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Optimisation of a Phosphate horizontal belt filter plant

by

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Submitted in partial fulfilment of the requirements for the degree of

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Executive Summary

The project covers the optimization and activities related to the improvement in process quality for the Horizontal belt filter plants at Foskor Phalaborwa. Foskor Phalaborwa is a phosphate producing mining operation located on the eastern edge of Limpopo South Africa in a town called Phalaborwa.

The need for a more in depth investigation and problem analysis focused on the Filtration department at Foskor Phalaborwa was requested. The investigation and problem analysis of the problem areas at the Filtration department serve as the back bone for the project conducted by the author.

The project aims to identify the main causes for the filtration plant not operating within desired specifications for moisture content percentage of the discharged phosphate product.

The identification of a number of issues that contribute to the failure of the Filtration section in meeting their 8.5% moisture content goal for discharged product were identified. The most evident of the identified issues were that of plant operation and maintenance.

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Introduction and background

The project covers the optimization and activities related to the improvement in process quality for the Horizontal belt filter plants at Foskor Phalaborwa. Foskor Phalaborwa is a phosphate producing mining operation located on the eastern edge of Limpopo South Africa in a town called Phalaborwa.

The horizontal belt-filter plant at Foskor Phalaborwa which is used for separation of liquid from the solid phosphate product has been struggling to achieve the desired goal of 8.5% moisture content for the plant's discharged product since the end of 2008.

The down-stream section that is directly affected by the high moisture content product produced by the filter plant is Drying and Dispatch. The product that is received by Drying and Dispatch is sent through drying ovens so that the phosphate product can be further dried so that a moisture content percentage of approximately 1.5% can be achieved before it can be sent to dispatch. The drying operation burns coal as energy source. The higher the moisture content of the phosphate product that is received by the drying ovens, the longer it has to spend in the drying process to achieve the desired moisture content for dispatch. Consequently the higher the moisture content of the product received from Filtration the more coal is burnt by the drying ovens and the higher the operating costs of the process becomes.

Problem statement

The Production management at Foskor Phalaborwa had expressed their concern with the high moisture content percentages of the phosphate product that is received by the Drying and Dispatch department. The request from Production management for an investigation and problem analysis regarding the high moisture content percentages of the phosphate product received by the Drying and Dispatch department, had led to the identification of problems at the filter plants.

The need for a more in depth investigation and problem analysis focused on the Filtration department was requested.

Project aim

The project will aim to identify the main causes for the filtration plant not operating within desired specifications. The identified causes will have to be investigated so that a decision to either eliminate or rectify them can be made.

The development of strategies and performance measurement tools are required to ensure that the filtration plant performance can in future be monitored continuously aiding in early identification of possible out of control plant operation.

The project will also aim to provide the Filtration department with the required knowledge and tools to identify problem areas in the filtration plant and to assess the performance of the operational and maintenance teams.

Project scope

The Filtration department at Foskor Phalaborwa has three separate filter plants; two of the plants namely New-filters and Old-filters, are built right next to each other in close proximity to the regular mining operations area. The other plant which is Bush pumps was built far from the regular mining operations area.

The investigations and problem analysis had been requested to be performed on New- and Old-filters only, as they were of most concern in terms of performance regarding moisture content percentage of discharged phosphate product and because of their close proximity to the regular mining operations area. The New- and Old-filters plants both operate two horizontal belt filters namely Filter 12, 13, 15 and 16.

The filter plants consist of three main operational areas: Thickeners, Vacuum system and the horizontal belt filter unit. The investigations are grouped according to the three main filter plant areas. The New- and Old-filters have slight differences in their basic layout and operation which will need to be investigated.

The operation and maintenance of the filtration plant as a whole as well as its three main areas individually will have to be understood and assessments of the plant's operational and maintenance performance will need to be made for the project to be conducted successfully.

The filtration plants will also be investigated with regard to the human-, equipment-, material- and financial factors as well.

The filtration plants will be in operation during investigations and problem analyses which create the need for proper communication of scheduled maintenance and irregular operation of the filtration plants during an observation period. The data used for problem analysis and identification of problem areas, will need to be defined in terms of operating conditions at time of measurement for the analyses to be done correctly.

The operation of the three main filter plant areas will be investigated individually so that any irregularities can be identified and to assess whether the plant is being run according to the design specifications.

The Thickeners have a specified Pulp density at which they should operate; this will be used as the primary variable measured during the investigation and problem analysis of the Thickeners.

The Vacuum system's performance is measured according to the achieved vacuum pressure. This will be used as the primary variable measured during the investigation and problem analysis of the Vacuum system.

The Horizontal belt filter unit will be inspected to see if the unit's operation is according to the design specification.

The Filtration plants' performance will be measured according to the combined moisture content of the discharged phosphate product.

The human factors to be addressed focus mainly on maintenance- and operating procedures. The performance of the operations and maintenance teams will be measured according to key performance indicators.

Figure 1: New filters

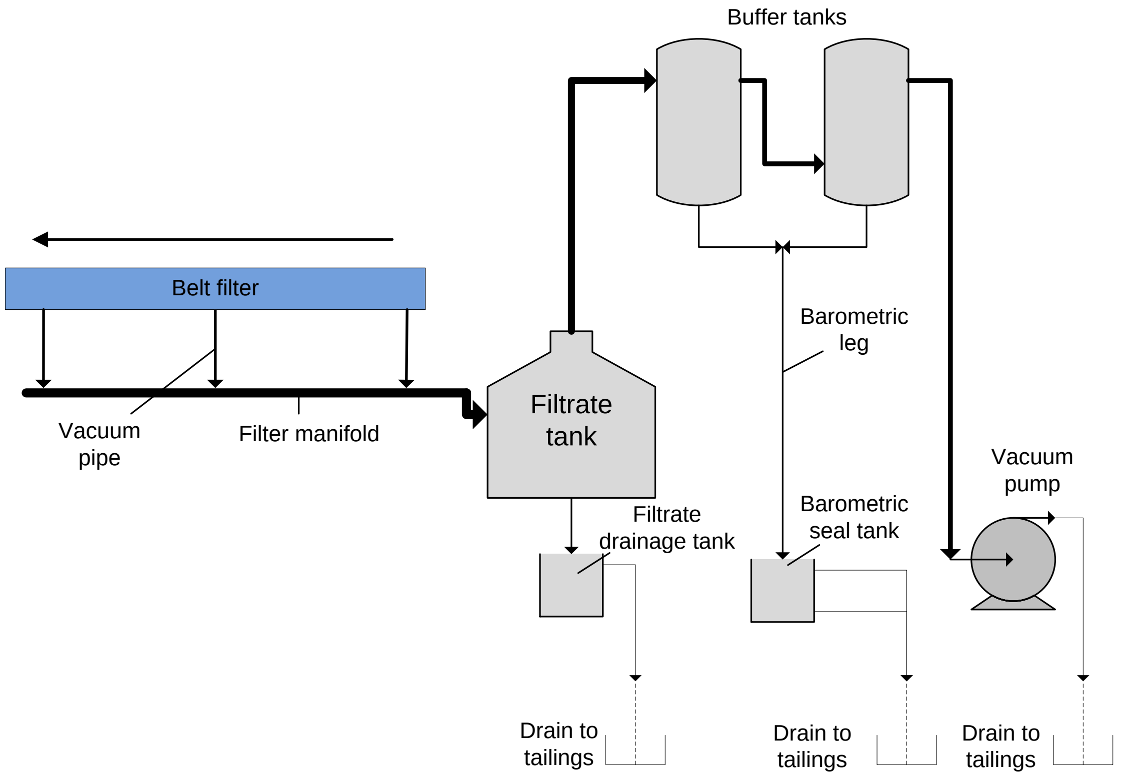
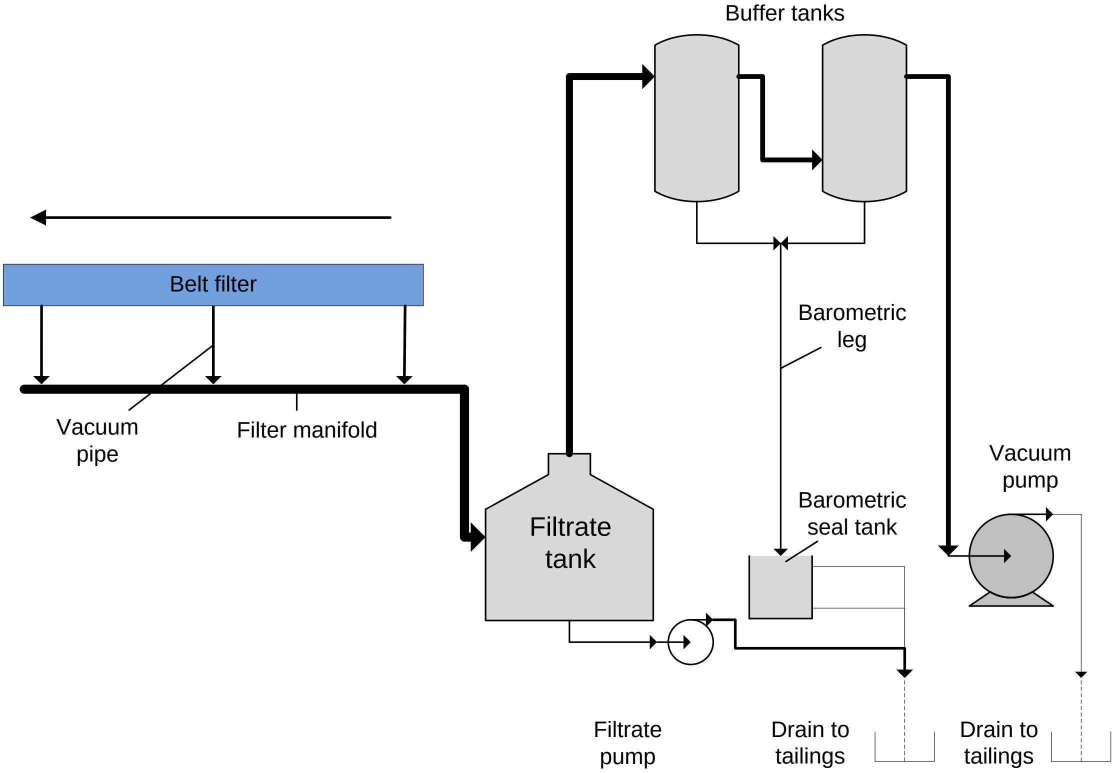


Figure 2: Old Filters Vacuum system



Literature review

Filtration Plants

Theory of Filtration

The process of separating minerals from an ore body requires the use of large quantities of water. The product or concentrate that is produced from the separation process should be relatively dry before it can be sent to customers. The process that is required to remove the water from the concentrate is called dewatering. The dewatering process consists of three main sub-processes they are: sedimentation, filtration and thermal drying. The dewatering process is done in the order of sedimentation then filtration and finally thermal drying.

