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The Investigation of Settling Processes for Tailing Thickener in Oyu Tolgoi

Bachelor Thesis

by

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Statutory Declaration

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I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

THE INVESTIGATION OF SETTLING PROCESSES FOR TAILING THICKENER IN OYU TOLGOI

I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Nalaikh, Ulaanbaatar

06.08.2020

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Abstract

This bachelor thesis based on the research work of Oyu Tolgoi (OT) LLC that OT concentrator's tailing thickener laundry for overflow water pipe scaling problem. OT concentrator plant is reused the overflow water from the tailings thickener and its recycling rate is at least 80 %. Tailing thickener plays the main role to produce clarified effluent and thickened sludge. The most considerable issue of performance tailing thickener is the sedimentation in which is the utilization of tailings; thus, it is very important to determine its settling process. This study aimed to investigate the parameters that aspect the settling process of tailings solution. This thesis presents the results of a study conducted on settling processes of copper mineral tailings. Moreover, the following goals were expected to investigate the tailing solution characteristics, make assumptions about the scale formation causes on the case, and suggest scaling removal and preventing environmental way.

The main reason for the thickener problem is the scale formation that occurs in the water riser pipe to make block it therefore there have to clean the pipe often. The scale formation is colloid calcium residue from the lime addition of copper concentrate processing for pH adjuster. Moreover, the amount of calcium doesn't settle down properly during the settling process in tailing thickener. Calcium present in overflow within 10.31 pH and about 24°C temperature that suitable condition to precipitate calcium. It can become a fundamental cause of scaling. Calcium removal by coagulants is recommended for scale prevention.

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1 Introduction

The mining sector is the second-highest water consumption of Mongolia and its consumption was about 90 million cubic meters in a year according to the statistics of 2019 (1). Oyu Tolgoi uses about 35 million cubic meters of water per year (2). During mining operations, a range of physical and chemical processes requiring water include grinding, flotation, the concentration of gravity, dense medium separation, and hydrometallurgical processes. Gold, silver, diamonds, nickel, and copper are associated with the highest water consumption because of the lower concentration in ores (3). Wastewater is produced as much as raw water consumption. Increased water recovery is important to many countries throughout the world due to the scarcity of fresh water.

The copper industry is the largest producer of tailings. Mine tailing is the final waste from mining the ore processing, ore body, and recovering the valuable metals and minerals. Thus, improvement within the solid-liquid separation of that's vital. One of the good solutions for increase recovery of the processed water, reduce the waste volume and reduce the consumption of raw water is the tailing thickener technique. The thickening method is the most widespread way of the water recovery process in mineral industries. Tailings thickener is used to settle out a slurry solution and return the treated water to the process (4).

Water recovery might have the potential to reduce the coming years cause of the decrease of the pipeline's inner diameter. It resulted from scaling in the water riser pump of tailings thickener cause of lime usage. Lime (calcium oxide or calcium hydroxide) is the most popular reagent used for extractive minerals in the copper processing industry and used as an effective and economical pH modifier in selective flotation. Scaling is the deposition of mineral salt and is a result of mineral ion supersaturation in the solution (5).

1.1 Overview of Oyu Tolgoi LLC

Oyu Tolgoi is one of the largest known high-grade copper and gold deposits in the world. It is also one of the most modern, safe, and sustainable operations in the world. The Oyu Tolgoi is a combined open pit and underground mining project. Open-pit mining in 2011 and the copper concentrator began in 2013 at Oyu Tolgoi which is Mongolia's largest industrial complex ever constructed (6). Oyu Tolgoi mine is located in Khanbogd soum, Javkhlant bag area within the south Gobi Desert 640 km south of the Ulaanbaatar city and 210 km east of the Umnugovi Province capital Dalanzadgad. The concentrator can process up to 100,000 tons of ore every day. Upon moving from the primary crusher on the overland conveyor, the ore enters the concentrator using a series of complex

mechanical and chemical processes to convert it into the final product ready for shipment. This product is called concentrate, a fine powder containing between 25% and 30% copper and smaller amounts of gold and other minerals. The concentrator plant of Oyu Tolgoi is shown in *Picture 1*. The concentrate is placed in two-tone bags, stamped with "Product of Mongolia" and loaded onto trucks after completing its process through the concentrator plant. These trucks depart in convoys to the border crossing at Gashuun Sukhait, 80 kilometers south of Oyu Tolgoi. The concentrates are ready for collection by customers after arrival at the border warehouse (7).

Picture 1. Concentrator Plant of Oyu Tolgoi LLC

1.2 Copper Concentrate Process

The Concentrator of Oyu Tolgoi produces annually about 35 million tonnes of copper-gold concentrate or 100,000 tonnes per day. The plant is located approximately 255 meters long and 144 meters wide, extending from west to east between Shaft №2 and the Open Pit. Within the framework of Oyu Tolgoi LLC's water management policy, aim to maintain water resources and quality in nature by using water properly in all mine operations, reusing water, and minimizing potential negative impacts on water resources and quality in the region where operate. The main source of water supply for the Oyu Tolgoi mine is the groundwater source and the accepted total groundwater resource is 918 L/s or 79315 m3/day. Oyu Tolgoi LLC is committed to reducing water reuse by at least 80%. To reduce the total water demand of the mine and increase the amount of water to be reused, and constantly monitors water use and water reuse. As of September 30, 2019, the recovered water rate is 87.33% of the total water usage (8).

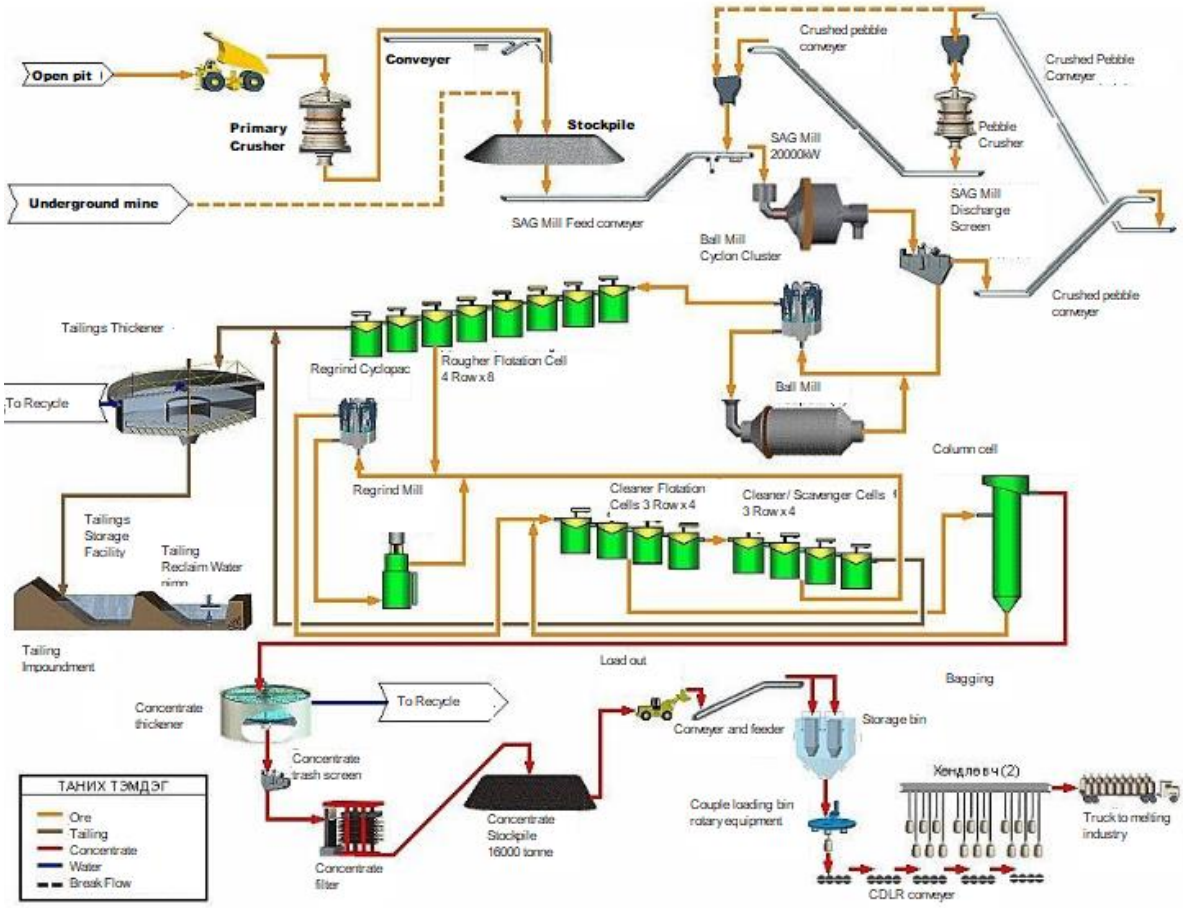

Figure 1. Simplified process flow diagram of copper concentrate process

In this section, the copper concentrator process is briefly explained based on *Figure 1*. The ore excavated in an open-pit mine is transported by a loader. At the very first stage, ore size is reduced in the primary crusher. The purpose of the crusher is to break large particles into small particles. After traveling on the overland conveyor from the primary crusher, the ore is stored in a stockpile. From the stockpile, the ore is transferred by SAG Mill Feed conveyer into SAG Mill. Milling is the process of grinding ore to a fine powder. After the milling, the ore is classified by the SAG Mill Discharge screen. Classification is the process of separating particles by size into two or more products according to their behavior in air or water (liquids). Oversized ore is transported by pebble conveyer to Pebble crushers and undersized ore is transported into Ball Mill Cyclone Cluster. Oversized ore is going to Ball Mill, thus it is recirculated into Ball Mill cyclone clusters. Next, the ore is transferred into Floatation cells that consist of 32 flotation cells. Froth flotation is a process for selectively separating hydrophobic materials from hydrophilic and used for the recovery and upgrading of sulfide ores. Recovered ore again is transferred into a cleaner flotation cell and cleaner Scavengers flotation cells. In these

stages, copper is extracted from the ore. Extracted ore from Scavenger flotation cell is transferred into the Regrind Cyclone cluster. The regrind cyclone overflow, that is based on the concentrate % solids feeding regrind circuit is grinded in Regrind Mills. Cleaner/scavenger flotation concentrate and regrind mill discharge are combined with rougher flotation concentrate and pumped to the cyclones for further particle sizing. Each regrind cyclone feed pump discharges to a dedicated regrind cyclopac (cyclone cluster). The flotation column cell is the froth washing system. Froth washing removes unwanted impurities from the flotation froth. After the column cells that are used to perform mineral separation, the ore is thickened by concentrate thickeners. When flotation is finished with the ore, a final concentrate would be produced. Both products go to a concentrate thickener before they are dried for shipping. The concentrated ore is passed through the concentrate trash screen and concentrate filters. The Concentrate filter is used at the end of the concentrator cycle to filter and dewater the copper slurry before the drying cycle and the smelting process. Certainly, the final step is the last product of mineral packaged in the bagging facility. Waste liquids resulting from the very last stages of cleaner scavengers flotation cells and rougher flotation cells are treated by the tailing thickeners.

