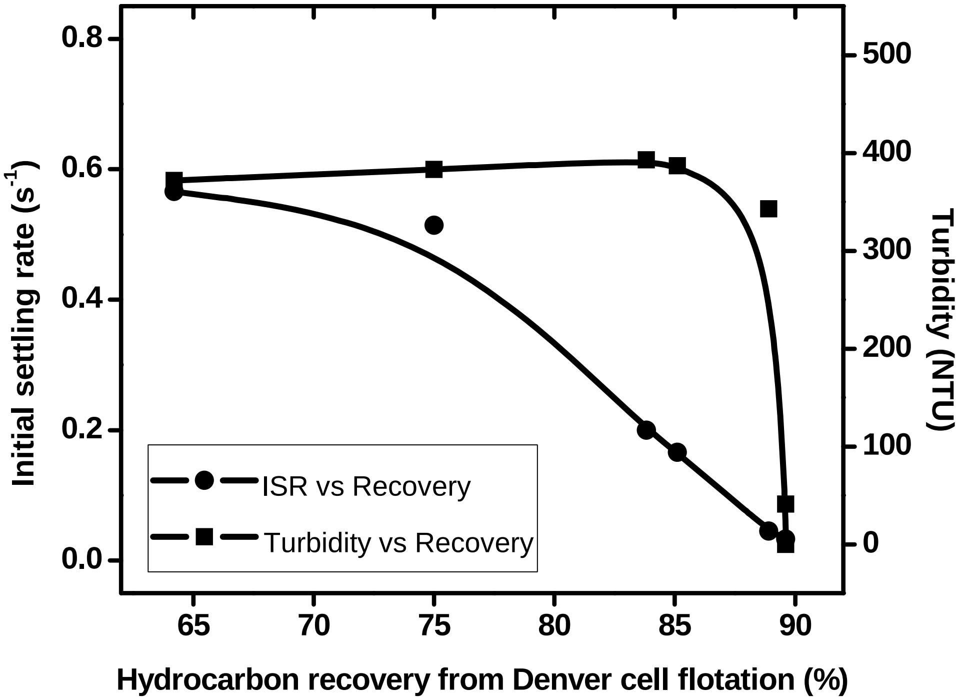

Figure 4.10 Effect of hydrocarbon recovery on settling of Denver cell flotation tailings

The effect of the presence of hydrocarbons on the performance of the polymer cannot be neglected from these findings. Moreover the turbidity data shows that with the addition of 100 ppm of Magnafloc-1011 polymer, the removal of more hydrocarbons produces clearer supernatant. However this clarity in the supernatant is seen at higher recoveries (greater than 90%). This is due to the fact that at lower initial settling rates a clearer supernatant is formed (smaller in volume when compared to the total volume in the cylinder) and is devoid of any fines. However this is offset by poorer settling rates.

The feed slurry (diluted MFT) having hydrocarbons perform better in flocculation in comparison with the Denver cell flotation tailings from which hydrocarbons have been removed. Magnafloc-1011 though has a better flocculating performance when compared to Al-PAM is seen to flocculate the feed slurry containing the hydrocarbons better than the tailings from the hydrocarbon recovery operations. It indicates that Magnafloc-1011 performs better with higher hydrophobic nature of the particles owing to the presence of hydrocarbons. We can conclude that the removal of hydrocarbons from the diluted mature fine tailings inversely affects its settling, even when aided by settling aids.

5 Conclusions and Future Work

5.1 Conclusions

In this study, flotation was used to recover the lost hydrocarbons from the waste streams of oil sands processing. Tailings from the tailings solvent recovery unit (TSRU) provided by Albian Sands, mature fine tailings (MFT) samples from both Syncrude and Suncor Energy were used. Effect of dilution of the samples, dilution medium, air flow rate and agitation speed were investigated using a laboratory Denver cell operated in batch mode for the recovery of hydrocarbons. The following conclusions can be made:

- Due to the viscous nature of the MFT feed from Syncrude, dilution was carried out using Aurora recycle water in the ratios of 1:0, 1:1 and 1:2 by weight. It was found that dilution of MFT with process water improved the recovery of hydrocarbons by froth flotation by more than 80%. The froth quality was improved with increased dilution.
- Dilution medium was then varied using tap water and de-ionized water in addition to the process water where it was strived to keep the pH of all the systems similar to negate any pH effect. It was found that varying the dilution media had no significant effect on the recovery of hydrocarbons. Process water was kept as the medium of dilution for the remaining tests.
- Flotation parameters such as aeration and agitation speed were varied to investigate their effect on recovery of hydrocarbons using Denver cell. It was observed that increase in air flow rate resulted in higher recovery of

hydrocarbons with better froth quality. Increase in agitation speeds saw similar spikes in the recovery of hydrocarbons with negligible effect on froth quality. Tests were then conducted to determine which among the two flotation parameters, aeration or agitation was favourable for the recovery of hydrocarbons. It was found that a froth product rich in the desired hydrocarbons and poor in undesired solids was obtained at minimum agitation speed and maximum air flow rate.

- Three different operating temperatures of 35°C, 50°C and 65°C were used to study the temperature effect on the recovery of hydrocarbons from the fluidized tailings of the TSRU. It was observed that recovery of hydrocarbons was independent of temperature. However there was depreciating froth quality with increase in temperature. Staged flotation was then conducted to improve the froth quality. It was noted that two stage flotation did improve the froth quality. It provided an onus to perform continuous froth flotation using a column. It was seen that more than 85% of the hydrocarbons with less undesired solids in the froth were recovered in the process. Further tests were not performed due to the non-availability of TSRU samples.
- Flotation column was also used to recover lost hydrocarbons from the mature fine tailings. Based on the dynamics established using the batch process, more than 80% of the hydrocarbons was recovered in the process.

The froth produced from the continuous flotation column was then cleaned using diluents such as naphtha to reduce the water content to 0.2 % by wt. Morphology was then done on the froth and cleaned froth using a confocal microscope to verify the obtained findings.

The n-heptane insoluble asphaltenes were extracted from the hydrocarbon-rich froth produced from the froth flotation experiments. It was seen that low asphaltene content in the MFT from Syncrude made the upgrading of the recovered hydrocarbons highly viable when compared to the asphaltene-rich hydrocarbon froth obtained from the froth flotation of the TSRU tailings.