The basic workings of a filtration process in a minerals operation can be simplified by comparing it to the filtering of coffee. The coffee filtering process makes use of a porous cloth or paper which allows the liquid to pass through, but the coffee which did not dissolve stays on the porous cloth or paper. The filtration process in a minerals operation also makes use of a porous medium which holds the minerals in solid form and allows for the liquid in the fed mineral pulp to pass through and thus a separation of solids and liquids is achieved. The mineral solids that do not pass through the porous medium build up over a period of time and form a filter cake.

The filtration process's efficiency and rate of filtration is not linear. The efficiency and the filtration rate of a filtration process will decline as the process elapses; this is due to the increasing resistance created by the build up of the filter cake.

There are certain factors that have a definite effect on the filtration rate of the process as stated in Will's Mineral Processing Technology:

- Pressure: The pressure difference measured from the feed to the far side of the filter. The feed of the filter is at atmospheric pressure and the far side is either at a negative pressure (vacuum pressure) or a positive pressure depending on the filter process.
- The filter's surface area.
- The filtrate's viscosity.
- The resistance created as the filter cake forms.
- The resistance of the filter medium used in the filter process as well as the resistance of the formed cake at the beginning of the filter process.

The filtration process's performance and efficiency is dependent on the filter medium used in the application. The filter medium should be able to hold the concentrate or solids throughout the filtration process and it should at no stage during the process restrict the draining of liquid from the filter cake. The filter medium should be able to withstand high straining forces and allow for as little flow of the filtrate or product through the medium.

Filtration Processes

The process of filtration can be achieved by many different methods. The different types of filtration processes differ by the means in which filtration is performed and the application of these processes are suited to specific situations.

The different types of filtration processes can be classified under pressure and vacuum filters.

- Pressure filters

Pressure filters can achieve excellent flow rates, washing and drying performance due to the high pressures that exist. The downside of pressure filters is the removal process of the filtered product which can be very difficult. Pressure filters are available in a continuous process configuration but is commonly found as a batch process application. The different types of pressure filters:

  - Filter presses
    - Plate and frame presses
    - Chamber press
  - Automatic pressure filters

The pressure filters can achieve throughputs of 150 tons/hour and more at moisture content of the filtered material ranging between 7.5 and 12.5%

- Vacuum filters

Vacuum filters make use of a vacuum system which is used to create a negative pressure underneath the filter medium which is supported by a system which function is to drain the liquid out of the system. Vacuum filters can be used for a batch filtration processes but continuous filtration processes are the ones that are most commonly used. The different types of vacuum filters:

  - Batch vacuum filters
    - Leaf filters
    - Tray filters
  - Continuous vacuum filters
    - Rotary-drum filter
    - Disc filters
    - Horizontal belt filters

The most effective filtration process in terms of discharged product moisture content is the horizontal belt filter system.

Process Importance

The filtration process should operate in such a way that the moisture content of the product which is sent from filtration to drying is as close to the desired finished product's moisture content; this is due to the fact that the drying process is expensive and the lower the moisture content of product fed into the drying the process, the lower the operating costs of the drying process will become.

The importance of a well functioning and efficient filtration process cannot be overstated and the correct choice of filtration process should be made to the application.

Horizontal Belt filter

Process Description

The horizontal belt filter process is a continuous process. The filtration process starts with a feed of slurry or pulp that flows onto the belt into a feed dam area, the belt is in constant motion while the filtration process is performed. The slurry or pulp which settles on the belt on top of the filter medium is discharged at the end of the belt where the filtration process is then finished. The filtration/dewatering of the slurry is made possible partly by means of gravitation but in large by means of a vacuum that is created beneath the horizontal belt filter.

The horizontal belt filter is designed to create an air seal everywhere except the filtrate cake; this enables the vacuum created by the vacuum system to be acting on the surface area of the filtrate cake which has air at atmospheric pressure above it. The pressure difference above and below the filter cake has the effect that the positive pressure above will want to occupy the vacuum existing below. The solids in the filter cake are not able to pass through the filter medium but the liquid and air are able to pass through the filter medium. The action of the positive pressure occupying the vacuum has the effect of pushing the liquid out of the filter cake and through the filter medium, effectively filtering the filter cake.

The effect of the pressure difference creates the same action as is performed during the operation of a press filter.

There are certain factors that give the horizontal belt filters an edge over other filtration processes:

- The speed of the filtration process can be adjusted, providing additional control.

- The filtrate cake is discharged in an effective manner.
- The discharge process allows for ease of conveyor material handling.
- The filter cloth is cleaned every cycle.

Design

The horizontal belt filter is a type of conveyor, which transports the material through a filtration process but which is also part of the filtration process itself.

The filter medium for the filtration process is a filter cloth and is the top most component of the horizontal belt filter. The filter cloth is stitched together so that a cloth covering is formed around the belt system

The filter cloth rests on top of a transport belt, which is a thick rubber belt with drainage trenches running across the width of the belt with two drain holes located in the middle of the trenches. The transport belt has skirting on its sides which act as the air seal between the sides of the filter cloth and transport belt. The transport belt is vulcanized together to form a transport belt around the belt system.

The transport belt and the filter cloth are supported by rollers on their return cycle; the rollers are used for alignment of both the transport belt and the filter cloth. The filter cloth is spread over multiple rollers just before the feed dam area in such a manner as to ensure that folds do not develop in the cloth.

The transport belt runs on top of wear strips that create an air seal between the transport belt and a vacuum box which is fixed below the transport belt. The vacuum box simultaneously serves as the vacuum housing for the horizontal belt filter and a drainage system. The vacuum system connects vacuum pipes from a manifold to the vacuum box. The liquid that is moved through the filter cloth and the transport belt flows into a drainage system in the vacuum box. The vacuum box stretches from the feed dam area to just before the discharge of the belt.

The feed dam area is where the slurry is deposited onto the horizontal belt filter and this is where the filtration process begins. The feed dam area can be fitted with overflow protection to ensure that feed overflows do not result in excessive losses. The dam of feed is formed with the aid of a skirting which stretches over the width of the transport belt.

The dimensions of the horizontal belt filter specifically in terms of length and width are calculated by the manufacturer who ensures that the correct filtration processing time and throughput can be achieved by the design dimensions.

Figure 3: Horizontal belt filter unit

Figure 4: Transport belt

Figure 5: Filter cloth and roller

Figure 6: Horizontal belt filter discharge of filtered cake

Process/Operation Control Systems

The Horizontal belt filter can be controlled by its belt speed and the rate of slurry being fed onto the belt. The controls of the horizontal belt filter can be programmed into a SCADA system. The belt speed and feed rate of the slurry, both affect the thickness of the filter cake on the horizontal belt filter.

Maintenance

The horizontal belt filter should be routinely inspected to ensure the effective operation of the parts on the filter. Faulty parts and operation of the horizontal belt filter can be identified up by inspection if done by one that understands the process and knows what to look for. The transport belt may require re-alignment at times. The vacuum box should be inspected for holes caused by rust, which will cause loss of the air seal. The rollers of the belt system should be kept clean and operational. The fans underneath the transport belt should be serviced to ensure their effective operation. Instrumentation equipment should be routinely checked and the correct functioning ensured.

There are certain parts that require routine changes, much like an oil change of a car; these are:

- The wear strips
- The filter cloth if damaged or worn
- The skirting on the transport belt
- Rollers if they are not functioning properly
- Drainage pipes

Areas of Concern and Observations

The horizontal belt filter process is fairly robust, but there are some areas which should be kept under close watch to ensure effective operation. The belt speed and feed rate should be monitored and fine tuned to ensure that a filter cake is produced that is not to thick or thin. The alignment of the transport belt is of utmost importance as misalignment can cause a loss of air seal thus creating a loss of filtration efficiency. The misalignment of the transport belt can also lead to discharge problems and in some cases the product can be lost to tailings and never be recovered. Torn transport belt skirting can cause a loss of air seal. The holes in a vacuum box lower the efficiency of the filtration process.

Vacuum system

Process/Operation Description

The vacuum system's purpose is to create a negative pressure (vacuum) through the use of a vacuum pump. The vacuum pressure can be used to apply force to a surface or object; this is achieved by creating the vacuum on one side of the surface or object while the other side is at atmospheric pressure or at a different pressure.

The use of vacuum pressure as a force mechanism reduces the required floor space and moving parts in a system, as there are no parts or tools required to transfer the produced force at the application area.

Vacuum pumps are used to create the required vacuum in the system. The vacuum pump that is installed in a vacuum system should have the enough capacity to achieve the desired vacuum pressure of an application. Vacuum pumps are rated by power (kW) and the achievable vacuum value.

The vacuum pumps that are being reviewed are liquid ring displacement pumps, which displace water to achieve a vacuum inside the pump. The achievable vacuum listed for a vacuum pump is for ideal conditions at sea level. The following is a calculation of the maximum attainable vacuum at Phalaborwa where the process is located:

The maximum attainable vacuum pressure for a Nash CL 3002 vacuum pump which is the pump used in the filtration plants is calculated by the formula:

Max attainable vacuum = (-) [(Atmospheric pressure at measured altitude (kPa)) x (Max rated level of vacuum pump (kPa)) / Absolute vacuum (kPa))]

Atmospheric pressure at 300m = 97.63 kPa
Maximum rated level of vacuum pump = - 81 kPa (From Nash catalogue CL3002 vacuum pump)
Absolute vacuum = - 101.3 kPa

Max attainable vacuum (300m altitude) = (-) [(97.63) x ((-81) / (-101.3))]

= - 78 kPa

Design

The vacuum system's heart is the vacuum pump, which the vacuum system cannot function without. The vacuum pump is not designed to handle solids and the hull of the pump will be damaged if solids are run through the pump. The vacuum pump inlet should ideally only be fed with air but liquids can enter the pump as well.