Picture 2. Concentrator Plant of Oyu Tolgoi LLC (front view)
1.Copper concentrator 2. Storage Facility 3.Tailing thickeners

The tailing waste from the concentrator plant thickened in tailing thickener before accumulated at the tailings impoundment (circulating polishing pond). Tailing thickener is used for produces overflow water from industrial tailing wastes for reuse in the process water of the concentrator. Two tailing thickeners are simple standard continuous thickener with a diameter of 80 m located at 500m south of the concentrator plant shown in *Picture 2* and *Picture 3.* The thickener is fed by 96,000 tonnes per day of slurry waste

with a pH of 9.5-10.5. The Tailings Thickener is designed to concentrate the feed solids to a high consistency. The feed stream enters the tailings thickener through a feed pipe and E-Duc feed dilution system. The E-Duc system enhances flocculation by mixing the feed slurry using internal dilution. Polymer feed piping is located to allow the addition of polymer to the feed stream at points to enhance the flocculation of the feed solids. The feedwell directs the feed downward, where the thickening of the solids takes place, while the clearer liquid moves outward and upwards to the effluent launder. The slurry flows directly from the thickener feed pipe to the thickener center point, where the settling process begins. The percentage of solids in the bottom stream of the thickener is approximately 64 percent by weight. During normal operation, the feed slurry flow rate for each thickener is 6109 m3/h and the overflow velocity is 4147 m3/h.

Picture 3. Tailings thickener of Oyu Tolgoi concentrate

1.3 Problem Statement

In recent years, OT concentrator's tailing thickener laundry for overflow water pipe scaling problem has been observed shown in *Picture 4.* It affects negatively on tailing thickener performance. The constant buildup of scale within the overflow water pipe allows less and less water to pass through the pipe. Moreover, a scale can complete pipe blockage. Thus, major safety issues follow the cleaning of the scaled riser water pipes. When scales buildup maintainers of concentrator clean the pipe by mechanical equipment made by themselves. The fundamental step of this thesis is to study to characteristics of slurry which enters to tailing thickener. The slurry settling

characteristics are the most important to control and perform a thickener in process industries. Lime (calcium oxide or calcium hydroxide) is the most popular reagent used in the copper processing industry for extractive minerals. Moreover, it is used as an effective and economical pH modifier in the selective flotation of the major sulfide minerals (9).

But lime causes tailings thickener laundry for overflow water pipe scaling problem. Scaling is commonly defined as minerals starting to precipitate when the concentration of mineral exceeds its saturation limit. One of the challenging difficulties is that lime is extremely difficult to handle in water pipe of tailing thickeners when a process is running because its particles are very jagged and will not dissolve, but rather merely suspended in solution. As a result, scaling causes damage pipe such as a pipeline's inner diameter to become smaller and smaller or blocked pipe and can even lead to potential economic disasters such as maintenance cost and it can affect the performance of the plant (5).

Picture 4. Scaled water riser pump

1.4 The objective of the Study

The overall objective of this research is to investigate the settling processes on tailing thickener in Oyu Tolgoi. This bachelor thesis will study on tailing thickener design and identify the concentration of tailing solution and its characteristics. Moreover, I believe that a good solution will be found which is research the possibility of scale removal and preventing environmental techniques in tailing solutions. The specific objectives are:

• Study characteristics of wastewater analyses on tailing thickener solution including lime solution;

• Study of tailings thickener design and its performance;

• Study of possibility to reduce problems.

2 State of the Art

2.1 Introduction to Tailing Thickener

Tailing thickener is solid-liquid separation and it produces a thickened pulp of perhaps 55-60 wt.% of solids. The Tailings Thickener is designed to concentrate the feed solids to a high consistency. The thickener's main purposes increase the concentration of the suspension solids by sedimentation and produce a clarified effluent. Up to 80 % of the water can be separated in this process. In mineral processing, gravity sedimentation or thickening is mostly used for solid-liquid separation technique application because it is a high capacity process that meaning is it requires low shear forces thus providing suitable conditions for flocculation of fine particles and relatively cheap. There are mainly two types of thickener which are batch or continuous unit (4).

In this case, continuous thickener is considered. The continuous thickener consists of a cylindrical tank with 13 m depth and 80 m of diameter. The effluent water or clarified liquid overflows a peripheral launder, whereas the solids which settle over the entire bottom of the tank are withdrawn as a thickened pulp from an outlet at the center within the raking mechanism. The successful operation of tailing thickener requires two main parameters which are effective feed flocculation and discharge flow rate to be controlled. The flow of feed reaches the thickener of tailings through a feed pipe and feed dilution system E-Duc, also known as eductor, and distributed to two tailing thickeners illustrated in *Figure 2.* The E-Duc method improves flocculation by using internal dilution to mix up the feed slurry. Polymer feed piping is positioned to allow the polymer to be applied to feed flux at points to improve feed solids flocculation. The feedwell directs the feed down, where the solids thicken while the clarified liquid moves outward and upward to the laundering of the effluents (10). In the eductor nozzle, the velocity of thickener feed has a stronger effect on the dilution efficiency than feed density (11).

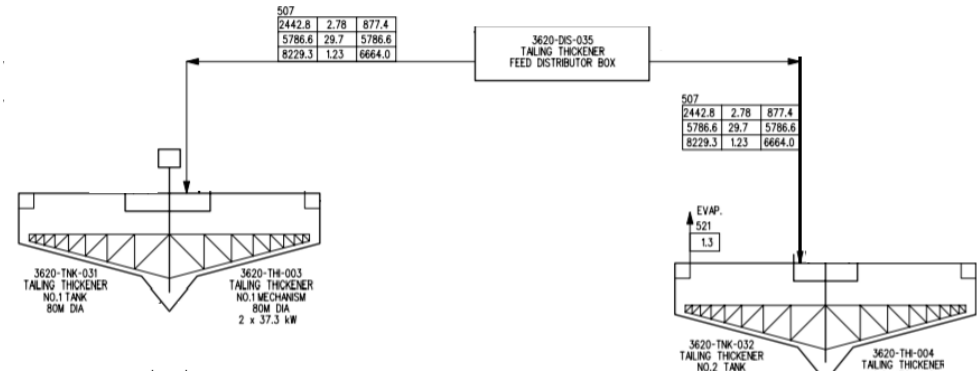

Figure 2. Simplified diagram of tailing thickeners with feed box

2.2 Theory of Settling Processes

The sedimentation process is a physical unit process in wastewater treatment that the removal of suspended solids and colloidal materials by gravity separation. Depending on the concentration and the tendency of particles to interact, the settling process can be divided into four zones: I) discrete particle zone 2) flocculation zone 3) hindered zone and 4) compression zone. This is illustrated in *Figure 3.*

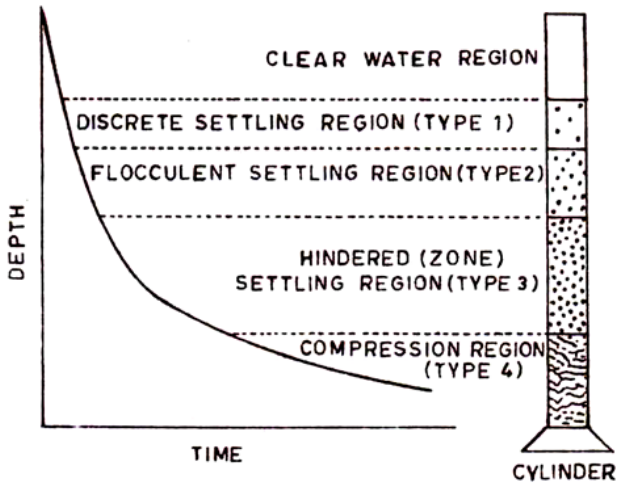

Figure 3. Region of Settling

1. Type I or discrete particle settling

   Particles that do not change in size, shape and specific gravity with time are called discrete particles. Type I sedimentation refers to the settlement of isolated particles in a dilute suspension, where the concentration of the particles is small enough to settle as individual entities.

2. Type II or flocculent settling

   Particles that coalesce or flocculate as they interact with other particles settling found in a suspension. It is due to increasing the size, shape, and mass of the particles, thus increasing the settling rate.

3. Type III or hindered settling

   This is also called zone settling. It refers to settling that occurs in an intermediate concentration suspension, where interparticle forces are sufficient to hinder adjacent particle settlement. The particle mass settles as an aggregate and a solid-liquid interface at the top of the mass forms.

4. Type IV or compression settling

   Settling results from the only compression of the structure and It happens in highly concentrated liquids, where a structure is created due to the high concentration. As more particles are added from the liquid to the structure, the

increasing solid content induces a settling of compression. This type of settling on the bottom of thickeners is observed (12).

The settling rates of particles in a liquid are represented by Stokes' or Newton's laws. Stokes' law is allowed for particles less than 50 microns in diameter. Very fine particles settle extremely slow by gravity alone. If settling with flocs in which the main role is agglomerated, created large lumps or flocculated is more quickly (4). Unflocculated or improperly flocculated solids will not properly settle to produce sufficient concentration of solids at the bottom of the thickener tank. In a continuous thickener, the dewatering slurry exhibits a clear liquid at the top, an intermediate settling zone, and a low compression zone. Upward drainage allows the liquid overflow to be collected at the top and the solid underflow to the bottom. The thickener retention time for a given set of operating conditions primarily depends on the rate and amount of slurry dewatering. *Figure 4* shown us that an easy understanding of settling processes and its main zone in tailing thickener (13). The dewatering slurry in a continuous tailing thickener exhibits a clear liquid at the top called an overflow of laundry, an intermediate settling zone, and a bottom compression zone.

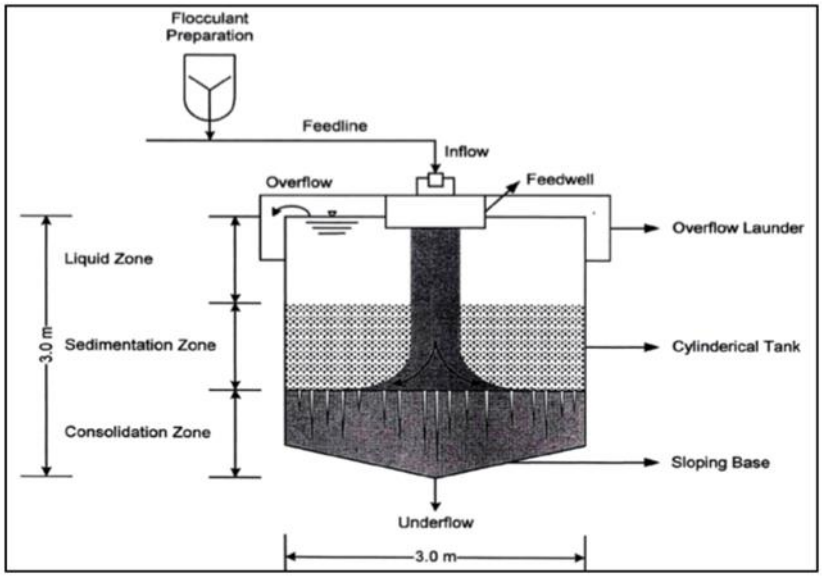

Figure 4. Schematic of a typical slurry thickener

2.3 Flocculation

Flocculation is one of the main ways of generating high-efficiency thickeners to increase the settling rate of solid particles (14). Flocculation is a well-established wastewater treatment technique and used by aggregating small particles into larger particles to

remove suspended particles. Flocculation is referred to as the following phenomenon. In a solution when colloidal particles undergo small, random fluctuations forms bridging bonds as a result of their collisions. Owing to further repetition of the cycle, more colloidal particles are added to the polymer chains, building up to larger flocks that settle steadily in suspension as illustrated in *Figure 5* (15).