The tailings produced from the froth flotation of the Syncrude MFT were then studied for their settling properties under the effect of polymer aids. Two polymers were used; a commercially available Magnafloc-1011 and in-house synthesized Al-PAM. It was seen that Al-PAM had negligible effect on the settling characteristics of either the feed slurry (diluted MFT) or the flotation column tailings produced. Magnafloc-1011 was seen to have a better effect in settling the feed slurry over the flotation column tailings. Optimum concentration of the polymer was then calculated and the experiments were done for the effluents produced from the batch flotation experiments that had different hydrocarbon recovery rates. It was seen that removal of hydrocarbons inversely affects the settling of MFT solids.

5.2 Future work

The recommendations for future work on the recovery of hydrocarbon are:

- Establish concrete reasons why the removal of hydrocarbon has no effect on the settling characteristics of MFT.
- Carry out further hydrocarbon recovery studies on the tailings of the TSRU and qualitative studies on the recovered hydrocarbons.
- Devise a strategy for proper hydrocarbon recovery techniques before the oil sands tailings are pumped into the tailings ponds.
- Study the forces between the hydrocarbons and clays and thereby obtain a better fundamental understanding of the problems faced from the consolidation of fines that form mature fine tailings.
- Investigate the various flotation parameters established here using a batch process for a continuous process.

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7 Appendix

7.1 *Appendix A (Analysis of feed samples)*

A1 **Sample Name** :

Syncrude Mature Fine Tailings

Experiment:

Content Determination

Wt. of Sample Taken (g) : 50.27

Dean Stark Measurements

Before Dean Stark		After Dean Stark		
Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
158.94	209.21	176.5	89.86	121.31

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper (g)	HC in froth (g)
1	1.176	1.2061	0.0301	1.508

Content Analysis

Wt.% of Hydrocarbons : 3

Wt.% of Solids : 35

Wt.% of Water : 63

Sample Calculations

Calculating the amount of solids:

Weight of sample (g) : (Jar + Full thimble)-(Jar + Empty thimble)
: 209.21-158.94
: 50.27

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)
: 176.5-158.94
: 17.56

Wt. % of Solids : $\frac{\text{Weight of solids (g)}}{\text{Wt. of sample (g)}} \times 100$

: $\frac{17.56}{50.27} \times 100 = 34.931 \sim 35\%$

Wt. % of Hydrocarbons : $\frac{\text{Hydrocarbons in Froth (g)}}{\text{Wt. of sample (g)}} \times 100$

: $\frac{1.508}{50.27} \times 100$

: 2.99 ~ 3 %

Wt. % of Water :

$$\frac{\text{(Wt of full water bottle - Wt of empty water bottle)}}{\text{Wt. of sample (g)}} \times 100$$

: $\frac{(121.31 - 89.86)}{50.27} \times 100$

: ~62 %

A2 **Sample Name** :

Mature Fine Tailings From Suncor

Experiment:

Content Determination

Wt. of Sample Taken (g) : 72.24

Dean Stark Measurements

Before Dean Stark		After Dean Stark		
Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
159.92	232.16	198.94	87.41	119.055

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper (g)	HC in froth (g)
1	1.1255	1.157	0.0315	1.575

Content Analysis

Wt.% of Hydrocarbons : 2.18

Wt.% of Solids : 54.01

Wt.% of Water : 43.81

Sample Calculations

Calculating the amount of solids:

Weight of sample (g) : (Jar + Full thimble)-(Jar + Empty thimble)
: 232.16-159.92
: 72.24

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)
: 198.94-159.92
: 39.02

Wt. % of Solids : $\frac{\text{Weight of solids (g)}}{\text{Wt. of sample (g)}} \times 100$

: $\frac{39.02}{72.24} \times 100 = 54.01 \sim 54\%$

Wt. % of Hydrocarbons : $\frac{\text{Hydrocarbons in Froth (g)}}{\text{Wt. of sample (g)}} \times 100$

: $\frac{1.575}{72.24} \times 100$

: $2.18 \sim 2\ \%$

Wt. % of Water :

$$\frac{(\text{Wt of full water bottle - Wt of empty water bottle})}{\text{Wt. of sample (g)}} \times 100$$

: $\frac{(119.055 - 87.41)}{72.24} \times 100$

: $43.81 \sim 44\ \%$

A3 **Sample Name** :

Tailings from TSRU

Experiment:

Content Determination

Wt. of Sample Taken (g) : 96.63

Dean Stark Measurements

Before Dean Stark		After Dean Stark		
Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
156.34	252.97	178.52	54.27	124.515

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper (g)	HC in froth (g)
1	1.147	1.2311	0.0841	4.205

Content Analysis

Wt.% of Hydrocarbons : 4.35

Wt.% of Solids : 22.95

Wt.% of Water : 72.69

Sample Calculations

Calculating the amount of solids:

Weight of sample (g) : (Jar + Full thimble)-(Jar + Empty thimble)

: 252.97-156.34

: 96.63

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 178.52-156.34

: 22.18

Wt. % of Solids :

$$\frac{\text{Weight of solids (g)}}{\text{Wt. of sample (g)}}\times 100$$

: $\frac{22.18}{96.63}\times 100 \quad = \quad 22.95$

Wt. % of Hydrocarbons :

$$\frac{\text{Hydrocarbons in Froth (g)}}{\text{Wt. of sample (g)}}\times 100$$

: $\frac{4.205}{96.63}\times 100$

: 4.35

Wt. % of Water :

$$\frac{\text{(Wt of full water bottle - Wt of empty water bottle)}}{\text{Wt. of sample (g)}}\times 100$$

: $\frac{(124.515 - 54.27)}{72.24}\times 100$

: 72.69 %

7.2 Appendix B (Calculations from flotation experiments)

Experiment: B1

Recovery of hydrocarbons from Syncrude MFT at no dilution (Study of Dilution Effect)

Wt. of Sample Taken (g) : 504.90

Wt. of Process Water Taken (g) : 0.00

Froth Flotation Conditions

pH : 7.90
Temperature (°C) : 35
Dilution Ratio (by wt.) MFT: Process Water : 1:0
Air flow rate (mL/min) : 150
Denver Cell Agitator Speed (rpm) : 1500

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 3.31

Wt. % of Solids : 37.88

Wt. % of Water : 58.81

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 16.71]

