LAPPEENRANNAN TEKNILLINEN YLIOPISTO

LUT School of Energy Systems

Energy Technology

Jari Päykkönen

DEVELOPMENT OF MEASUREMENTS AND CONTROLS IN WHITE LIQUOR PLANT

Examiners: Prof (Tech) Esa Vakkilainen

TkT Katja Kuparinen

Supervisor: M.SC. (Tech) Piia Parviainen

ABSTRACT

LUT University
School of Energy Systems
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Jari Päykkönen

Development of measurements and controls in white liquor plant

Master´s thesis

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67 pages, 31 figures, 1 table.

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The aim of this Master of Science thesis was to investigate what instruments could be modernized in white liquor plant. In addition, the aim was investigate possible cost savings with different kinds of valve selection at big valves.

Liquid solid separation technology is having high importance in the chemical recovery cycle of Kraft mills. By improving process control measurements at white liquor plant the amount of unreactive chemicals can be decreased and also energy consumption can be improved. In addition, capital investment costs can be reduced by concentrating on big valves when doing valve type selection.

The research was done by interviewing Andritz white liquor plant personnel. From the results of interviews, the known problem points at instruments were collected. Also, experiences from different kinds of valves used in the previous project were collected through interviews.

Real-life or laboratory tests are excluded from this Master of Science thesis. Tests are the next step for the new type of instruments. For big valves, experience from previous project need to be collected and evaluated.

TIIVISTELMÄ

LUT yliopisto
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Energiatekniikan koulutusohjelma

Jari Päykkönen

Mittausten ja säätöjen kehittäminen valkolipeälaitoksella

Diplomityö

2020

67 sivua, 31 kuvaa, 1 taulukko.

Työn tarkastajat: Professori, Esa Vakkilainen

TkT Katja Kuparinen

Työn ohjaaja: DI Piia Parviainen

Tämän diplomityön tavoitteena oli tutkia mitä instrumentteja voitaisiin nykyaikaistaa valkolipeässä. Lisäksi tavoitteena oli tutkia mahdollisia kustannussäästöjä erityyppisillä venttiilivalinnoilla isojen venttiilien osalta.

Nestemäisten ja kiinteiden aineiden erotustekniikalla on suuri merkitys sellutehtaiden kemikaalikierrossa. Parantamalla valkolipeälaitoksen prosessinhallinnan mittauksia reagoimattomien kemikaalien määrää voidaan vähentää ja myös energiankulutusta parantaa. Lisäksi pääomasijoituskustannuksia voidaan pienentää keskittymällä isojen venttiilien venttiilityyppeihin venttiilivalintaa tehdessä.

Tutkimus tehtiin haastattelemalla Andritzin valkolipeäosastolla työskentelevää henkilöstöä. Haastattelujen tuloksista koottiin havaittuja ongelmakohtia. Haastatteluilla kerättiin myös kokemuksia erilaisista venttiileistä, joita oli käytetty edellisissä projekteissa.

Tehdasmittakaavantestit tai laboratoriotestit jätettiin tämän diplomityön ulkopuolelle. Testit ovat seuraava askel uudentyyppisille instrumenteille. Suurten venttiilien osalta aiempien projektien kokemukset on kerättävä ja arvioitava.

ACKNOWLEDGEMENTS

I thank Andritz Oy and Lappeenranta University of Technology for the opportunity to conduct this Master's thesis.

I would like to express my gratitude to my supervisor Piia Parviainen for the useful comments, remarks and engagement through the writing process of this Master's thesis. Especially I would like to thank Mika Kottila for introducing me to the topic and engagement as well as for the professional support on the way. I would also like to thank staff members at Andritz who have eagerly shared their valuable time during the work helping me putting pieces together. I would like to express my sincere gratitude to Prof. Esa Vakkilainen for the continuous support of my study and professional advices given during my thesis work.

I have to be grateful for the children and my spouse, without them life would be meaningless. Kids also make sure I don't sleep for too long and lose my nerve fast.

Savonlinna, 29rd of June, 2020

Jari Päykkönen

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SYMBOLS AND ABBREVIATIONS

Roman letters

C_A	capacitance
C_B	capacitance
dC	capacitance difference

Abbreviations

AA	active alkali
AC	alternating current
CPR	continous pre-coat renewal
$CaCO_3$	calcium carbonate
CaO	calcium oxide, lime
$Ca(OH)_2$	calcium hydroxide, slaked lime
CO	carbon monoxide
CO_2	carbon dioxide
CO_3	carbon trioxide
ds	dry solids
DN	diamètre nominal
EA	efective alkali
NaOH	sodium hydroxide
Na_2S	sodium sulfide
Na_2CO_3	sodium carbonate
Na_2SO_4	sodium Sulfate
$Na_2S_2O_3$	sodium thiosulphate
NO_x	nitrogen oxides
OH^-	hydroxide
NPE	non-process element
ppm	parts per million
RC	resistor-capacitor circuit
RF	radio frequency

S%	sulfidity
TTA	total titratable alkali

1 INTRODUCTION

The White liquor plant is the kidney of the pulp mill. (Golmaei, M et al 2017) The Purpose of the white liquor plant is to produce as clean as possible and as hot as possible white liquor with minimum amount of unreactive chemicals for the cooking process. In addition, energy consumption of the white liquor plant needs to be as low as possible.

Figure 1. The kraft process is the major pulping process currently used in the pulp and paper industry. White liquor is the cooking liquor of this process and mainly contains sodium hydroxide and sodium sulfide. Black liquor is the remaining solution of the cooking process and it contains dissolved organic and inorganic substances from pulping. A chemical recovery process has been used to recycle pulping chemicals, sodium hydroxide and sodium sulfide, at pulp mills for decade's (Tran, H. et Vakkilainen, E 2007). Figure 1 is showing the kraft process chemical cycle.

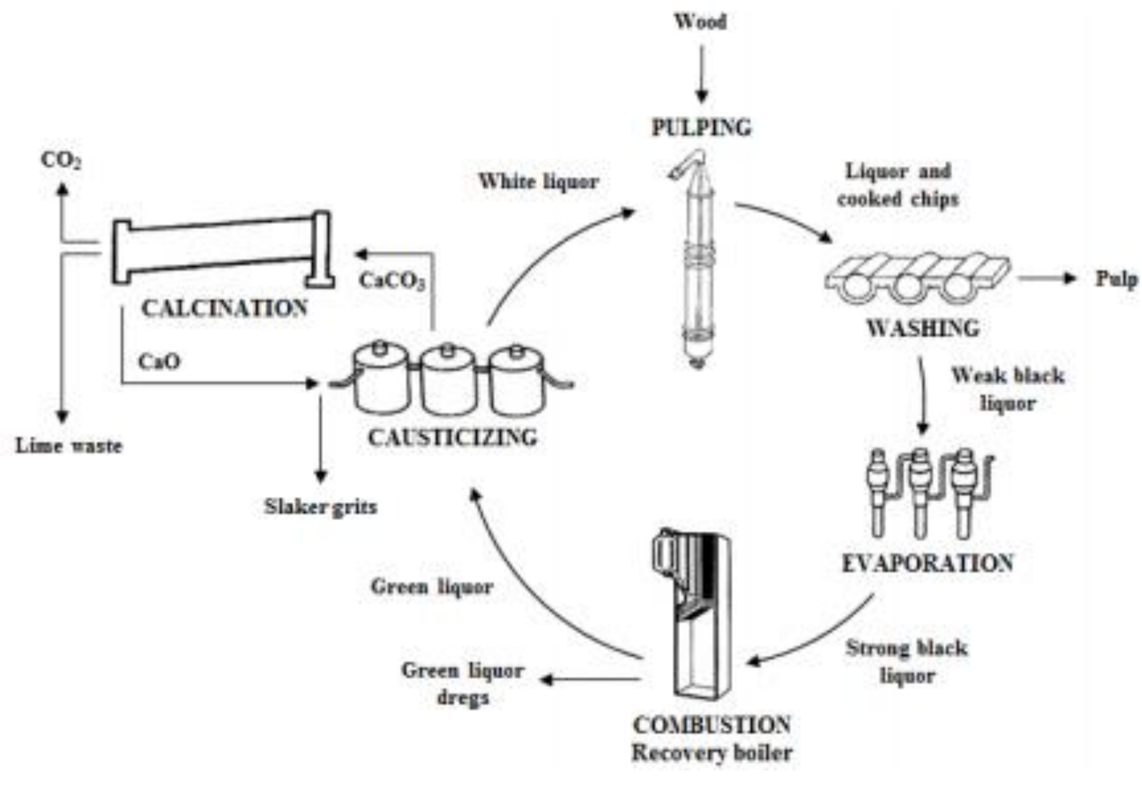

Figure 1. The chemical recovery circuit of a pulp mill (Mäkelä 2012, page 12)

Liquid solid separation technology is of high importance in the chemical recovery cycle of Kraft mills. Solid-liquid separation is performed for green liquor to remove the dregs, and for the lime slurry to get rid of grits from the slaker and to separate lime mud from the white liquor after causticizing process. (Sanchez et al, 2005)

By improving measurements at white liquor plant the amount of unreactive chemicals can be decreased and also energy consumption can be improved. In addition, capital investment costs can be reduced by concentrating on big valves to valve type selection. Mill standards are causing restriction for valve selection but valve types can be always negotiated, especially with good references from the previous projects.

2 CAUSTICIZING PROCESS

The Causticizing process produce white liquor for the digester from inorganic chemicals generated in Recovery Boiler and Lime Kiln. This process consist of solid liquor separations with simple reactions. Different kind of filters and equipment's are used for solid liquid separation in causticizing process.

White liquor in the kraft process is produced from smelt. Smelt is an inorganic chemicals generated from Recovery Boiler. Inorganic chemicals are coming to recovery boiler from cooking through evaporation plant where dry solid content is increased before burning in recovery boiler. Liquor from cooking is also including organic chemicals but those are burning away in recovery boiler. This smelt further diluted with weak wash liquor. That mixture is called as green liquor. Reburnt lime generated from Lime kiln is slaked in green liquor. Due to chemical reaction in between green liquor and lime, it is producing white liquor and lime mud (Calcium Carbonate) .These two are separated and white liquor send back to the digester for pulp cooking. Separated lime mud further washed and calcined in a lime kiln to produce the burnt lime. The wash liquor generated during the lime mud washing is called as weak wash liquor, which is using for smelt dissolving in recovery boiler (Sanchez et al 2007).

The chemical reaction can be described as follows:

Green Liquor + Burnt Lime = Lime Mud + White Liquor

$$\mathbf{Na_2CO_3 + H_2O + CaO = CaCO_3 + 2\ NaOH}$$

Sodium Carbonate + Water + Calcium Oxide = Calcium Carbonate + Sodium Hydroxide

In Figure 2 is shown simplified block diagram represents the white liquor plant process flowsheet.

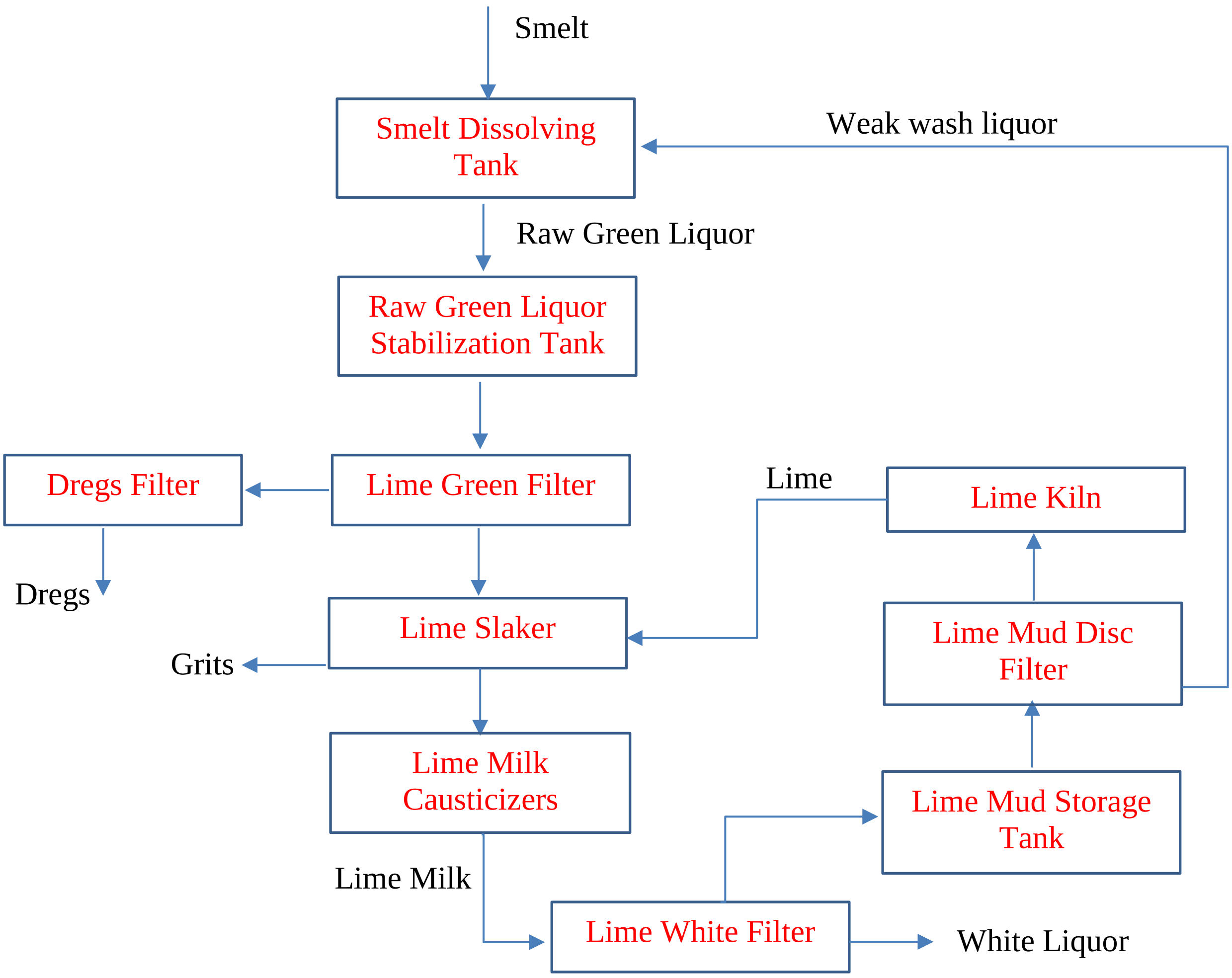

Figure 2. simplified white liquor plant block diagram

2.1 Chemicals in causticizing process

Sodium Carbonate (Na_2CO_3) is the major chemical present in the smelt. This smelt dissolved with weak wash liquor in smelt dissolver of recovery boiler and the liquor is called as Raw Green Liquor.

Calcium Carbonate ($CaCO_3$) is called as Lime Mud. It is generated from slaking reaction in between green liquor and burnt lime. Calcium Oxide (CaO) is called burnt lime. It is produced in Lime kiln due to calcination of lime mud (Calcium Carbonate)

$$CaCO_3 + \text{Heat} \rightarrow CaO + CO_2$$

Sodium Hydroxide (NaOH) is the major chemical present in white liquor. This chemical dissolves the lignin bonding in the wood fiber. This happens at high temperature and pressures. This chemical produced by slaking reaction in between lime and green liquor.

Sodium Sulfide (Na_2S) is the second major chemical present in the white liquor. This chemical helps for reduction of damage to the wood fibers cell walls.

Sodium Sulfate (Na_2SO_4) is the chemical called as salt cake. It is used as make up chemical in recovery process. It is added in the recovery boiler or evaporation plant. At causticizing plant it is only circulated through as dead load in chemical recovery cycle.

Apart from the mentioned chemicals, some other chemicals is also present in the causticizing process such as sodium sulfite (Na_2SO_3) and sodium thiosulphate ($Na_2S_2O_3$). In addition some metal compounds as iron, manganese, silica, phosphorous and aluminum are present in chemical cycle. These chemicals can cause limitations for causticizing process because they are disturbing process equipment, if composition increases too high. However to minimize these chemicals in the process, mills are opening the chemical cycles. Need for cycle opening amount is depending from raw materials. Higher content of iron, manganese, silica, phosphorous or aluminum in raw materials limits the process of causticizing. (Sanchez D. R., 2007).

2.1.1 Chemistry involved in white liquor preparation

The major parameter observed in white liquor is effective alkali (EA). This effective alkali content is helpful to quantify the volume of the white liquor charged to the digester. Based on the wood chips, white liquor volume is charged to the digester. (Sanchez R., 2007, page: 9)

$$\text{Effective Alkali (EA)} = NaOH + \tfrac{1}{2}\, Na_2S$$
$$\text{Active Alkali (AA)} = NaOH + Na_2S$$

These chemical concentrations are expressed in terms of Sodium Oxide or Sodium Hydroxide. The required amount of active alkali is starting point for the required amount of the white liquor volume for the cooking process.

Total Titratable Alkali (TTA), Active Alkali (AA) and Sulfidity (% Na2S) are set based on cooking design requirement. Based on the values causticizing plant is designed accordingly. To ensure the consistency in the concentration, routine test are conducted in causticizing section to identify the stability and deviations in white liquor production. There is two reactions happening in causticizing. First reaction in lime slaker is the hydrolysis of burnt lime. This reaction is exothermic in nature. The reaction as follows

$$CaO + H2O = Ca(OH)_2 + Heat$$

This reaction happens fast, in operation temperature slaking reactions take 10 to 30 minutes. If temperature in slaker is below 70 degrees reaction rate is significantly slower. Slaking reaction generates heat to the slaker and cause a risk of slaker boiling, that is the reason why green liquor temperature need to be reduced before the slaker in many process solutions. Second reaction is causticizing reaction.

$$Ca(OH)_2 + Na_2CO_3 = 2 NaOH + CaCO_3$$

Subsequent causticizing reaction begins in practice simultaneously with slaking. This is an equilibrium reaction and reversible reaction. This never reacts completely, typically the reaction converts about 80 %, which indicates 80 % of Na_2CO_3 is converted in white liquor to NaOH. This conversion is varying with sulfidity and total titratable alkali levels as shown in Figure 3. Other constituents present in the reaction $Ca(OH)_2$ and $CaCO_3$ are in insoluble phase. As a result, major reaction occurs in between OH^- and CO_3 ions at solid liquid interface.