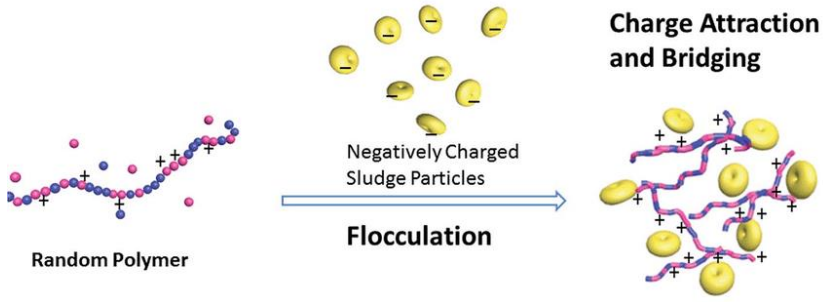

Figure 5. Simplified diagram of random polymer flocculation mechanism (16)

It is a complex process and its efficacy depends on the composition of minerals, and the dosage and procedure of adding appropriate coagulants, flocculants, and so on. The nature of flocs depends on factors that physical properties of solids and nature parameters. The surface property, size, size distribution, shape, and density are the physical properties of solids. Nature parameters referred as the nature of the flocculant (chemical properties of main part and chains, molecular weight, molecular weight distribution, electric charge, the density of electric charge), the nature of the suspension (electric charge, pH, ion strength, temperature), and the nature of the liquid (viscosity, dielectric constant). Floc properties such as floc size, density, structure, and strength have a major influence on settling rate and hence the efficiency of solid-liquid separation (17).

The flocculant type has a great influence on the settling behavior of the tailings. Typical settling behavior of suspension in the absence as well as in the presence of flocculant dosage. The main three types of commercial flocculants which are anionic, cationic, and nonionic flocculating agents were used to enhance the settling behavior of suspensions. The anionic flocculant is more effective in improving the slurry settling rate compared to cationic and nonionic flocculants. The small dose of the anionic flocculant is found to be more effective, but the other flocculants even at higher dosages are less effective (18).

In the case study, anionic acrylamide or sodium acrylate co-polymer is used as flocculant that is a type of FLOPAM – AN934SH and manufactured by SNF INC. Acrylamide is an

odorless white granular solid and its chemical formula represented as (C3H5NO)n. The designed adding a dosage of flocculant was a range between 21.3g/t and 31.7 g/t. Polyacrylamide (PAM) is an acrylic resin that has the unique property of being soluble in water. The polyacrylamides are formed by acrylamide polymerization (19). Polyacrylamide (PAM) polymers are synthetic group includes macromolecular compounds possessing neutral (non-ionic) and ionic character that anionic, cationic, and amphoteric (20). Also, FLOPAM – AN934SH is an anionic polyacrylamide flocculant type.

Before using FLOPAM – AN934SH, MAGNAFLOC 336 (MF336) is used as a flocculant and it is a high molecular weight anionic polyacrylamide flocculant.

2.4 Tailing Thickener Performance

Generally, improvements in industrial thickener performance have been based on the selection of conditions that produce desired properties in settling test behavior, such as free settling rate, a final concentration of sediment solids, viscosity or shear yield stress (21). The thickener operation aims to achieve a high density of underflow solids while maintaining an adequate clear effluent.

Which will then decide the changes to the control variables must be made to achieve the desired performance, the control indicators are used to track the state of the tailings thickener. The following *Table 1* shown the performance indicators that are control variables used to maintain acceptable performance for the tailings thickener (10).

Table 1. Performance indicators of Tailings thickener

Performance Indicators	Control Indicators	Control Variables
Effluent Clarity	Rake Torque	Flocculant Dosage
Underflow Density	Bed level sensor	Underflow Pumping Rate
	Bed Pressure Transmitter	Rake Speed
		Feed Rate

The torque indicator is a measurement of the number of solids in the thickener and the composition of the slurry. A high reading of the torque typically means the amount of solids is too small and coincides with the high accuracy of the underflow. This reading should be assessed in conjunction with the reading of the underflow density. The bed level or level transmitter measures the height of the solids in the thickener. If the bed level keeps rising, the solids will eventually reach the laundering overflow and

contaminate the effluent. The bed level will rise if solids are fed at a higher rate than are removed to the thickener. Also, bed pressure is a measure of the weight of the slurry in the thickener (10).

Moreover, the feed dilution system affects the performance of the tailings thickeners. Slower feed velocity could produce higher concentration underflow but lower clarity overflow water (22). Improvements in the performance of thickeners typically include efforts to improve feed systems, from the thickener upstream to the feedwell (23). Dilution of the feed slurry can increase flocculation efficiency by affecting both flocs size and density and reduce the consumption of flocculant. Mineralogical composition of tailings also had a noticeable effect on the thickener performance reflecting a remarkable reduction in thickener performance with an increase of 15 percent and 3 percent in Illite and Albite fractions in the ore (11).

2.5 Factors Effect Settling

The efficiency of a thickener that both settling and compression is affected by a variety of factors including feed solid loadings, tailing's properties, flocculant characteristics, and sediment compressibility. Tailing's properties defined by particle size, particle surface charge, solution chemical composition, solids density, and flow rate. Tailing's mineralogical composition also had a noticeable effect on the thickener performance reflecting a remarkable reduction in the thickener performance with a surge in Illite and Albite fractions by 15% and 3% in the ore. It will explain with details in the next section. Also, the flocculant is characterized by the molecular weight, charge density, solution concentration, strength, and dosage (24).

Suspension solids concentration is an important variable within the efficiency of thickening. Thickener discharge solids concentration was reduced with increasing solids concentration. Lower solids concentration during flocculation led to far better compression. Dilution of suspension was an important stage of thickening (25).

2.5.1 Feed Dilution

Dilution of thickener feed is typically used for improved flocculation and compressibility of the sediments. Dilution of feed slurry can increase flocculation performance by affecting both floc size and density. With feed dilution, the clarity of the thickener recovered water was increased and the dilution rate in the eductor was also impacted by the feed rate of thickeners. Under the optimum conditions, both flocculation and settling rates of red mud were enhanced with thickener feed dilution. There is optimum solid

loading during the dilution which can result in maximum settling flux. Settling flux is defined as the amount of solids passes through a unit area of a thickener in a unit of time (*Equation 1*). Where S is settling flux, V(C) is settling velocity of a layer of suspension with a solids concentration of C

$$S = C \times V(C) \quad (1)$$

The compressive yield stress and strength of the feed slurry also play an essential role in the performance of the thickeners, particularly deep bed thickeners. An improvement of a thickener's output is required upon dilution of thickener feed. During flocculation through dilution, the solid loading of thickener underflow slurry increased by 3 to 7% with reduced solid loading of feed by 5 to 6%. Due to the vital function of compression of their underflows, thickener feed dilution becomes more important with increasing bed depth. In the eductor nozzle, the velocity of thickener feed has a greater effect on the dilution efficiency than feed density. Besides, thickener feed with a comparatively higher solid charge is favored to reduce the water loss in the discharge. A smart dilution system was proposed to maintain optimum dilution in thickeners by modification of existing eductors by automatically changing the geometry of the eductor depending on the variable properties of thickener feed. However, the optimal feed dilution depends on a great number of variables including ore characteristics (24).

2.5.2 Effect of Flocculant

The main role of flocculation is to shape aggregates or flocculants of finely dispersed particles with the aid of natural and synthetic polymeric substances referred to as flocculants. Flocculation occurs either by bridging, charge neutralization, polymer complex formation, or by the combination of two or more of these mechanisms. The main role of flocculation is to shape aggregates or flocculants of finely dispersed particles with the aid of natural and synthetic polymeric substances referred to as flocculants. Flocculation occurs either by bridging, charge neutralization, polymer complex formation, or by the combination of two or more of these mechanisms. Flocculation is a complex process, and the performance of the process depends not only on the use of suitable flocculants but also on how they are applied. The performance of the flocculant that terms of sediment intensity, supernatant turbidity, and sediment volume in any application are determined by a complex interplay between several factors. These factors can include slurry properties such as solid ratio, particle size, surface load, solution chemistry, pH, and physical variables such as mixing strength (rate), mixing time, and flocculant addition rate. Each of them determines the rate and efficiency of the flocculation. Thus, the determination of the flocculation behavior of the suspensions is very critical for solid and liquid separation. The efficiency of the flocculation is strongly

influenced by the mixing conditions. Essentially rapid mixing is required to distribute the flocculant species as quickly as possible among the particles. This may be particularly important in the case of flocculants that adsorb onto particles and neutralize their charge. Slow mixing may contribute to local accumulation of flocculants and, as a consequence, to the destabilization of some particles. A short duration of severe, turbulent mixing is therefore desirable. So overdosing can be a significant mistake in that it can lead to a well-established suspension that is incredibly difficult to separate. In theory, a significant degree of flocculation can be obtained with a much lower dose of polymer than is usually required. Hydrodynamic factors resulting from mechanical agitation play a major role in flocculant adsorption. The vigorous agitation of the flocculating suspension causes flocculation and the exposure of fresh surfaces to polymer adsorption, thereby increasing the adsorption capacity. However, increased agitation leads to the production of smaller flocs, indicating that increased adsorption does not make up for increased floc breakage (24). Excessive flocculant dose can decrease suspension compressibility. Suspension compressibility may be reduced by increasing the flocculant dose. Although increasing flocculant dosage increased sediment flux (25).

2.5.3 Effect of pH and Temperature

Temperature and pH are the significant factors that affect flocculation efficiency and properties of settling. Temperature is known to affect processes of flocculation and settling. Decreasing water temperature can affect the strength of the floc and effectiveness of essentially flocculating forming, causing bad settling. Hence prolonged flocculation time at low temperatures would again break the largely shaped flocs into smaller ones and reduce the efficiency of settling. With the increase of the initial turbidity, the effect of temperature on floc formation and strength becomes less effective. The effect of the gradient of flocculation velocity on flock formation and strength was important at low temperatures. By contrast, the effect will less when the temperature increases. High flocculation time would hinder floc strength and practically floc formation efficiency and cause bad sedimentation as this longer flocculation period will break the largely formed flocs into smaller ones more easily at low-temperature raw water and cause of increased shear stress due to greater water viscosity. The flocculation is slow at lower temperatures and the flocs become less than at higher temperatures. Alum flocs at low temperatures were very susceptible to break up due to fluid shear, and only the weakest ferric flocs were better than the strong alum flocs. Alum is typically seen to be less efficient at low temperatures owing to lower density flocs and aggregate size. Water temperature affects flocculation by affecting floc size, strength, and ability to reform after shear rupture. This would impact the process that clarity and filtration, along with the

consequences of changes in viscosity due to temperature. Warmer temperatures typically create larger flocs that break more quickly and re-form less well than at lower temperatures. Aluminum-based coagulants generate flocs that differ more with temperature, size, and intensity than ferric sulfate flocs (26).

2.6 Ore properties and tailing characteristics

Tailing is a processing waste from the concentrator plant and produced by in the particulate suspension form which is a fine-grained sediment-water slurry. Gangue or unwanted minerals such as silicates, oxides, hydroxides, carbonates, and sulfides and little amounts of valuable minerals can be found in tailing. The grain size of tailing solids has ranged clay, silt, and sand. Typically tailing is made up of sand-sized particles and finer clay-sized particles corresponding 70-80 wt.% and 20-30 wt.%. Also, tailings liquids contain high concentrations of process chemicals. Generally tailing composition depends on the processing methods and it might change over time (27).

The ore properties including density, particle size, and mineralogy are one of the remarkable factors in the thickening process. Metallic minerals (as ore properties) are might be more considerable in the settling behavior than the flocculant dosage (operating parameter) because changes in the flocculant dosage have shown no significant effect on the thickening behavior. Negative surface loading (OH in alkali solution), swelling characteristics, and small particle size of clay minerals negatively affect the sedimentation behavior of the sludge fraction in the thickening process. These factors also affect the rheology of the slurry as it affects the concentration of the solids and how the particles stack during sedimentation (28).