Wt. of Solids (g) [S] : 191.26

Wt. of Water (g) [W] : 296.93

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	160.21	210.14	175.57	89.86	121.6
2	5	161.55	196.87	172.58	89.63	112.28
3	10	158.42	206.64	173.45	88.42	115.08
4	20	159.27	266.65	195	87.12	133.02

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper (g)	HC in froth (g)
1	1.1214	1.1696	0.0482	2.41
2	1.1246	1.1549	0.0303	1.515
3	1.1232	1.1678	0.0446	2.23
4	1.1246	1.2106	0.086	4.3

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	15.36	2.41	31.74	15.36	2.41	31.74
2	5	11.03	1.52	22.65	26.39	3.93	54.39
3	10	15.03	2.23	26.66	41.42	6.16	81.05
4	20	35.73	4.30	45.90	77.15	10.46	126.95

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	14.42	6.37	13.17
2	5	23.49	6.72	13.86
3	10	36.83	6.73	13.17
4	20	62.56	7.38	12.14

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 158.42

Jar + Full thimble (g) : 206.64

Jar + dried thimble (g) : 173.45

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 173.45 -158.42

: 15.03

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1)+ (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (15.36+11.03+15.03) = 41.42

Calculating the amount of water:

Empty water bottle (g) : 88.42

Full water bottle (g) : 115.08

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 115.08 -88.42

: 26.66

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (31.74+22.65+26.66) = 81.05

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.1232

Filter paper +HC (g) : 1.1678

HC on paper (g) : 0.0446

HC in froth (g) : (HC on paper x 50) = 2.23

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 2.41+1.515+2.23 = 6.16

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (6.16/16.71) x 100 = 36.83 %

Cumulative Solids to HC ratio:

(Cumulative Froth Solids) / (Cumulative HC) = (41.42 / 6.16) = 6.73

Cumulative Water to HC ratio:

(Cumulative Froth Water) / (Cumulative HC) = (81.05 / 6.16) = 13.17

Experiment: B2

Recovery of Hydrocarbons from Syncrude MFT diluted with 1 part of Process Water by weight (Study of Dilution Effect)

Wt. of Sample Taken (g) : 353.00

Wt. of Process Water Taken (g) : 353.00

Froth Flotation Conditions

pH of Process Water : 8.2
Temperature (°C) : 35
Dilution Ratio (by wt.) MFT: Process Water : 1:1
Air flow rate (mL/min) : 150
Denver Cell Agitator Speed (rpm) : 1500

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 3.31

Wt. % of Solids : 37.88

Wt. % of Water : 58.81

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 11.68

Wt. of Solids (g) [S] : 133.72

Wt. of Water (g) [W] : 207.60

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	158.19	231.78	168.13	94.49	151.69
2	5	159.36	213.32	166.79	22.08	64.03
3	10	156.02	220.93	165.78	22.46	73.64
4	20	158.02	219.78	166.75	22.31	71.27

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper (g)	HC in froth (g)
1	1.1933	1.2524	0.0591	2.955
2	1.1273	1.1618	0.0345	1.725
3	1.1296	1.1744	0.0448	2.24
4	1.119	1.1524	0.0334	1.67

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	9.94	2.96	57.20	9.94	2.96	57.20
2	5	7.43	1.73	41.95	17.37	4.68	99.15
3	10	9.76	2.24	51.18	27.13	6.92	150.33
4	20	8.73	1.67	48.96	35.86	8.59	199.29

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	25.29	3.36	19.36
2	5	40.05	3.71	21.19
3	10	59.22	3.92	21.72
4	20	73.52	4.17	23.20

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 156.02

Jar + Full thimble (g) : 220.93

Jar + dried thimble (g) : 165.78

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 165.78 -156.02

: 9.76

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1)+ (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (9.94+7.43+9.76) = 27.13

Calculating the amount of water:

Empty water bottle (g) : 22.46

Full water bottle (g) : 73.64

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 73.64 - 22.46

: 51.18

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (57.20+41.95+51.18) = 150.33

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.1296

Filter paper +HC (g) : 1.1744

HC on paper (g) : 0.0448

HC in froth (g) : (HC on paper x 50) = 2.24

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 2.96+1.73+2.24 = 6.92

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (6.92/11.68) x 100 = 59.22 %

Cumulative Solids to HC ratio:

(Cumulative Froth Solids) / (Cumulative HC) = (27.13 / 6.92) = 3.92

Cumulative Water to HC ratio:

(Cumulative Froth Water) / (Cumulative HC) = (150.33 / 6.92) = 21.72

Experiment: B3

Recovery of hydrocarbons from Syncrude MFT diluted with 2 parts of process water by weight (study of dilution effect)

Wt. of Sample Taken (g)	:	300.45
Wt. of Process Water Taken (g)	:	600.90

Froth Flotation Conditions

pH of Process Water	:	8.2
Temperature (ºC)	:	35
Dilution Ratio (by wt.) MFT: Process Water	:	1:2
Air flow rate (mL/min)	:	150
Denver Cell Agitator Speed (rpm)	:	1500

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons	:	3.00
Wt. % of Solids	:	35.00
Wt. % of Water	:	62.00

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g)	[H]	:	9.01
Wt. of Solids (g)	[S]	:	105.16
Wt. of Water (g)	[W]	:	186.28

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	161.84	221.49	168.23	14.9429	64.7529
2	5	161.57	219.04	167.62	14.9105	64.3455
3	10	157.81	216.83	163.95	15.28	66.69
4	20	159.55	214.83	165.1	15.0004	64.0804

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper	HC in froth
1	1.1793	1.2483	0.069	3.45
2	1.1826	1.2223	0.0397	1.985
3	1.1888	1.2182	0.0294	1.47
4	1.1862	1.1992	0.013	0.65

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	6.39	3.45	49.81	6.39	3.45	49.81
2	5	6.05	1.98	49.44	12.44	5.43	99.25
3	10	6.14	1.47	51.41	18.58	6.90	150.66
4	20	5.55	0.65	49.08	24.13	7.55	199.74

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	38.28	1.85	14.44
2	5	60.30	2.29	18.26
3	10	76.61	2.69	21.82
4	20	83.82	3.19	26.44

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 157.81

Jar + Full thimble (g) : 216.83

Jar + dried thimble (g) : 163.95

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 163.95 -157.81

: 6.14

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1)+ (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (6.39+6.05+6.14) = 18.58

Calculating the amount of water:

Empty water bottle (g) : 15.28

Full water bottle (g) : 66.69

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 66.69 – 15.28

: 51.41

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (49.81 + 49.44 + 51.41) = 150.66