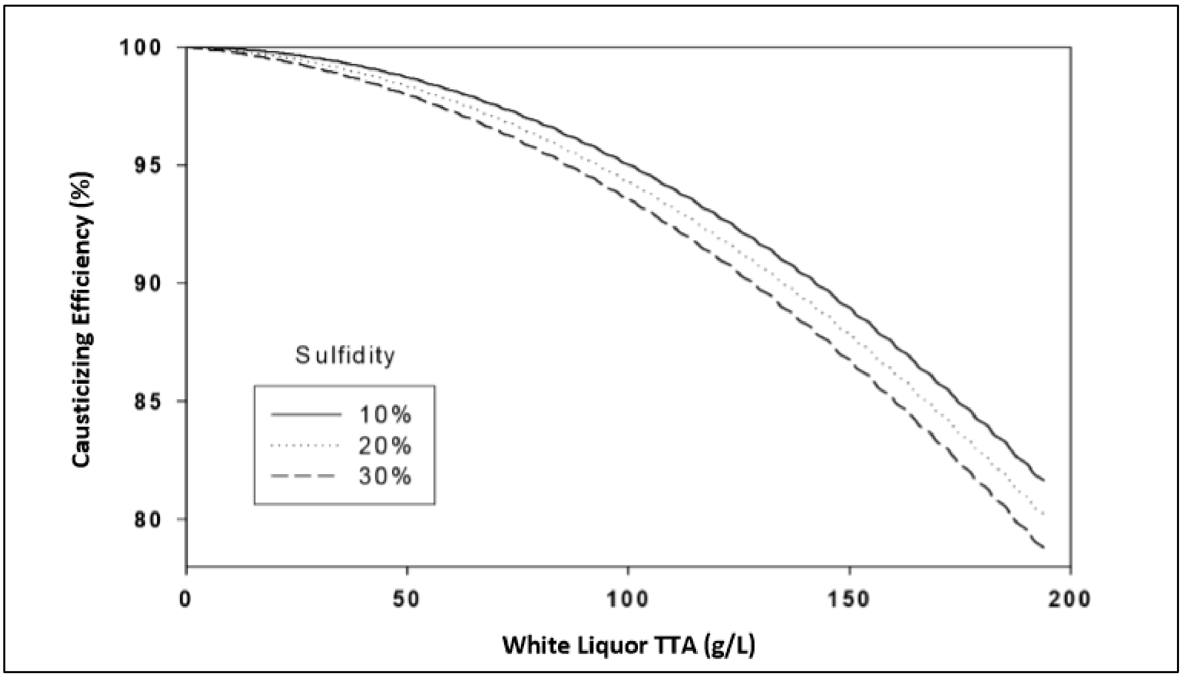

Figure 3. Equilibrium of Causticizing Efficiency versus White Liquor TTA

As shown in figure this reaction further shift to right by adding more lime. But, at some point this has an adverse effect on separation equipment because of free lime formation .In causticizing cycle, there is a threshold limit for the causticizing efficiency. Above this limit, free lime becomes a major obstacle for processing equipment especially for white liquor pressure filter and lime mud filter. The above reactions occur in slaker and causticizing line, so control of the lime slaker operation plays major in causticizing operation. (Sanchez R., 2007, page: 3)

Slaker operation is controlled by following green liquor total titratable alkali and lime quality. Based on those values lime amount to slaker and green liquor inlet temperature is controlled. Success of the control is followed by lime milk temperature after slaker and by taking samples from causticizing line and analyzing those samples.

Green liquor handling

In view of causticizing plant operation control, it begins with inlet of raw green liquor to raw green liquor storage or stabilization tank. Some of the mills having a direct clarifier that collects the incoming raw green liquor from recovery boiler. Nevertheless, due to uncertainty in the densities, green liquor stabilization tank or raw green liquor storage tank is introduced. In modern mills following process is green liquor filtration systems. Filtration has replaced sedimentation clarification process due to higher separation efficiency. Inlet raw green liquor density is controlled in recovery boiler smelt dissolver by adjusting the weak wash volume. This density control plays a major role in causticizing process cycle but is it not part of the causticizing plant (Golmaei, M et al 2017).

Green liquor is prepared by dissolving the smelt in weak wash liquor in recovery boiler smelt dissolving tank. This liquor is called as raw green liquor and this is pumped to raw green liquor stabilization tank and from there to a clarifier or to raw green liquor storage tank and from there to a pressure filter for the removal of dregs (Sanchez et al. 2007).

2.1.2 Smelt dissolving tank

Molten smelt from the recovery boiler char bed discharge into smelt dissolving tank through series of spouts mounted to recovery furnace. Weak wash liquor is pumped from causticizing section to smelt dissolver to dissolve the smelt. This tank is equipped with a gas scrubbing vent system because huge amount of steam is generated while molten smelt comes in contact with weak wash liquor inside the tank. This tank equipped with propeller type of agitators which helps for uniform dissolving of smelt. This helps to get uniform concentration of raw green liquor. Steam generated in dissolver passes through the vent and vapors scrubbed with weak wash spray system and condensed matter drop back to dissolver tank through droplet separators (Sanchez et al. 2007).

2.1.3 Raw green liquor stabilization tank or storage tank

Selection between stabilization tank and storage tank is made based on following process. When clarifier process is next, selection is normally stabilization tank and when filtration process is next, selection is storage tank. Difference between storage tank and stabilization tank is volume. Stabilization tank is designed to give a retention time of two to four hours and it needs to be operated with as stable outlet flow as possible. Storage tank is designed to give a retention time of eight to twelve hours and outlet flow is operated more in batches. Both tanks are equipped with side mounted propeller type agitators for proper mixing in the tank. This will help to maintain the uniform temperature and density inside the tank also helpful to avoid the density fluctuations due to irregular flows and input liquor variations.

Incoming raw green liquor is lead to the tank through a pipe to the bottom of the tank rather than a free discharge from the top of the tank. The free discharge of liquor may leads to the entry of the air into the tank and may cause for the floating of green liquor dregs. This will create non-uniformity in the green liquor density, which creates problem in slaker operation. Second possible problem from a free discharge is the risk of cold liquor entering to hot vapor space. Sudden vapor cooling is creating vacuum and it can cause tank collapse.

2.1.4 Green Liquor Swapping Lines

It is quite common solution to have swapping lines for transferring the raw green liquor from smelt dissolver to green liquor stabilization tank. In this piping system, one pipeline carries the raw green liquor and another pipeline carries the weak wash from causticizing. Over a certain hours of time, these lines are swapped and media interchanged in between the pipes. This is helpful to avoid the scaling in pipe internals due to flowing of weak wash liquor, which dissolves the scale. (Sanchez et al. 2007).

2.1.5 Green Liquor Clarifier

This is the most common type of green liquor clarification device in old mills. Sedimentation type of clarifiers with raking device mechanism, which moves the settled solids called dregs towards the center of the clarifier and further to sludge pit. Normally clarifier can storage dregs inside. For that purpose, clarifier rake is equipped with lifting and lowering mechanism. Lifting and lowering is working based on rake turning torque. Inlet raw green liquor flows to feed well. This helps for easy separating conditions for dregs separation from green liquor. Feed well design plays a key role in clarifier operation. There is a pipe for gas removal in the feed cylinder. Tray type clarifiers are used for raw green liquor processing in old days. These type of clarifiers are complicated in arrangement and the operating is more complicate compared to sedimentation type of clarifier. Tray type clarifiers are multi compartment type with a series rake mechanism, which place one above another in a tank. In Figure 4 is shown sedimentation type green liquor clarifier main parts.

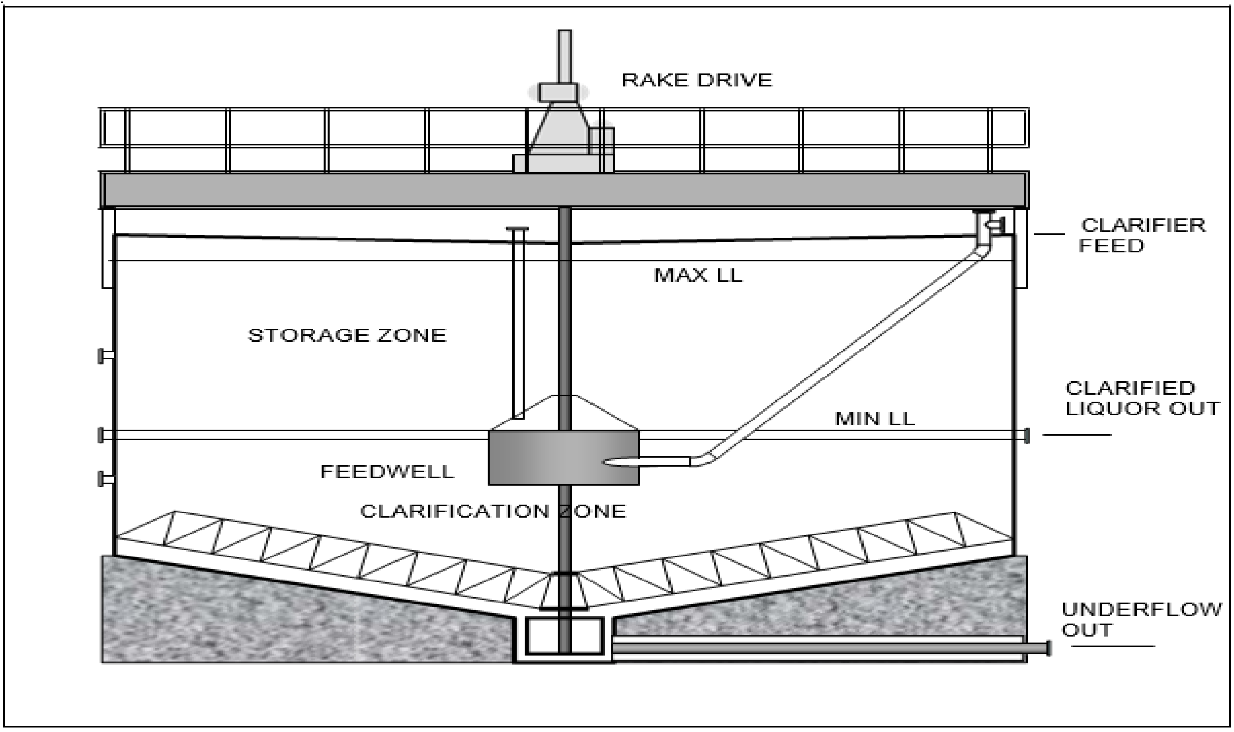

Figure 4. Sedimentation type green liquor clarifier (Andritz product manual).

To attain the required green liquor clarity to use in slaker, this sedimentation type clarifiers loaded rise rate is about 0.3 to 0.9 millimeter per minute. .A good conservative loading rate will give good green liquor clarity and helpful to minimize the process related problems in the rest of the causticizing process. It is very important to get a good clarity of green liquor for a mill, which is operating, with pressurized white liquor filter for white liquor separation. If dregs carryover is more than 100 milligrams per liter of green liquor dregs will blind the filter cloth and reduces the filtering efficiency in the filter. Typical outlet clarity of green liquor from a clarifier outlet is less than 80 milligrams per liter.

Green liquor feed pipe enters from the tank top roof level and pipe is tapered with 45 degrees angle. In case a vertical feed pipe it may generate vacuum and scaling chances are higher. Another advantage with this feed pipe arrangement is that cleaning is very easy without draining the clarifier. In case any horizontal feed pipes, it is very difficult to clean because tanks needs to be emptied. Feed well is arranged with a vent line to exhaust the entrained air that comes with raw green liquor. After raw green liquor enters into the feed well dregs and green liquor get separated and dregs settle down at the bottom of the clarifier and it is collected through a under flow pipe and pumped to the dregs storage tank. Clarified green liquor is collected from the collection header, above the feed well. Clarifier storage volume is between clean green liquor collection header and clarifier overflow pipe (Sanchez D. R., 2007)

2.1.6 LimeGreen filter

The Andritz LimeGreen is a green liquor filtration system, which offers an efficient method for removing non process elements (NPEs) from raw green liquor. The tightening of the mills' water balance affects the raw green liquor quality by increasing the impurities and non-process element levels in the green liquor.

NPEs that are present in raw green liquor, as suspended solids or dregs, tend to form gelatinous compounds. Magnesium hydroxide, which is formed from the magnesium sulfate or carbonate addition in the oxygen delignification stage, is one of the NPEs present. These compounds have a negative impact on the settling rate of dregs in green liquor, which would lead to problems if a standard green liquor clarifier was used. A Green liquor clarifier would normally suffer from poor settling and high carryover of NPEs and dregs in the clarified green liquor, which would contaminate the lime mud and lime circulation and would negatively impact the performance of the entire White Liquor Plant and the Chemical Recovery System. The LimeGreen filter uses cross-flow filtration technology to remove NPE inert components and other impurities from green liquor. In Figure 5 is shown the LimeGreen filter main parts.

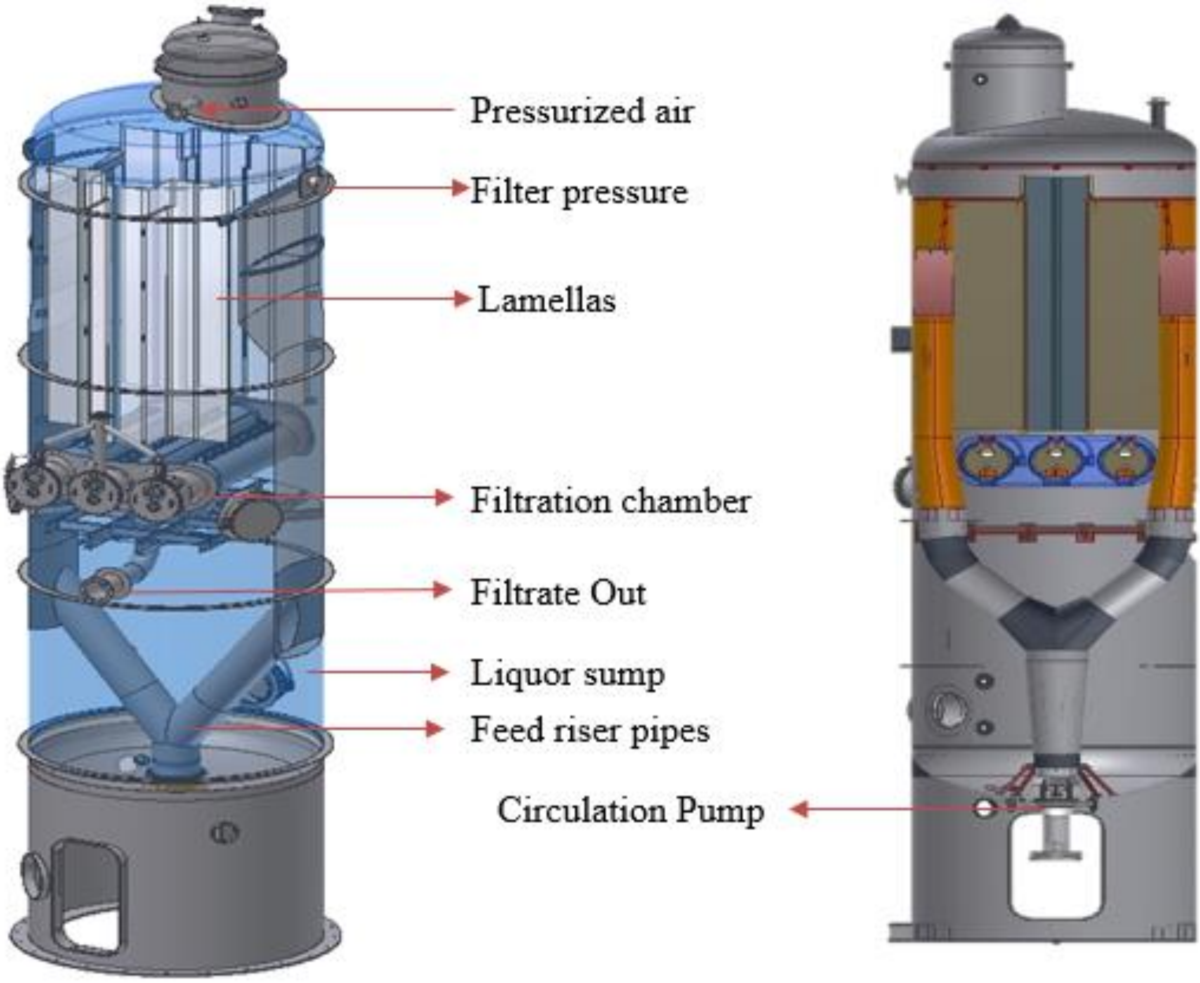

Figure 5. The LimeGreen filter front and side views

Green liquor is circulated from the bottom of the LimeGreen filter vessel to the top with a help of a circulation pump. Green liquor is distributed evenly as a falling film over the filtering elements. When green liquor flows downwards over the surface of the filtering elements, a portion of the green liquor will pass through the filter cloth due to the pressure difference across the elements. The heavy downward circulation flow keeps the filter surface clean. No cake is formed on the filtering surface and no pre-coat is required. The pressure differential is developed by pressurizing the vessel with compressed air, however during normal operation because the falling film of liquid completely covers the filter media, the air consumption is minimal. The pressure across the elements can be equalized to enable the circulating liquor flow to remove any dregs that have become imbedded in the filter media and are reducing the filter capacity.

Dregs are enriched in the circulation flow and periodically the LimeGreen feed is interrupted and dregs from dregs tank is pumped to the filter instead of green liquor to allow the dregs to become further concentrated prior to discharging to the dregs tank. Concentrated dregs are pumped to the dregs filter for further dewatering and washing.

Filtered green liquor is collected in the bottom of each element and it flows through a pipe to a filtrate receiver. From filtrate receiver green liquor is pumped to storage. Generally clarity of the filtrate is about 4-6 ppm and filter fabric designed to obtain the clarity less than 20 ppm.

In order to maintain capacity, the filter cloths are regularly washed with hot water. During cloth washing, the wash water is circulated inside the LimeGreen. After washing wash water is discharged to weak wash tank. Periodically it may be necessary to wash the filter with a mild acid solution. The LimeGreen is totally enclosed for safe acid washing.