Copper is most commonly found in the earth's crust as copper-iron-sulfide and copper-sulfide minerals, e.g. chalcopyrite (CuFeS2), bornite (Cu5FeS4) and chalcocite (Cu2S). The recovery of these copper minerals from ores, usually containing 0.5 percent TCu (open pit mines) and 1-2 percent TCu (underground mines), by flotation or hydrometallurgy is of considerable commercial significance. The rising complexity of mineral deposits, decreasing grades of mineral, and increased global demand for copper have resulted in increased floatation processing of ore. Froth flotation is characterized as a physicochemical process that utilizes the differences in the electrochemical properties of mineral surfaces, between hydrophobic and hydrophilic surfaces which are either naturally or artificially induced by chemical reagents (29).

Reagents are the most important component of the flotation process. Depending on the role of a particular reagent, flotation reagents can be divided into three major groups. They are made of collectors, frothers, and modifiers. Collectors are organic chemical

compounds, differing in their chemical structure and function. The basic aim of the collector is to selectively form a hydrophobic layer in the flotation pulp on a given mineral surface and thus provide conditions for the attachment of the hydrophobic particles to air bubbles and the recovery of these particles in the froth substance. Frothers are heteropolar surface-active compounds that lower water surface tension and are capable of adsorbing on the air bubble – water interface. Natural chemicals like pine oil, cresylic acid, and synthetic reagents such as methyl isobutyl carbinol (MIBC) and polyglycol ethers are among the most commonly used frothers. However, alcohols (OH) are the most widely used, since they have no collector properties and are superior to other frothers like carboxyls, which are still effective collectors in this regard. Modifiers are chemicals that are widely used in flotation to modify the collector's behavior, allowing collector activity more selective against other minerals. Modifiers may be classified as activators, pH modifiers, and depressants. Activators react with the mineral surface such that they become hydrophobic due to collector activity, depressants improve flotation selectivity by making other minerals hydrophilic and pH-modifiers control the ionic composition by increasing the hydrogen ion concentration in the pulp. Collector, frother, activator, depressants, and pH modifications are widely used reagents in commercial flotation plants (29).

Moreover, any other purpose with chemicals such as anti-corrosion, anti-scaling, process water softener, etc used in a pipeline system. Scale inhibitor or antiscalant is usually organic compounds containing functional groups of sulphonate, phosphonate, or carboxylic acid and chelating agents such as iron, alum, and zeolites that sequester and neutralize a particular ion that may be formed. Solutrix II (phosphorous acid) product can also be used for general descaling. Sodium Chloride solution is used for process water softener. A traditional water-softening system eliminates and substitutes calcium and magnesium ions with sodium ions from the hard water. WTS5-1125 corrosion inhibitor is used for anti-corrosion. It is caustic alkali liquid and less than 25 % is consisting of sodium tolytriazole. A corrosion inhibitor is a chemical compound that, when applied to a liquid or gas, decreases the rate of corrosion of a substance, usually a metal or alloy, that comes into contact with the fluid.

2.7 General Copper Concentrate Processing

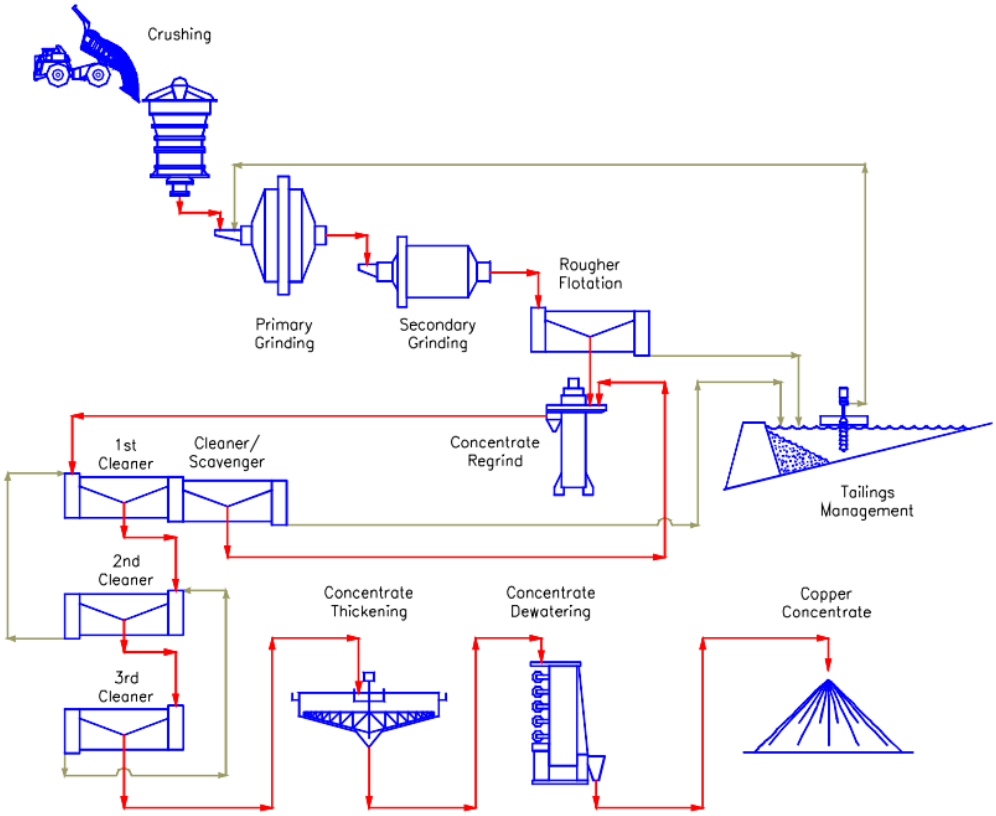

Figure 6. A typical process flow diagram of copper concentrate production

An example of a simplified flowsheet of copper flotation is described in Figure 1*Figure 6*. In a primary crusher (gyratory crusher used in this case), run-of-mine open pit ore is crushed. The crushed ore is processed to produce copper concentrate using semi-autogenous and ball mill grinding followed by rougher flotation, regrinding, cleaner, scavenger flotation, and dewatering. The concentrate is trucked to a port facility for shipments to smelters via the existing road network in the area. Tailings from the process should be impounded in a tailings pond, water from the tailings pond will be reclaimed, and reused in the process (30).

The copper ore usually contains approximately 0.5 to 2 percent copper in the form of disseminated and stringers. In primary crusher (jaw and cone crushers), the run of mine ore is reduced from 150 mm to 25 mm. In ball mills, the crushed ore is grinded to the size of 74 mm. The ore is processed by froth flotation which consists of rougher and scavenger cells. The common reagents for copper ore flotation are xanthates as a collector, pine oil as a frother, sodium cyanide as a depressant, and lime to maintain slurry alkalinity. The concentrate in the form of froth and slurry contains higher than 20% copper (31).

2.8 Lime usage and Scaling formation

Scaling is caused by precipitation or crystallization of inorganic salts and their scale deposits are calcium sulfate (CaSO4,), calcium carbonate (CaCO3), calcium fluoride (CaF2), calcium phosphate (Ca3(PO4)2), magnesium hydroxide (Mg(OH)2), magnesium carbonate (MgCO3). Precipitation is defined as results in the rapid formation of solids that can initially create small crystals, facilitating the formation of a scale and its deposition. Supersaturation is the main point that occurs precipitation and it happens when ion activity in the solution exceeds its saturation limit. This condition is suitable for the rapid nucleation of scale formation and its growth. Nevertheless, the pH of the liquid, the presence of impurities, pressure difference, hydrodynamics, and flow rate are other factors that cause inorganic salt precipitation. The deposition of scale depends on the industrial concentrating process (5). Also, those inorganic salt's main source comes from the utilization of lime. Lime is represented as a form of calcium oxide (CaO), or calcium hydroxide (Ca(OH)2)) and used as a common modifying reagent in mineral processing. Modifying reagents plays a critical role in the flotation pulp by reacting either with the mineral surfaces or with collectors and other ions, resulting in a modified and controlled flotation response that pH control. Ca2 + ions in lime can increase mineral depression and flotation selectivity across a variety of ores. Following figure (fig3) shown the possibilities of lime usage on the sulfide flotation plant. Control of pH is also the most commonly used strategy for achieving selective flotation of minerals in sulfide ores, using lime addition (9). Simple understanding explained by that lime used in industry is considered to be chemically highly hydrated or raw lime, as it reacts with water to heat reaction and react with air to precipitate into form carbonate as its result due to scaling problem.

The lead to the formation of solid calcium carbonate reactions is as following equations. At first, carbonic acid produced while carbon dioxide reacts with water as seen by *Equation 2*.

$$CO2\ (g)+H2O\ (l) \rightleftharpoons H2CO3\ (aq) \quad (2)$$

This carbonic acid will continue to dissociate hydrogen, creating newly deprotonated species of carbonic acid, as shown in *equations 3 and 4*.

$$H2CO3\ (aq)+H2O\ (l) \rightleftharpoons H3O+\ (aq) + HCO3\ (aq) \quad (3)$$

$$HCO3\ (aq)+H2O\ (l) \rightleftharpoons H3O+\ (aq) + CO3\ (aq) \quad (4)$$

a mixture of the species H2CO3, HCO3, and CO3 will be in the water mixture. Finally, in the presence of calcium and carbonic acid, calcium carbonate will precipitate out as seen in *equation 5*.

$$CO3\ (aq) + Ca2+\ (aq) \rightleftharpoons CaCO3\ (s) \qquad (5)$$

Since the water produced usually contains carbonic acid and calcium ions, the recombination of these reactions will provide a better picture of the situation as seen in *equation 6.*

$$Ca\ (HCO3)2\ (aq) \rightleftharpoons CO2\ (g) + H2O\ (l) + CaCO3\ (s) \qquad (6)$$

In liquid form, calcium and carbonic acid together will be in equilibrium with water, solid calcium carbonate, and CO2 gas (32)

3 Research Methodology

As a review methodology, there are general steps namely, description, search, appraisal, synthesis, and analysis. The research study is conducted by the state-of-art review method with data analysis for the OT company. In a description of the selected methodology, there were to address more current matters which is scaling formation to due calcium in contrast to other combined retrospective and current approach that is to increase precipitation.

This study aimed to investigate the parameters that affect the settling behavior of tailings thickener. This thesis presents the results of a study conducted on settling processes of copper mineral tailings. The topic of the thesis is motivated by the student research work that annually offered by Oyu Tolgoi LLC. Our team is working on tailings thickener laundry for overflow water pipe scaling problems. We went excursion at the Oyu Tolgoi mining site to introduce the current situation, what process is going on, and observe the exact problem. This excursion was of huge support for understanding the topic.

In the analysis part, the data was collected from the Tailings thickener Lab at the Concentrator plant of Oyu Tolgoi. Provided data about that relevant tailing thickener such as overflow water composition, tailings feed, flocculant, etc within the last two years (2018-2019) by daily to weekly. These data analyzed by IBM SPSS 23 statistics software and Microsoft Excel 2016. SPSS Statistics is a software package used for various kinds of researchers for complex statistical data analysis such as interactive, or batched, statistical analysis (33). Measurement with error and some missing measurements are excluded from the data analysis.