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.1888

Filter paper +HC (g) : 1.2182

HC on paper (g) : 0.0294

HC in froth (g) : (HC on paper x 50) = 1.47

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 3.45+1.985+1.47 = 6.90

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (6.90/9.01) x 100 = 76.61 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (18.58 / 6.9) = 2.69

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (150.66 / 6.9) = 21.82

Experiment: B4

Recovery of hydrocarbon from Syncrude MFT diluted at 2 times with process water and an air flow rate of 20 mL/min (study of the air effect)

Wt. of Sample Taken (g) : 315.00

Wt. of Process Water Taken (g) : 630.00

Froth Flotation Conditions

pH of Process Water : 8.20
Temperature (°C) : 35
Dilution Ratio (by wt.) MFT: Process Water : 1:2
Air flow rate (mL/min) : 20
Denver Cell Agitator Speed (rpm) : 1500

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 3.00

Wt. % of Solids : 35.00

Wt. % of Water : 62.00

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 9.45

Wt. of Solids (g) [S] : 110.25

Wt. of Water (g) [W] : 195.30

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	161.69	235.4	169.08	14.9044	78.4494
2	5	161.64	225.98	168.2	14.8598	70.4898
3	10	158.35	224.46	165.2	15.0569	72.2219
4	20	159.83	223.41	166.56	14.9707	71.3957

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper	HC in froth
1	1.1825	1.238	0.0555	2.775
2	1.1775	1.2205	0.043	2.15
3	1.1811	1.223	0.0419	2.095
4	1.1776	1.1861	0.0085	0.425

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	7.39	2.77	63.55	7.39	2.77	63.55
2	5	6.56	2.15	55.63	13.95	4.92	119.18
3	10	6.85	2.10	57.17	20.80	7.02	176.34
4	20	6.73	0.42	56.43	27.53	7.44	232.77

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	29.37	2.66	22.90
2	5	52.12	2.83	24.20
3	10	74.29	2.96	25.12
4	20	78.78	3.70	31.26

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 158.35

Jar + Full thimble (g) : 224.46

Jar + dried thimble (g) : 165.2

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 165.2 -158.35

: 6.85

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1)+ (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (7.39+6.56+6.85) = 20.80

Calculating the amount of water:

Empty water bottle (g) : 15.0569

Full water bottle (g) : 72.2219

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 72.2219 – 15.0569

: 57.17

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (63.55 + 55.63 + 57.17) = 176.34

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.1811

Filter paper +HC (g) : 1.223

HC on paper (g) : 0.0419

HC in froth (g) : (HC on paper x 50) = 2.095

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 2.77+2.15+2.10 = 7.02

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (7.02/9.45) x 100 = 74.29%

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (20.80/ 7.02) = 2.96

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (176.34/ 7.02) = 25.12

Experiment: B5

Recovery of hydrocarbons from MFT diluted at 2 times with process water and an air flow rate of 525 mL/min (study of the air effect)

Wt. of Sample Taken (g) : 300.00

Wt. of Process Water Taken (g) : 600.00

Froth Flotation Conditions

pH of Process Water : 8.20
Temperature (°C) : 35
Dilution Ratio (by wt.) MFT: Process Water : 1:2
Air flow rate (mL/min) : 525
Denver Cell Agitator Speed (rpm) : 1500

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 3.00

Wt. % of Solids : 35.00

Wt. % of Water : 62.00

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 9.00

Wt. of Solids (g) [S] : 105.00

Wt. of Water (g) [W] : 186.00

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	161.51	221.1	168.9	15.0806	63.3506
2	5	161.55	214.59	167.59	14.9984	59.8384
3	10	158.04	195.92	162.05	15.2524	48.3224
4	20	159.56	213.98	165.19	15.0239	62.9189

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper	HC in froth
1	1.1826	1.2612	0.0786	3.93
2	1.1829	1.2261	0.0432	2.16
3	1.1885	1.2045	0.016	0.8
4	1.1851	1.203	0.0179	0.895

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	7.39	3.93	48.27	7.39	3.93	48.27
2	5	6.04	2.16	44.84	13.43	6.09	93.11
3	10	4.01	0.80	33.07	17.44	6.89	126.18
4	20	5.63	0.90	47.90	23.07	7.79	174.08

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	43.67	1.88	12.28
2	5	67.67	2.21	15.29
3	10	76.56	2.53	18.31
4	20	86.50	2.96	22.36

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 158.04

Jar + Full thimble (g) : 195.92

Jar + dried thimble (g) : 162.05

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 162.05 -158.04

: 4.01

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1)+ (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (7.39+6.04+4.01) = 17.44

Calculating the amount of water:

Empty water bottle (g) : 15.2524

Full water bottle (g) : 48.3224

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 48.3224 – 15.2524

: 33.07

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (48.27 + 44.84 + 33.07) = 126.18

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.1885

Filter paper +HC (g) : 1.2045

HC on paper (g) : 0.016

HC in froth (g) : (HC on paper x 50) = 0.8

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 3.93+2.16+0.8 = 6.89

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (6.89/9) x 100 = 76.56 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (17.44/ 6.89) = 2.53

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (126.18/ 6.89) = 18.31

Experiment: B6

Recovery of hydrocarbons from MFT diluted at 2 times with process water and an air flow rate of 730 mL/min (study of the air effect)

Wt. of Sample Taken (g) : 306.00

Wt. of Process Water Taken (g) : 612.00

Froth Flotation Conditions

pH of Process Water : 8.20
Temperature (°C) : 35
Dilution Ratio (by wt.) MFT: Process Water : 1:2
Air flow rate (mL/min) : 730
Denver Cell Agitator Speed (rpm) : 1500

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 3.00

Wt. % of Solids : 35.00

Wt. % of Water : 62.00

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 9.18

Wt. of Solids (g) [S] : 107.10

Wt. of Water (g) [W] : 189.72

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	161.69	255.37	172.08	14.8857	92.2957
2	5	162.65	212.14	166.71	14.8471	58.8271
3	10	158.46	193.77	161.73	14.9585	46.4835
4	20	159.68	213.83	164.37	14.8504	63.9154

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper (g)	HC in froth (g)
1	1.1764	1.294	0.1176	5.88
2	1.1778	1.2068	0.029	1.45
3	1.1812	1.1915	0.0103	0.515
4	1.1762	1.1841	0.0079	0.395