The LimeGreen operation is fully automatic and the filtration, concentration and water washing are performed by sequential logic (Andritz product manual).

2.1.7 Green Liquor Cooler

Incoming green liquor from recovery boiler is having the high temperature and it needs to be cooled before processing it in lime slaker. Green liquor cooler, which cools down the temperature of filtered green liquor to required level. If green liquor temperature varies too much, it is difficult to operate the lime slaker so green liquor temperature plays a major role in stable operation of slaker.

In lime slaker, hot burnt lime from the lime kiln enters into the lime slaker and it is combined with green liquor. If the green liquor temperature is too high it can cause boiling over when trying to achieve the required causticizing efficiency. Green liquor cools down to required temperature in green liquor cooler to achieve the slaker outlet temperature in optimum range from 100 celsius degrees to 104 celsius degrees. Generally, inlet temperature of the green liquor at cooler inlet is 95celsius degrees and green liquor cools down the temperature about 10celsius degrees inside the green liquor cooler.

To cool the green liquor, a kind of green liquor cooler used which is equipped with an expansion vessel along with a shell and tube heat exchanger. Green liquor cooler pumped from green liquor storage tank to expansion vessel through a feed pipe. Green liquor vapors flashed in the expansion vessel and a small vacuum pump sucks these vapors. These vapors are cooled down due to coolant flow in counter current manner. Condensed vapors are collected and used for filters washing. In Figure 6 is shown green liquor cooler main parts.

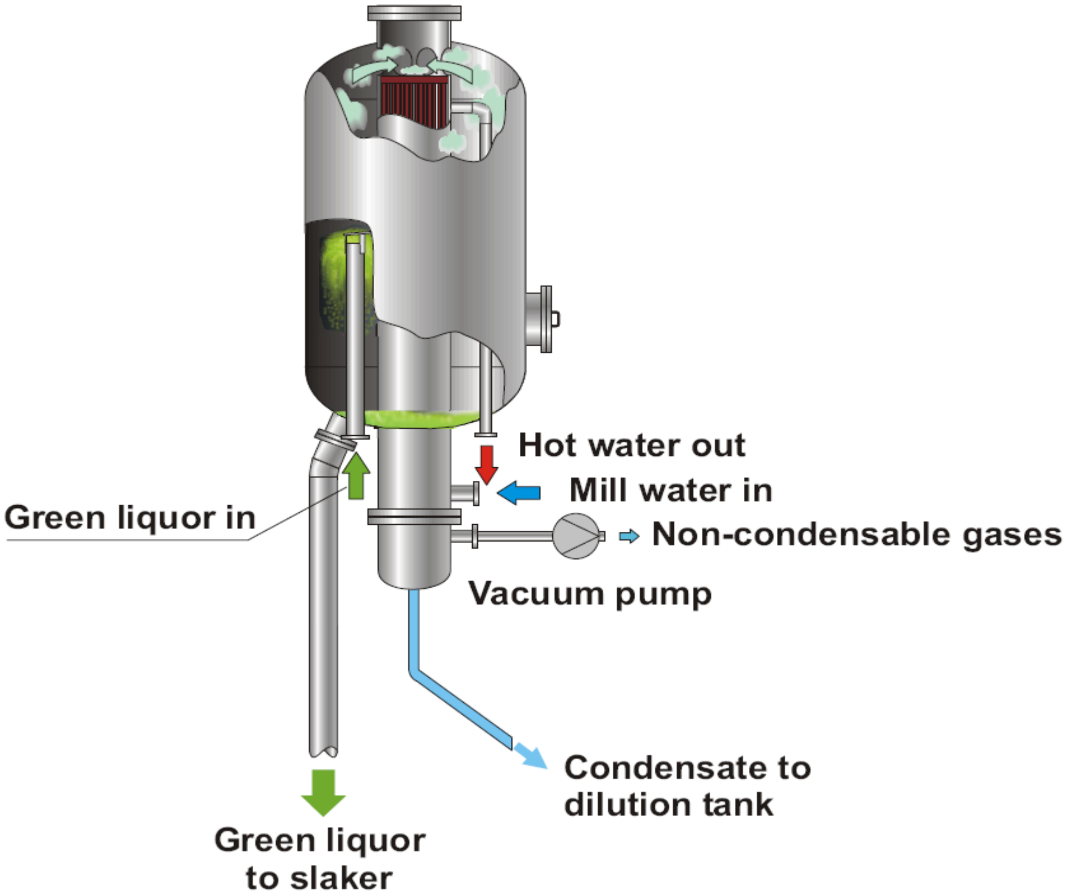

Figure 6. Green liquor cooler (Andritz product manual).

Green liquor cooler operation is fully automatic. Operators set desired green liquor outlet temperature and automation controls coolant flow through the cooler. Needed coolant flow changed based on inlet green liquor flow and desired green liquor outlet temperature (Andritz product manual).

2.2 Dregs handling

Dregs removal is one of the most important step in causticizing plant. Today, the most important way to expel non-process elements is via the green liquor dregs. The causticizing process acts as a kidney in the pulp mill in which non-process metals are purged from the process, and are subsequently precipitated in the green liquor as dregs. However, green liquor dregs is difficult to utilize, and is therefore mostly disposed of in landfills. Typically, the dregs contain carbonates, for instance, sodium carbonate and calcium carbonate, sodium hydroxide, sulfides, unburned carbon, and traces of heavy metals. The dissolved sodium hydrosulphide is the reason for the green color of the sludge. In addition to the listed compounds in dregs, the crystals of calcium phosphate can be precipitated from green liquor. Generally, calcium is the most abundant element in the dregs.

If dregs is not removed from green liquor, it will cause many problems in the rest of liquor cycle. It will plug filters, disturb clarifiers operation and cause problems at lime kiln operation. After raw green liquor filtration or sedimentation process, dregs is storage in dregs tank. Green liquor dregs dewatering and washing is carried on a centrifuge or on a vacuum pre-coat drum filter. Also some mills are using press filters and cassettes type wire type filters. The purpose of the dregs separation or dregs washing is to dilute and displace green liquor from dregs by wash water. Green liquor is returned to the process and the washed dregs are discharged from the process (Nurmesniemi, H 2005).

2.2.1 Dregs drum filter

Green liquor dregs dewatering and washing can be carried on a vacuum pre-coat drum filter. This filter is pre-coated with lime mud. Lime mud pre-coat forms on drum about 5 to 10 centimeters depth due to vacuum application. A scraper blade will cut the very thin layer of pre-coat cake of lime mud.

Generally this lime mud pre-coat is stand for 4 to 12 hours. Based on the dregs load to the filter. Drum rotation increases based on the dregs feed load. Once the pre-coat time ends, filter blows the cake with the help of compressed air. After blowing the filter cake, filter is washed with hot water and make ready for a fresh layer of pre-coat before feeding the green liquor dregs. The filtrate received from green liquor dregs flows to a vacuum tank, where gases are being separated and sucked by vacuum pump. Filtrate is pumped to weak wash storage tank or raw green liquor storage tank or in stabilization tank. Filtrate is almost only green liquor so that is why it can be returned to raw green liquor. If filtrate is pumped to weak white liquor storage tank, it will be pumped from there then recovery boiler smelt dissolver. This usage helps to keep the alkali content in the recovery cycle. Under continuous running dregs forms layer on the lime mud pre-coat and scrapper blades along the drum length cut the dregs layer off. Dregs layer drops on to the dregs transfer conveyer which dumps the dregs to dregs collection point. In Figure 7 is shown dregs drum filter main parts (Sanchez D. R., 2007)

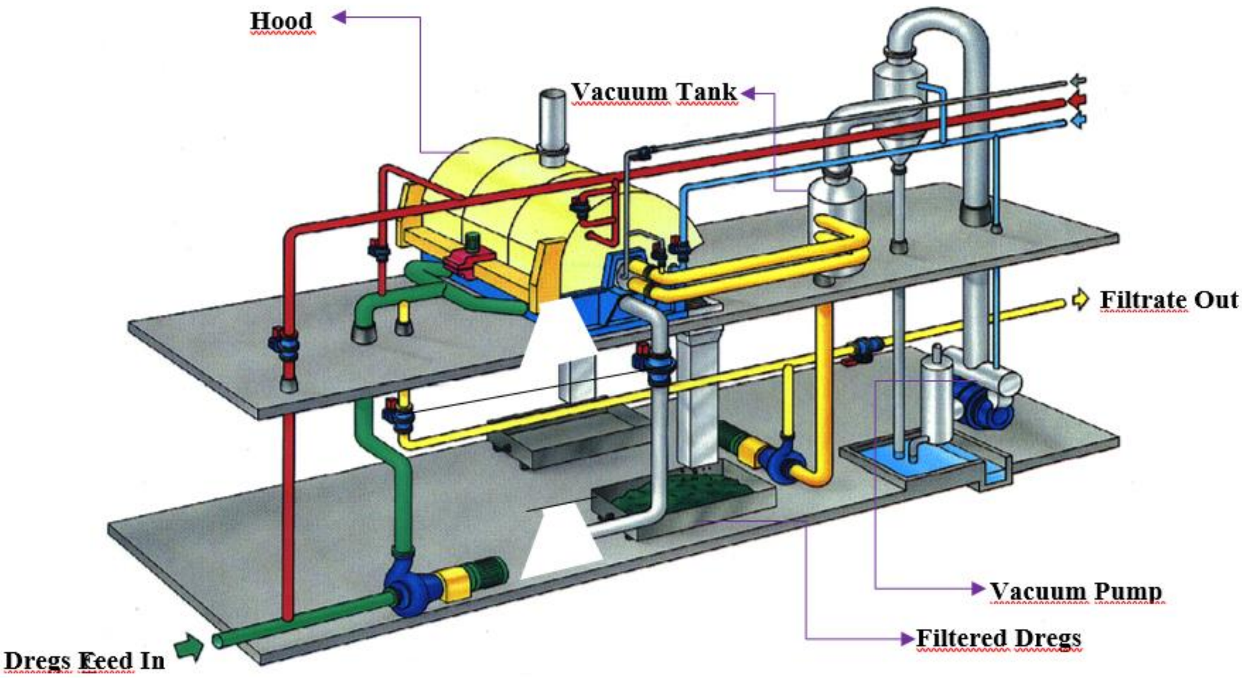

Figure 7. Dregs drum filter (Andritz product manual)

2.2.2 Centrifuge

A centrifuge is a piece of equipment, driven by electric motors, that puts a material in rotation around a fixed axis, applying a force perpendicular to the axis. The centrifuge works using the sedimentation principle, where the centripetal acceleration causes denser substances to separate out along the radial direction. By the same token lighter objects will tend to move to the center.

Green liquor dregs dewatering and washing can be carried on a centrifuge. Dregs centrifuge operates close to atmospheric pressure. Inside the centrifuge the dregs are separated by centrifugal force. Polymer is added to the centrifuge feed, in order to get maximum dry solids in the discharged dregs cake and to minimize the carry over of dregs into the filtrate. The polymer flocculates dregs particles to form conglomerates, which are easier to separate from the liquor than fine individual dregs particles. In Figure 8 is shown centrifuge main parts (Beer, C et al 2006).

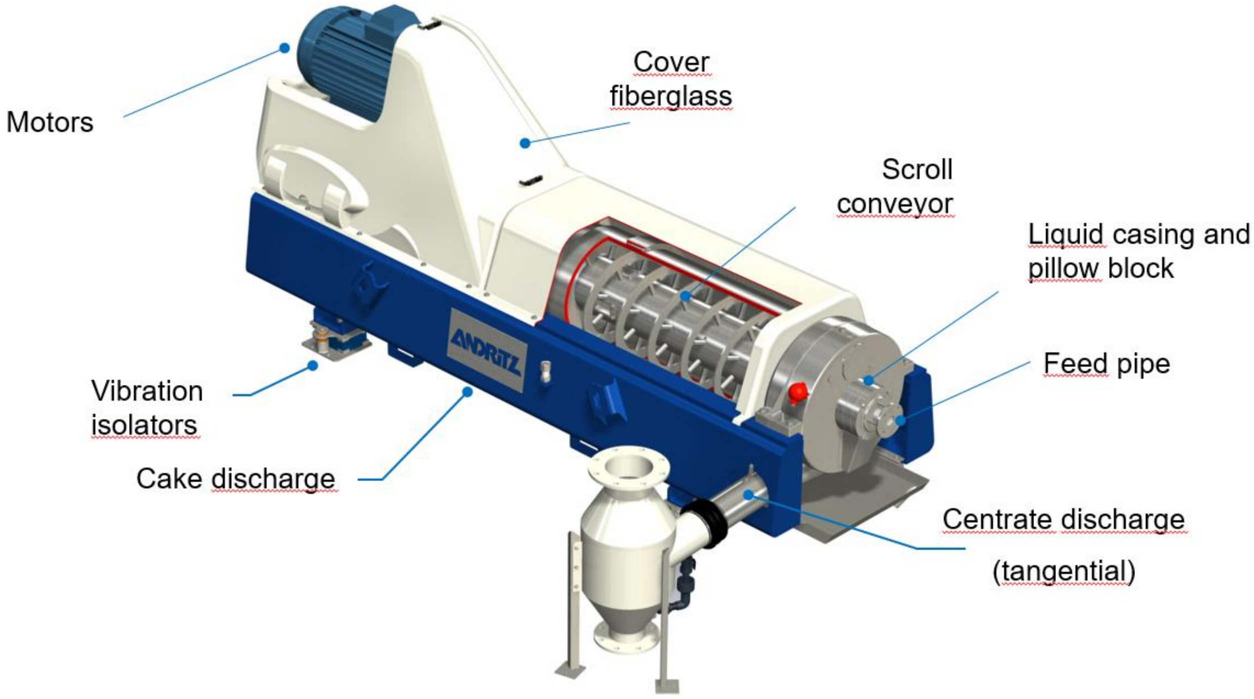

Figure 8. Centrifuge overview (Andritz product manual)

The centrifuge is combined by a main motor and a secondary motor. Both motors are driven by frequency converters. The primary motor controls the bowl speed. The speed between bowl and scroll has to be different so that conveying and evacuating the decanted dregs is possible. By adjusting the speed between bowl and scroll outlet dregs dry solid content can be increased and decreased. Centrate cleanliness can be adjusted by adjusting liquor level inside the centrifuge. Inside the centrifuge is overflow weirs which height can be adjusted and those are effecting to liquor level inside the centrifuge (Andritz product manual).

The high rotational velocity of the centrifuge bowl will create higher forces, which is making the liquid form a layer around the bowl. The heavier solids of the slurry are settling on the bowl wall and the lighter liquor, the centrate, is flowing through the overflow weirs of the centrifuge. The solids that have settled on the bowl wall will be transported towards the solids discharge end of the centrifuge by a conveyor screw, which is rotating with a differential speed to the bowl. At the solids discharge end the bowl is tapered so that the dregs will be conveyed above the surface of the liquid ring in the centrifuge. There it will be dewatered before being discharged through the solids discharge openings on the bowl and fill into the dregs discharge chute. Flocculation polymer can be dosed to ensure best dewatering and clear overflow to the weak wash system (Beer, C et al 2006).

2.3 Slaking and causticizing

The main requirement of the slaking and causticizing process is to generate white liquor with as high sodium hydroxide content as possible from raw materials. Raw materials are green liquor and burnt lime. Reaction between white liquor and burnt lime is equilibrium reaction. That's why all carbonate cannot be converted to hydroxide. The precipitating calcium carbonate, called lime mud, must be transformed into an easily separable form.

2.3.1 Lime Slaker

The lime slaker is the heart of causticizing process. Slaking reaction takes place in the lime slaker and it determines the white liquor chemical composition, which used in digester. Lime mud particle sizing leaving the slaker is majorly depends on how slaker is operated. Appropriate lime and green liquor feed ratio plays a major roles in stable operation of lime slaker.

Nowadays modern lime slaker is equipped with two separate compartments. Top compartment is called mixing compartment, where the burnt lime and green liquor are fed. Both compartments are equipped with an agitator to maintain the lime mud particles in the suspension at the chambers. Agitator blades uniformly mix the burnt lime and green liquor to ensure reaction between them. Reacted slurry flows down to the second compartment and further reaction continuous. This compartment structure gives enough retention time for the reactions. In general, slaker retention time is decided based on how much is the design green liquor flow to the slaker. Typical residence time of a lime slaker is about 20 minutes.

From the slaker bottom compartment, the lime milk slurry flows to the classifier compartment. This classifier compartment comprises a screw and a grits washer. Classifier compartment fills gradually with the lime milk. Once it reaches full level, lime milk flows into over flow channel and then flows through the slaker overflow pipe to first causticizer in the series. Addition purpose for slaker is removal grits from the lime milk slurry. Girts normally settles at bottom of the slaker-classifier. Grits are un-slaked lime and reject material that comes from the lime kiln internals like refractory pieces, chain and other components from make-up lime stone also. Sometimes, not wanted materials comes from purchased lime. Classifier screw is located in the classifier bottom. It conveys the grits from bottom compartment to grits washer and then out from the slaker. Slaker overview is shown in Figure 9 (Sanchez R., 2007).