To analyze the data and obtain a result, the state of the part is studied. The following parts were reviewed. At the first, settling process theory, typical tailing thickener's working principle, and its performance control are studied to get the fundamental knowledge. Also, in this part has one difficulty that the overflow laundry mechanism of OT’s tailing thickener is different than conventional tailing thickener. Thus conventional continuous tailing thickener is studied. Second, affecting factors of the settling process is researched and reviewed from literature reviews and journal articles. After that, found parameters such as flocculation type, solution condition, and characteristics of tailing solution are studied with details. According to the research, the determination of ore properties and chemicals used in the process was one of the main factors. The copper ore properties and any chemicals which are used in the whole process that copper flotation is determined because it was helpful to define the slurry sedimentation behavior.

Moreover, the theory of flocculation mechanisms and properties of flocculant parameters (floc type, floc dosage, floc dilution) are studied. In the final part of the state of the art, a theory of scaling formation and lime usage in the process are reviewed. In this part more focused on the lime slurry characteristics based on the determination of used chemicals in-process and ore characteristics. The result is analyzed on the provided data by obtained knowledge from the state of the art.

In a synthesis of the methodology, the case study of Oyu Tolgoi has reviewed a comparison of typical copper concentrate processing technology. Stages of processes are generally similar to typical copper concentrate production technology. Lime usage for selective flotation to adjust pH is common reagent in copper ore processing. Thus scaling formation is challenging issue for most copper concentrate plant.

4 Result and Discussion

The results were addressed into the following sections, i.e. given in four sections that are a determination of copper tailings characteristics, water analysis on overflow, parameter analysis of tailing thickeners, and the effects of flocculant types and dosages were also be discussed.

4.1 Characterization of copper tailings

Table 2. Copper Mineral Species

Copper Mineral	
Azurite	$2CuCl_2O_3 \cdot Cu(OH)_2$
Bornite	Cu_5FeS_4
Chalcocite	Cu_2S
Chalcopyrite	$CuFeS_2$
Chrysocolla	$CuSiO_3 \cdot 2H_2O$
Covellite	CuS
Cuprite	Cu_2O
Enargite	Cu_3AsS_4
Malachite	$2CuCO_3(OH)_2$
Native copper	Cu
Tetrahedrite	$(Cu,Fe,Ag,Zn)Sb_4S_{13}$

Copper can be present in more than 200 minerals, but only around 10% of this occurs in the form of sulphide minerals (e.g., chalcopyrite, bornite, and chalcocite) or oxidized minerals (e.g., cuprite) that are important as copper ores (34). Typical copper mineral species are present in *Table 2.* Thus after the copper concentrate process, rejected gangue minerals from those copper mineral species can found in tailings. Copper tailings are a finely ground waste after extraction of copper mineral from the ores during the beneficiation.

Moreover, the slaked lime system is used to modify the pH of the concentration process for reagents to the grinding and flotation process. The dual lime slaking system is identical and each lime slaking system is designed to convey dry quicklime at a specified feed rate of 11 tons per hour and produce 26 percent solids by weight lime slurry, which in turn is diluted by weight to 15 percent solids with optimized water substitute (35). Thus, the tailings from copper concentrate might have lime slurry characteristics. About 80% of the particles were found to be less than 157.36 µm size fractions. The tailings feed into tailing thickener contained a low amount of zinc, copper, phosphate, silica, and highly contaminated by calcium, chloride phosphates which are measured by OT as shown in *table 3* by concentration with ppm unit. The feed tailings have approximately 21°C temperature and 9.71 pH is discharged into tailing thickeners.

4.2 Water quality analysis of overflow water

According to the data given by OT, the chemical analysis of water provides considerable insight that parameters of raw water are significantly increased during processes, after that processed water resulted in overflow water with a high amount of all parameters from tailings thickeners. The calculated mean value of parameters within the last two years (2018-2019) by a raw, process, and overflow water is shown in *Table 3*. This summary table may help observe the clarity of overflow water. Overflow water has 1511.51 ppm of hardness, about 24°C temperature with 10.31 pH. It contained a low amount of zinc, copper, and phosphate is 1.6 ppm, 6.3 ppm, and 1.87 ppm respectively, a large amount of sulfate and chloride are corresponding 1828.64 ppm and 1533.52 ppm.

Table 3. Summary table of chemical analysis on raw, process, and overflow water

Water type		Overflow		Process		Raw	
		Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
pH	-	10.31	0.65	9.71	0.87	7.74	0.34
Temperature	°C	23.57	5.52	21.21	4.93	15.71	3.75
TDS	uS/cm	6707.32	1212.81	6635.97	1313.48	3701.22	188.13
Conductivity	ppm	8207.43	1349.85	8096.97	1431.07	4743.70	214.70
Turbidity	FAU	20.33	55.54	12.40	7.40	3.85	16.83
Ca Hardness	ppm	1403.75	293.86	1318.11	287.63	511.11	62.61
Total Hardness	ppm	1511.51	301.60	1448.76	291.85	671.96	74.10
Chlorides	ppm	1828.64	324.54	1863.53	333.50	1279.51	163.24
Sulphates	ppm	1533.52	514.75	1499.00	509.26	593.44	153.29
Zinc	ppm	1.60	0.94	1.48	0.92	0.40	0.23
Copper	ppm	6.29	2.31	6.04	2.30	2.37	0.78
Phosphate	ppm	1.87	1.17	2.34	1.08	2.35	1.73

From *Figure 7,* the content of calcium is not settled in tailings thickener and directly passes through process resulted as present in overflow water. When the calcium or carbonic acid concentration is increased, then an equilibrium (*equation 5*) changes towards the right and further calcium carbonate precipitation will occur. It gives the idea that a high concentration of calcium is a fundamental reason to build scaling in riser water pipe.

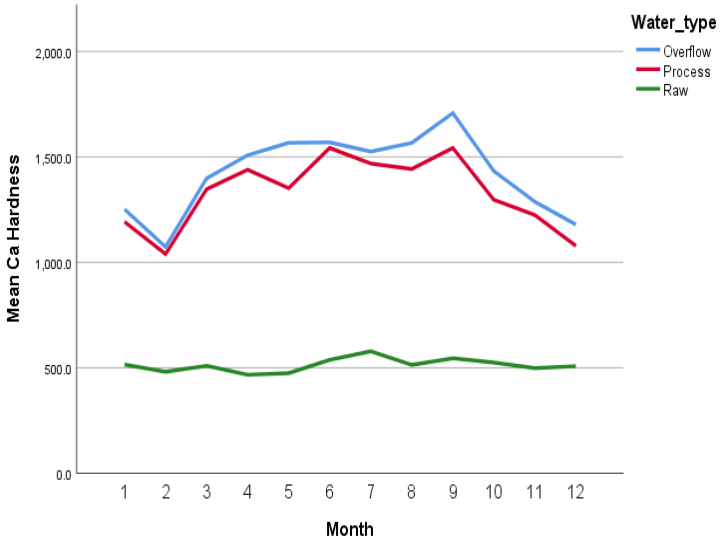

Figure 7. Mean value of Ca Hardness [ppm] by monthly

Also, temperature and pH have a great influence on precipitation of calcium. The temperature of overflow water is generally higher than the process and raw water is shown in *Figure 8*. The overflow water average temperature is 23.57°C. Correlation of temperature and calcium concentration is observed by the scatter plot as shown in *Figure 9.* Even temperature increases, the concentration of calcium hardness is increased. It means calcium is not dissolved during settling processes. It leads to precipitation of calcium carbonate. Calcium carbonate solubility will decrease with increasing temperature. Cause the precipitation of calcium carbonate requires endothermic energy as seen in equation 7.

$$\text{energy} + Ca(HCO_3)_2\,(aq) \rightleftharpoons CO_2\,(g) + H_2O\,(l) + CaCO_3\,(s) \qquad (7)$$

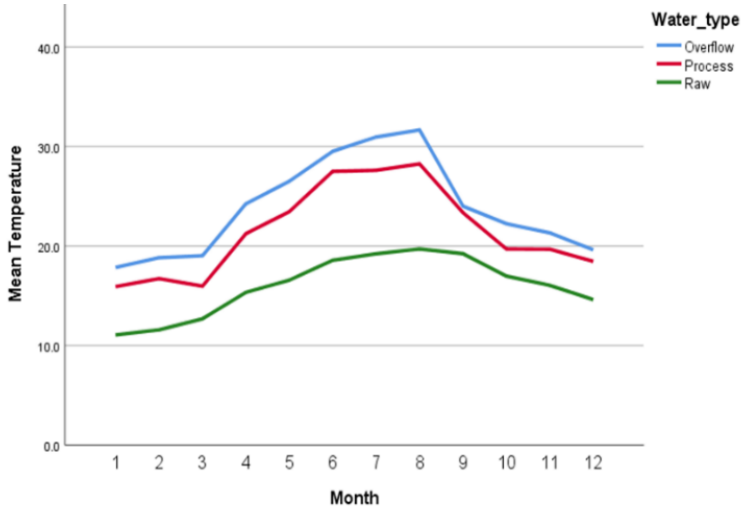

Figure 8. Mean value of temperature [°C] by Monthly

As the temperature rises, the energy also increases, and by consuming energy, the equilibrium can seek to overcome this. Then, the equilibrium is moved to the right, preferring calcium carbonate precipitation.

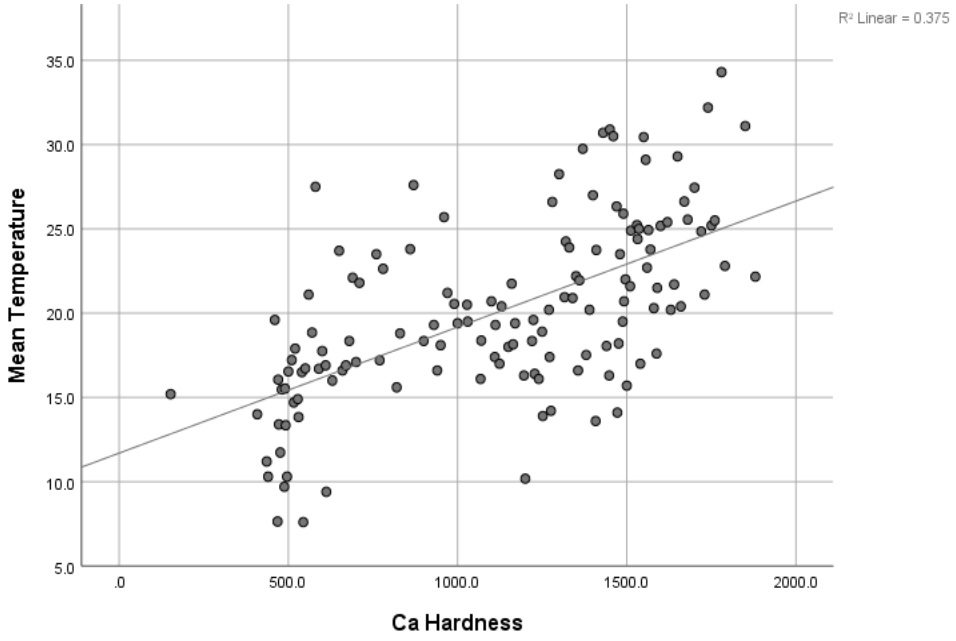

Figure 9. Scatter Plot of Mean Temperature [°C] vs Ca hardness [ppm]

Increase in solution pH results in acceleration of the formation of calcium carbonate and the growth of crystals. Also, the pH of overflow water is 10.31 and is high compared with the process and raw water as shown in *Figure 10*. This scatterplot (*Figure 11*) shows a low positive correlation association between mean pH and concentration of Ca hardness.