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	10.39	5.88	77.41	10.39	5.88	77.41
2	5	4.06	1.45	43.98	14.45	7.33	121.39
3	10	3.27	0.51	31.53	17.72	7.85	152.92
4	20	4.69	0.40	49.07	22.41	8.24	201.98

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	64.05	1.77	13.16
2	5	79.85	1.97	16.56
3	10	85.46	2.26	19.49
4	20	89.76	2.72	24.51

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 158.46

Jar + Full thimble (g) : 193.77

Jar + dried thimble (g) : 161.73

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 161.73-158.46

: 3.27

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1) + (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (10.39+4.06+3.27) = 17.72

Calculating the amount of water:

Empty water bottle (g) : 14.9585

Full water bottle (g) : 46.4835

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 46.4835 – 14.9585

: 31.53

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (77.41 + 43.98 + 31.53) = 152.92

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.1812

Filter paper +HC (g) : 1.1915

HC on paper (g) : 0.0103

HC in froth (g) : (HC on paper x 50) = 0.515

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 5.88+1.45+0.51 = 7.85

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (7.85/9.18) x 100 = 85.46 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (17.72/ 7.85) = 2.26

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (152.92/ 7.85) = 19.49

Experiment: B7

Recovery of hydrocarbons from MFT diluted at 2 times with process water and an agitation speed of 900 rpm (study of the agitation effect)

Wt. of Sample Taken (g) : 300.13

Wt. of Process Water Taken (g) : 600.25

Froth Flotation Conditions

pH of Process Water : 8.20
Temperature (°C) : 35
Dilution Ratio (by wt.) MFT: Process Water : 1:2
Air flow rate (mL/min) : 150
Denver Cell Agitator Speed (rpm) : 900

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 3.00

Wt. % of Solids : 35.00

Wt. % of Water : 62.00

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 9.00

Wt. of Solids (g) [S] : 105.04

Wt. of Water (g) [W] : 186.08

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	161.73	198.35	165.55	15.14	45.9
2	5	161.73	194.36	165.18	15.11	42.8
3	10	156.95	197.41	161.8	15.29	49.14
4	20	159.9	205.85	164.95	15.08	54.515

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper (g)	HC in froth (g)
1	1.1732	1.214	0.0408	2.04
2	1.1789	1.2087	0.0298	1.49
3	1.178	1.2132	0.0352	1.76
4	1.1776	1.2069	0.0293	1.465

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	3.82	2.04	30.76	3.82	2.04	30.76
2	5	3.45	1.49	27.69	7.27	3.53	58.45
3	10	4.85	1.76	33.85	12.12	5.29	92.30
4	20	5.05	1.47	39.44	17.17	6.76	131.74

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	22.66	1.87	15.08
2	5	39.21	2.06	16.56
3	10	58.75	2.29	17.45
4	20	75.02	2.54	19.50

20 **Sample Calculations**

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 156.95

Jar + Full thimble (g) : 197.41

Jar + dried thimble (g) : 161.80

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 161.8-156.95

: 4.85

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1) + (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (3.82+3.45+4.85) = 12.12

Calculating the amount of water:

Empty water bottle (g) : 15.29

Full water bottle (g) : 49.14

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 49.14 – 15.29

: 33.85

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (30.76 + 27.69 + 33.85) = 92.30

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.178

Filter paper +HC (g) : 1.2132

HC on paper (g) : 0.0352

HC in froth (g) : (HC on paper x 50) = 1.76

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 2.04+1.49+1.76 = 5.29

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (5.29/9) x 100 = 58.75 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (12.12/ 5.29) = 2.29

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (92.30/ 5.29) = 17.45

Experiment: B8

Recovery of hydrocarbon from MFT diluted at 2 times with Process water and an agitation speed of 2100 rpm (study of the agitation effect)

Wt. of Sample Taken (g) : 300.00

Wt. of Process Water Taken (g) : 600.00

Froth Flotation Conditions

pH of Process Water : 8.20
Temperature (ºC) : 35
Dilution Ratio (by wt.) MFT: Process Water : 1:2
Air flow rate (mL/min) : 150
Denver Cell Agitator Speed (rpm) : 2100

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 3.00

Wt. % of Solids : 35.00

Wt. % of Water : 62.00

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 9.00

Wt. of Solids (g) [S] : 105.00

Wt. of Water (g) [W] : 186.00

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	159.78	308.79	177.24	15.03	139.83
2	5	161.7	174.3	162.95	14.94	25.78
3	10	156.77	197.92	160.7	15.21	52.05
4	20	211.21	235.59	213.39	15.01	36.87

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper (g)	HC in froth (g)
1	1.1718	1.3069	0.1351	6.755
2	1.1798	1.1901	0.0103	0.515
3	1.1717	1.1794	0.0077	0.385
4	1.1731	1.18	0.0069	0.345

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	17.46	6.76	124.80	17.46	6.76	124.80
2	5	1.25	0.51	10.84	18.71	7.27	135.64
3	10	3.93	0.39	36.84	22.64	7.66	172.48
4	20	2.18	0.34	21.86	24.82	8.00	194.34

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	75.06	2.58	18.48
2	5	80.78	2.57	18.66
3	10	85.06	2.96	22.53
4	20	88.89	3.10	24.29

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 156.77

Jar + Full thimble (g) : 197.92

Jar + dried thimble (g) : 160.7

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 160.7-156.77

: 3.93

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1) + (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (17.46+1.25+3.93) = 22.64

Calculating the amount of water:

Empty water bottle (g) : 15.21

Full water bottle (g) : 52.05

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 52.05 – 15.21

: 36.84

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (124.80 + 10.84 + 36.84) = 172.48

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.1717

Filter paper +HC (g) : 1.1794

HC on paper (g) : 0.0077

HC in froth (g) : (HC on paper x 50) = 0.385

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 6.755+0.515+0.385 = 7.66

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (7.66/9) x 100 = 85.06 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (22.64/ 7.66) = 2.96

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (172.48/ 7.66) = 22.53

Experiment: B9

Recovery of hydrocarbons from MFT diluted at 2 times with Process water and an agitation speed of 900 rpm and air flow rate of 730 mL/min

Wt. of Sample Taken (g) : 302.04

Wt. of Process Water Taken (g) : 604.08

Froth Flotation Conditions

pH of Process Water : 8.20
Temperature (°C) : 35
Dilution Ratio (by wt.) MFT: Process Water : 1:2
Air flow rate (mL/min) : 930
Denver Cell Agitator Speed (rpm) : 900