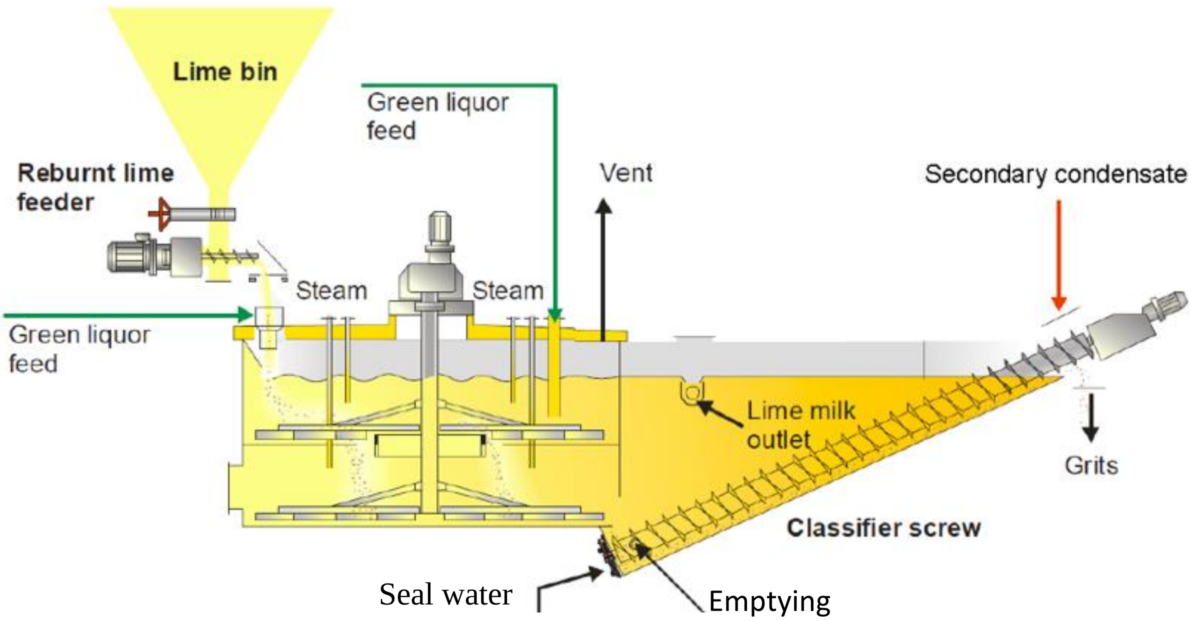

Figure 9. Lime Slaker overview (Andritz product manual)

Some mills using fresh or imported lime as make up lime for the causticizing process. Some mills are having limestone handling system to feed the limestone to the kiln for lime make-up for the causticizing process. This limestone is calcined in the lime kiln and converted into burnt lime. The green liquor flow to the slaker is controlled with flow control valve and density is normally measured and controlled before slaker. To maintain the constant density, condensate dosing is done in the suction of slaker feed pump. Green liquor and lime feed ratio controller helps to maintain proportionate feed to the slaker.

The lime slaker is placed normally under a re-burned lime bin. Lime is feeds in a controlled manner with re-burned lime screw feeder. Screw feeder conveys lime and discharges it into the slaker. This screw feeder is equipped with variable speed drive to maintain the lime ratio according with green liquor flow to the slaker. The screw feeder is equipped with a variable speed drive to maintain the lime to green liquor ratio.

If the fresh lime directly added to the re-burnt lime bin, then layered lime with different proportions makes unstable operation of the slaker. This happens mainly due to different reaction speeds and rates of purchased lime and re-burnt lime. Nowadays, good practice to add the purchase lime is by adding a small purchased lime bin with screw feeder. Lime cycle is recommended to open 3 to 5 percent. With separate purchased lime silo and speed controlled screw feeder this lime inlet can be easily controlled.

The temperature of lime milk leaving the slaker outlet is maintained by controlling the green liquor inlet temperature. Green liquor to lime ratio set to a constant value based on the slaker outlet temperature. When the constant slaker outlet temperature is maintained with constant inlet temperature, then it is need to be ensure about the inlet green liquor density. Green liquor density is telling quite well green liquor total titratable alkali amount. Keeping liquor values constant slaker operation is good and stable.

Nowadays lime slaker is equipped with feed cyclone arrangement, this helps to avoid the huge amount of the vapors. In general, lime slaker is equipped with a gas scrubbing arrangement. During the slaker reaction, large amount of the vapors generated and those are condensed with spray nozzle system and pure gases vent to atmosphere or to a gas collection system.

To a achieve typical causticizing degree of 81 to 84 percent at the last causticizer outlet, the slurry leaving the slaker-classifier needs to have the causticizing degree about 70 to 75 percent . The causticizing reaction speed slows down when causticizing degree increases, which is the reason why causticizing degree target after slaker-classifier cannot be higher. Further reaction occurs in the series of causticizers (Sanchez R., 2007).

2.4 Causticizers

The lime milk slurry causticizing degree is about 70 to 75 percent while leaving the slaker. Required causticizing degree is achieved in causticizers from 75 percent to 80 to 82 percent by passing the lime milk slurry through a series of lime milk causticizers. These causticizers are kind of mixed flow reactors arranged in a series manner. These are multi compartment type and installed in small foot print area with a residence time of 150 to 180 minutes. In Figure 10 is shown typical flow simplified flow sheet for causticizing.

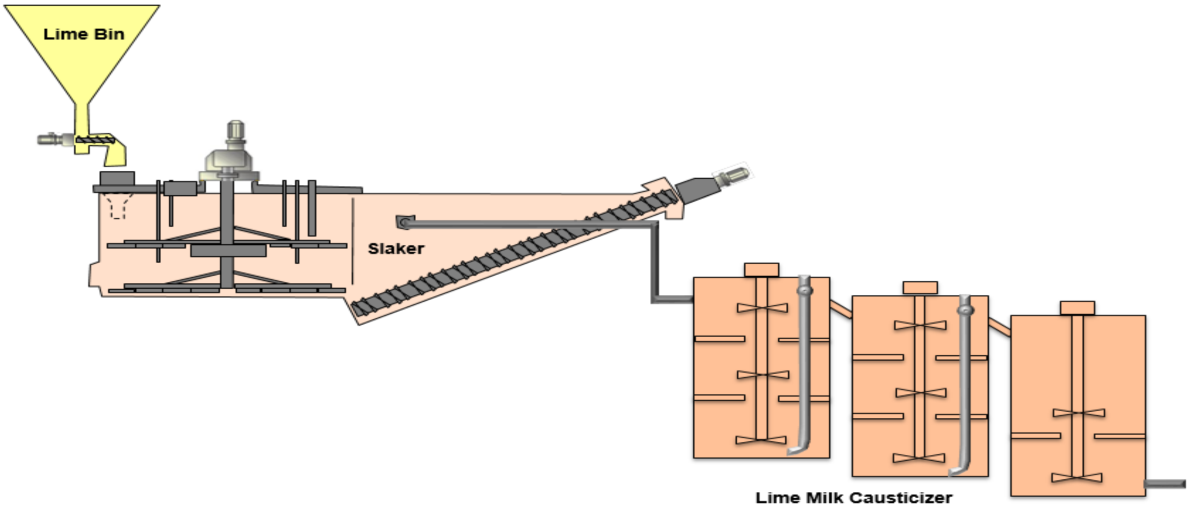

Figure 10. Lime Slaker and causticizers typical flow sheet (Andritz product manual)

Causticizers are large tanks with two or more compartments. Horizontal plates are mounted inside the tank to separate these compartments. Lime milk flow enters in top compartment and then flows to the next compartment through an annular space between shaft and compartment partition plate. This ensure first in first out flow pattern inside the causticizer tanks. These tanks are equipped with Riser pipes, placed inside the tanks and the openings are at bottom compartment, which allows the lime milk to flow through from bottom compartment to next causticizer. This gives enough retention time for the lime milk in a single causticizer. The lime milk causticizers outlets are connected to large diamter pipes for easy flowing and equipped with ample arrangement for cleaning provision. A vertical top entry agitator is with multiple blades as showing in Figure 11 at different elevations for the suspense of lime particles in the lime milk. (Sanchez R., 2007)

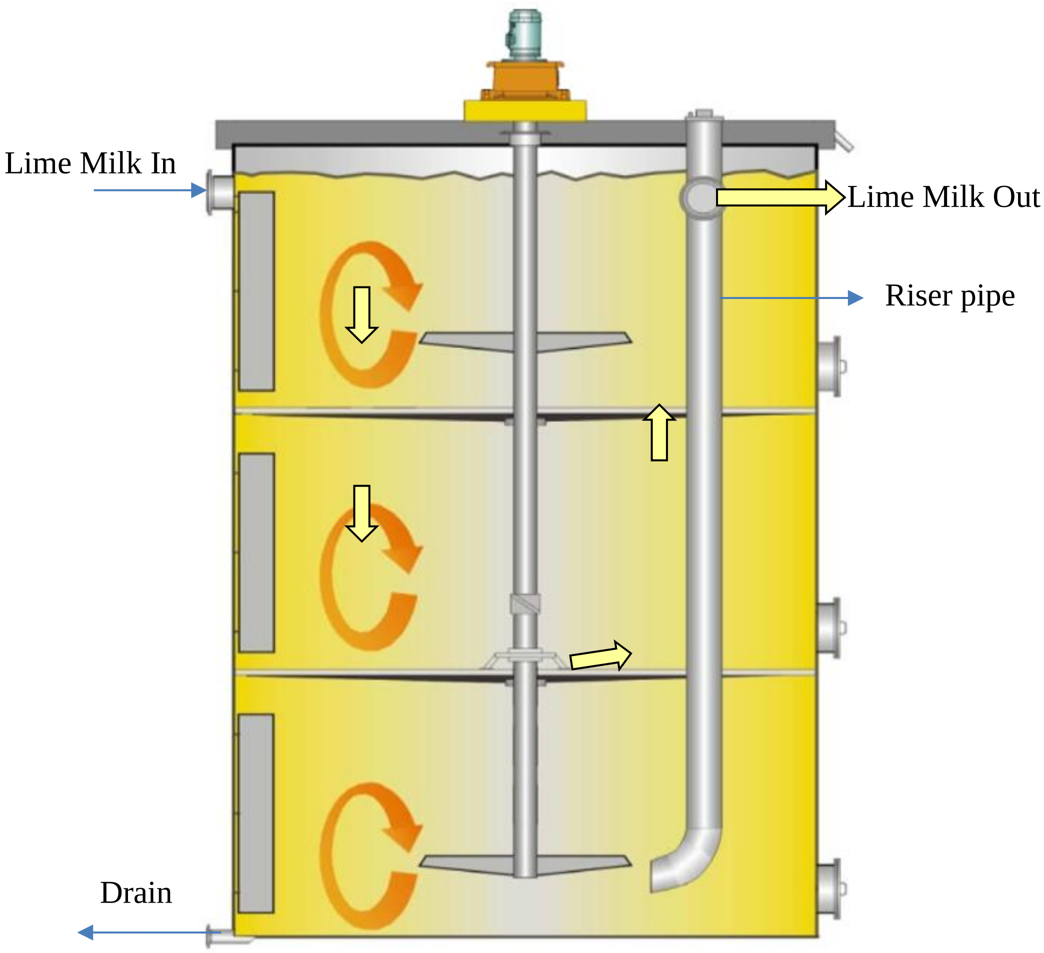

Figure 11. LimeMilk Causticizer with multi compartment liquor flow (Andritz product manual)

Generally, these overflow pipes are keep as short as possible for easy maintenance and to reduce the amount of cleaning in main process line. This main process lines also having bypass lines in case of any maintenance or cleaning activities for a shorter period of time. Liquor from the last causticizer is pumped to a clarifier or pressurized white liquor filter or sock type filter.

2.5 White liquor handling

When lime milk reaches the last caustizer it is fed to lime mud and white liquor separation. Separation is done with white liquor clarifier or filtration. For filtration options are disc filter or vertical tube filter. The last causticizer is equipped with two compartments with less retention time compared with other causticzers,. After the last causticizer lime milk reaches the typical causticizing degree 81 to 84 percent.

To send the white liquor to the digester lime mud needs to be separated from the white liquor. This process done in white liquor handling section. Lime milk is pumped from last causticizer to a sedimentation type clarifier or to filtration. White liquor clarity is depends on the type of separation equipment is used. Clarifiers are bascially easy in operation but outlet clarity is higher compared to pressure filters. Typically, outlet clarity from a white liquor clarifier is about 80 to 100 ppm. Whereas for a pressure filter white liquor outlet clarity is about 0 to 20 ppm.

2.5.1 White liquor clarifier

In old mills, white liquor clarifier is the most commonly used method for lime mud and white liquor separation. Sedimentation type of clarifiers with raking device mechanism, which moves the settled solids towards the center of the clarifier and further to sludge pit. Normally clarifier can storage lime mud inside, for that purpose, clarifier rake is equipped with lifting and lowering mechanism. Lifting and lowering is working based on rake turning torque. Inlet lime milk flows to feed well, this helps for easy separating conditions for lime mud from white liquor. Feed well design plays a key role in clarifier operation. There is a pipe for gas removal in the feed well. In Figure 12 is shown sedimentation type white liquor clarifier main parts.

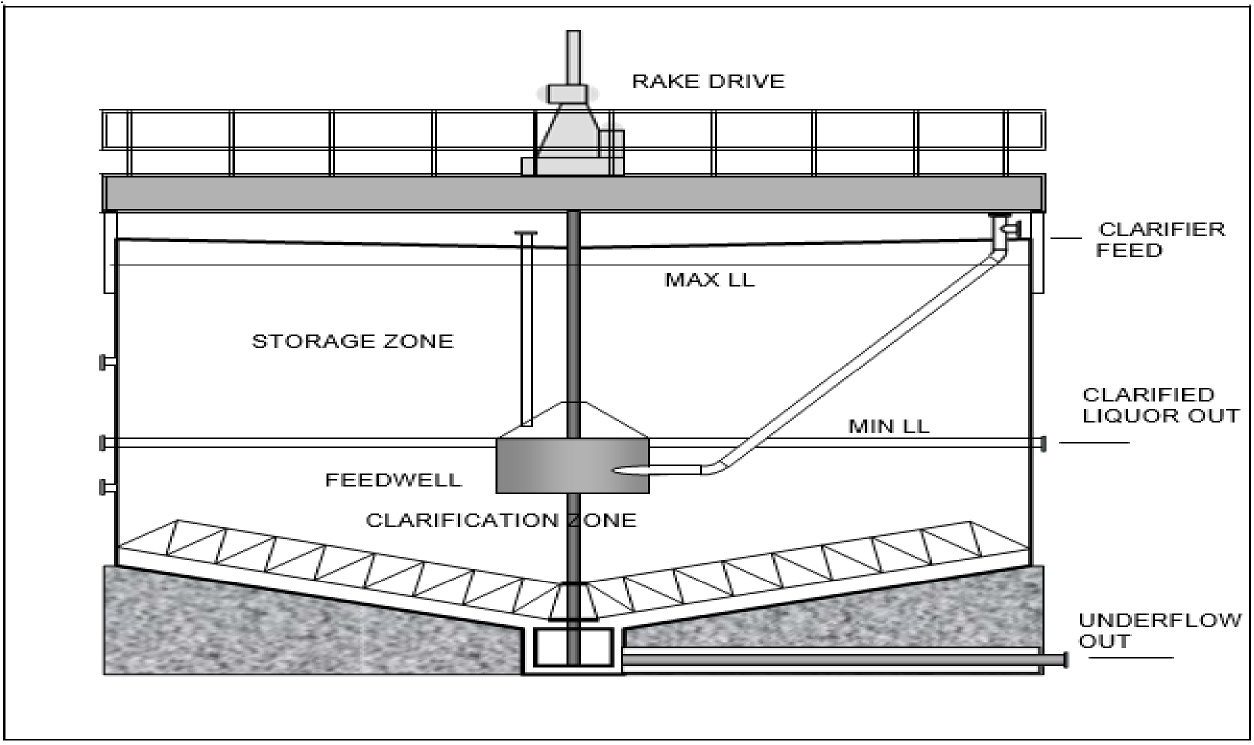

Figure 12. Sedimentation type white liquor clarifier (Andritz product manual).

To attain the required white liquor clarity to use in slaker, this sedimentation type clarifiers loaded rise rate is about 0.4 to 0.7 millimeter per minute. A good conservative loading rate will give good white liquor clarity and helpful to minimize the lime mud related process problems in the cooking plant. Typical outlet clarity of white liquor from a clarifier outlet is less than 80 milligrams per liter.

Lime milk feed pipe enters from the tank top roof level and pipe is tapered with 45 degrees angle. In case a vertical feed pipe it may generate vacuum and scaling chances are higher. Another advantage with this feed pipe arrangement is that cleaning is very easy without draining the clarifier. In case any horizontal feed pipes, it is very difficult to clean because tanks needs to be emptied. Feed well is arranged with a vent line to exhaust the entrained air that comes with raw green liquor. After lime milk enters into the feed well lime mud and white liquor get separated and lime mud settle down at the bottom of the clarifier and it is collected through a under flow pipe and pumped to the lime mud washing. Clarified white liquor is collected from the collection header, above the feed well. Clarifier storage volume is between white liquor collection header and clarifier overflow pipe (Sanchez D. R., 2007)

2.5.2 Lime White Filter

The pressure disc filter system consists of a horizontal pressurized filter vessel with integrated lime mud agitator, a filtrate vessel and compressors with water separators. The pressure disc filter contains several filtering discs and each disc consists of several sectors fitted with filter cloths. Filtering sectors are connected to a rotating shaft. Channels, located inside the shaft transfer white liquor from the discs through the shaft and filtrate valve to the filtrate vessel, where gases and white liquor are separated and white liquor is pumped to white liquor storage tank. In Figure 13 is shown overview of Andritz pressure disc filter called LimeWhite.