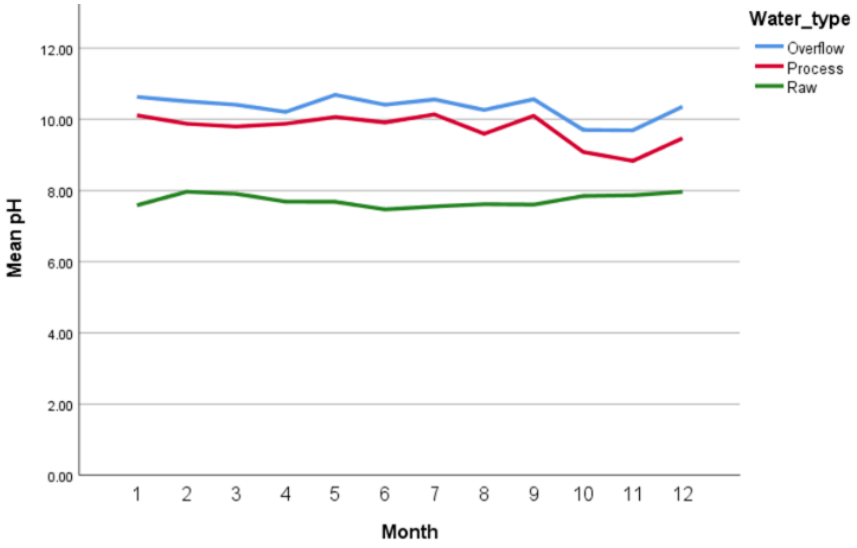

Figure 10. Mean pH value by monthly

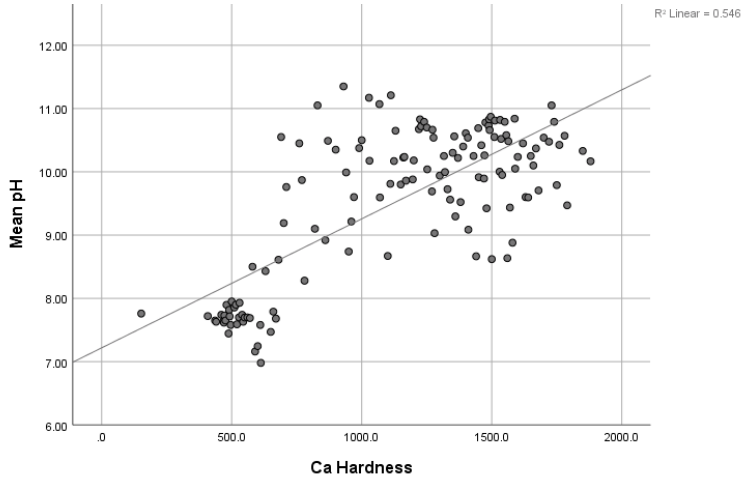

Figure 11. Scatter plot of mean pH vs Ca hardness [ppm]

Turbidity is one of the measurements of the quality of water. Strong turbidity means that a lot of particles are suspending in the water. Also, turbidity is measured by FAU or Formazin Attenuation Units. Though the three scales differently measure turbidity, they are essentially the same in value. 1 NTU = 1 FTU = 1 FAU. From *Figure 12*, amounts of turbidity in overflow and process water are higher than raw water and are 20.33 FAU and 12.44 FAU respectively. Generally, these values considered there is a presence in a low amount of turbidity. However, natural waters are nearly always below 5 NTU (36). According to this result, more of suspended particles required to settle down in tailings thickener is present in overflow water.

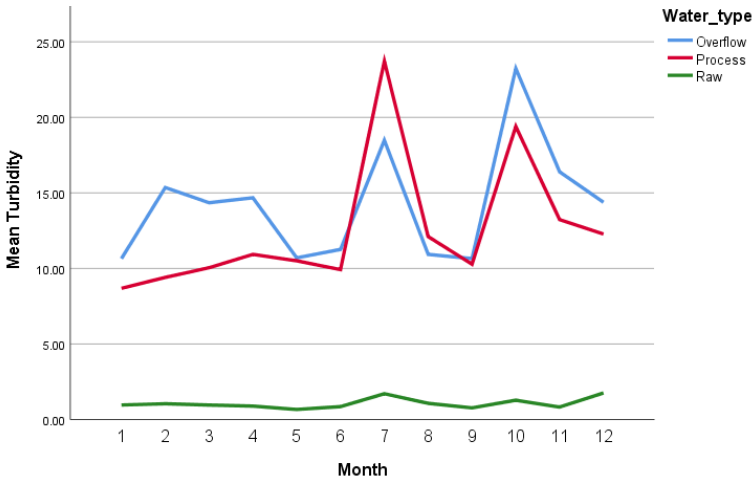

Figure 12. Mean value of Turbidity by monthly

Also, the amount of conductivity is about 8000 ppm same as overflow and process water shown in *Figure 13*. The concentration of total dissolved solids (TDS) of overflow and process water are corresponding averagely 6707.32 mg/L and 6635.97 mg/L. Total Dissolved Solids (TDS) refers

to the amounts of substances dissolved within the liquid. These substances may include both organic and inorganic salts, minerals, metals, calcium, and other compounds. Good quality water should usually range between 0 and 600 ppm, and readings above 1200 ppm are often considered an unsatisfactory TDS level. Thus the amount of conductivity says TDS in tailing thickener breaks into ions, both anions, and cations. From *Figure 14*, TDS of overflow water is higher than approximately 6000 ppm.

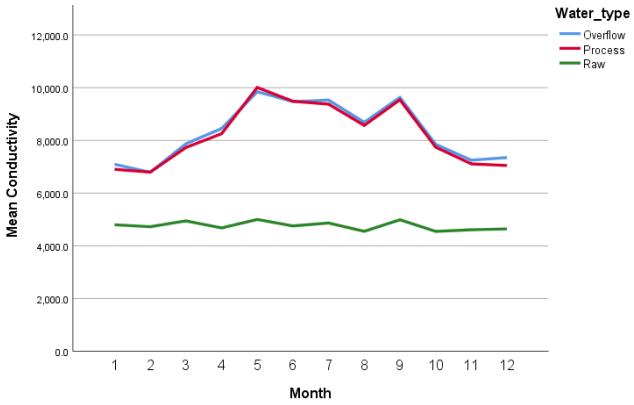

Figure 13. Mean value of conductivity by monthly

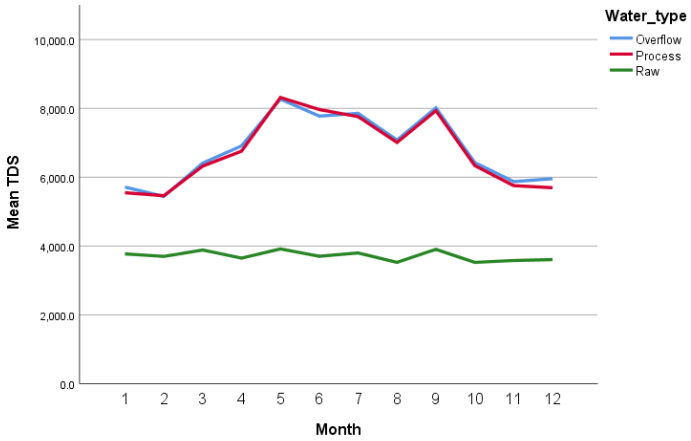

Figure 14. Mean value of TDS by monthly

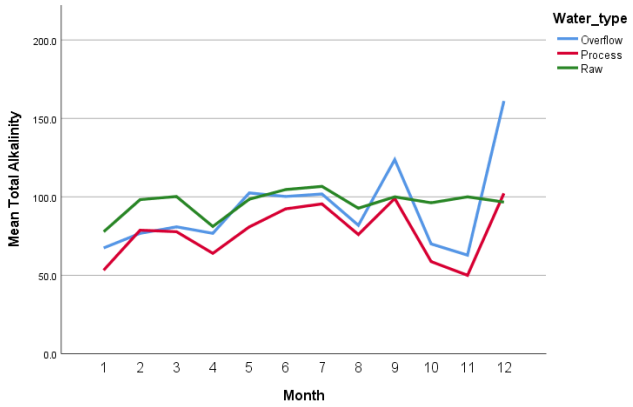

Figure 15. Mean value of Total alkalinity by monthly

Alkalinity is a measurement of water's acid-neutralizing potential. Most of the parameters mean value is increased in overflow water except alkalinity. It might be due to a lime addition for pH adjuster. Reduces or changes the alkalinity or extreme loss of CO2 may lead to precipitation of CaCO3. According to the analyzes, there is a high concentration of calcium and suspended solids are present in overflow water which is not settled properly. Moreover, the condition of slurry in tailing thickeners has become the main reason for build scaling in the riser pump.

4.3 Parameter analysis of Tailings thickener

Tailings with approximately 2100 tons of mass flow rate are fed into two tailing thickeners and its solid content is about 30.5% as shown in *table 4*. After settling processes, tailings thickened as sludge output that underflow solid content is averagely 57.64% and it generally reached 77.5% at maximum performance. It gives the idea that tailing thickeners working normally at its standard. As mentioned in the state of the art section, tailing thickener produces a thickened pulp of perhaps 55-60 wt.% of solids.

Table 4. Tailings thickeners of feed and underflow

Tailings thickener		Feed mass flow rate	Feed density	underflow density	underflow flowrate	underflow solids mass
		t/h	% solids	% solids	m3/h	t/h
Tailings thickener #1	Mean	2104.84	30.46	57.74	2682.76	2587.13
	Std. Deviation	652.34	3.84	9.62	544.98	556.25
Tailings thickener #2	Mean	2076.91	30.46	57.54	2481.19	2429.09
	Std. Deviation	667.96	3.84	11.31	548.20	567.97
Total	Mean	2090.87	30.46	57.64	2581.98	2508.11
	Std. Deviation	660.10	3.84	10.50	555.63	567.48

Table 5 is shown the mean value of the considerable parameters of tailing thickeners. As we know, the torque parameter is a measurement of the number of solids in the thickener and the composition of the slurry. About 44 % of the torque means the amount of solids is too small and coincides with the high accuracy of the underflow.

Now we can see the height of the solids in the thickener from the bed level parameter. The mean value of the bed level is 39 % or 1.76 m. The bed level must not raise a too high cause of the solids will eventually reach the laundering overflow and contaminate the effluent. The bed level will rise if solids are fed at a higher rate than are removed to the thickener. The bed pressure is linked by the relationship to the mean density of the slurry the pressure sensor and expressed as Pressure = density x height x gravity. Thus higher reading of bed pressure means solids percent of underflow is high.

Table 5. General info of tailings thickener's parameters

Tailings thickener		Torque	Water level	Bed level	Bed pressure	Liquid level	Interface	Mud filtered
		%	m	%	kPa	mm	mm	mm
Tailings thickener #1	Mean	44.775	4.127	38.407	122.746	7076.229	2585.330	2500.550
	Std. Deviation	10.728	0.543	8.105	13.953	95.614	521.079	534.005
Tailings thickener #2	Mean	43.201	4.054	39.498	119.611	6958.903	2449.791	2257.035
	Std. Deviation	12.204	1.167	17.420	17.485	260.311	650.521	634.582
Total	Mean	43.988	4.090	38.953	121.179	7017.566	2517.561	2378.793
	Std. Deviation	11.513	0.911	13.592	15.890	204.620	593.050	598.772

The feed rate solids flux shown is calculated in the next step. The calculated mean value of solid flux is shown in *Table 6*. Averagely 434.9 kg of solids pass through a unit area that square meter of a thickener in a second and is related to slurry concentration and settling velocity as explained in *equation 1*.