The vacuum system is connected directly to the horizontal belt filter's vacuum box. The liquid that is removed by the horizontal belt filter contains traces of solids commonly referred to as fines. The liquid moves from the vacuum box into a manifold which in turn leads to a filtrate tank.

The filtrate tank is the first line of defence against solids entering the vacuum pump. The filtrate tank is fitted with a slurry pump, which removes the solids (fines) through gravitational settling in the tank. The less dense air-liquid mixture is pulled through to the buffer system which is raised above the rest of the vacuum system. The filtrate tank is not 100% effective in removing all of the solids from the vacuum system, thus requiring the need for the buffer system.

The buffer system is responsible for acting as a safety measure that removes solids from the system before they can reach the vacuum pump. The system normally consists of two buffer tanks, a barometric leg and barometric seal tank. The first of the two buffer tanks may have solids mixed with liquid and air, but the second buffer tank should have no trace of solids. The solids are removed by the buffer system by means of gravity; the heavier solids should drop down the barometric leg which is located between the pipe sections connecting the buffer tanks.

The barometric leg drains into the barometric seal tank where the solids are removed from the vacuum system and sent to the tailings. The barometric leg should be submerged in the barometric seal tank so that an air seal is achieved. The barometric leg should be able to drain into the seal tank without any resistance.

The buffer system is directly connected to the inlet manifold of the vacuum pump.

Figure 7: Vacuum Pump

Process/Operation Control Systems

The vacuum pump can be switched on and off and the valves of the vacuum system pipes can also be controlled. The control of these elements can be programmed into a SCADA system. This will allow for more effective control of the system and the vacuum pressure readings of the vacuum pumps can be read for the system.

Maintenance

The vacuum system does not have many maintenance tasks and inspections, but they can become difficult and cumbersome. The vacuum system maintenance consists mostly of routine inspections to ensure that the system is functioning properly.

The vacuum pump should be inspected for any leaks in the hull, water pipes, manifolds and valves. Holes should be patched and the cause for these holes should be identified. The vacuum pump's performance in terms of vacuum pressure should be noted as well.

The vacuum lines/pipes should be inspected for any visible holes and they should be patched.

The barometric seal tank should be cleaned every shift to ensure that there is no slurry blocking the outlet of the barometric leg. The seal tank is drained by means of a valve located at its bottom, during the draining process the water level should be kept above the outlet of the barometric leg.

The filtrate tank's slurry pump should be serviced so that it can perform its function properly. The tank should be flushed if needed. The manifold linked to the filtrate tank should be inspected for blockages during filter down times.

Areas of Concern and Observations

The vacuum pump develops leaks in the hull due to carry over of solids through the vacuum system. The carry over should be prevented by the buffer system's barometric leg. The barometric seal tank inspections should be made a high priority task if holes appear in the vacuum pump. These holes in the hull of the vacuum pump can lead to its premature failure.

The vacuum system should be checked for irregularities if the vacuum pump does not achieve acceptable vacuum levels (below -60 kPa). Without vacuum the filtration process will not exist. The horizontal belt filter process should not be regarded as efficient while the vacuum is not acceptable. The filtration process will only be able to run at maximum efficiency if the vacuum system is providing the best possible attainable vacuum value.

Vacuum losses can be attributed to these problems:

- Vacuum lines in poor condition (holes etc.)

- Vacuum box in poor condition (holes etc.)
- Blockage in the filtrate tank
- Worn gland seals on the vacuum pump
- Barometric seal tank not used correctly
- Blockage in the barometric leg
- Excess water in the vacuum system
- Vacuum pump not receiving enough gland water
- Transport belt misalignment
- Worn wear strips
- Filter cloth has holes in it
- Tears and rips in the transport belt skirting

Thickeners

Process/Operation Description

The process of thickening is based on the principles of gravity sedimentation. The gravity sedimentation process separates solids and liquids producing a slurry like discharged product. The slurry is produced by the solids in a liquid are settled and the less dense clear liquid can be removed out of the process, leaving behind slurry. Gravity sedimentation also called thickening can process large amounts of feed at lower cost than some of the other sedimentation processes. Thickeners produce very low shear forces during operation and this allows for fine particles to be flocculated.

The particle size of the solids affects the rate at which the settling of these solids takes place during the sedimentation process. The smaller the particle size of the solids the longer they will have to be in suspension before they will settle, this can be attributed to gravity; there are however processes to speed up the settling rate of a solid in suspension. Coagulation and flocculation are two processes that enable the particles of the suspended solids to bond together thus increasing the particle size of the suspended solids which increases their settling rate.

The coagulation and flocculation processes are also necessary for the process of filtration in some applications; the filtration process cannot be fed with slurry which is made up of solids with small particle sizes (fines) as this slurry will clog the filter medium. The blinding of the filter medium will reduce the efficiency of the filtration properties of a filter medium.

The slurry produced by the process of thickening is measured in terms of pulp density (Pd); the higher the Pd of the slurry the more dense it becomes and will have relatively low moisture content.

Design

Thickeners are cylindrical tanks, which can be built of steel or concrete whichever will suit the application. The dimensions of a thickener can range from a diameter of 2-200 meters and depth of 1-7 meters. The thickener has a feed well in its centre where the feed for the thickening process is pumped in. The feed well feeds into the thickener up to 1 metre below the surface of the liquid, which aids in creating as little influence to the settling process of the thickener.

The clear liquid that is produced by the thickener is located in the clarifying zone at the surface. The clear liquid is removed from the thickener as the process continues and the thickener fills and the liquid flows into the thickener's overflow. The settled solids form slurry at the bottom of the thickener where it is extracted by an outlet located at the centre of the thickener's bottom.

The thickener uses rakes at its bottom, which are fitted with blades that further increase the density of the slurry by compacting it. The rakes move the slurry to the outlet at the bottom of the tank.

Figure 8: Thickener

Figure 9: Thickener rakes

Process/Operation Control Systems

The thickening process can control the amount of feed and additives which promote flocculation or coagulation. The process control can be programmed into a SCADA system allowing for improved control of the process. The feed rate, feed tons and pulp densities (Pd) of the process can be read from the system.

Maintenance

Thickeners do not have many moving parts and the ones that are present are fairly robust. The maintenance procedure for thickeners is centered on the servicing of moving parts and motors. The rakes of the thickener can become damaged, this will require that the thickener be drained and excess slurry be washed out before repairs can be done.

The thickeners undergo thorough cleaning, but this is not a regular maintenance activity. The cleaning ensures that the feed well and outlet is clean and will not be blocked or choked. The rakes and axes will also undergo inspection during these cleaning operations.

The slurry pumps that are used by the thickeners undergo inspections and services should be done to ensure their correct functioning.

Areas of Concern and Observations

The main area of concern for the thickeners is the pulp density of the slurry that is discharged. The horizontal belt filter is designed to filter slurry with a certain pulp density. When the pulp density of the slurry produced by the thickener is too high the filter cloth of the horizontal belt filter will either blind or the filter cake will be too dense and will prohibit the filtration process. When the pulp density of the slurry produced by the thickener is too low the filter cake will not be able to form on the horizontal belt filter and vacuum losses will be too high as there will be no air seal, thus the filtration process will not be achieved.

The standard operating procedure for the filtration plant at Foskor Phalaborwa specifies a pulp density range for the thickeners of between 1.7 and 1.9. This Pd range was set with the capability of the filter cloth's properties in mind.

The thickener should not be fed with too much flocculent as this will increase the Pd of the liquid at a rate that cannot be handled by the rakes and the thickener will become choked, The choking of a thickener is a costly mistake as the thickener will be shutdown to be cleaned out.

Quality and Process Control Tools and Techniques

The filtration plant's three main areas of concern namely the thickener, vacuum system and horizontal belt filter will be analyzed and quality control and process improvement techniques will be used to asses and improve their performance.

The quality control and process improvement techniques where obtained from, *Quality management 3rd edition written by H.S. Gitlow, A.J.Oppenheim, R. Oppenheim and D.M Levine*

Control charts will be used to analyze the performance of the moisture content of the plant's discharged product and the pulp densities at which the thickeners are operating. The charts will be plotted over hourly intervals. The charts will be assessed daily and out of control points will be linked to activities or irregularities that might have occurred during these out of control periods.

Root-cause analysis will be used in many of the problem identification activities, drawing cause-and-effect diagrams will help during this activity.

Check sheets are to be implemented for shift related maintenance and problem identification activities. The check sheets will aid in identifying problem areas as soon as they arise.

Meetings will be scheduled with the maintenance and operations employees at the filtration plant. These meetings will be used to obtain information and data that is critical to the identification of problem areas as well as to gain insight into the process from the people who work on the process daily.

The change concepts that are listed in chapter 10 of the book Quality management 3rd edition will be implemented to further improve the process after the major problem areas are resolved.

Investigation Design & Analysis

Method

Standard operating procedures (SOP's) at Filtration

The purpose of the investigation was to observe and understand the SOP's of the whole filtration process, so that a very clear understanding of the process can be obtained and to ensure that the process investigation has a sound foundation.

Best practices for Horizontal belt filter operations

The identification of best practice Horizontal belt filter, Thickener and Vacuum system operation was obtained from the manuals and design specifications. The SOP's that were studied and further research had also provided a list of best practices for horizontal belt filter operation. The identification of these best practices before any physical investigation at the filters took place had aided in identifying problem areas and troubleshooting exercises.

Observation of filtration process

The physical investigation process started with the observation of the three main areas of the filtration process. The initial observation focused on the three main areas working together. The individual studies of these areas were done in a later stage. The combined filtration process observation had assisted in seeing the filtration process working as a whole and the visual operation could be linked to the best practice and SOP's which had the effect of problems and irregularities standing out.