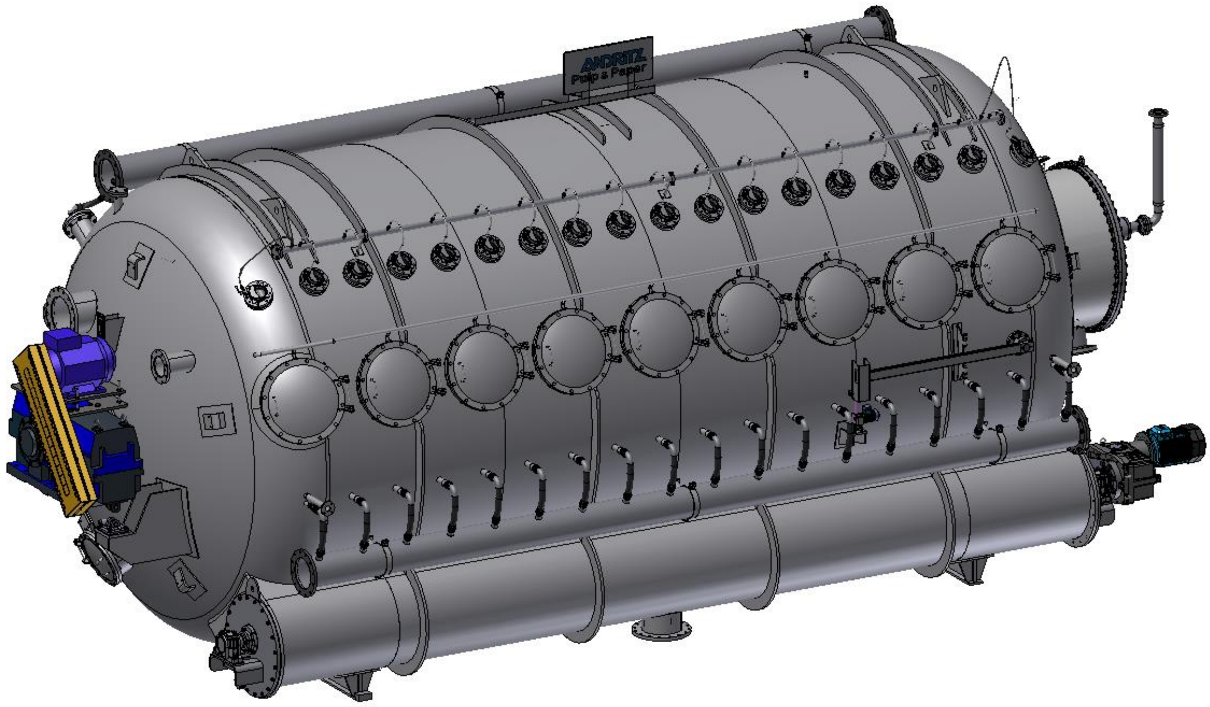

Figure 13. Andritz LimeWhite pressure disc filter overview (Andritz product manual)

Initially filter is pressurized with the help of compressed air. Filtration gases flow from the top of the filtrate vessel to a filtration compressor, which pressurizes and circulates them back to the filter to provide the filtration pressure difference. Part of the filtration gases flow to a separate booster compressor that feeds the air agitators, which are located on the bottom of the filter pressure vessel. The air agitators operate as air lifts to maintain the lime mud in suspension and prevent build-ups in the bottom of the filter pressure vessel.

A pressure difference of approximately 1.2 bars causes the lime mud to form a cake on the filter media and forces white liquor into the sectors. White liquor flows from the sectors through the channels inside the central shaft and into the filtrate vessel. Lime mud, which is separated from white liquor, stays on the surface of the rotating filtering discs. Hot water showers wash soda from the lime mud cake, which is further dewatered prior to discharge. A pre-coat of lime mud is maintained on the discs and the outer layer of lime mud is scraped from the discs by scraper blades into the lime mud chutes, where lime mud is diluted.

Filtration capacity is controlled by level changes in the pressure vessel, changing the discs rotation speed and changing the pressure difference over the disc. By increase or decreasing the level inside the pressure vessel, we are increasing or decreasing the filtering area of the disc. By increasing or decreasing the rotation speed of the disc we are effecting the time what is for cake drying and for white liquor flow out. By increasing pressure difference over the disc we are increasing power which force liquor through the pre-coat.

As the lime mud pre-coat layer starts to plug, the level inside the pressure vessel increases. That leads rotation speed and the pressure difference are automatically increase, which maintains the filter production rate. If the liquid level inside the filter increases more and the maximum rotation speed and pressure difference are reach the automatic scraper diving sequence starts. In Figure 14 is shown Andritz LimeWhite filter typical flow sheet.

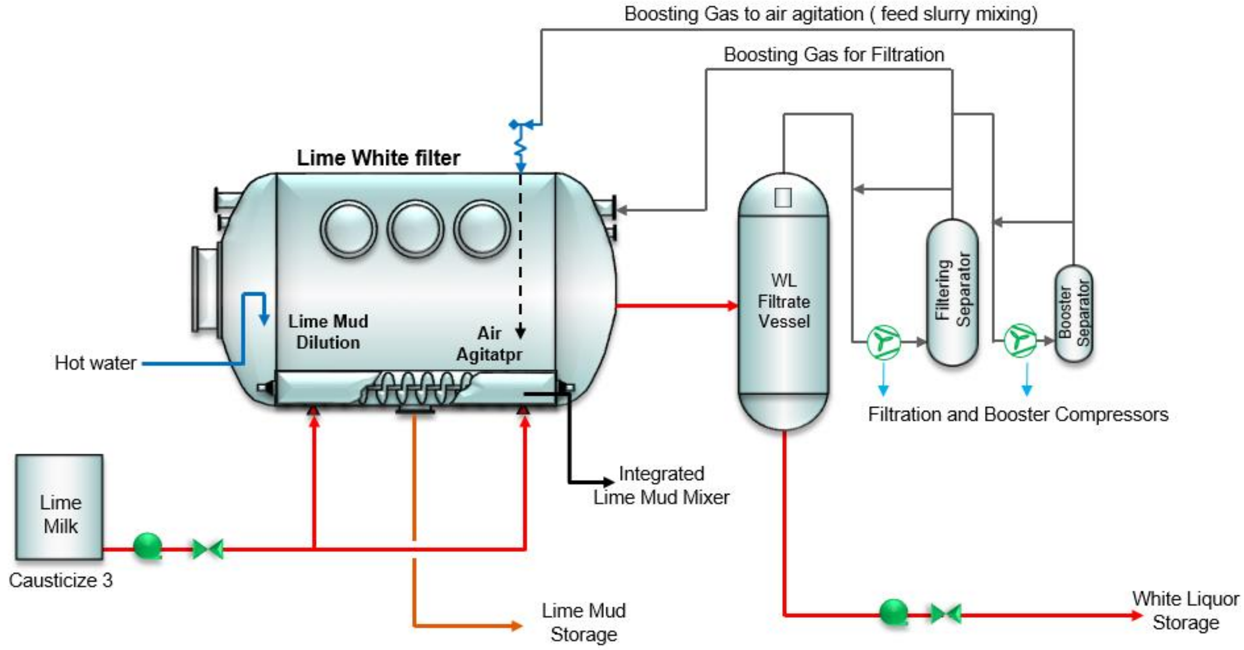

Figure 14. LimeWhite Filter typical flow sheet (Andritz product manual)

During scraper diving, the scraper blades are moved to the inner position. The outer, plugged layer of the lime mud pre-coatis removed, which improves the filterability of the lime mud pre-coat. After scraper diving, the scraper blades will be moved back to a normal position. Scraper diving prolongs the normal filtration sequence and ensures sufficient capacity without the need of changing the whole lime mud pre-coat. After scraper diving, the level in the filter vessel reduces and the filter speed and pressure difference are automatically reduced. The cycle of increasing speed, pressure difference and scraper diving is automatically repeated to maintain the required production rate.

After some interval of time, pre-coat need to be renewed because lime mud pre-coat layer plug completely, surface renewing is not enough. For that, filter clothes are blown with boosting gas. Gas from the booster compressor blows in the filtrate channels and results cake blow on filter clothes. A new pre-coat will form on filter clothes which helpful to maintain the production rate.

Under long running conditions based on the filter performance, it is necessary to clean the filter internals with hot water for a better performance. Different operation sequences and logics are present to conduct the washing to the filter internals.

After extended operating periods, water washing will not restore the capacity of the filter and acid washing is occasionally required. The acid wash frequency is dependent on the impurity levels in green liquor and the control precision of the lime slaker. Sulfamic acid or formic acid are suitable for acid washing of the filter (Andritz product manual).

3 LIME KILN PROCESS

Lime kiln is part of the recausticizing plant. In lime kiln calcium carbonate is converted back to calcium oxide. Calcium oxide is used to convert green liquor to white liquor. That is called lime cycle, in slaker and causticizing line calcium oxide is converted to calcium carbonate and in lime kiln back to calcium oxide.

Causticizing needs calcium oxide to convert green liquor into active white liquor for the cooking process. In this reaction, the calcium oxide is first slaked to calcium hydroxide in a slaker. During this process, a very high temperature is generated. In compliance with the causticizing reaction, the calcium hydroxide reacts further with sodium carbonate generating sodium hydroxide and calcium carbonate also known as lime mud.

After causticizing, the lime has been converted into calcium carbonate. The objective of lime reburning is to convert the calcium carbonate back to calcium oxide. The main equipment for lime reburning is a rotary lime kiln. Lime burning is controlled based on the residual carbonate amount. This conversion needs high temperature and that is why a lot of external heat need to be transformed in lime kiln. Reaction happens when lime kiln temperature exceeds 850 Celsius degrees. Speed of the reaction increases when temperature increases. Normal operation temperature for lime kiln burning end is about 1 000 Celsius degrees.

3.1 Lime mud washing

Lime mud discharged from the pressure filter or from white liquor clarifier contains still quite a lot of alkali. Before feeding, the sludge to the lime kiln, this slurry need to be dewatered and the white liquor needs to be washed out from the lime mud as much as possible. Generally, for lime mud washing two kind of filters available one is Lime mud pre-coat filters and another is lime mud disc filters. The alkali content in the lime mud is removed by washing with hot water. In ancient days lime mud washers was used to wash the alkali content before feeding the slurry to lime mud filter. However, if the lime milk is treated in the pressure filters, filter is doing enough alkali washing with lime mud dilution and Cake washing. Lime mud washers are very similar that white liquor clarifiers.

Single stage lime mud filter is enough to wash the lime mud before it enters into the lime kiln. Required weak wash liquor for smelt dissolver is available from Lime mud filter. It is very important not to lose the chemical content in the wash liquor from the lime mud filter.

To avoid this weak wash storage tanks are provided with enough storage volume. In case of pressure disc filter, required weak wash storage will be less due to single stage lime mud washing at lime mud filter.

3.2 Lime Mud Storage Tank

The lime mud storage tank is used as buffer storage in between lime kiln and causticizing plant. This helps to keep plant running the operations of causticizing for short duration in case of lime mud filter or lime kiln is not operating. As well as it is helpful to keep the lime kiln in operation for short duration while causticizing is not running like lime white filter acid washing or minor maintenance.

The lime mud from lime white filter is stored in large tank with a slow speed agitator. Lime mud solids are about 30 to 35 percent. Due to slow speed agitator mixing, lime mud is fairly homogenous. Generally, this storage tank is equipped with rake kind of agitator. In recent days, propeller type vertical agitators are started to use. Benefits is that it is giving the better mixing efficiency in the lime mud storage tank. These agitators occupies less foot print, less power consumption and are easier for maintenance also. To avoid settling of lime mud during the power failures, these tank agitator drive is equipped with an emergency power supply. In addition, lime mud circulation with pump can be used to avoid lime mud settling in the storage tank.

3.2.1 Lime Mud Pre-coat Filter

The lime mud pre-coat filter operates at low submergence of drum in the vat. Lime mud is fed in to the vat in water suspension. Normally density at lime mud filter vat is close to 1 100 kg per cubic meter. Large drum is rotating in a submerged vat and due to vacuum action lime mud pre-coat forms on filter cloth surface. Filter equipped with a scraper arrangement, the scraper blade set approximately 10 to 20 millimeters from the cloth surface. Pre-coat forms gradually on the filter cloth surface and it is scrapped by scrapper blade. Layer thickness is increased until it reaches the scraper blade. Once the layer comes close to the scraper tip, scraper gradually cut the filter cake top layer, which is helpful to form a new pre-coat on filter disc. In Figure 15 is shown lime mud drum filter in operation.

Figure 15. Lime mud drum filter in operation

Typically these drum filters are rotations speed about 3 to 6 rations per minute. In older days, the drum rotation speed was lower compared to present. Higher drum rotation speed helps to get a thin layer of cake formation and it is easier to wash and easier to dry. The filter cake is washed by a series of hot water showers to remove the alkali present on the cake. Typical hot water temperature used for cake washing is about 70 to 80 Celsius degrees (Sanchez R., 2007).

Lime mud pre-coat filters are equipped with adjustable or movable scraper blade or with continuous pre-coat renewing unit. Both options allows the removal of blind layer of lime mud at periodic intervals during the filtration cycle. If movable scraper blade is in use pre-coat get plugged over the time. Pre-coat need to be blown away complete and form new pre-coat. Blowing happens between 6 to 12 hours. If continuous pre-coat renewing unit is in use, it can have high pressure washing option and that is washing completely pre-coat away from 10 to 20 millimeters area. That way filter does not need blowing.

3.2.2 Lime Mud Disc Filter

Disc filter is the latest technology for the lime mud dewatering and washing. It provides large filtration in a small filter footprint of the filter, even for high lime mud capacity. It is a lime mud pre-coat filter consists of a disc filter and it is equipped with a continuous pre-coat renewal system (CPR).

Lime Mud Disc Filter is equipped with several filtering discs and each disc consists of several sectors fitted with filter cloths. Filtering sectors are connected to a rotating shaft. Channels, located inside the shaft transfer lime mud filtrate from the discs through the shaft and filtrate valve to the vacuum tank. From the vacuum tank the vacuum pump sucks gases, which is the driving force for the filtration. Filtrate from the vacuum tank is pumped to weak wash storage tanks and from there to recovery boiler smelt dissolver through weak wash transfer pumps. In Figure 16 is shown Andritz LimeDry disc filter overview where can be seen discs and scrappers.

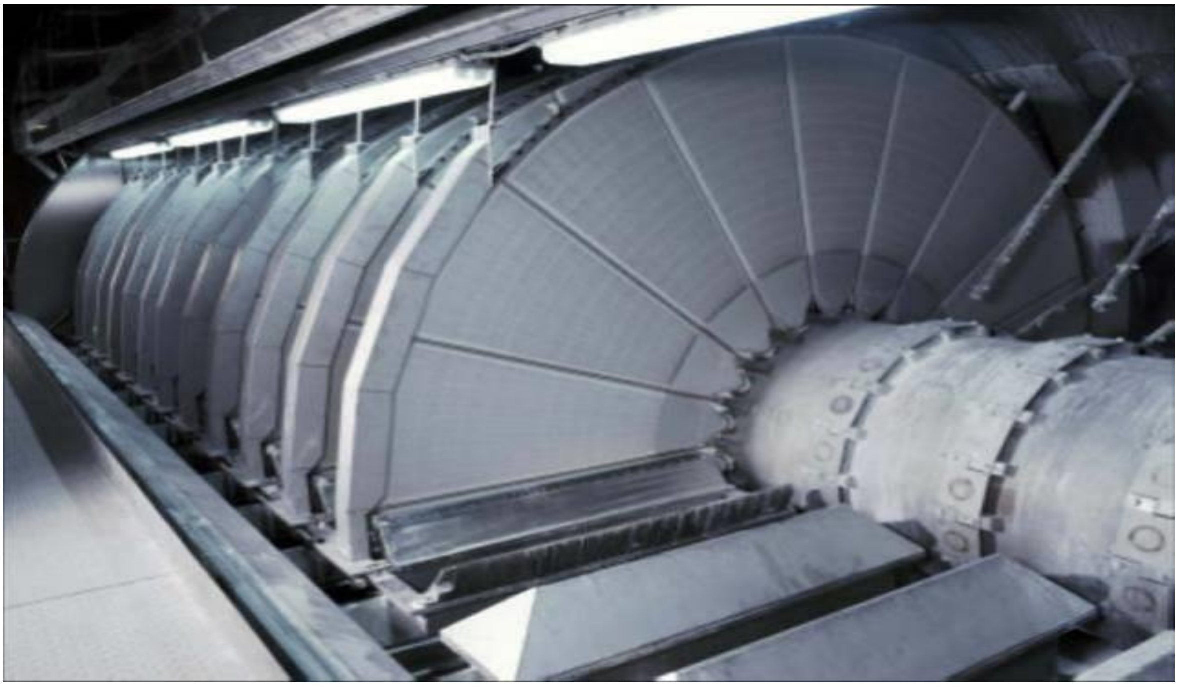

Figure 16. LimeDry disc filter overview (Andritz photos)

Lime mud at pumped to the mud filter vat from lime mud storage tank where the initial solids in the tank about 30-35 %. Before feeding to the feed pump solids diluted up to 25 % by using hot water at pump suction point. Lime mud pre-coat forms on filter discs due to vacuum. A large liquid ring vacuum pump provides this vacuum. Jet condenser is equipped before the vacuum pump suction to condense the vapor content in the gas going to the vacuum pump suction manifold. Cold water is used as sealing media for vacuum pump. Fixed scrapper blades are positioned on two sides of filter discs in the distance about 10 to 25 millimeters from the filter cloth for cake discharge. In Figure 17 is shown Andritz continuous pre-coat renewal system.

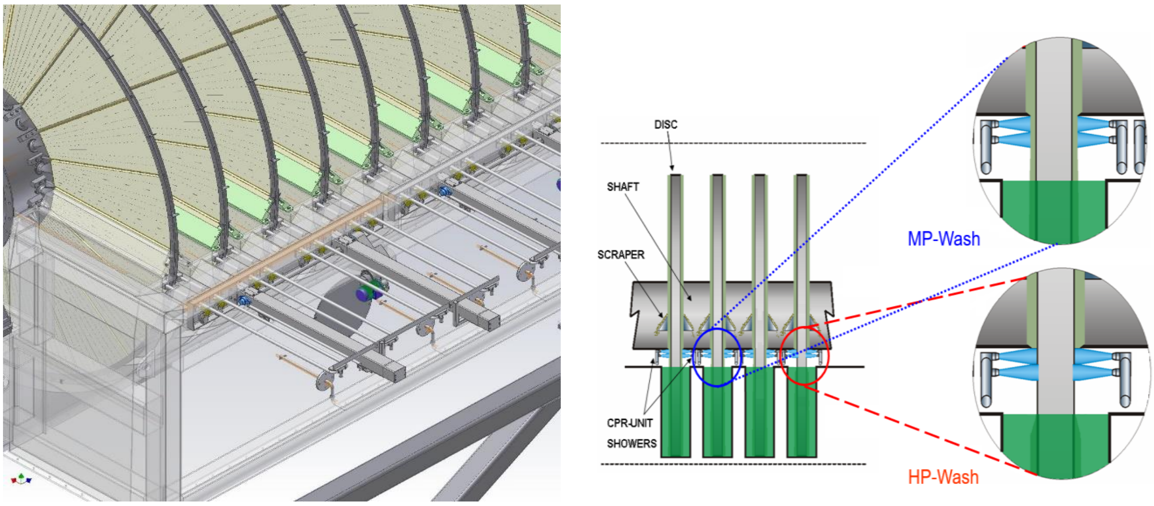

Figure 17. LimeDry filter continuous pre-coat renewal system (Andritz product manual)

In addition to it, Lime mud is pre-coat removal process is continuous by continuous pre-coat renewal (CPR) system, which includes a high – pressure pump unit and CPR nozzle beams. Lime mud pre-coat is renewed continuously on the filter discs with the CPR-system, which includes a high-pressure pump unit and CPR-beams. This CPR-system has two washing sequences. Those are low and high-pressure washing, which maintain optimum performance and keep the filter media clean. Medium washing pipe continuously cleaning the cake plugged surface and high-pressure jet will cut the cake on the filter cloth, which helps to form a new cake on filter cloth surface. A common hot water spray pipe is spraying hot water on CPR unit pipes for the free movement. Water used for CPR unit should be free from dirt because of high-pressure pump and small nozzles, however strainers are fixed in the process lines to the CPR nozzles.