Table 6. The calculated mean value of velocity, concentration, and solid flux

Parameter	Velocity [mm/min]	Underflow concentration [kg/m3]	Solid_flux [kg/m2/s]
Mean	39.04	188.07	434.91
Std. Deviation	5.08	58.52	99.73
Minimum	10.25	46.72	74.36
Maximum	48.28	800.11	962.49

The resulting solid flux-density data pairs are then plotted as solid flux vs. underflow solids percent as shown in *Figure 16*. It shows a low positive correlation association and if the solid flux is increased, the density of underflow will increase. In the case of measurement with two years, underflow solids content has about 60% is achieved even not directly related to feed rate solid flux. Now see the correlation of solid flux and solids concentration as illustrated in *Figure 17*. The increasing concentration of solids from about 0 to 300 kg per cubic meter led to an increase of solids flux from about 100 to 700 kg/ m2h. Also, solids concentration raising from 300 kg per cubic meter results as a reduction of the average settling flux roughly from 700 to 400 kg/ m2h. The reason may be attributed to the transition from free to obstructed settlement in settling regime.

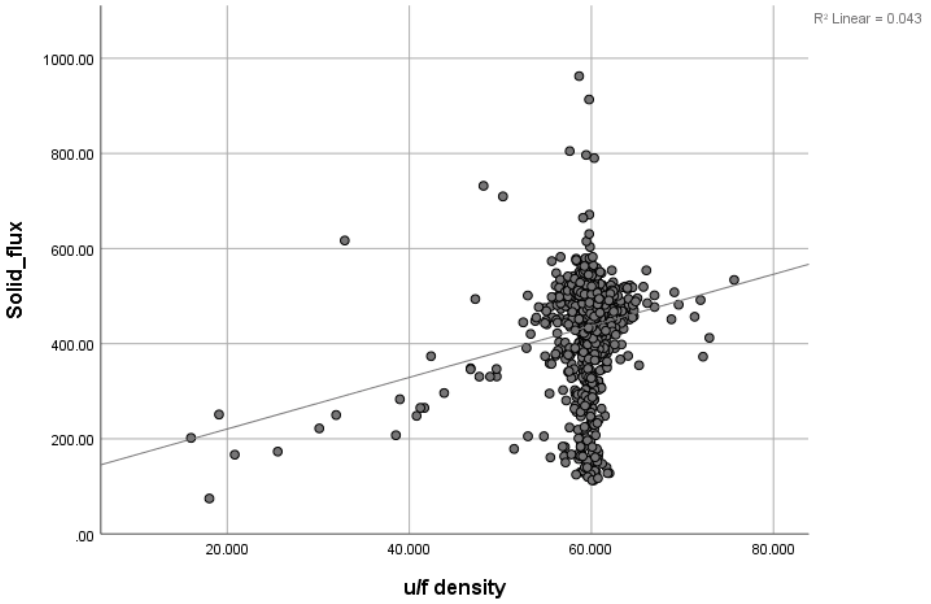

Figure 16. The relationship between solid flux [kg/(m2 x h)] and underflow density [% solids].

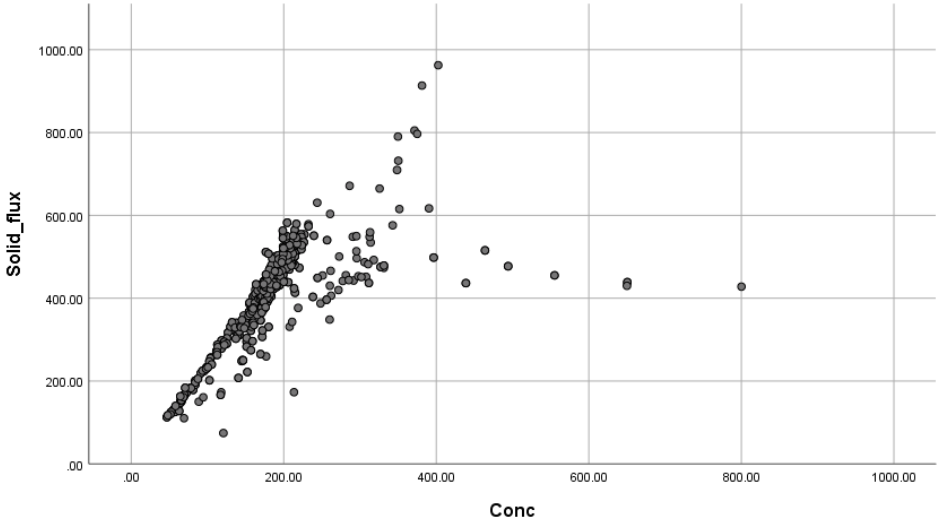

Figure 17. The Relationship between solid flux [kg/(m2 x h)] and underflow concentration [kg/m3]

4.4 Analysis of flocculant

Attempts made to observe the natural settling behavior of solid particles with two different flocculants that are AN934SH and MF336. For this purpose, the comparison was carried out as seen in *table 6*. According to this table, AN934SH flocculant is used with a little bit higher dosage has 20.65 g/t than 18.67 g/t of dosage with MF336 flocculant.

Table 7. Flocculant info comparison

Flocculant type		Floc.Strength	Floc dosage	Floc flow	Floc dilution
		%	g/t	m3/h	%
AN934SH	Mean	0.497	20.648	5.224	5.704
	Std. Deviation	0.005	7.385	4.848	5.650
MF336	Mean	0.465	18.661	7.600	8.491
	Std. Deviation	0.122	5.125	3.367	3.532
Total	Mean	0.478	19.470	6.637	7.361
	Std. Deviation	0.096	6.222	4.197	4.714

There is no huge difference between these two flocculants. Cause of AN934SH and MF336 are the same flocculant type that an anionic polyacrylamide. Thus general characteristics of the flocculation mechanism are might be similar to each other. Narrative result of which flocculant is a good solution for in a case can not be discussed due to settling data in the laboratory.

Table 8. Flocculant info on tailings thickeners

Tailings thickener		Floc.Strength	Floc dosage	Floc flow	Floc dilution
		%	g/t	m3/h	%
Tailings thickener #1	Mean	0.478	19.333	4.253	4.858
	Std. Deviation	0.096	8.585	4.421	4.985
Tailings thickener #2	Mean	0.478	19.604	9.021	9.865
	Std. Deviation	0.096	2.157	2.081	2.658
Total	Mean	0.478	19.470	6.637	7.361
	Std. Deviation	0.096	6.222	4.197	4.714

The efficiency of flocculant consumption is expected to improve once further improvements to the design and operation of thickeners are more widely adopted. Flocculant attachment points will be properly positioned in the shorter term, with the reporting and monitoring of flow rate to thickener. The results of the studies on the effect of flocculant dosage on the underflow concentration of copper tailings are illustrated in *Figure 18* and *Figure 19.*

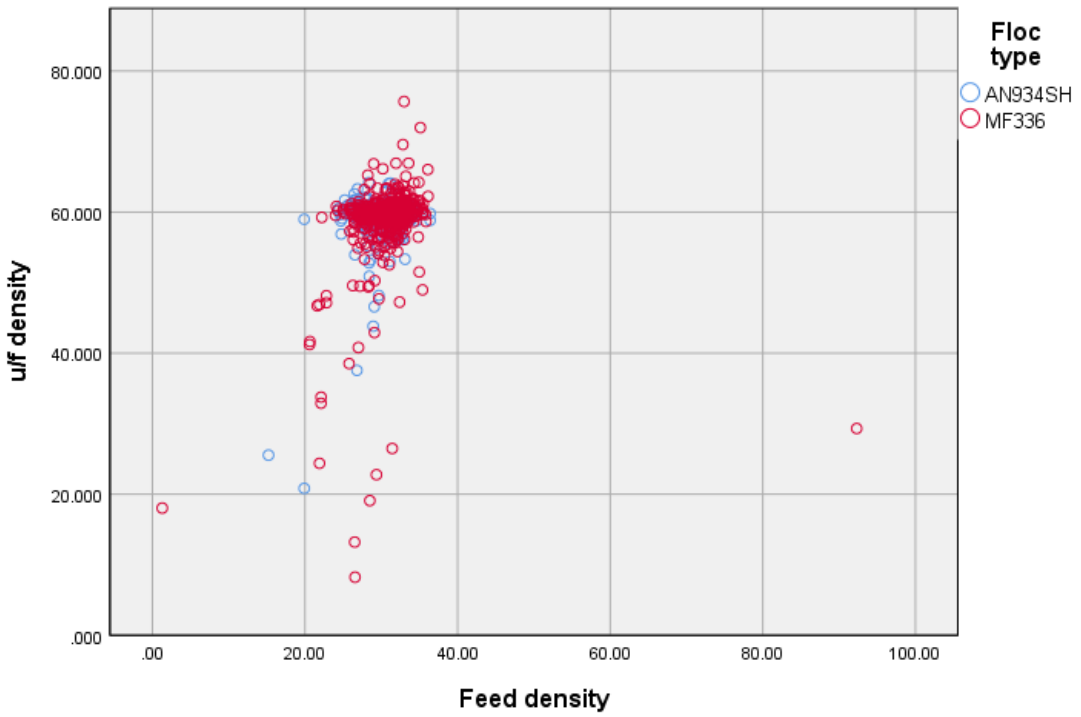

Figure 18. The effect of underflow vs feed solids by flocculant type

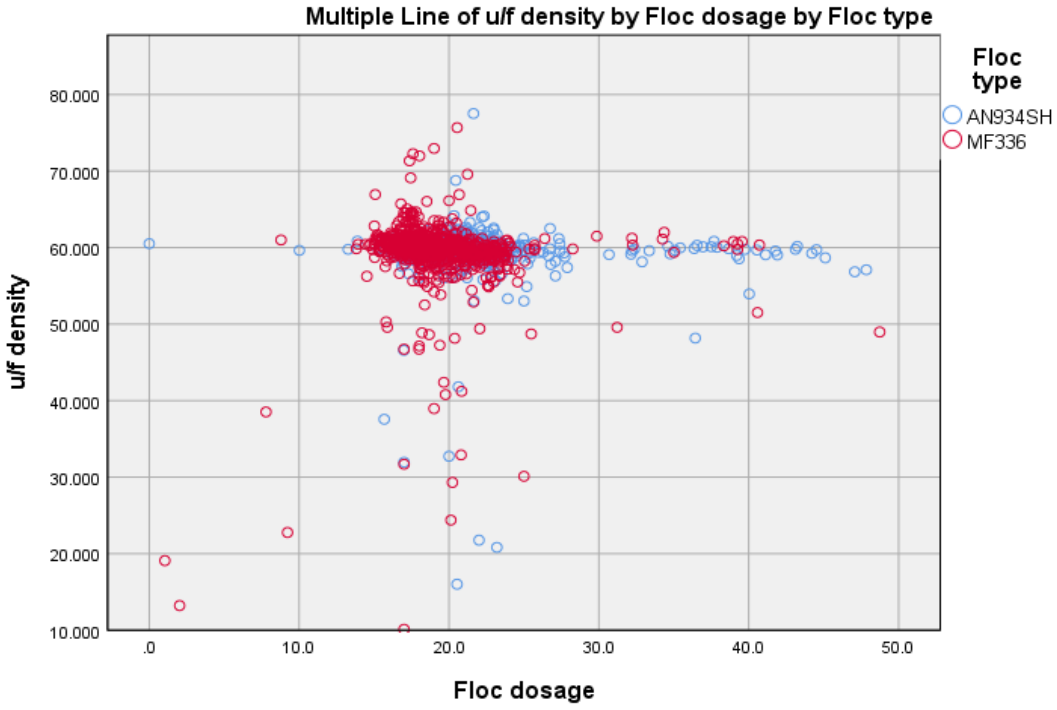

Figure 19. Correlation of underflow density [%solids] vs floc dosage [gpt] by flocculant type.