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 3.00

Wt. % of Solids : 35.00

Wt. % of Water : 62.00

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 9.06

Wt. of Solids (g) [S] : 105.71

Wt. of Water (g) [W] : 187.26

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	157.99	182.57	161.09	15.26	33.88
2	5	163.32	192.93	166.34	15.14	40.63
3	10	164.55	208	170.14	15.2	50.66
4	20	162.26	193.05	165.79	15	40.92

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper	HC in froth
1	1.2009	1.2581	0.0572	2.86
2	1.2035	1.2256	0.0221	1.105
3	1.2014	1.2494	0.048	2.4
4	1.1998	1.2267	0.0269	1.345

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	3.10	2.86	18.62	3.10	2.86	18.62
2	5	3.02	1.11	25.49	6.12	3.97	44.11
3	10	5.59	2.40	35.46	11.71	6.37	79.57
4	20	3.53	1.35	25.92	15.24	7.71	105.48

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	31.56	1.08	6.51
2	5	43.76	1.54	11.12
3	10	70.24	1.84	12.50
4	20	85.09	1.98	13.68

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 164.55

Jar + Full thimble (g) : 208

Jar + dried thimble (g) : 170.14

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 170.14-164.55

: 5.59

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1) + (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (3.10+3.02+5.59) = 11.71

Calculating the amount of water:

Empty water bottle (g) : 15.2

Full water bottle (g) : 50.66

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 50.66 – 15.2

: 35.46

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (18.62 + 25.49 + 35.46) = 79.57

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.2014

Filter paper +HC (g) : 1.2494

HC on paper (g) : 0.048

HC in froth (g) : (HC on paper x 50) = 2.4

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 2.86+1.105+2.4 = 6.37

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (6.37/9.06) x 100 = 70.24 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (11.71/ 6.37) = 1.84

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (79.57/ 6.37) = 12.50

Experiment: B10

Recovery of hydrocarbons from MFT diluted at 2 times with process water and an agitation speed of 2100 rpm and air flow rate of 20 mL/min

Wt. of Sample Taken (g) : 300.50

Wt. of Process Water Taken (g) : 601.00

Froth Flotation Conditions

pH of Process Water : 8.20
Temperature (°C) : 35
Dilution Ratio (by wt.) MFT: Process Water : 1:2
Air flow rate (mL/min) : 20
Denver Cell Agitator Speed (rpm) : 2100

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 3.00

Wt. % of Solids : 35.00

Wt. % of Water : 62.00

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 9.02

Wt. of Solids (g) [S] : 105.18

Wt. of Water (g) [W] : 186.31

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	161.15	232.9	171.9	14.82	74.27
2	5	163.05	224.12	169.19	14.9	68.52
3	10	160.41	197.67	164.34	15.46	47.86
4	20	159.13	227.57	166.49	15.1	74.19

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper (g)	HC in froth (g)
1	1.2032	1.2342	0.031	1.55
2	1.2036	1.2298	0.0262	1.31
3	1.2098	1.2285	0.0187	0.935
4	1.2001	1.2399	0.0398	1.99

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	10.75	1.55	59.45	10.75	1.55	59.45
2	5	6.14	1.31	53.62	16.89	2.86	113.07
3	10	3.93	0.93	32.40	20.82	3.79	145.47
4	20	7.36	1.99	59.09	28.18	5.78	204.56

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	17.19	6.94	38.35
2	5	31.72	5.91	39.53
3	10	42.10	5.49	38.33
4	20	64.17	4.87	35.36

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 160.41

Jar + Full thimble (g) : 197.67

Jar + dried thimble (g) : 164.34

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 164.34-160.41

: 3.93

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1) + (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (10.75+6.14+3.93) = 20.82

Calculating the amount of water:

Empty water bottle (g) : 15.46

Full water bottle (g) : 47.86

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 47.86 – 15.46

: 32.40

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (59.45 + 53.62 + 32.40) = 145.47

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.2098

Filter paper +HC (g) : 1.2285

HC on paper (g) : 0.0187

HC in froth (g) : (HC on paper x 50) = 0.935

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 1.55+1.31+0.93 = 3.79

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (3.79/9.02) x 100 = 42.10 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (20.82/ 3.79) = 5.49

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (145.47/ 3.79) = 38.33

Experiment: B11

Recovery of hydrocarbons from MFT diluted at 2 times with deionised water adjusted to a pH of 8.2

Wt. of Sample Taken (g) : 305.00

Wt. of Process Water Taken (g) : 610.00

Froth Flotation Conditions

pH of Deionised Water : 8.20
Temperature (°C) : 35
Dilution Ratio (by wt.) MFT: Deionised Water : 1:2
Air flow rate (mL/min) : 150
Denver Cell Agitator Speed (rpm) : 1500

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 3.00

Wt. % of Solids : 35.00

Wt. % of Water : 62.00

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 9.15

Wt. of Solids (g) [S] : 106.75

Wt. of Water (g) [W] : 189.1

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	161.83	246.58	171.25	15.11	81.72
2	5	161.89	222.31	168.27	14.97	59.25
3	10	156.94	197.69	161.15	15.25	50.89
4	20	160.93	217.93	166.72	15.49	65.58

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper (g)	HC in froth (g)
1	1.2019	1.2835	0.0816	4.08
2	1.2081	1.2482	0.0401	2.005
3	1.2096	1.2321	0.0225	1.125
3	1.209	1.2294	0.0204	1.02

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	9.42	4.08	71.25	9.42	4.08	71.3
2	5	6.38	2.01	52.04	15.80	6.09	123.3
3	10	4.21	1.13	35.42	20.01	7.21	158.7
3	10	5.79	1.02	50.19	25.80	8.23	208.9

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	44.6	2.31	17.46
2	5	66.5	2.60	20.26
3	10	78.8	2.78	22.01
4	20	89.9	3.13	25.38

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 156.94

Jar + Full thimble (g) : 197.69

Jar + dried thimble (g) : 161.15

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 161.15-156.94

: 4.21

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1) + (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (9.42+6.38+4.21) = 20.01

Calculating the amount of water:

Empty water bottle (g) : 15.25

Full water bottle (g) : 50.89

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 50.89 – 15.25

: 35.42

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (71.25+52.04+35.42) = 158.7

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.2096

Filter paper +HC (g) : 1.2321

HC on paper (g) : 0.0225

HC in froth (g) : (HC on paper x 50) = 1.125

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 4.08+2.005+1.125 = 7.21

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (7.21/9.15) x 100 = 78.8 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (20.01/ 7.21) = 2.78

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (158.7/ 7.21) = 25.38

Experiment: B12

Recovery of Hydrocarbon from Syncrude MFT diluted at 2 times with Tap Water adjusted to a pH of 8.2

Wt. of Sample Taken (g)	:	300.00
Wt. of Process Water Taken (g)	:	600.00

Froth Flotation Conditions

pH of Deionised Water	:	8.20
Temperature (°C)	:	35
Dilution Ratio (by wt.) MFT: Process Water	:	1:2
Air flow rate (mL/min)	:	150
Denver Cell Agitator Speed (rpm)	:	1500

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons	:	3.00
Wt. % of Solids	:	35.00
Wt. % of Water	:	62.00

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g)	[H]	:	9.00
Wt. of Solids (g)	[S]	:	105.00
Wt. of Water (g)	[W]	:	186.00

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	159.94	245.06	169.26	15.02	87.43
2	5	158.45	222.08	165.25	15.03	69.75
3	10	156.56	226.47	163.75	15.36	76.36
4	20	160.48	205.03	165.11	15.63	54.705

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper (g)	HC in froth (g)
1	1.1977	1.2655	0.0678	3.39
2	1.1982	1.2404	0.0422	2.11
3	1.1899	1.2243	0.0344	1.72
4	1.2	1.2169	0.0169	0.845

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	9.32	3.39	72.41	9.32	3.39	72.41
2	5	6.80	2.11	54.72	16.12	5.50	127.13
3	10	7.19	1.72	61.00	23.31	7.22	188.13
4	20	4.63	0.85	39.08	27.94	8.07	227.21

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	37.67	2.75	21.36
2	5	61.11	2.93	23.11
3	10	80.22	3.23	26.06
4	20	89.61	3.46	28.17

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 156.56
Jar + Full thimble (g) : 226.47
Jar + dried thimble (g) : 163.75
Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)
: 163.75-156.56
: 7.19
Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1) + (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)
: (9.32+6.80+7.19) = 23.31

Calculating the amount of water:

Empty water bottle (g) : 15.36
Full water bottle (g) : 76.36
Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)
: 76.36 – 15.36
: 61.00
Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)
: (72.41+54.72+61.00) = 188.13

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.1899
Filter paper +HC (g) : 1.2243
HC on paper (g) : 0.0344
HC in froth (g) : (HC on paper x 50) = 1.72

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 3.39+2.11+1.72 = 7.22

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (7.22/9.00) x 100 = 80.22 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (23.31/ 7.22) = 3.23

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (188.13/ 7.22) = 26.06

Experiment: B13

Recovery of hydrocarbon from TSRU Tailings at 35C

Wt. of Sample Taken (g) : 400.22

Wt. of Process Water Taken (g) : 0.00

Froth Flotation Conditions

pH : 8.50
Temperature (°C) : 35
Air flow rate (mL/min) : 150
Denver Cell Agitator Speed (rpm) : 1500

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 4.35

Wt. % of Solids : 23.37

Wt. % of Water : 72.28

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 17.41

Wt. of Solids (g) [S] : 93.53

Wt. of Water (g) [W] : 289.28

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	159.88	205.1	165.42	86.77	118.93
2	5	157.98	190.42	160.96	86.61	103.89
3	10	158.21	191.42	163.22	87.79	129.21
4	20	160.48	205.03	165.01	15.63	54.705

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper	HC in froth
1	1.1934	1.3072	0.1138	5.69
2	1.1824	1.2476	0.0652	3.26
3	1.1866	1.2807	0.0941	4.705
4	1.2	1.2275	0.0275	1.375

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	5.54	5.69	32.16	5.54	5.69	32.16
2	5	2.98	3.26	17.28	8.52	8.95	49.44
3	10	5.01	4.70	41.42	13.53	13.66	90.86
4	20	4.53	1.38	39.08	18.06	15.03	129.94

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	32.68	0.97	5.65
2	5	51.41	0.95	5.52
3	10	78.43	0.99	6.65
4	20	86.33	1.20	8.65

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 158.21

Jar + Full thimble (g) : 191.42

Jar + dried thimble (g) : 163.22

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 163.22-158.21

: 5.01

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1) + (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (5.54+2.98+5.01) = 13.53

Calculating the amount of water:

Empty water bottle (g) : 87.79

Full water bottle (g) : 129.21

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 129.21 – 87.79

: 41.42

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (32.16+17.28+41.42) = 90.86

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.1866

Filter paper +HC (g) : 1.2807

HC on paper (g) : 0.0941

HC in froth (g) : (HC on paper x 50) = 4.705

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 5.69+3.26+4.705 = 13.66

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (13.66/17.41) x 100 = 78.43 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (13.53/ 13.66) = 0.99

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (90.86/ 13.66) = 6.65

Experiment: B14

Recovery of Hydrocarbon from TSRU Tailings at 50C

Wt. of Sample Taken (g) : 400.18

Wt. of Process Water Taken (g) : 0.00

Froth Flotation Conditions

pH : 8.50
Temperature (°C) : 50
Air flow rate (mL/min) : 150
Denver Cell Agitator Speed (rpm) : 1500

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons : 4.35

Wt. % of Solids : 23.37

Wt. % of Water : 72.28

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g) [H] : 17.41

Wt. of Solids (g) [S] : 93.52

Wt. of Water (g) [W] : 289.25

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	161.91	219.32	170.51	85.64	125.77
2	5	157.3	193.66	162.3	61.17	83.91
3	10	155.33	202.78	161.5	22.74	57.09
4	20	160.48	205.03	165.01	15.63	54.705

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper	HC in froth
1	1.1877	1.3075	0.1198	5.99
2	1.1449	1.2123	0.0674	3.37
3	1.1698	1.2486	0.0788	3.94
4	1.2	1.2545	0.0545	2.725

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	8.60	5.99	40.13	8.60	5.99	40.13
2	5	5.00	3.37	22.74	13.60	9.36	62.87
3	10	6.17	3.94	34.35	19.77	13.30	97.22
4	20	4.53	2.73	39.08	24.30	16.03	136.30