Discharged cake from the dropping chute is conveying to the lime kiln by a drag chain conveyor. These conveyers have provision to operate in both direction in such a way that to feed as well as for purging is possible.

3.3 Calcination

The term calcination refers to the process of Calcium carbonate thermal decomposition into calcium oxide, which is called lime and carbon dioxide. Lime mud discharged from lime mud filter is almost free from alkali content but have some moisture content. This lime mud from lime mud filter is feed into the lime kiln, the calcium carbonate present in the lime mud decomposes by heat treatment into calcium oxide and carbon dioxide. The reaction may be expressed as:

Lime Mud + Heat → Lime + Carbon Di Oxide

$CaCO_3$ + Heat → CaO + CO_2

Lime kiln produce burnt lime from the lime mud and lime is reused in the causticizing for white liquor production. Rotary lime kilns are long cylindrical steel vessels with refractory brick lining inside to sustain the heat inside the kiln. Lime kilns are positioned slightly inclined manner from horizontal. Lime kiln is slowly rotated on a set of support rollers with a help of riding ring. Riding ring arranged around the circumference of kiln shell and this riding ring is roll on support roller set. Kiln is inclined from feed end to discharge end. Feed end called as uphill and product end called as downhill. Lime mud is fed at uphill of the kiln, lime mud slowly rolls inside the kiln due to rotation and inclination. Lime is conveyed to the product end. A burner is positioned at the downhill of the lime kiln at discharge end, and it provides continuous heat by combusting the fuels like heavy oil and natural gas. Heat is transferred from burner flame and heat is carried with flue gas to the other end of the lime kiln. Due to counter current flow of heat and lime mud, heat transfer occurs and helps to get the lime mud heat up to the required reaction temperature.

The entire weight of the lime kiln is supported on riding rings that are encircle around the kiln shell circumference. These riding rings contacted with carrying support rollers, which are placed on large concrete piers. An electric motor with reduced gearbox with pinion drives helps to rotate the kiln at low rotation speed. These pinion drive arrangement is called as girth gear. This girth gear having a separate lubrication arrangement to keep the gear teeth free from erosion. Typically, lime kiln rotation speed in the range of 0.5 rotation per minute to 2 rotations per minute with variable speed drive option. Kiln main drive is given with variable speed frequency converter, which helps the kiln to rotate in specified range. In Figure 18 is shown lime kiln area over all layout Figure from 3D model (Adams N. 1996).

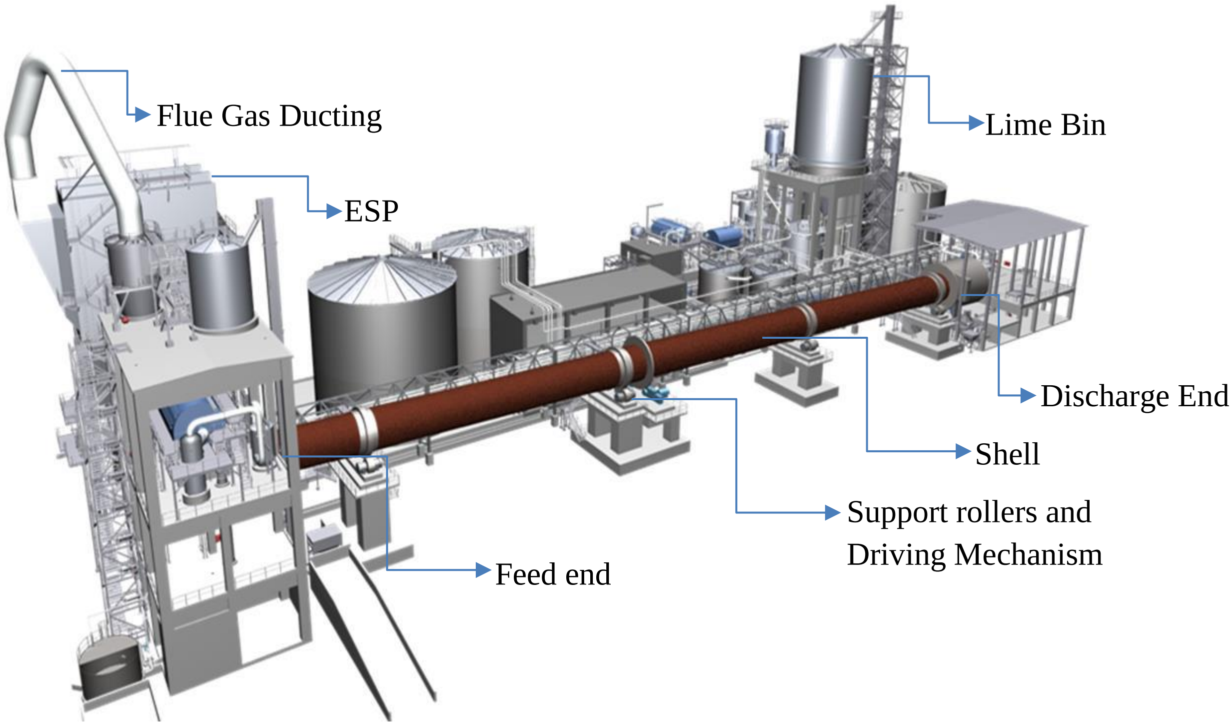

Figure 18. Lime kiln layout overview

The lime kiln entire shell length is divided into four process zones:

I. **Drying Zone:** Evaporation of moisture content in the lime mud.

II. **Heating zone:** Heating up dried lime mud up to the required temperatures.

III. **Calcination:** Dissociation reaction of calcium carbonate to calcium oxide and carbo dioxide.

IV. **Cooling zone:** Cooling of hot product lime before discharge to the lime storage silo.

In Drying phase wet lime mud enter into the lime kiln and water content in the mud gets evaporated due to counter heat obtains from kiln flue gas. As a result dry solids content in the mud gets increase. Dried mud starts rolling from the kiln feed end to discharge end slowly due to kiln rotation and inclination and gets heated up due to heat transfer. Heated lime mud started decomposes into calcium oxide and carbon dioxide while moving towards the burner. Due to high temperature at burner end, which is about 900 celsius degrees to 1100 celsius degrees, calcination reaction occurs and maximum amount of calcium carbonate converts into lime. This product lime temperature is too high for conveyors to handle and it needs to be cool down. Also due to energy savings, heat energy from the product need to be restored back in the process. Lime kiln is equipped with cooler arrangement to cool down the product lime. Secondary air that is enters into the kiln gets heat up in the product lime cooling process. (Know pulp, 2016)

The first three process zones required enough heat for the reaction. To provide this heat usually natural gas or heavy oil is used as main fuel. Combustion of this fuel gives enough heat generation. Heat transfer occurred in lime kiln mainly due to heat radiation. Maximum extent of heat transfer occurs in the drying zone due to heat transfer in between cold lime mud and hot flue gas. In this zone, there is a significant drop in the flue gas temperature. Heat dissipates from the burner and moves directly towards the feed zone. Walls of brick lining gets heated up and radiation heat reflects from brick wall to the lime mud. Calcination reaction required high reaction temperatures, over 850 Celsius degrees, so kiln is operating at high combustion temperatures.

The main aim of the combustion to produce homogenous porous lime from the lime mud, which can go under slaking easily as well as it should be easily separate from the white liquor. Excessive operating changes in the lime kiln causes change in the crystal structure of lime. Very high temperature may produce the brittle lime, which is not slaking properly and create problems in causticizing process. It is necessary to ensure the stable operation of lime kiln for good quality of burnt lime. Lime kiln burner flame play key role in product lime quality as well as kiln brick lining life. (Know pulp, 2016)

Based on the drying application lime kilns are differentiated into two types, those are conventional lime kilns and flash dryer kilns. In conventional lime kilns lime mud drying process occurs inside the kiln itself. A special chain zone present in the kiln where the chains are linked to the kiln shell and rotate along with kiln rotation. These chains capture the heat from the flue gas and transfer the heat to the lime mud through conduction. While wet lime mud enters into the chain zone, water content in the mud is evaporated due to rolling with the chain. Different kind of chain zone profiles are present like curtain and garland profiles. After the chain zone, calcination process starts.

In flash dry kilns, lime mud is dried by flue gas in the Lime mud dryer before it feeding inside the kiln. Lime mud is almost 100 % dryness at the feeding end of the lime kiln. The lime mud dryer begins at feeding end of the kiln and it is about 15 meters ducting up to the feed cyclone. Dry lime mud from the cyclone is fed to the kiln feed end, flue gas temperature is about 500 to 700 Celsius degrees at feed end. Due to counter current heat exchange in between lime mud and flue gas, the temperature of the flue gas drop to 200 to 300 Celsius degrees before it enters into electro static precipitator (ESP). Due to high contact surface between lime mud and flue gas quick drying is possible and heat transfer is more effective. The main advantage from the Lime mud dryer kilns are reduce at the kiln dimensions, length and diameter. That is due to reduction in drying zones and chain sections when compared to convention lime kiln. In Figure 19 is shown lime mud dryer lime kiln overview (Andritz, 2017).

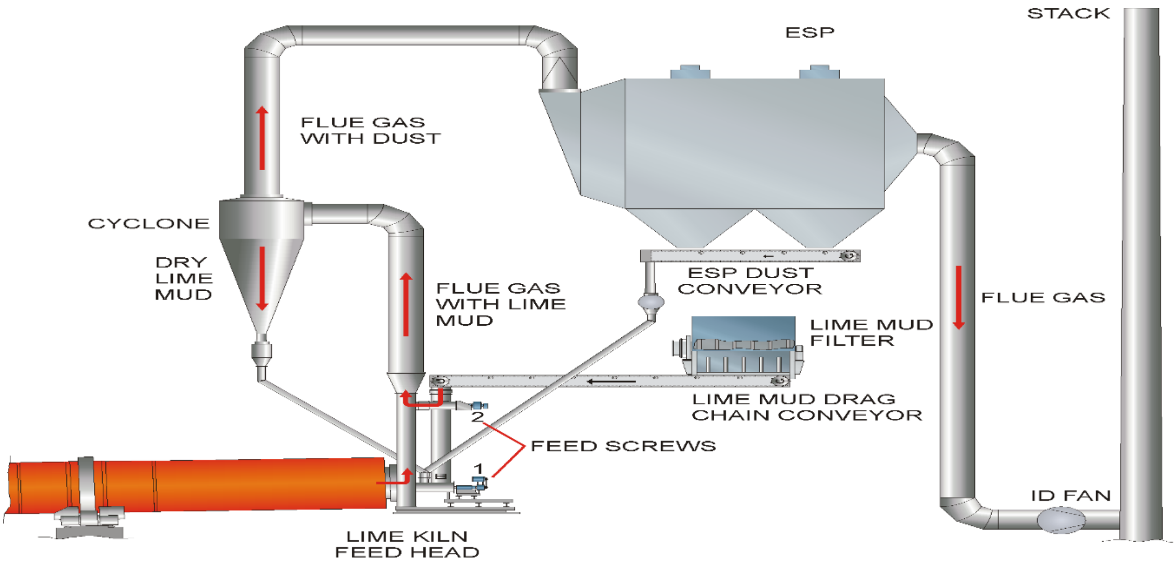

Figure 19. Lime mud dryer kiln overview

The separation of the dried lime mud from flue gas occurs in feed cyclone. Flue gas duct from the lime mud dryer connected at top portion of the cyclone as shown in Figure 19. Lime mud along with flue gas carried and separated in cyclone. Form the cyclone, lime mud is dropped to a feed screw number one and then it is conveyed inside kiln feed spiral. Flue gases from the cyclone flows upward and passed through electrostatic precipitator, which capture the dust and purifies the flue gas before gases goes out from the electrostatic precipitator. Collected dust from electrostatic precipitator falls into the drag chain conveyer through electro static precipitator dust hopper. This drag chain conveyer discharge is connected to the feed screw number one and the dust is fed to the kiln feed spiral. (Andritz, 2017)

For combustion and circulating the hot flue gases lime kiln is equipped with primary air fan, which is placed at burner end. This fan supply a small amount of air to the burner flame for better shape and stability. This primary fan draws hot gases from the kiln cooler section and discharge the burner at higher pressures. Typical quantity of primary air is about 5 to 25 percent of the kiln combustion air. Remaining air make up is done by atmospheric air which was sucked by induced draft fan and it get heated up due to counter current cooling process of product lime inside the sector cooler. The induced draft fan is at cold end of the lime kiln and it creates the driving force to draw the hot flue gases from the burner end to feed end. This helps for heat transfer between mud and combustion gas and finally draws the carbon dioxide from the kiln. The induced draft fan helps to control the total airflow to the kiln. The induced draft fan drive is arranged with variable speed drive option to control the flue gas suction and draft inside the kiln as well as excess air in the flue gas leaving the kiln.

The energy efficiency of lime kiln is expressed in the form of heat rate. This heat rate is calculated by taking the reciprocal of energy efficiency. Calcination reaction is an endothermic reaction, which required a heat input to convert Calcium Carbonate to Calcium Oxide in the lime kiln. Apart from energy required for reaction, some additional energy require to compensate the kiln shell heat losses. So overall energy requirement shall be combination of heat required for reaction, lime mud drying heat as well as kiln heat reactions plus heat losses. Heat losses are coming with the hot flue gas after drying going atmosphere and with product lime going to lime bin. (Adams N.,1996)

Available Calcium oxide in the produced lime is in the ranges about 80-85 % with a residual carbonate content 2-3 % and some inerts. In lime kiln, only thing where can be effected is residual carbonate. Residual carbonate amount should be followed and lime kiln operation adjustment should be done based on those measurement results. If available Calcium oxide level is followed it will lead over and under burning based on the inert amount changes. This kind of over or under burning for lime is causing operation problems at causticizing plant.

4 NEW MEASUREMENT TYPE WORKING METHOD

4.1 Radio frequency measurement concept

A radio wave is electromagnetic radiation, similar to light, and thus propagates at the speed of light. In the case of radio waves, the wavelength of the radiation is considerably longer. An electromagnetic wave is made up of two elements, an electric field and a magnetic field. The level of the fields are perpendicular to each other and against the direction of travel. The electric field of a radio wave is made by a voltage change applied to the antenna of a radio transmitter. The direction or polarization of the electric field is the same as the change in antenna voltage direction. In air, the strength of an electric field is measured by the change in electric potential at a certain distance, example, volt per meter (V/m). This measurement is used when measuring electromagnetic field strength at a specific location. The magnetic field consists of the current from the antenna. Like all electromagnetic waves, radio waves can be reflected, refracted, or bent from surfaces. As a rule, the strengths of the electric and magnetic fields change over time and location based on sine wave and are linearly polarized (Stalling W, 2002).

The received signal must be strong enough for the receiver to interpret message. The attenuation caused to the signal by the atmosphere is frequency dependent. Attenuation is higher at higher frequencies. The frequency dependence causes the signal to be distorted as the distance increases.

When a radio wave encounters a large area compared to the wavelength, reflection occurs. When the reflection surface is flat, the signal is not distorted. The wavelength and propagation speed of the reflected waves do not change. The angle of the reflected wave is with respect to the surface same as the angle of incidence. The attenuation of the reflected signal depends on the reflection surface, part of the power is absorbed into the material. Numerous materials reflect radio waves.

Refraction also occurs with radio waves, just like a stick inserted into the water looks like refracted from surface of the water. The direction of the radio wave changes as the wave travels to a material with a different refractive index. There is usually no sudden change in material with radio signals. It is more common for the change to be gradual, with the radio wave bending rather than suddenly changing direction.

Diffraction, or bending, occurs when a radio wave hits the edge of a surface larger than a wavelength. The radio wave bends and spreads. It has been found that the bending is stronger, when the shape of the obstacle is sharp. Low frequency signals bend better than high ones frequencies.

Scattering occurs when a radio wave encounters a surface of a size equal to or less than a wavelength. Some of the energy in a radio wave generates new waves in different directions. Scattering weakens the signal because the energy is scattered in many different directions. As a result of all the surfaces encountered by the radio signal along the way, the radio signal travels to the receiver along several paths, called multipath propagation (Caspers, F., Kowina, P. 2014).

4.2 Capacity type level measurement

Capacitive technology is based on electrical property. Capacitance occurs between any two conductors, which are separated by a nonconductor. The easiest example from this is two metal plate with an air gap between them. When turning capacitive phenomenon to capacitive measuring device sensor is one of the metal plates and the target is the other. Measuring device is measuring changes in the capacitance between the sensor and the target by creating an alternating electric field between the sensor and the target and monitoring changes in the electric field. Three things are affecting to capacitance between sensor and target. First is size of the sensor and target surface. Second is the distance between the sensor and target surface. Third is the material between the sensor and target surface. In the most common applications, the size between the sensor and target surface does not change. When using in level applications also the distance between the sensor and target surface does not change. The only remaining variable is the material between the sensor and target surface. Capacitive level sensors are calibrated to produce a certain output change to correspond to a certain change in the material between the sensor and target. This is called the sensitivity. Measuring set-up is shown in Figure 20. (Wilson, 2005, s. 193-194).