According to these graphs, the quality of the two flocculants is close and produced about 60 % percent of thicked sludge at approximately 15 - 25 g/t dosage. Therefore flocculant dosage is optimized by normally and settling processes in tailing thickeners are working properly. However, the content of calcium could not be settled in this case. So assumed that the coagulant process is needed in this thickener. Cause of calcium particle doesn't enough into larger particles building up to larger flocks that settle steadily in suspension and calcium present dominated by a form of ion in a slurry.

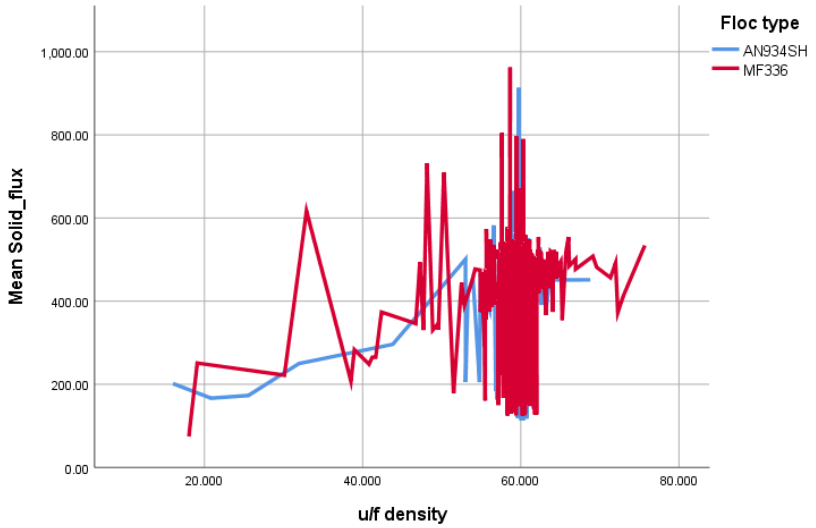

Figure 20. Settling flux versus solids concentration by flocculant type

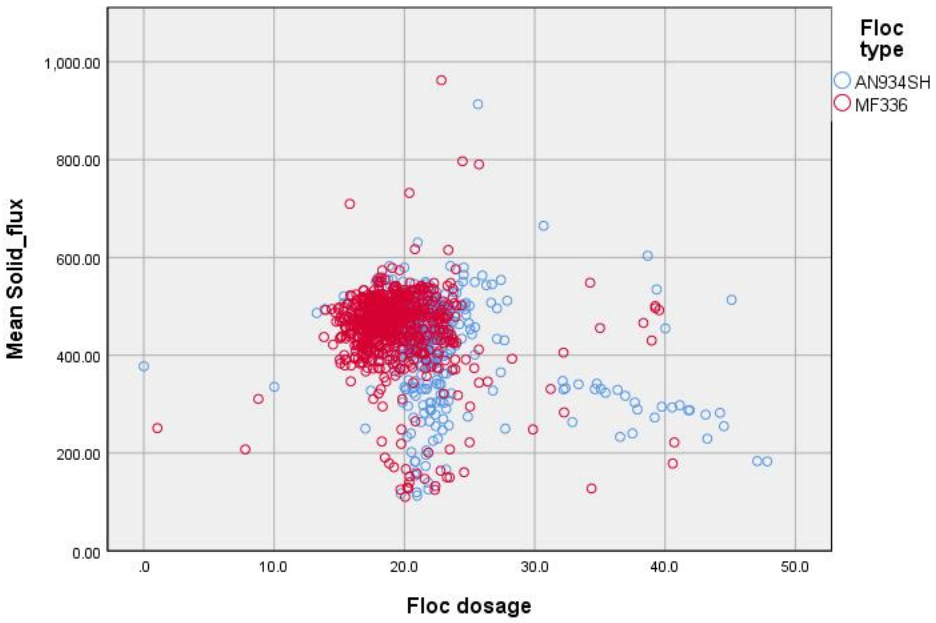

Figure 21. Settling flux versus flocculant dosage

As can be seen from *Figure 20,* the effect of solids concentration on the compressibility of suspension was investigated by flocculant type. AN934SH flocculant type shows a

more clear correlation between solid flux and underflow density. The solids content of underflow increased even solid flux increases. Figure 21 shows the effect of flocculant dosage on settling flux. As is shown, increasing flocculant dosage from 25 g/t led to a decrease in settling flux from 600 to 200 kg/ m2h. The reason is attributed to an increase in floc size and settling rate with flocculant dosage. Notice that, excessive flocculant dosage may reduce the compressibility of suspension. The same trend was observed in the mean velocity vs flocculant dosage as shown in *Figure 22*. Too low amounts of flocculant dosage and, high amount of flocculant dosage have resulted in slower settling velocity. Thus optimal dosage of flocculant on two different types of flocculant is about 15 to 25 g/t is observed.

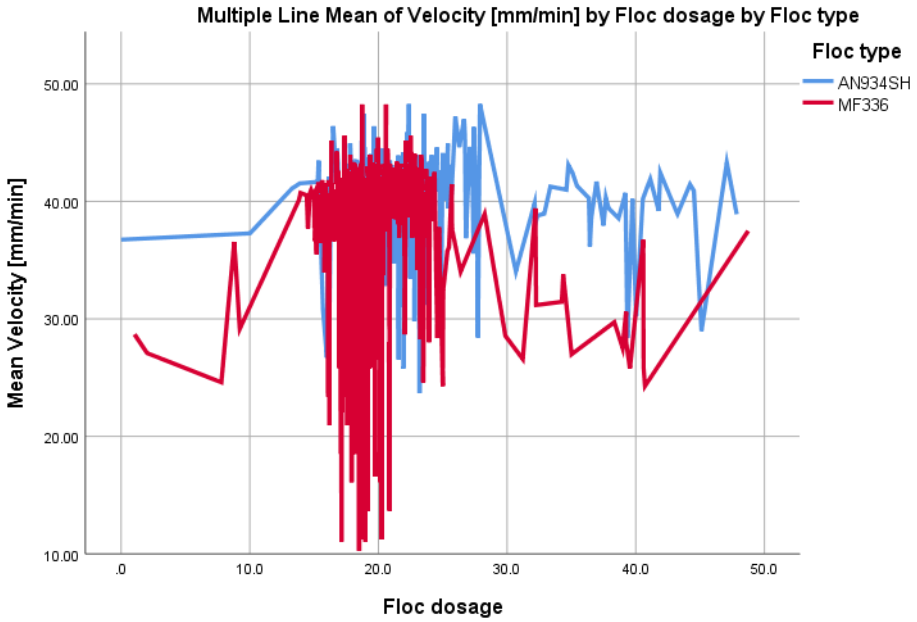

Figure 22. Mean velocity [mm/min] vs flocculant dosage [g/t]

Therefore above four graphs result proven that flocculant dosage is optimized by normally and settling processes in tailing thickeners are working properly. However, the content of calcium could not be settled in this case. So assumed that the coagulant process is needed in this thickener. Coagulation means a process involving agglomeration of the dispersed colloidal particles as illustrated in *Figure 23*. Typically, the suspended particles are very small in size, and they can have electrical charges on or between them. These are usually negative charges which cause them to repel one another. To neutralize those charges, coagulants are used. By surrounding them, they neutralize the repulsive electrical charges between the small particles. This allows the particles to take part in and form larger clumps (37). Coagulation is defined as adding inorganic salts for its importance in destabilizing the suspension of fine solids. In the

coagulation process, a combination of colloidal particles and suspensions with very fine solid particles may form large agglomerates. The slightly large particles produced by coagulation are called micro flocs which are small in size but are more compact and not visible to the naked eye. Also, flocculation is through particle size from submicroscopic micro-floc to visible suspended particles (38). Coagulants and flocculation methods are combined will remove efficiently colloidal impurities from the polluted water: suspended contaminants such as bacteria, clay, silts, and organic matter. This creates large flock aggregates which may be separated from the water in subsequent processes of clarification.

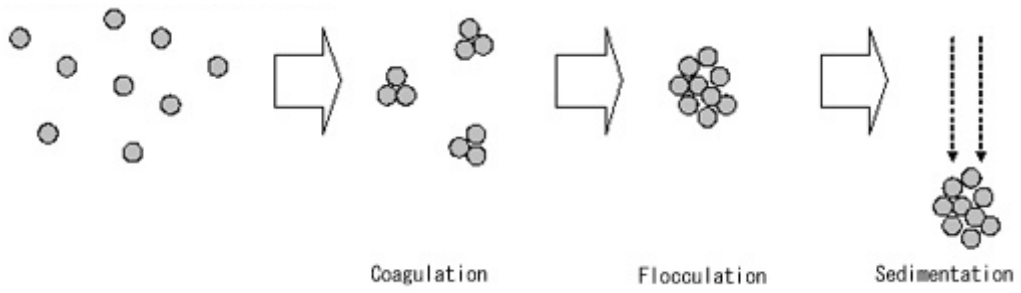

Figure 23. Illustration of coagulation and flocculation

Metal coagulants widely used fall into two general categories: aluminum-based and iron-based coagulants. Coagulants in aluminum include sodium aluminate, aluminum chloride, and aluminum sulfate. Ferric sulfate, ferrous sulfate, ferric chloride, and ferric chloride sulfate are the iron-based coagulants. Other chemicals used as coagulants include hydrated lime and carbonate made from magnesium.

Directly recommendation of efficient coagulants in the case is a little bit hard. Cause, there is no coagulant for only calcium removal, and its researched paper is not found. Moreover, the selection of an efficient coagulant requires experimental results. After observation of the result, the choice of coagulant is better. However, from very my first assumption, an aluminum-based coagulant is recommended. For example, aluminum-silicate polymer composite is a new kind of inorganic coagulant and works as a better coagulant for industrial wastewater treatment.

5 Conclusion

In this work, the effectiveness of high rate tailing thickeners settling processes is investigated by the state-of-art review method. According to the result, tailing thickeners are working well under control with daily to the weekly measurement of thickener's parameter. Used flocculant dosage is optimized at 15 g/t to 25 g/t with high efficiency. However, the settling processes did not go perfectly. From that characteristic of the overflow water, produced effluent from tailing thickener is not well clarified. High amounts of copper, sulfate, and chloride with high turbidity, conductivity, and TDS are present in overflow water.

A high concentration of calcium precipitates at water riser pumps under a suitable atmosphere with high temperature and pH. Even temperature increases, calcium carbonate solubility will decrease. It can become a suitable condition for precipitation of calcium carbonate requires endothermic energy. Also, an increase in pH results affects the acceleration of the formation of calcium carbonate. Its result has shown us that calcium and sulfate removal is required.

To prevent scaling problems, calcium removal is a fundamental step. The removal of calcium by the coagulant method is recommended.

6 Recommendation

After a thorough this study, the following recommendations are hereby made.

1. This research study suggests that lime usage in the process and its properties of lime milk used as a process are further research points. Moreover, the possibility of a reduction of lime usage dosage is required.
2. If laboratory work has able to perform, settling tests with cylindrical tubes and dynamic tests are recommended. Samples might be collected from a feed of tailing thickener and overflow water of tailing thickener. If more interested in the efficiency of flocculant should use a different flocculant on each experiment.
3. Further study can be focused on efficient coagulant for calcium removal or in the case of copper tailings. If a selection of coagulants will be based on literature review comparison and experimental test result, it might good solution for scale prevention in tailing thickeners overflow water riser pump.

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