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	34.41	1.44	6.70
2	5	53.77	1.45	6.72
3	10	76.40	1.49	7.31
4	20	92.06	1.52	8.51

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 155.33

Jar + Full thimble (g) : 202.78

Jar + dried thimble (g) : 161.5

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 161.5-155.33

: 6.17

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1) + (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (8.60+5.00+6.17) = 19.77

Calculating the amount of water:

Empty water bottle (g) : 22.74

Full water bottle (g) : 57.09

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 57.09 – 22.74

: 34.35

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (40.13+22.74+34.35) = 97.22

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.1698

Filter paper +HC (g) : 1.2486

HC on paper (g) : 0.0788

HC in froth (g) : (HC on paper x 50) = 3.94

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 5.99+3.37+3.94 = 13.30

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (13.30/17.41) x 100 = 76.40 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (19.77/13.30) = 1.49

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (97.22/ 13.30) = 7.31

Experiment: B15

Recovery of hydrocarbons from TSRU Tailings at 65C

Wt. of Sample Taken (g)	:	463.66
Wt. of Process Water Taken (g)	:	0.00

Froth Flotation Conditions

pH	:	8.50
Temperature (ºC)	:	65
Air flow rate (mL/min)	:	150
Denver Cell Agitator Speed (rpm)	:	1500

Standard Sample Analysis using Dean Stark

Wt. % of Hydrocarbons	:	4.35
Wt. % of Solids	:	23.37
Wt. % of Water	:	72.28

Wt. of different constituents in the sample

Wt. of Hydrocarbons (g)	[H]	:	20.17
Wt. of Solids (g)	[S]	:	108.36
Wt. of Water (g)	[W]	:	335.13

Flotation Measurements

Jar #	Flotation time (min)	Before Dean Stark		After Dean Stark		
		Jar + Empty thimble (g)	Jar + Full thimble (g)	Jar + dried thimble (g)	Wt of empty water bottle (g)	Wt of full water bottle (g)
1	3	162.28	245.81	174.58	46.97	107.92
2	5	157.66	193.14	162.78	61.16	86.53
3	10	155.58	208.58	163.8	22.84	65.59
4	20	160.48	205.03	165.81	15.63	54.705

Hydrocarbon Analysis *(After Dean Stark)*

Jar	Filter paper (g)	Filter paper +HC (g)	HC on paper	HC in froth
1	1.151	1.3077	0.1567	7.835
2	1.1526	1.2176	0.065	3.25
3	1.154	1.2497	0.0957	4.785
4	1.2	1.257	0.057	2.85

Cumulative Analysis

Jar	Flotation time (min)	Solids in froth (g)	HC in froth (g)	Water in froth (g)	Cum. Froth Solids (g)	Cum.Froth HC (g)	Cum.Froth Water (g)
1	3	12.30	7.84	60.95	12.30	7.84	60.95
2	5	5.12	3.25	25.37	17.42	11.09	86.32
3	10	8.22	4.79	42.75	25.64	15.87	129.07
4	20	5.33	2.85	39.08	30.97	18.72	168.15

Flotation Results

Jar	Flotation time (min)	HC Recovery	SHR	Water: HC
1	3	38.85	1.57	7.78
2	5	54.96	1.57	7.79
3	10	78.68	1.62	8.13
4	20	92.81	1.65	8.98

Sample Calculations

Taking Jar no. 3

Calculating the amount of solids:

Jar + Empty thimble (g) : 155.58

Jar + Full thimble (g) : 208.58

Jar + dried thimble (g) : 163.8

Weight of solids (g) : (Jar + dried thimble)-(Jar+ Empty thimble)

: 163.8-155.58

: 8.22

Cumulative Froth Solids (g) : (Wt. of solids in Jar no.1) + (Wt. of solids in Jar no.2)+ (Wt. of solids in Jar no.3)

: (12.30+5.12+8.22) = 25.64

Calculating the amount of water:

Empty water bottle (g) : 22.84

Full water bottle (g) : 65.59

Weight of water (g) : (Wt. of full water bottle)-(Wt .of empty water bottle)

: 65.59 – 22.84

: 42.75

Cumulative Froth Water (g) : (Wt. of water in Jar no.1)+ (Wt. of water in Jar no.2)+ (Wt. of water in Jar no.3)

: (60.95+25.37+42.75) = 129.07

Calculating the amount of hydrocarbons:

Filter paper (g) : 1.154

Filter paper +HC (g) : 1.2497

HC on paper (g) : 0.0957

HC in froth (g) : (HC on paper x 50) = 4.785

Cumulative HC (g) : (Wt. of HC in Jar no.1)+ (Wt. of HC in Jar no.2)+ (Wt. of HC in Jar no.3)

: 7.84+3.25+4.79 = 15.87

Cumulative HC Recovery for Jar No. 3: (Cumulative HC) / (Overall Wt. of Hydrocarbons) x 100

: (15.87/20.17) x 100 = 78.68 %

Cumulative Solids to HC ratio for Jar No. 3:

(Cumulative Froth Solids) / (Cumulative HC) = (25.64/ 15.87) = 1.62

Cumulative Water to HC ratio for Jar No. 3:

(Cumulative Froth Water) / (Cumulative HC) = (129.07/ 15.87) = 8.13

Experiment: B16

Ideal mass balance developed from column flotation experiments on Syncrude MFT

Syncrude MFT: 5 kg Process Water : 10 kg		Froth Produced		Tailings Produced
Slurry feed to Column Flotation: 15 kg	▶	3 kg	+	12 kg
Hydrocarbon: 1% Solids: 12%		Hydrocarbon: 4% Solids: 12%		Hydrocarbon: 0.25 % Solids: 12%

Hydrocarbon recovery: $\frac{0.04\times 3}{0.01\times 15}\times 100 = 80\%$

Experiment: B17

Denver Cell flotation on Suncor MFT: Initial Results

No.	Flotation Time (min)	HC Recovery %	SHR	W:HC	HC Recovery %	SHR	W:HC
0	0	**MFT(wt): PW(wt)::1:1**			**MFT(wt): PW(wt)::1:2**		
1	3	28.11	2.66	15.97	36.27	2.91	24.22
2	5	38.19	2.71	16.58	52.39	3.25	25.38
3	10	57.39	2.75	16.71	72.39	3.58	29.38
4	20	71.21	2.98	18.05	81.76	3.85	32.64