Interviews

The personnel at the filtration plant and management were informally interviewed so that input from the people working in the plant could be obtained. The filtration personnel specifically the operation and process control personnel work with the filtration process and are good sources of information regarding the problems and irregularities observed as well as those that might have been missed or not present during the observations.

The interviews had followed a planned structure and the same set of questions was asked to everyone, ensuring that biased opinions and incorrect operation observations could be detected. The questions were structured in terms of historic - and current operation of the Thickeners, Vacuum system and Belt filter. The interviewees were urged to raise concerns on issues and areas which they perceived to be problematic. The interviews had aided in understanding how the plant was run as well as the thought process of the operation personnel.

Daily observations

The observations had shifted to more area specific tasks. The daily observation of specific areas of the filtration process was done to get an understanding of how the plant is operated. The daily observations allowed for area/process focused observation and increased observation time, thus increasing the chance of identifying any irregularities. These observations proved to be very important as the personnel began to share in the cause and many of the operation irregularities were identified. The daily observations also aided in the identification of day to day changes in the process.

Information gathering and documentation

The information gathered during the initial observations and interviews had been documented periodically to assist in keeping track of any changes to the system and to ensure that future reference of this information was readily available.

Observation of the three main filtration areas

The horizontal belt filter unit

The horizontal belt filter unit was the first area that was under close observation. The focus for the observation of the horizontal belt filter was put on the main components of the belt filter unit namely: cloth, transport belt, vacuum box, wear strip positioning, belt alignment and the filter cake.

The vacuum system

The vacuum system was the second area to be observed. The focus for the Vacuum system's observation was the vacuum pump, vacuum system pipe conditions, barometric seal tank and leg, possible leakage areas and line chokes. The vacuum pressure values were measured at the vacuum pump as well as at the filter manifold; these two readings were compared to identify any losses in the vacuum system.

The thickeners

The focus of the thickener observation was on the operation of the thickener. The overflows of the thickeners were observed for signs of fines and other dissolved solids not processed by the thickener. The pulp densities of the thickeners were also observed to see if whether they were operating at the specification limit specified in the manual and design specifications.

The moistures were measured by a manual moisture analyzer by taking samples from the belt at the time of the observations.

Sample gathering and operation observations

The sample gathering and filtration operation observations were conducted on one belt filter namely belt filter 15. The samples were taken from the discharge of belt filter 15 every thirty minutes and the moisture content was measured. The operation observations that were done together with the samples were: cake thickness, vacuum pressure at the pump and vacuum pressure at the manifold, belt filter speed and the level of the feed dam area.

The results were documented and graphed. The graphs were used to identify correlations between the different observations.

Historic and current database product moisture content analysis

The daily moisture content readings for the product from the Filtration process from January 2008 until December 2011 were downloaded from Foskor's MES database and used for analysis. The readings were plotted on a graph showing average monthly moisture readings for the given time period. The graphs were used to identify the time at which the moisture content had exceeded the desired moisture content of 8.5% and to also see how the achieved moisture content of the current product compares to that of previous months.

Analysis of current plant operation

The filter plant's operation for belt filter 12, 13, 15 and 16 for January 2012 and March 2012 was analyzed in regard of the achieved moisture content of the product, vacuum pressures and the pulp densities at which the thickeners were operated. The data for the vacuum pressures and pulp densities for each individual belt filter and thickener were obtained from Foskor's MES database. The moistures for each belt filter individually were not available and an unknown blend of Filter 12, 13, 15 and 16 was all that was available for conveyors 51 and 152.

The lack of individual belt filter moisture readings had impacted the analysis and no correlations could be made regarding an individual belt filter's moisture content reading and the achieved vacuum pressure or concentrate feed pulp density.

Vacuum system focused investigation

The vacuum systems of the whole filtration process namely Old filters (15 & 16) and New filters (12 & 13) were studied and thoroughly investigated for possible causes of vacuum losses and inefficient operation.

The vacuum systems were analyzed in terms of number of vacuum pumps in operation and pump condition, filtrate tank height and drain system, Buffer tank heights and barometric leg and barometric seal tank operation as well as the possibility of holes and chokes in the vacuum system's pipes, filter manifold, vacuum pipes and vacuum box.

The investigation regarding the loss in vacuum pressure at the filters was conducted in the form of a Value driver tree and a Root cause analysis. An overall clean out for the vacuum system of Filter 15 was requested being that chokes negatively impact the ability of the vacuum pump to create the maximum achievable vacuum so that any further system changes' impact could be measured properly with no influence from a dirty system.

Analysis of Plant Operation

Control charts would be used to analyze the performance of the moisture content of the plant's discharged product and the pulp densities at which the thickeners are operating. The charts would be plotted over hourly intervals. The charts would be assessed daily and out of control points linked to activities or irregularities that might have occurred during these out of control periods.

Root-cause analysis would be used in many of the problem identification activities, drawing cause-and-effect diagrams to assist during this activity.

Investigation of plant inspections and maintenance

The observations and focused investigations brought to light issues regarding the inspection and maintenance of the plant. The issues were documented over the duration of the investigation and were monitored to see when they were addressed.

A shift related checklist was designed to systematically assist plant inspections and maintenance tasks. The checklist completion and implementation can be monitored and any neglect of the plant would become apparent. The checklist serves as a simple control measure for plant operation.

Results

Standard operating procedure and best practices for the horizontal belt filter plant

Thickeners

The correct Thickeners' pulp density operation range of fed concentrate from the thickeners should be between 1.7 and 1.8. The pulp density of the concentrate or rather the suspended product in the thickener can be controlled by the process controller by the use of a Scada control system.

Horizontal belt filter operation

The operation of the horizontal belt filter can be controlled in terms of belt running speed, concentrate feed rate from feed distributor tanks; both of which have an influence on the filtrate cake thickness on the belt. It should be noted that when the pulp density of the feed concentrate increases the filtrate cake thickness will increase for a specific belt speed and concentrate feed rate. The optimal filtrate cake thickness will be between 20 mm to 35 mm. The filter cloth should allow the draining of liquid whilst retaining the product in solid form on the cloth. The transporter belt is responsible for the draining of the liquid separated from the filter cake, which drains the liquid into drain holes in the middle of the belt and into the vacuum box under the transport belt.

Vacuum system

The heart of the filtration process is the vacuum pump. The vacuum pump is responsible for creating a vacuum beneath the filtrate cake. This vacuum is used to draw liquid out of the filtrate cake. Without it the filtration process will not succeed.

The maximum attainable vacuum pressure for a Nash CL 3002 vacuum pump which is the pump used in the filtration plants is calculated by the formula:

Max attainable vacuum = (-) [(Atmospheric pressure at measured altitude (kPa)) x (Max rated level of vacuum pump (kPa)) / Absolute vacuum (kPa))]

Atmospheric pressure at 300m = 97.63 kPa
Maximum rated level of vacuum pump = - 81 kPa (From Nash catalogue CL3002 vacuum pump)
Absolute vacuum = - 101.3 kPa

Max attainable vacuum (300m altitude) = (-) [(97.63) x ((-81) / (-101.3))]

= - 78 kPa

The maximum attainable vacuum of – 78 kPa should be the measurement that is attained if the valve to the rest of the vacuum system is closed if the pump is in good working condition. The pressure reading at the gauge on the filter manifold will show a difference of between 2% and 5% which is the result of friction head losses in the vacuum system’s pipes; therefore a reading of around -75 kPa at the filter manifold is achievable.

The SOP for the filtration plant lists a number of factors that affect the vacuum pressure these are:

- Holes/Wear in the vacuum lines
- Holes/Wear in the vacuum box
- Wear of the wear strips
- Holes in the filter cloth
- Uneven transport belt wear
- Transporter belt moving off centre
- Poor gland water supply to the vacuum pumps
- Defective packing/seals on the vacuum pumps
- Defective packing/seals on the filtrate pumps
- Barometric seal tank water level too low, loss of seal
- Barometric leg and tank chokes
- Dam area level too low
- Not enough vacuum pumps running
- Too much water in the vacuum system
- Vacuum pump feed valve is not fully opened
- The filtrate pumps are not taking the load
- The standby filtrate pump feed and drain valves are open
- Too many filtrate pumps in use

The vacuum system design:

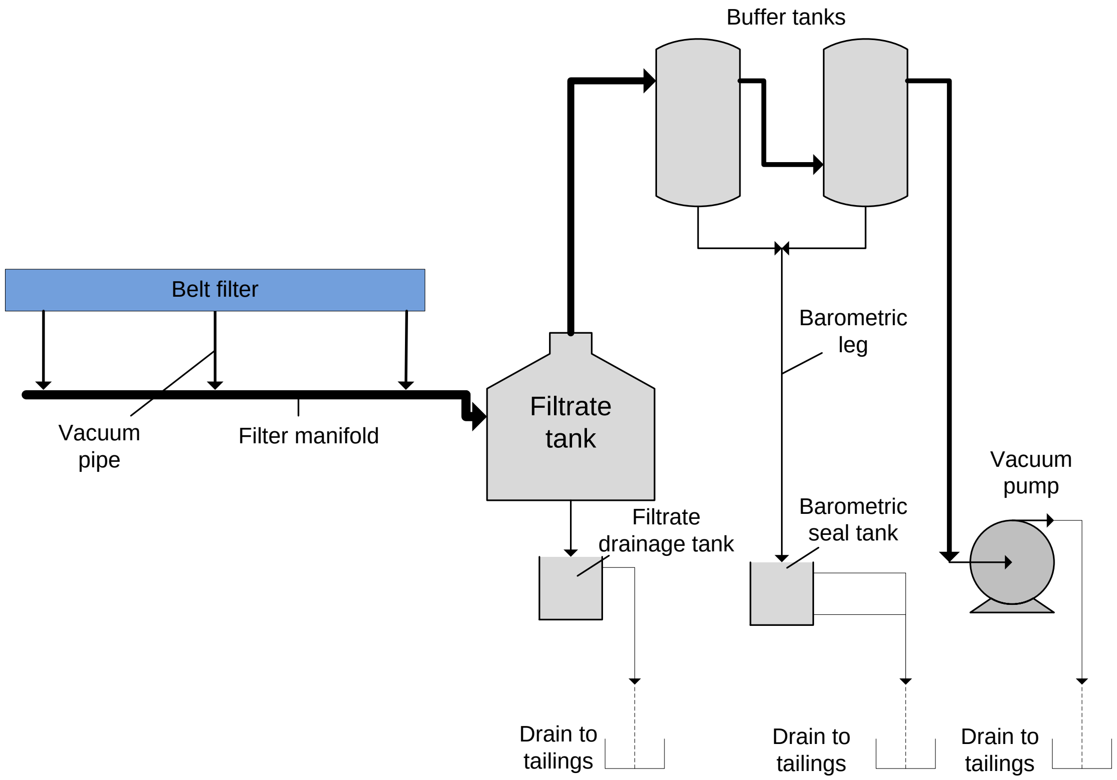


Figure 10: New filters Vacuum system

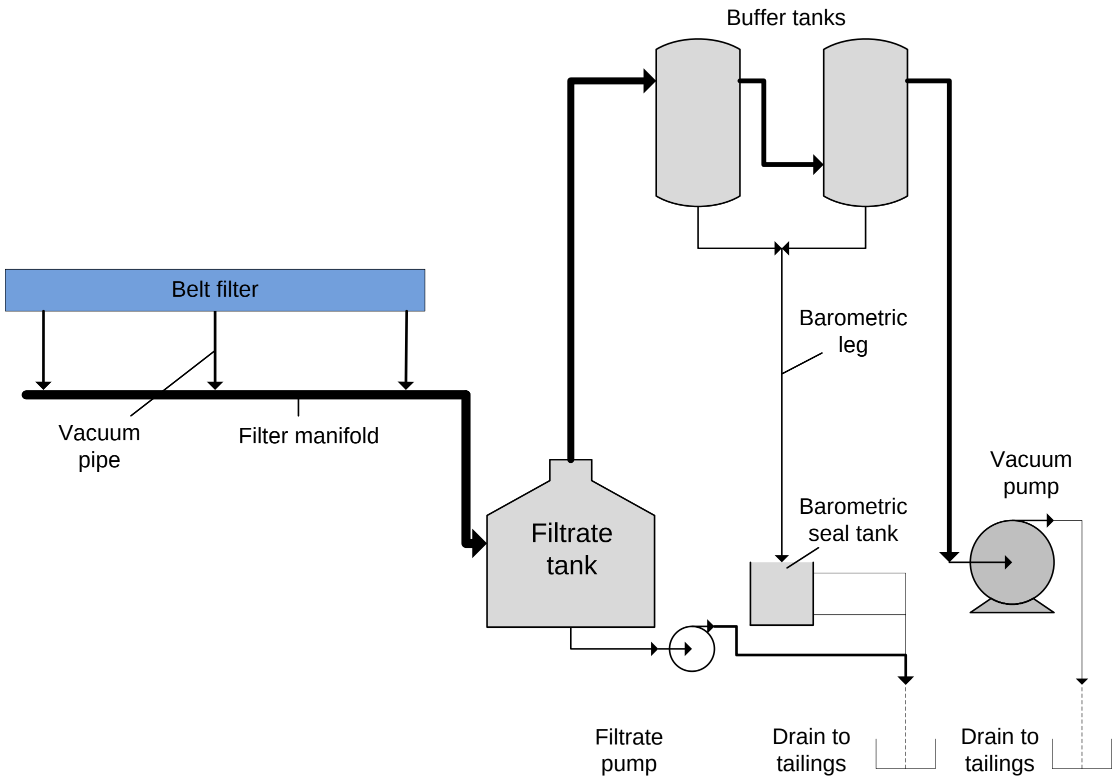


Figure 11: Old filters vacuum system

The Old - and New filters have different processes for removing liquid from the filtrate tank: The filtrate tank at Old filters is coupled to a slurry pump which pumps the liquid out of the tank, while the filtrate tank at New filters uses gravity to release the liquid into a barometric seal tank. The New filters system only works because of the height at which the Horizontal belt filters are installed which allows the filtrate tank to be placed higher as well as using gravity for liquid separation.

The filtrate tank is designed to remove the liquid and dissolved solids so that air only is moved through the rest of the vacuum system, since this function is not always achieved, two buffer tanks are installed between the filtrate tank and vacuum pump with a barometric leg and barometric seal tank acting as the liquid air separator for the buffer tanks. The liquids and dissolved solids should never enter the vacuum pump through the system, as this creates friction in the vacuum pump which is destructive to the vacuum pump and over time the performance of the vacuum pump wanes and the vacuum pump can eventually develop leaks. The vacuum pump will inevitably be replaced after leaks develop as it will become inefficient.

The proper operation and upkeep of the barometric seal tank and barometric leg should be a priority to ensure that a vacuum pump is useable throughout its specified operational expectancy. The barometric leg and barometric seal tank should be checked regularly to ensure that they are not choked and functioning properly. The Barometric seal tank should at all times be filled with water to a level which ensures that an air seal is created at the barometric leg's opening.

Problem identification

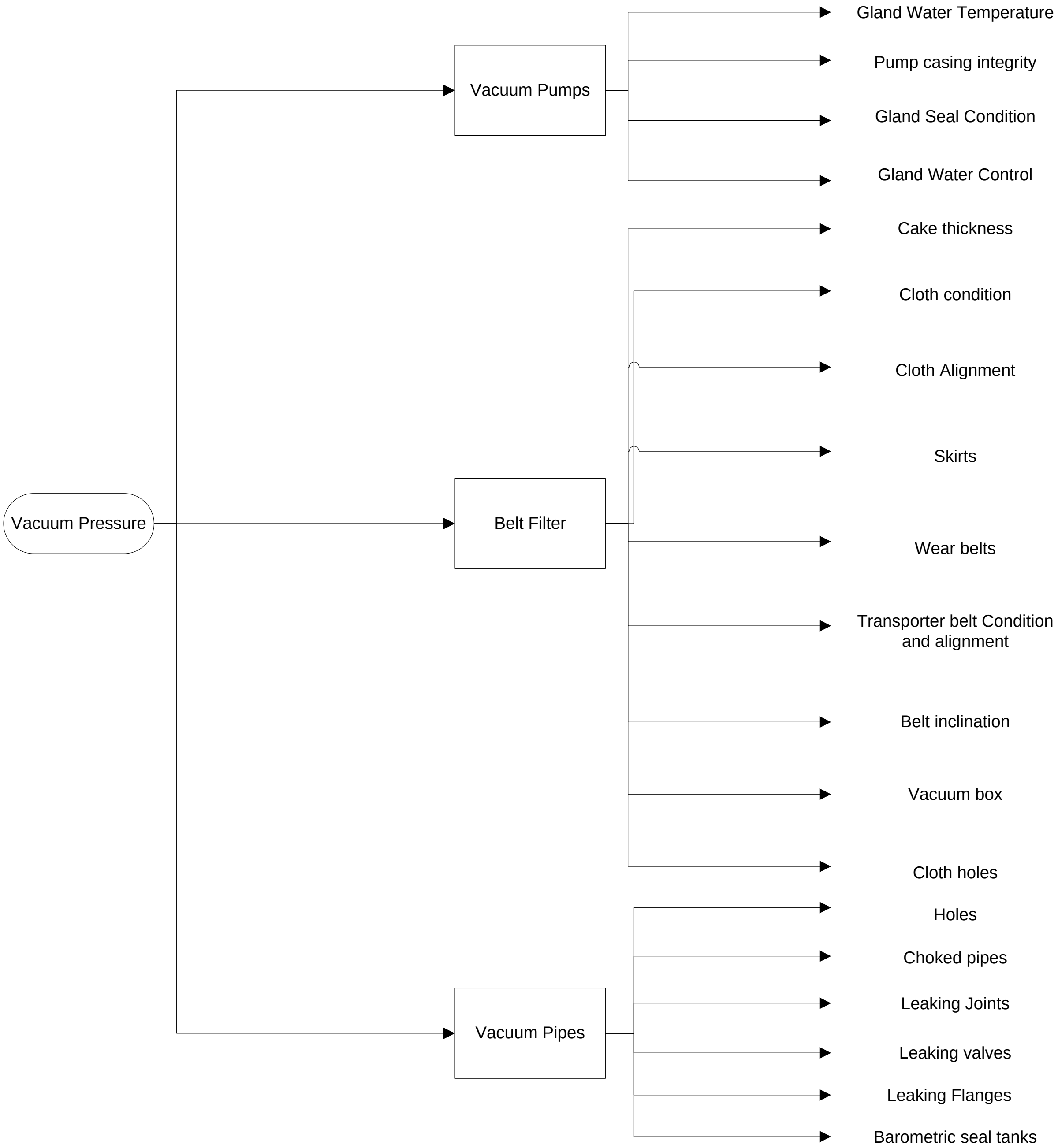


Figure 12: Value driver tree

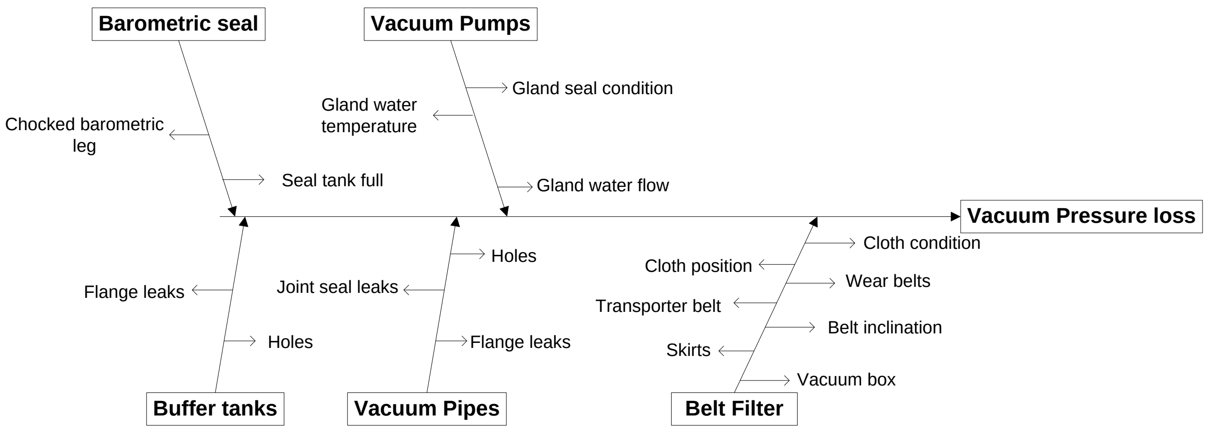


Figure 13: Root cause analysis

The Value driver tree and the Root cause analysis was developed by the use of the information in the manuals and by information gathered from observation of the plant's operation. The above procedure will be executed for the Thickeners as well.