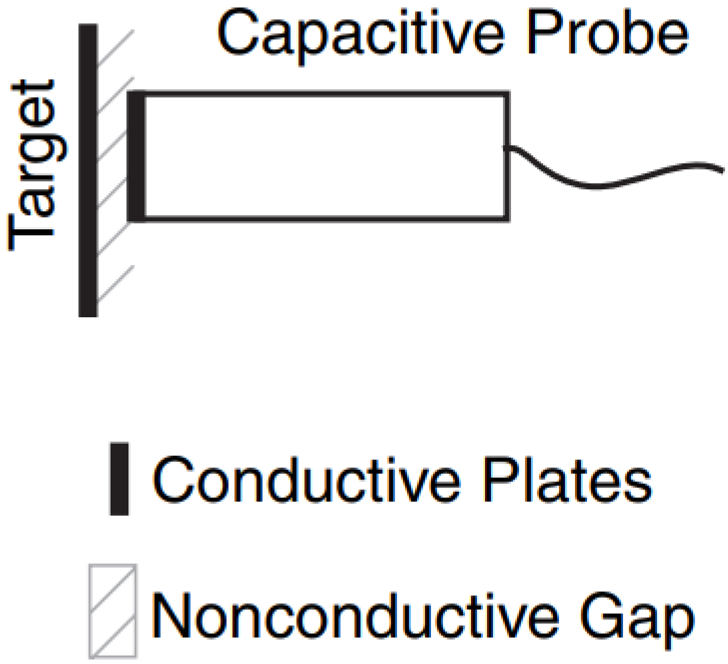

Figure 20. A capacitor is formed by the target and the capacitive probe's sensing surface. (Wilson, 2005, s. 194)

In a straightforward capacitance probe-type sensing element, when the level decreases sensing element revealed and when level rises material covers the probe. Capacitance measuring device can work two different ways, in conductivity applications the capacitance within the circuit between the probe and the media increases. In insulating application, the capacitance increases between the probe and the vessel wall. This capacitance increases or decreases based on the level is due to the dielectric constant of the material, which causes a bridge imbalance. The signal is rectified and amplified, that way then the output is increased. (Intellipoint RF manual)

The working principle for capacitance level transmitters is that a capacitive circuit can be formed between a probe and a vessel wall. All common liquids have a dielectric constant higher than air, when liquid level changes the measured capacitance change. The sensing element is connected to radio frequency transmitter, which is mounted externally on the tank. Transmission of the level measurement can be in various forms, it depends where information is used. It can be send to local programmable logic controller or distributed control system or just computer recording (Wilson, 2005, s. 251).

Capacitance sensors are advantageous in sensing the levels of a variety of aqueous and organic liquids and slurries, and liquid chemicals such as lime milk. Sensors with correct coating are immune for scaling on sensing element, which is high advantage. Level sensors that can be used to sense the interface between two liquids that have very different dielectric constants. That kind of application is using dual probe capacitance level sensors (Wilson, 2005, s. 251).

Capacitance sensors are durable because they do not have any moving parts. In addition, sensors are easy to use after set-up is done and also easy to clean. Sensors can be designed to high pressure and high temperature applications. There are two variations of the basic radio frequency systems called radio frequency Impedance and radio frequency Admittance. Impedance is the total opposition to current flow in an AC or RF circuit; admittance is the reciprocal of impedance and measures how readily current flows in a circuit. These techniques offer better reliability and a larger range of applications compared to the basic capacitance method. (Wilson, 2005, s. 251)

5 BIG ON/OFF VALVES

Valves can be divided into shut-off valves and control valves. This section covers the plug and ball type shut-off valves, constructions, features and price comparison for white liquor plant purposes.

The valves consist of two main parts: the valve body and the valve actuator. The valve body contains all the mechanical components which are in contact with fluid flow. To move valve internal components, the actuator is manufacturing the mechanical power what is needed to move valve internal components. Main difference between control valve and on/off valve is the actuator type applied to the valve. Control valves actuators needs to be able to accurately position the valve internal parts any position between fully open and fully closed position. On/off valve actuator needs to move valve internal components only to extreme positions, fully closed position or fully open position.

Valves can be divided into two main groups. Groups are sliding-stem valves and rotary-stem valves. Sliding-stems are valves that operate by linear motion, up and down or right and left, of the valve stem and valve internal components attached to stem. The most common valve types based on the linear motion internal components are globe, gate and diaphragm valves. Sliding-stem valves operation types shown in Figure 21. (Hydraulics & Pneumatics, 2012)

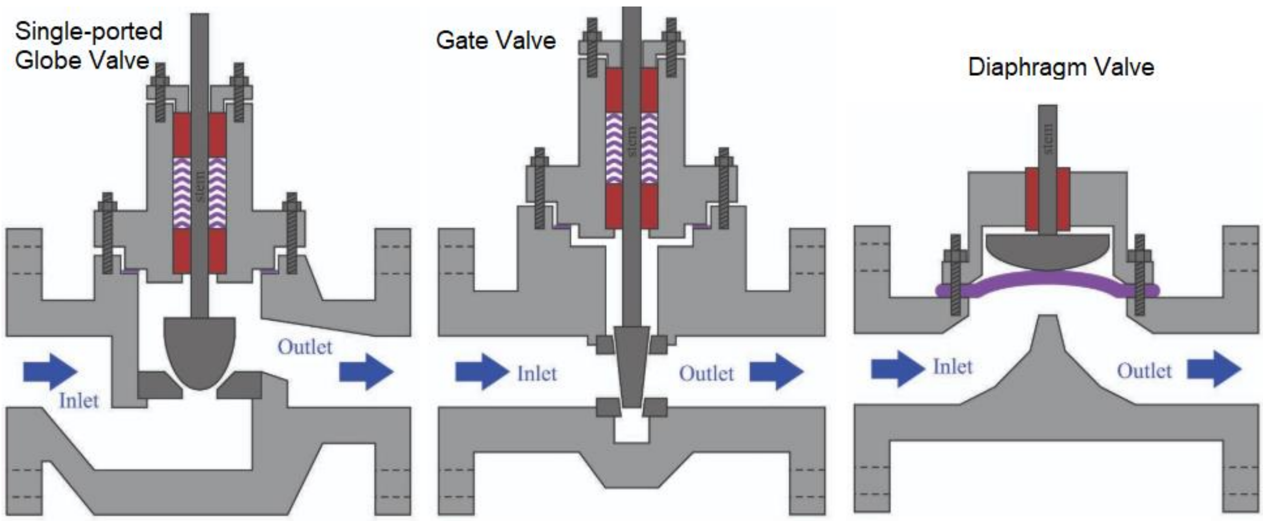

Figure 21. Sliding-stem valves operation types (Kuphaldt. T., 2019, Page 2084)

Rotary-stem valves are operate by rotating the stem and the internal components attached to stem. Instead of linear motion a stem up and down of the valve body to adjust the valve opening for fluid, rotary valves are rotating the stem to adjust the valve opening for fluid. The biggest advantage when comparing sliding-stem valves and rotary-stem valves is that when the rotary valve is full open the opening for fluid is fully open. At sliding-stem valves the opening for fluid is never fully open. The most common valve types based on the rotary-stem internal components are ball, plug, disk and butterfly valves. Rotary-stem valves operation types shown in Figure 22 (Kuphaldt. T., 2019)

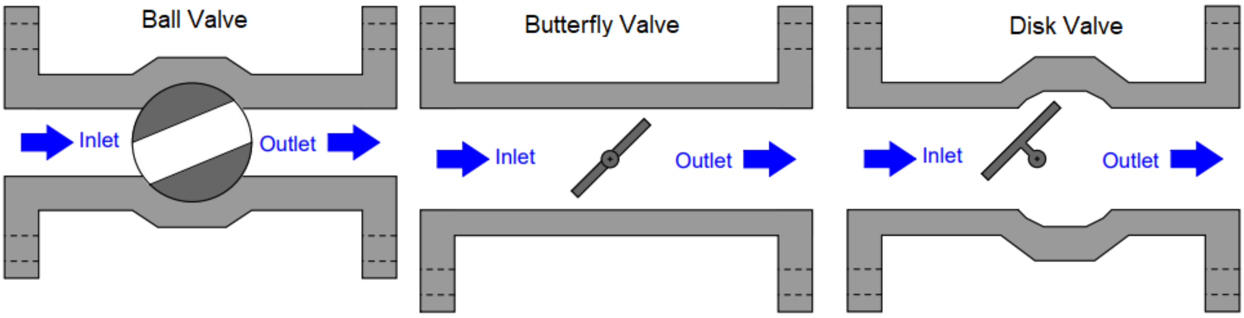

Figure 22. Rotary-stem valves operation types (Kuphaldt. T., 2019, Page 2096)

Valve selection and dimensioning are affected by flowing material and process conditions (Toukonummi 1983). The valve mechanical selection includes the choice of the appropriate valve type, materials and pressure class. The selection must also take into account local laws and regulations. End user may have also standard where is defined how to select valves. After the valve has been mechanically selected, the valve must be dimensioned to get the process working. (Kirmanen et al., 2011).

5.1 Plug valve

In process technology valves are used in continuous operation over the years and valves must perform with as high as possible reliability. Any failures leading to outages or unplanned maintenance cannot be accepted. Reasons for damages in valves are, high pressure, high temperature or example wearing. Material flows in process technology are abrasive and corrosive. Particles within the fluid medium can wear valve seats and sealing components. Wearing of the valve seats and sealing can cause process leakages and even safety hazards. For reliable operation of the valve, the preferred valve type is plug valve, which is shown in Figure 23. Also plug valve need to be designed for using purpose. In high pressure applications the most preferred selection is pressure balanced plug valve. It is with metal-to-metal seats for good shutoff and high resistance to erosion and abrasion. Plug valves long using history has proved that it is one of the best selection for high performance and long lasting in white liquor plant applications. Plug valve is providing good reliability and easy services. (Flowserve 2017).

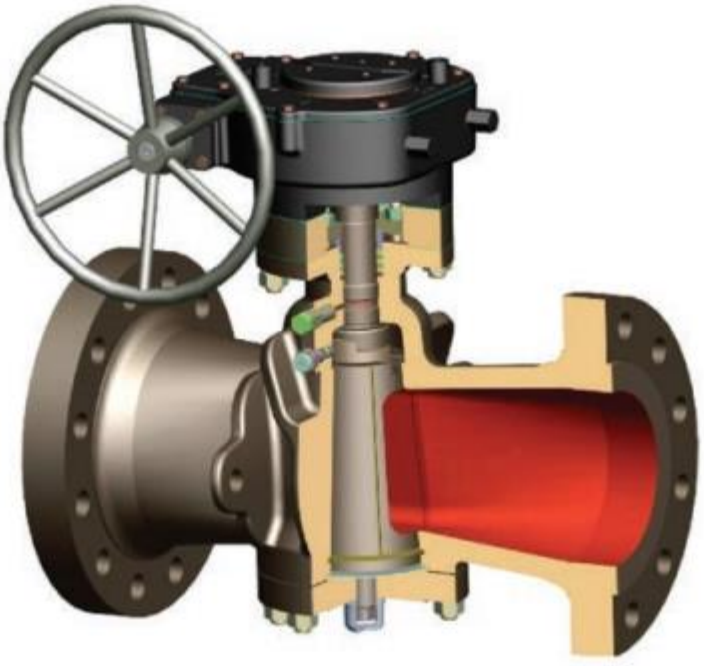

Figure 23. Pressure-balanced plug valve (Flowserve 2017)

5.1.1 Plug valve benefits

Sturdy metal-to-metal seats adapt well to the particles included in process streams. Particles can flow at high speed in close proximity to the integral seating surfaces, especially when the valve is opened against a high differential pressure over the valve. Plug valves are the favored selection for bypass and equalization on main gas pipelines by most major gas transportation companies. In Figure 24 is shown flow behaving when plug valve is opened against high differential pressure.

Figure 24. Plug valve opening against a high differential pressure

Sturdy metal-to-metal seats have additionally high protection to solids particles of gap/cavity between plug and body guarantee that particles are not caught between fitting and body thus avoiding harm to the seats while shutting the valve. In Figure 25 is shown how particles behave at plug valve when it is closed.

Figure 25. At plug valve particles do not become trapped between plug and body

The huge seating area furthermore enhances the resistivity to corrosion. The broad area maximizes the effectualness of sealant, so that if the valve starts leaking it can be rapidly resolved by injecting sealant, restoring the valve's bubble tight shut-off capabilities without the need of valve replacement or modernization. Sealant can be injected with the valve in any location and also under process conditions, making the valve in-line maintainable. In Figure 26 is shown plug valve completely closed.

Figure 26. Plug valve is valve in-line maintainable

At the point when the valve is open, dissimilar to in other valve structures, the seats are well protected from the process media. This guarantees regardless of whether the valve is left open for long periods of time, its seating areas won't get harmed, hence guaranteeing good sealing and long valve life time. Plug valves have no cavities where solids can deposit and impair valve operation. In Figure 27 is shown plug valve fully open and how seats are well protected in that situation.

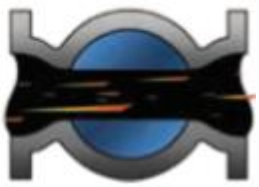

Figure 27. When the plug valve is open, the seats are well protected

(Flowserve2017)

5.2 Ball valve

The industry has a lot of application where the ball valve is in use. Ball valves can be divided in five general bodies' construction type. Those are three piece bodies, two piece bodies single body top entry, a split body and welded body. As shown in Figure 28, ball valves consist of valve body and a ball, which is attached to stem, that opens and closes the valve. Valve opens by turning the ball, when ball is fully turned the ball hole is align with the pipe end. When valve is same size than pipe, there is no restrictions for flow. When the ball hole is perpendicular to the pipe ends, the valve to close and pipe shut completely. If flow characteristics needs adjustment at the valve it can be done by shaping the ball hole to something else than standard (Kuphaldt. T., 2019).

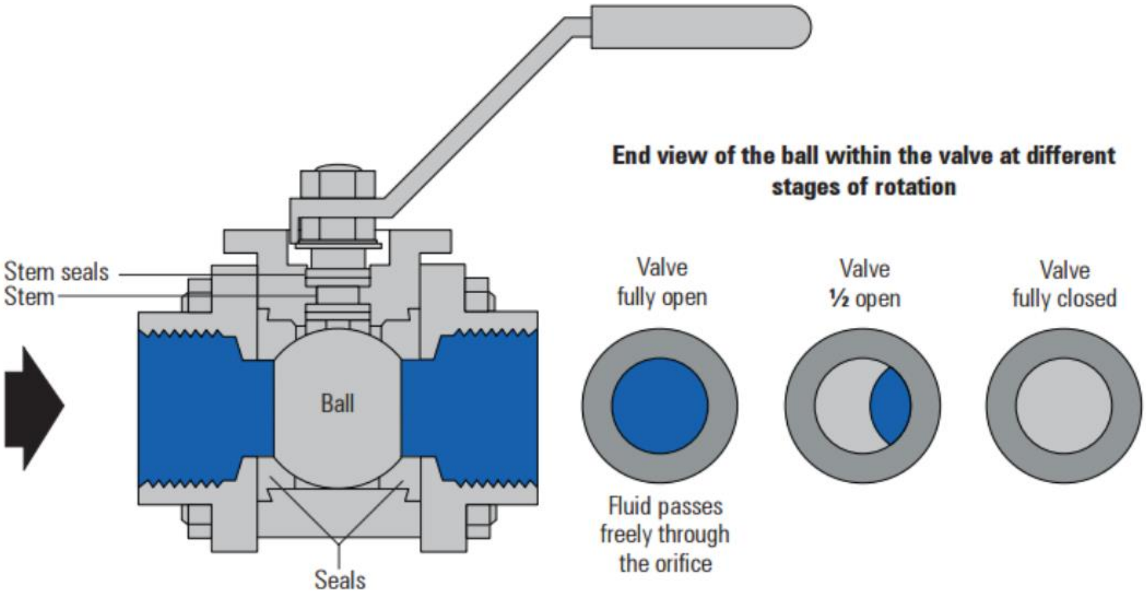

Figure 28. Ball valve opening positions (Spiraxsarco, 2005)

5.2.1 Ball valves benefits

The biggest benefit when comparing ball and plug valve is the higher sealing capability. Ball valves offers bubble-tight seal with low torque. Needed torque is about half than what plug valve need in same application for turning. Ball valves do not need any lubrication to be able to operate easily. Ball valves has longer expected operation lifetime. Ball valve offer a longer service life and, when used under the intended conditions, it provide many years of reliable operation. The ball valves are appropriate for a wide range of industrial applications where it is necessary to regulate the flow of liquids or gases. In addition, Ball valves, when correctly selected for process, can maintain and regulate high pressure, high volume flow and high temperatures. Maintenance for ball valves are simple and easy. Seats are easily accessible when a valve requires fixing. In addition, if ball valve is compared to gate valves, ball valves have smaller dimensions and they are lighter (Boson, 2018).

5.3 Valve price comparison

Table 1 compares the price lists of two different Andritz valve suppliers for the ball and the plug valves. Table 1 is showing how much ball valve more expensive than plug vale. Blue bars are shoving price difference in PN10 pressure class and red bars are showing price difference in PN25 pressure class.

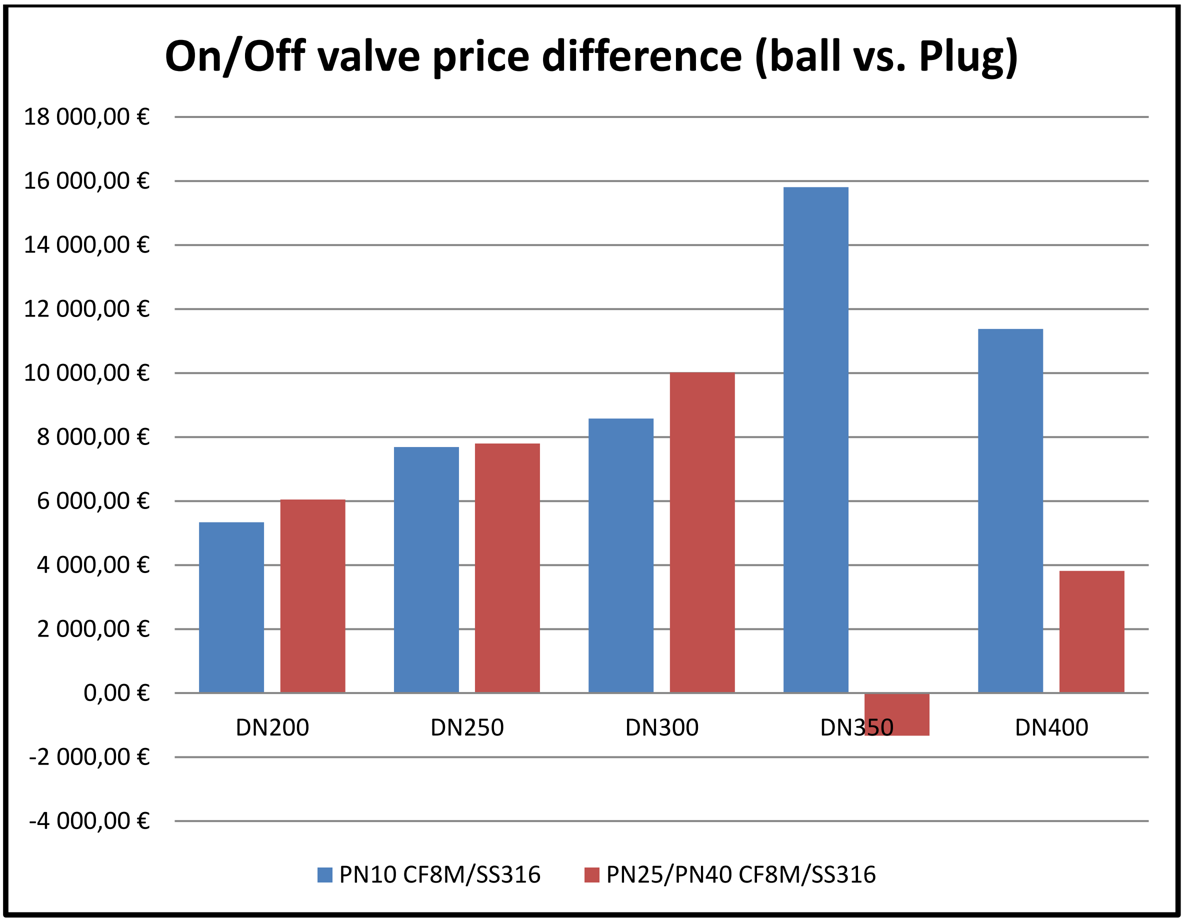

Table 1. Ball valve price compared to plug valve price

From table 1 can be seen that plug valves are cheaper than ball valves. Savings amount increases when valve size increases. Also in higher pressure class savings are bigger. Only exception is in size DN350 in PN25 pressure class. This is most probably due that DN350 size is not commonly used for pipes or valves.

This same change, from ball valve to plug valve, can be done for manual valves also. When white liquor plant capacity is more than 15 000 cubic meter per day we have over 50 big manual ball valves and over 40 big automatic on/off valves installed in white liquor plant. As we can see from table 1 average saving from one big automatic on/off valve is about 6 000 euros. Then total capital investment savings for white liquor plant automatic on/off valves will be more than 200 000 euros. At big manual valves total savings will be similar. Manual plug valves instead of ball valves has been in use in couple project and so far, those has been working well. Also automatic on/off plug valves has been in use in couple project and so far, those has been working well.

6 MEASUREMENT TO IMPROVE

Andritz has faced sometimes problems with level measurement in the filters. Level measurement is used for equipment operation, which is why measurement need to be exact and reliable. Dregs amount in raw green liquor and dregs amount in process streams is very important information for process control. Nowadays Andritz doesn’t have working solutions for dregs amount measurement online.

6.1 LimeWhite and LimeDry level measurement

For LimeWhite and LimeDry filters Andritz has tested pressure transmitter-based level measuring technology and radar-based level measuring technology. Those has been working well but accuracy has not been enough good for equipment control and over the time the measurement zero points is moving. That is why Andritz has started to search new options for level measuring.

For LimeWhite and LimeDry applications, Drexelbrook manufactured radio frequency admittance and capacitance continuous level measurement should be tested. It has proven Cote-Shield technology that ignores coating build-up on the probe. Sensor has been used in mineral industry and paint industry with good references. In addition, vapor, dust or foam is not disturbing the measurement reliability. Zero point of the measurement is staying where it is defined. Tank obstructions such as nozzles, ladders, pipes and agitators are not affecting to measurement, device can all the time measure absolute level.

The Drexelbrook radio frequency admittance level transmitter measures the capacitance between the sensing probe and the reference ground to determine the level of the material in the vessel. Measurement function is same than all other capacitance type level measurement devices. The improvement compared to other suppliers is the Cote-Shield technology. Zero point is determined in normal way, when the sensing probe is in air only, so no material around the sensing probe, the amount of capacitance is measured and that is determined as zero point. That capacitance represents empty vessel. As the level in the tank start to increase and surround the sensing probe, the capacitance changes relatively until the maximum material level is reached. When maximum material level is reached, that is determined as hundred percent level. The difference in capacitance between the value with material present at any given point on the probe and the value in air only is telling the material level inside the vessel. Capacitance change when the material present at any given point on the probe is linear.

Radio frequency admittance level transmitter utilizes the capacitance formed between the sensing probe and the metal vessel wall to calculate the level of the medium inside the vessel according to the capacitance theory that the capacitance and vessel are ratable increased. In Figure 29 is shown the calculation method.

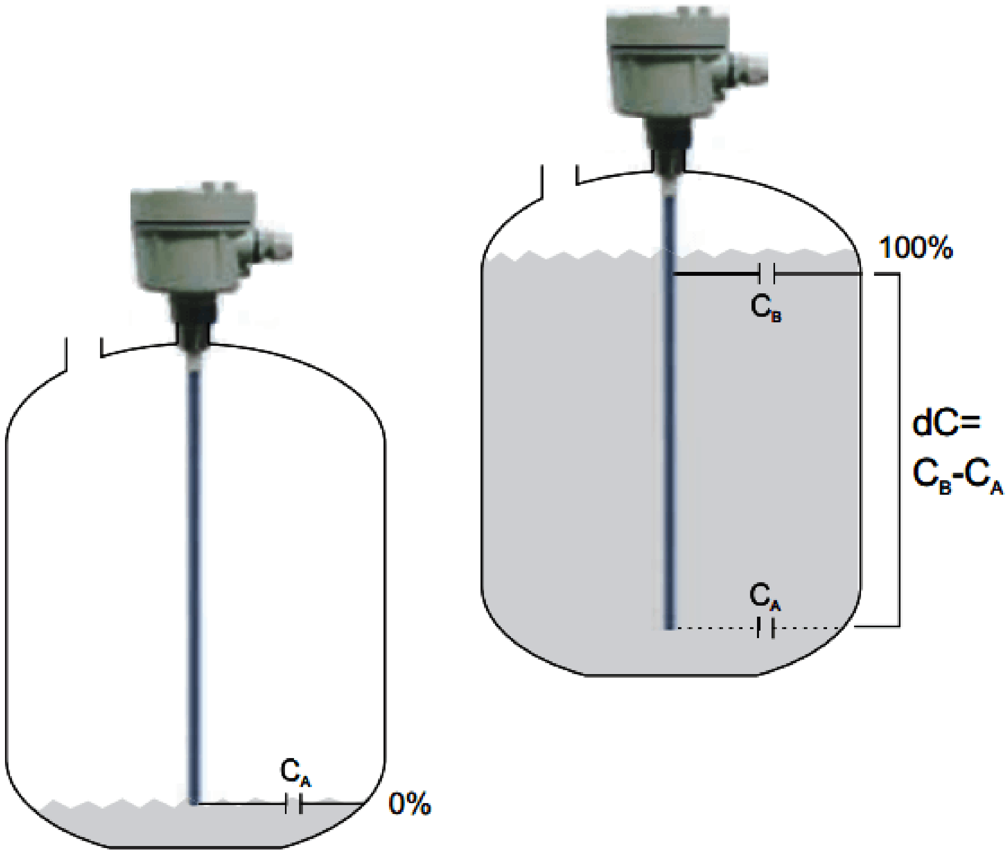

Figure 29. Radio frequency admittance level transmitter working principle (FineTek 2016)

When the probe is surrounding by the air, little capacitance (C_A) is measured by the equivalent capacitor, the capacitance increase gradually as computing media, the maximum capacitance (C_B) will be measured while the tank is full, the difference (dC) between C_A and C_B is corresponding to the level. (FineTek 2016)

Andritz has already tested this device at one filter. Experiences need to collect from the mill. Problem is at the moment, that device is having only local screen for measuring results. Device should be connected to mill Distributed control system. That way results could be compared to existing differential pressure measuring device and other measured parameters from the plant.

6.2 Flow measurement for solid particles

For cyclone level switch Andritz standard solution has been radioactive level detector. Radioactive measurements are always complicated to import other countries. Also measurement is complicated to set-up and if settings are not done correctly measurement is not reliable. The best non-radioactive solution could be Drexelbrook IntelliPoint™ RF RML Series Point Level Switch. Level switches detect the presence or absence of material and supply a relay output for control functions. Device is detecting the material flow or presence of material.

IntelliPoint radio frequency admittance level transmitter is new development for level switch. It is similar to the capacitance concept, IntelliPoint uses a radio frequency signal for detecting the level and adds the Cote-Shield circuitry within the electronics unit. This Drexelbrook patented Cote-Shield circuitry is designed into the IntelliPoint series. Cote-Shield circuitry make possible the instrument to ignore the effect of buildup around the sensing element. Sensing element does not react the material coating on the sensing element. The sensing element is attached in the vessel and provides a change in radio frequency admittance. The changes in radio frequency admittance is indicating the presence or absence of material.

The Cote-Shield element of the sensor prevents the passage of radio frequency current through the coating of the sensor element. The only way to ground for the radio frequency current is through the material being measured, the coating is preventing all other ways. That way result are an accurate measurement. Sensing element is careless of the amount of coating on the sensing element, this makes it the most versatile of the technologies currently available. It is well working to a very wide range of conditions, from vacuum all the way to 10 000psi pressure, from high temperature to cryogenics, it work also with many kind of materials.

Correct installation location for the sensing element is in the flow stream. In Figure 30 is shown different installation locations for sensing element. Installation location is important to prevent excessive buildup of material on the face of the sensing element. Sensing Element in an angle chute is not good selection. The best location is mounted on either side of sensing element at the bottom. These sensing elements are designed and built to withstand the impact of hard material hits example coal, rock, wood, and so on. Sensing element can be protected from falling material with extra protection. That kind of protections increase excessive build up. Typically build up are consisting of wet and or sticky fines. Same sensor can be used as low-level sensors or to detect a plug or to insure that a seal is present, chute is full at this point (IntelliPoint RF manual).

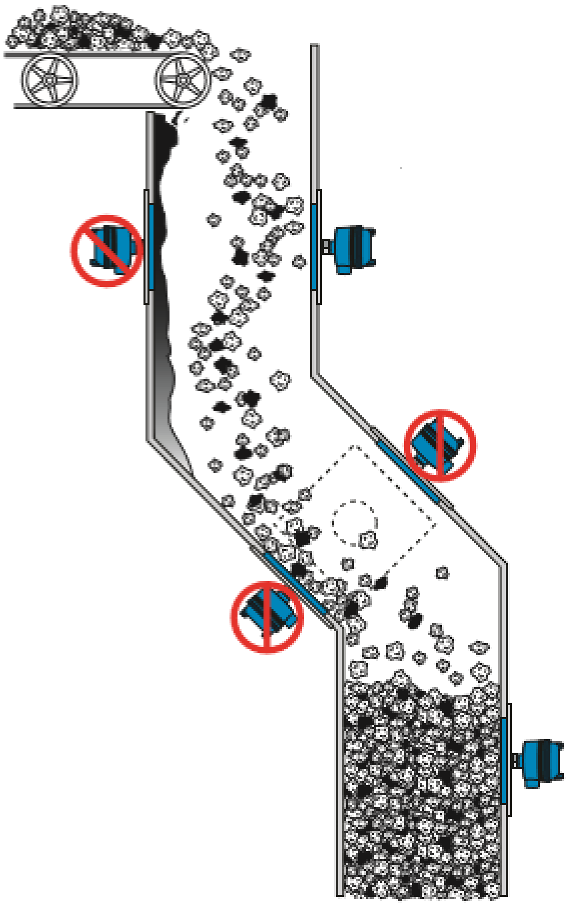

Figure 30. IntelliPoint™ RF RML Series Point Level Switch installation positions (Intellipoint RF manual)

Andritz has already tested this device at one cyclone. Experiences need to collect from the mill. Problem is at the moment, that device is having only local screen for measuring results. Device should be connected to mill Distributed control system. That way results could be compared to existing radioactive measuring device and other measured parameters from the plant.

6.3 Green liquor dregs

Efficient dregs handling is needed for decrees of land waste amount and decrees of losses from the process. In addition effective green liquor purification is important because at white liquor plant the level of non-process elements (NPE) need to be controlled. In modern mills there is two point where liquor cycle is opened for non-process elements removal. First point is dregs removing from the process and second point is electrostatic precipitator dust removal. Normally, the dregs contain carbonates, for instance, sodium carbonate and calcium carbonate, sodium hydroxide, sulfides, unburned carbon, and traces of heavy metals. Depending of green liquor total titratable alkali there can be also the crystals of calcium phosphate, which are precipitated from green liquor based on total titratable alkali and temperature. Dregs is dark green color, reason for the color is the dissolved sodium hydrosulphide.

Because of the presence of dregs, green liquor cannot be directly used for causticizing process. Dregs need to be first separated from green liquor. Separation process includes two main stages, separation of dregs from the green liquor in clarifier or filtration and dregs washing and dewatering in pre-coat filter or decanter-type centrifuge or filter press to an appropriate moisture level for disposal. The amount of the dregs is depending of the cooking raw material. In modern mills dregs amount coming from the recovery boiler is 3 to 4 kilos per ton of pulp. Dregs concentration is raw green liquor is from 0.6 to 2 grams per liter (Golmaei, M et al 2017).

6.3.1 Collo technology

Collo technology is having radio frequency sensor which could be suitable for dregs amount measurement from liquor stream. Collo sensor is the radio frequency resonator that emits an electromagnetic field into the liquid. The system sweeps through a frequency bandwidth to measure a response from multiple frequencies. The generated radio frequency field is harmless, similar to signals used in common telecommunication systems like mobile phones, television or radio.

When these signals are injected in liquid they are distorted depending on the liquid quality. Different types of liquids and chemicals lead to different resonance frequencies. Even another phase, such as solid particles in the surrounding liquid changes the signal. Dregs flow streams are like that, solid particles are in liquid. Collo compares the emitted signals with the received signals, this commonly known as frequency response. All this data is processed with ColloidTek's proprietary algorithms to determine the fingerprint of a liquid and thus it can be linked with physical liquid parameters.

Principle behind the measurement is in the electromagnetic field that Collo emits in the liquid. The field vibrates the particles and/or the molecules in the liquid. From this electromagnetic field, Collo measures parameters related to dielectric constant, this is known as relative permittivity. Dielectric constant has two parts: The imaginary part of dielectric constant is related to ion viscosity and loss tan, and is strongly interlinked with the chemical changes in the liquid. The real part of dielectric constant is related to overall permittivity, which is strongly interlinked with specific physical properties of substance, such as phase/state of matter or its density. In other words, it corresponds with energy stored in a material from the measuring field and the changes in the amount of different phases within the measuring field change the relative permittivity.

Based on the above, each substance can be characterized by its dielectric constant. If characteristics are known, a mixture ratio or changes in solid content can be measured by monitoring the dielectric constant. For example, sand has the real part of a dielectric constant close to 4 whereas water has 80, should you mix sand and water with the ratio of 1:1 the overall constant would be roughly $80 + 4 / 2 = 42$, should you have different sand with a different dielectric constant, you would also recognize that. In more detail, both components, the imaginary and the real part of dielectric constant, depend on the frequency of the field variation. Consequently, more information can be obtained from a liquid when more than one measurement frequency is used.

Collo technology is doing liquid fingerprint. It is a set of parameters that enable to identify the liquid. Collo measures a matrix of data that contains 15 different proprietary parameters enabling accurate detection of liquids. These 15 parameters behave differently in different liquids.

For Collo to identify liquids correctly, it needs to be taught what the liquid is. When the liquid in the process consists of multiple components, or has a recipe, Collo can identify the relative concentrations and composition of the liquid, when it first knows the fingerprint of the individual components. After the teaching process it can accurately measure the composition, detect changes in chemicals, and identify many features in solids and different phases (Collo-technology 2018).

Collo technology is having good references, example:

- Ceramic slurry to measure suspension stability, changes in solid content and agglomeration.
- Mining industry for measuring changes in solid content
- In chemical industry to recognize sedimentation
- Drug industry for solid content and agglomeration
- Lime stone process for solid content and agglomeration
- Lime stone process for particle size measuring
- Paint and coating industry for changes in dissolved chemicals, solid content and homogenization of the liquid
- Nuclear industry for water analysis
- Milk industry for fat content and souring measuring
- For food industry dry mass content in vegetable puree

In Figure 31 is shown Collo sensor submerged in paint mixing vessel.

Figure 31. Collo sensor submerged in paint mixing vessel (Collo-technology 2018)

Collo technology has previously co-operated with South-Eastern Finland University of Applied Sciences fiberlaboratory. There Andritz could test how Collo sensor is working with dregs. Mill dregs samples should be collected from Joutseno mill, Kaukopää mill and Äänekoski mill, which are nearby the laboratory.

7 CONLUSIONS

The aim of this Master of Science thesis was to investigate what instruments could be modernized in white liquor plant. In addition, the aim was investigate possible cost savings with different kinds of valve selection at big valves.

For level measurement device we are having promising results. Research should be continued to find out is this system really working well in years of operation. At the moment device is having only local screen for measuring results. Device should be connected to mill Distributed control system. That way results could be compared to existing differential pressure measuring device and other measured parameters from the plant.

For solid particle flow device we are having promising results. Research should be continued to find out is this system really working well in years of operation. At the moment device is having only local screen for measuring results. Device should be connected to mill Distributed control system. That way results could be compared to existing radioactive measuring device and other measured parameters from the plant.

For dregs amount measuring from liquor stream Andritz should start co-operation with South-Eastern Finland University of Applied Sciences fiberlaboratory and Collo technology. Andritz should test how Collo sensor is working with dregs. Mill dregs samples should be collected from Joutseno mill, Kaukopää mill and Äänekoski mill, which are nearby the laboratory.

With different kinds of valve selection at big valves total cost saving can be 400 000 euros. When white liquor plant capacity is more than 15 000 cubic meter per day we have over 50 big manual ball valves and over 40 big automatic on/off valves installed in white liquor plant. Average saving from one big automatic on/off valve is about 6 000 euros. Then total capital investment savings for white liquor plant automatic on/off valves will be more than 200 000 euros. At big manual valves total savings will be similar.

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