Filtration moisture content trend 2008 – 2011

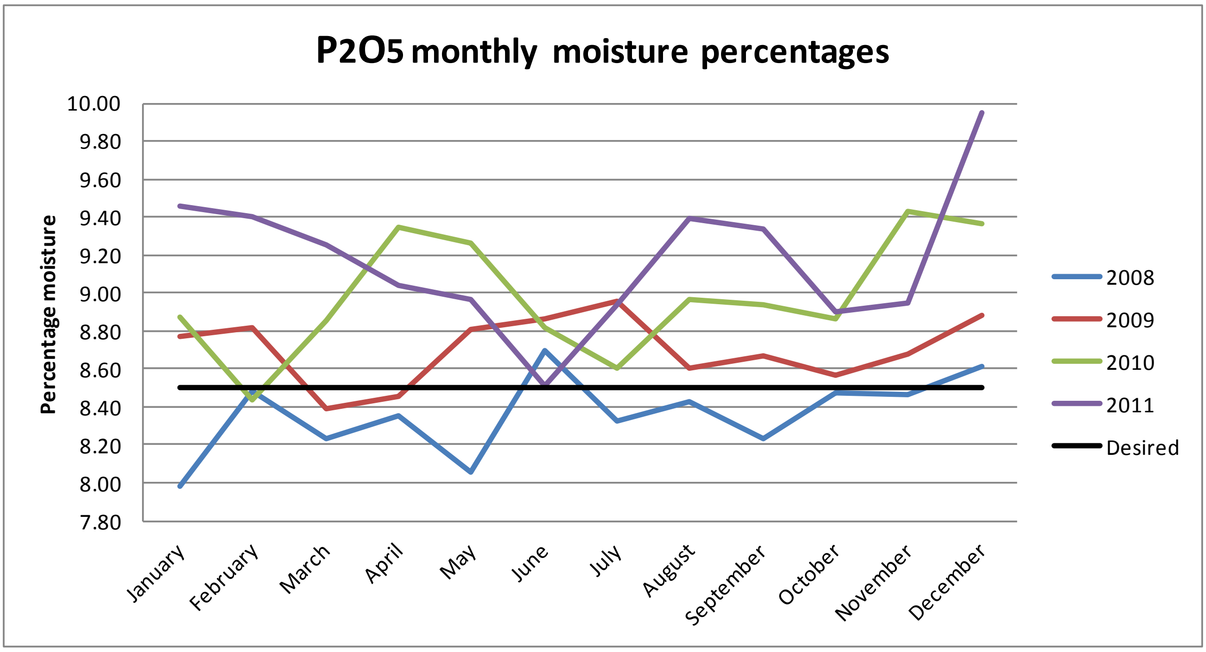


Figure 14: Moisture content trend 2008 - 2011

The analysis showed that throughout 2008 the filtration plant were achieving the goal in terms of the desired 8.5% moisture content, but a steady climb in moisture content could be observed from then on. The rise in moisture content should normally have been noticed by the end of 2009. A spike in moisture content during the middle of the year occurred which seemed to have been addressed as the moisture content had gone down again. The decline in moisture content by the end of 2009 had not been sufficient to reach the 8.5% goal and they were never truly able to get close to the 8.5% goal after that period.

During June 2011 they had succeeded in reaching the moisture content goal of 8.5%, but this was short lived and the Filtration section has had its worst performance for the past four years from then on.

Filtration samples and MES database analysis for January 2012 and March 2012

The analysis on Thickener Pulp densities, Vacuum pump pressure and Moisture content of discharged phosphate was done for January 2012 and March 2012. During December 2011 and January 2012 the operation team of the filter plants had not received any feedback on the initial improvement study, therefore this time period was used as a base line test. The analysis of the readings for March 2012 was used to assess if any of the proposed changes and maintenance issues had been addressed.

Thickener Pulp densities

Table 1: Pulp densities January 2012

January 2012: Number of Pd readings between				
Pd	New filters Thickeners 1 & 2		Old filters Thickeners 3, 4 & 5	
below 1700	476	66%	363	51%
1700 - 1799	81	11%	57	8%
1800 - 1899	81	11%	105	15%
1900 - 2100	79	11%	192	27%

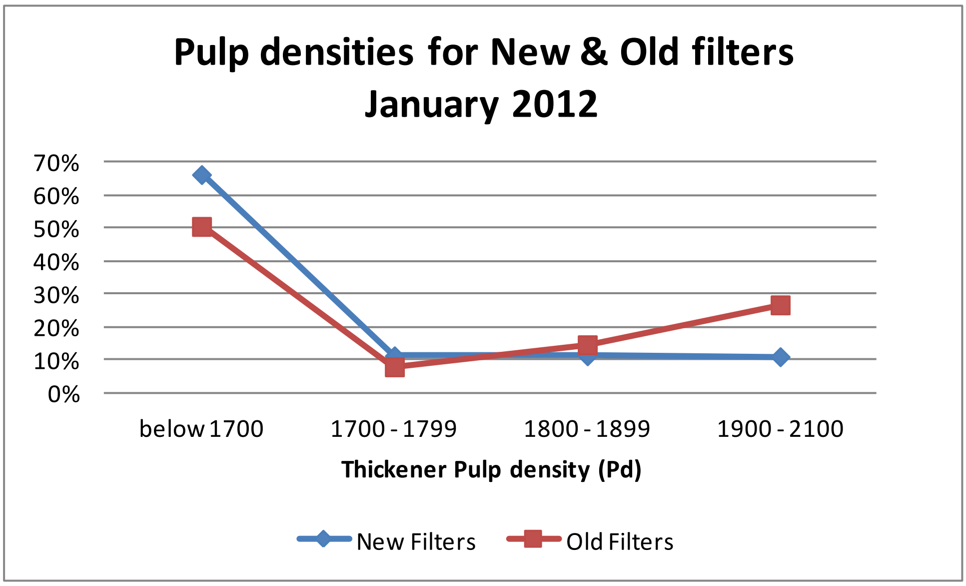


Figure 15: Pulp densities January 2012

The Pd readings for January 2012 were within the prescribed range of 1.7 -1.8 for a total percentage 11% for New filters and 8% for Old filters. The Pd readings below 1.7 were 66% for New filters and 51% for Old filters. The Pd readings above 1.8 were 22% for New filters and 42% for Old filters. The Thickeners for New – and Old filters were rarely operated in the prescribed range of 1.7 – 1.8.

Table 2: Pulp densities March 2012

March 2012: Number of Pd readings between				
Pd	New filters Thickeners 1 & 2		Old filters Thickeners 3, 4 & 5	
below 1700	323	44%	272	37%
1700 - 1799	87	12%	156	21%
1800 - 1899	159	22%	189	26%
1900 - 2000	163	22%	115	16%

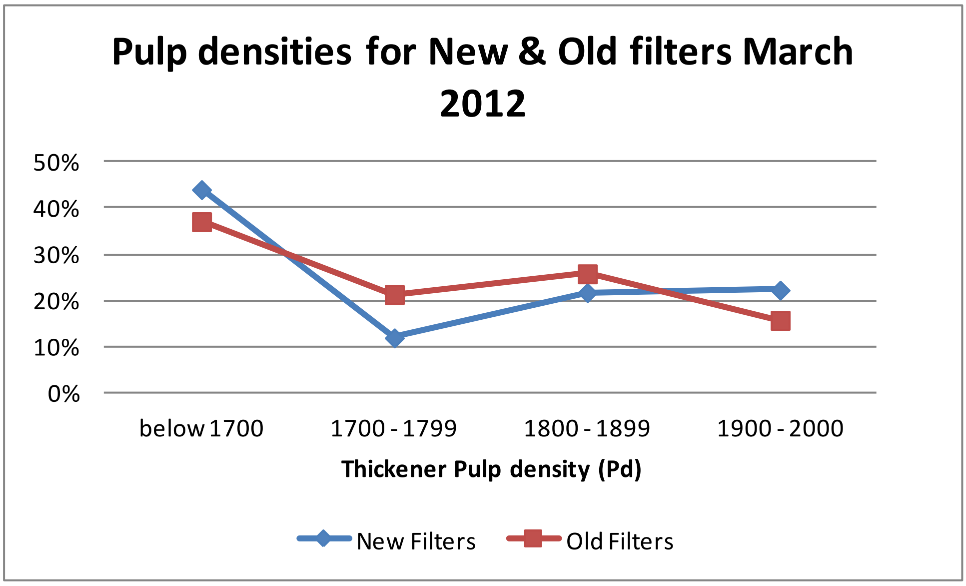


Figure 16: Pulp densities March 2012

The Pd readings for March 2012 were within the prescribed range of 1.7 -1.8 for a total percentage 12% for New filters and 21% for Old filters. The Pd readings below 1.7 were 44% for New filters and 37% for Old filters. The Pd readings above 1.8 were 44% for New filters and 42% for Old filters. The Thickeners for New – and Old filters were rarely operated in the prescribed range of 1.7 – 1.8

Vacuum pump pressure readings

Table 3: Vacuum pressure readings for January 2012

Vacuum pump pressure readings for January 2012					
	New filters			Old filters	
Week	VP 181 (kPa)	VP 183 (kPa)	VP 184 (kPa)	VP 186 (kPa)	VP 190 (kPa)
January	-1	-8	-46	-38	-50
2012/01/01 - 2012/01/07	-1	-33	-59	-39	-61
2012/01/08 - 2012/01/14	-1	-4	-41	-41	-55
2012/01/15 - 2012/01/21	-1	0	-50	-31	-35
2012/01/22 - 2012/01/28	-1	0	-43	-43	-49
2012/01/29 - 2012/01/31	-1	0	-33	-38	-47

Table 4: Vacuum pressure readings for January 2012

January 2012: Number of Vacuum pressure readings between								
kPa (-)	VP184		VP186		VP190		VP183	
0 - 39	118	16%	289	40%	101	14%	638	89%
40 - 49	248	35%	182	25%	38	5%	15	2%
50 - 59	197	28%	133	19%	324	45%	2	0%
60 - 69	124	17%	78	11%	259	36%	65	9%
70 - 80	31	4%	36	5%	0	0%	1	0%

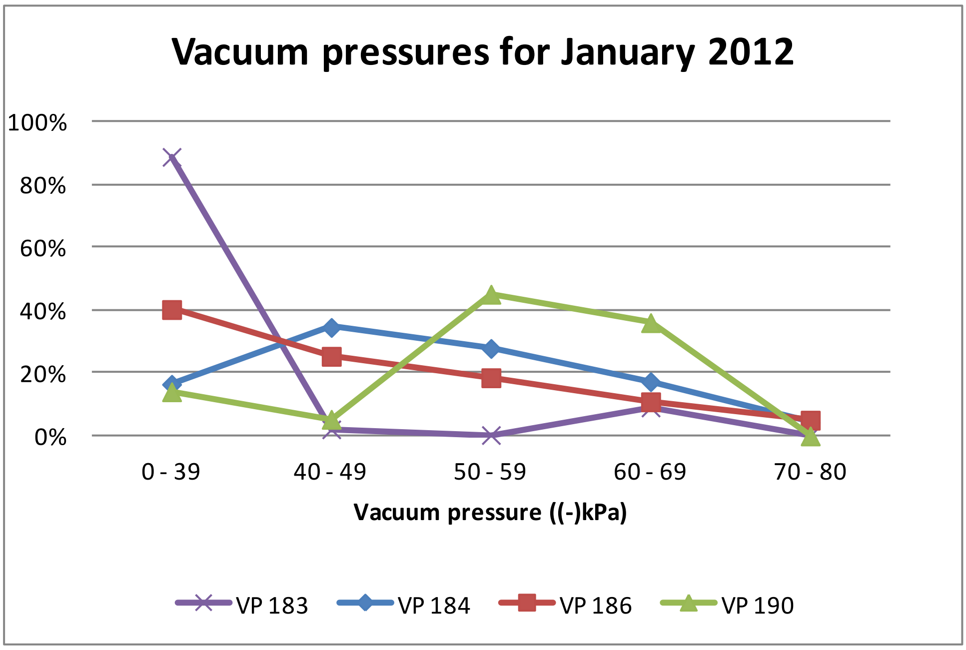


Figure 17: Vacuum pressure readings for January 2012

The vacuum pump readings for January 2012 were mainly focused on vacuum pumps 184, 186 and 190 as Filter 12 which uses vacuum pump 181 was on a shutdown for maintenance and there was an instrumentation issue with the valve on vacuum pump 183.

The readings for the vacuum pumps should ideally be between – 70 kPa and – 75 kPa.

The vacuum system for New filters allows for an extra vacuum pump (vacuum pump 183) to run together with vacuum pump 181 for filter 12 or vacuum pump 184 for filter 13. It was observed during the first half of December 2011 that when filter 12 was still running and vacuum pump 183 was used on filter 12 that very weak vacuum pressures in the region of – 30 kPa were being achieved on all three pumps for New filters namely vacuum pumps 181, 183, 184. During the shutdown of filter 12, vacuum pump 183 was running together with vacuum pump 184 and vacuum pressures in the region of – 70 kPa were observed on many of the inspections. During the said period, multiple moisture samples were taken from filter 13 and moisture contents of around 8% were achieved. The process controller was asked to switch off the back – up vacuum pump for filter 13 and the vacuum pressure reading for vacuum pump 184 dropped to the region of – 55 kPa and a visible increase in moisture content of product from filter 13 could be seen on the conveyor in the form of sludge sections. The loss in vacuum pressure for vacuum pump 184 once the back – up was switched off could be contributed to the possibility of leaks in the vacuum system, which the back – up vacuum pump had nullified.

The difference in vacuum pressure at the vacuum pump and the filter manifold for filter 13 could not be read, as the filter manifold's pressure gauge had been painted red.

The vacuum system for Old filters does not provide the use of a back – up vacuum pump.

Vacuum pump 186 for Filter 16 of Old filters was by far the worst performing of the three vacuum pumps in question. Vacuum pump 186 had been plagued with continuous leaks in the pump casing which weakened the pumping capacity of the vacuum pump. Vacuum pump 186 had been replaced in January 2012 and an improvement in vacuum was noted. The difference in vacuum between the vacuum pump and the filter manifold was in the region of 20 kPa, which is an indication of major vacuum losses in the vacuum system. The vacuum system of Filter 16 had undergone a major clean out during the new - year period. The wear strips on Filter 16 had failed during the 2nd week of January and they had finished the installation of the new wear strips by Friday the 13th of January (the same week). The vacuum achieved by vacuum pump 186 of Filter 16 had improved remarkably after the repairs, to within the region of – 65 kPa. The improved vacuum of pump 186 could not be sustained.

The vacuum pump for Filter 15 is vacuum pump 190. The vacuum pressures for vacuum pump 190 were in the region of – 55 kPa for the better part of December 2011. The difference in vacuum pressures between the vacuum pump and the filter manifold were in the region of 5 kPa during the observation periods. The small difference of 5 kPa shows that the vacuum system of Filter 15 is not in such a bad state in terms of pipe leaks and other possible maintenance problems. The performance of vacuum pump 190 should not be accepted and the goal should be to achieve the – 75 kPa mark.

Table 5: Vacuum pressure readings for March 2012

Vacuum pump pressure readings for March 2012					
Week	New filters			Old filters	
	VP 181 (kPa)	VP 183 (kPa)	VP 184 (kPa)	VP 186 (kPa)	VP 190 (kPa)
March	-1	-19	-36	-48	-48
2012/01/01 - 2012/01/07	-1	0	-30	-42	-45
2012/01/08 - 2012/01/14	-1	-14	-34	-48	-49
2012/01/15 - 2012/01/21	-1	-38	-41	-49	-47
2012/01/22 - 2012/01/28	-1	-33	-39	-53	-51
2012/01/29 - 2012/01/31	-1	0	-37	-52	-50

Table 6: Vacuum pressure readings for March 2012

March 2012: Number of Vacuum pressure readings between								
kPa (-)	VP184		VP186		VP190		VP183	
0 - 39	362	49%	75	10%	66	9%	467	64%
40 - 49	93	13%	177	24%	43	6%	102	14%
50 - 59	266	0%	436	59%	623	85%	156	21%
60 - 69	6	0%	44	6%	0	0%	3	0.4%
70 - 80	0	0%	0	0%	0	0%	1	0.1%

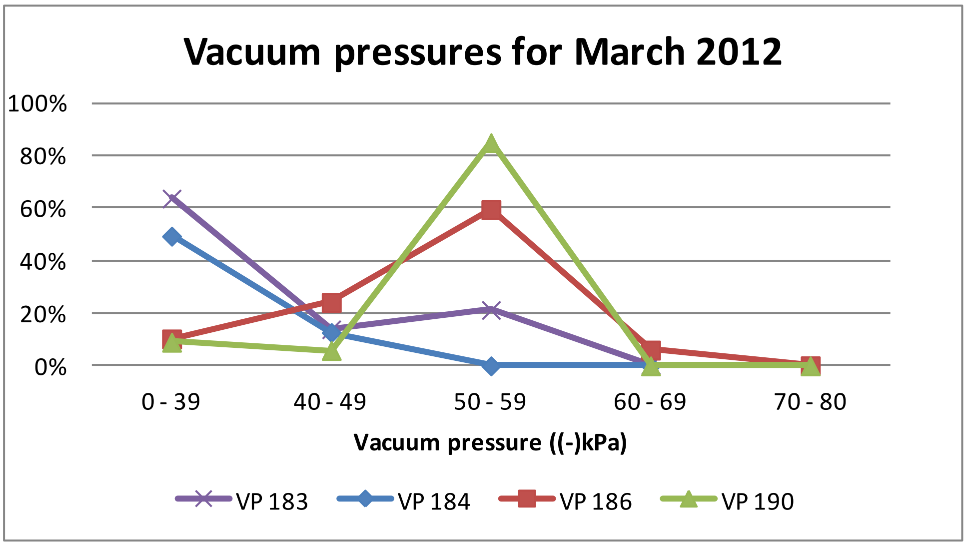


Figure 18: Vacuum pressure readings for March 2012

The vacuum pump readings for March 2012 showed null readings for vacuum pump 181 which was still being repaired and in shutdown. The instrumentation issue on vacuum pump 183 had been resolved.

The readings for the vacuum pumps should ideally be between – 70 kPa and – 75 kPa.

The performance of the vacuum system for filter 13 had not been up to standard. The best practices in terms of operation and maintenance of the vacuum system had been neglected. The difference in vacuum at the vacuum pump and the filter manifold for filter 13 could not be read, as the filter manifold's pressure gauge had been painted red.

The vacuum system for Old filters does not provide the use of a back – up vacuum pump.

The vacuum achieved by both vacuum pump 186 and 190 had been operating constantly around the – 50 kPa mark. The absence of major fluctuations in the vacuum depicts better control. The vacuum should be brought up to the – 70 kPa region by eliminating the possible causes for vacuum loss, as displayed in the root cause analysis.

Moisture Content of Discharged Phosphate

Table 7: Moisture content January 2012

January 2012: Average moisture content (%)			
Week	Conveyor 51	Conveyor 151	Combined
January	9.2	9.7	9.4
2012/01/01 - 2012/01/07	9.2	9.6	9.4
2012/01/08 - 2012/01/14	9.0	9.5	9.2
2012/01/15 - 2012/01/21	9.3	9.7	9.5
2012/01/22 - 2012/01/28	9.5	9.8	9.7
2012/01/29 - 2012/01/31	9.1	9.8	9.4

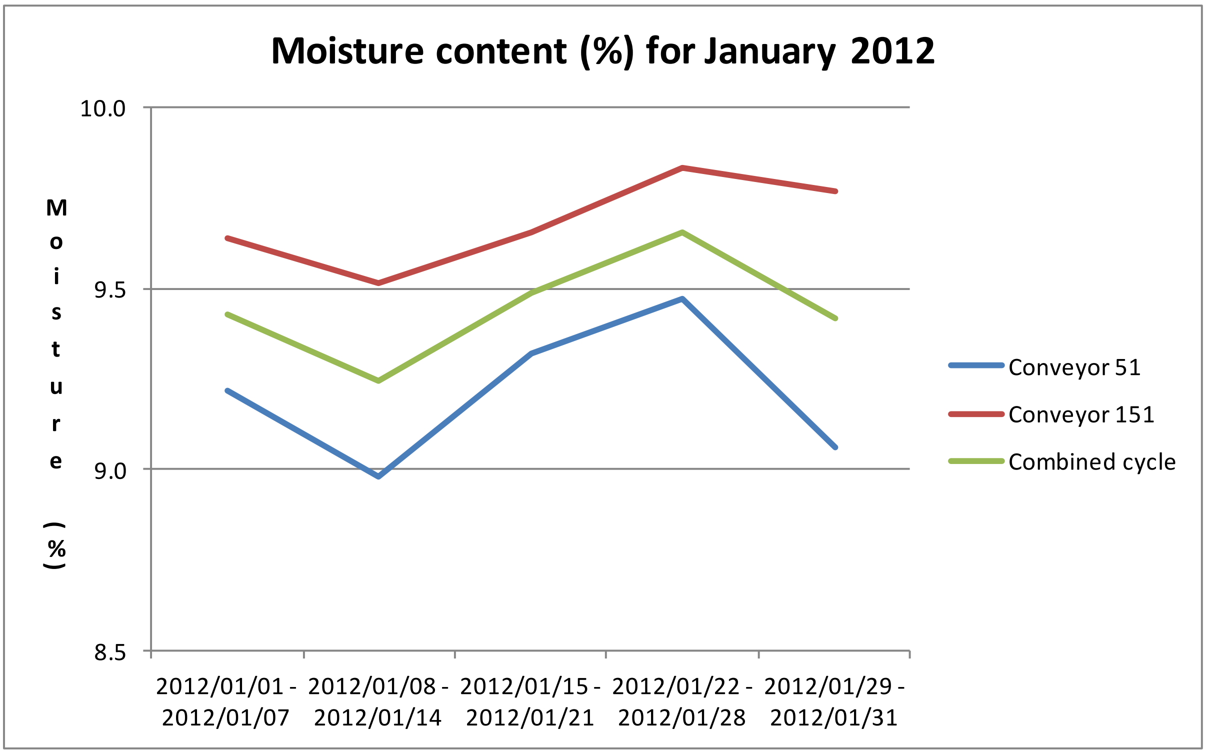


Figure 19: Moisture content January 2012

The average weekly moisture content percentage for January 2012 was at its lowest 9.3% which is 0.8% above the desired goal of 8.5%. During this period the operation of the plant was not according to the Standard operating procedures, as can be seen from the Thickener and Vacuum system output readings; these issues were mentioned to the end of January 2012.

Table 8: Moisture content March 2012

March 2012: Average moisture content (%)			
Week	Conveyor		Combined
	51	151	
March	9.1	9.2	9.1
2012/01/01 - 2012/01/07	9.4	9.1	9.3
2012/01/08 - 2012/01/14	9.4	9.2	9.3
2012/01/15 - 2012/01/21	9.0	9.1	9.0
2012/01/22 - 2012/01/28	8.7	9.3	9.0
2012/01/29 - 2012/01/31	8.6	9.6	9.1

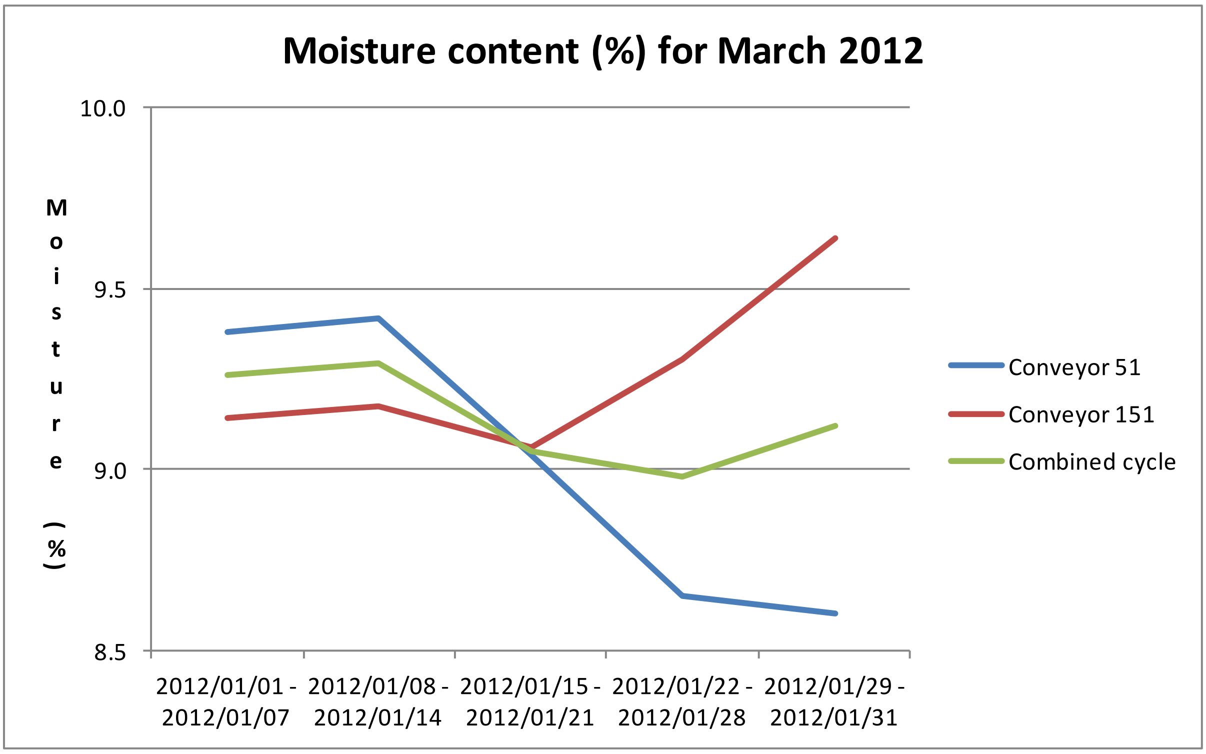


Figure 20: Moisture content March 2012

The average weekly moisture content for March 2012 had been just below 9% at its lowest. This 9% could have been close to the desired goal of 8.5% if the product from both conveyors could have been low. The product on conveyor 51 can very likely be of the discharge from Old Filters as during this same period their thickeners and vacuum systems where being operated closer to specification and the New filters' thickeners and vacuum systems were not operated within specification.

The readings from weeks 3, 4 and 5 of March 2012 gave a good indication of when the plant is operated according to the design specification; achievement of the 8.5% goal is possible.

Process Control Analysis

The level of control that is achieved by the operation of the plant was analyzed with the use of Individual and Moving range control charts. The control charts are used to obtain a visual representation of the process and is used to analyze the process' control.

The Control charts were used to analyze the control of the filtration process in terms of the discharged product's moisture content for January 2012 and March 2012. The Thickeners were analyzed for March 2012 only; the reason for this is that during the December 2011 and January 2012 there was specific mention of the importance of the control of thickener operation and they were given time to fix this..

Moisture content Control charts for the first two weeks of both January 2012 and March 2012 are shown. The control chart for the first week of March 2012 is shown only, as this gives a good visual representation of the operation of the thickeners.

The Moving range charts clearly show a lack of control over the plants' operation, as spreads of 2% in moisture content is a common feature. The positive is that from the charts it can be seen that there are periods during which they achieve some control of operations.

Table 9: Moisture content January 2012 - 1st week

X and MR chart - Phosphate moisture content			
Section	Filtration	Duration	2012/01/02 - 2012/01/08
Process	Belt filter discharge		

Date	2012/01/02																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	9.115	9.365	8.4	8.685	9.715	10.235	8.485	11.425	10.07	8.635	9.1	10.48	10.285	10.4	11.24	9.65	9.24	9.435	10.02	9.25	9.185	8.665	9.205	9.36
Moving Range		0.25	0.965	0.285	1.03	0.52	1.75	2.94	1.355	1.435	0.465	1.38	0.195	0.115	0.84	1.59	0.41	0.195	0.585	0.77	0.065	0.52	0.54	0.155
Date	2012/01/03																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	9.45	8.665	9.595	8.305	8.125	8.725	9.525	8.965	8.46	7.56	10.31	8.595	8.71	8.925	9.045	9.345	9.35	8.9	9.42	10.65	9.49	8.92	8.8	8.77
Moving Range	0.09	0.785	0.93	1.29	0.18	0.6	0.8	0.56	0.505	0.9	2.75	1.715	0.115	0.215	0.12	0.3	0.005	0.45	0.52	1.23	1.16	0.57	0.12	0.03
Date	2012/01/04																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	8.61	8.6	8.975	8.765	9.115	9.195	9.13	9.47	10.035	10.735	8.225	9.85	9.83	9.025	8.445	8.065	8.53	9.075	8.815	8.95	9.365	8.115	8.61	8.64
Moving Range	0.16	0.01	0.375	0.21	0.35	0.08	0.065	0.34	0.565	0.7	2.51	1.625	0.02	0.805	0.58	0.38	0.465	0.545	0.26	0.135	0.415	1.25	0.495	0.03
Date	2012/01/05																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	8.405	8.42	8.07	7.93	7.69	7.53	9.99	10.51	9.615	10.7	10.425	10.54	10.25	9.555	10	8.82	8.595	8.795	8.91	9.125	8.615	9.32	10.37	10.165
Moving Range	0.235	0.015	0.35	0.14	0.24	0.16	2.46	0.52	0.895	1.085	0.275	0.115	0.29	0.695	0.445	1.18	0.225	0.2	0.115	0.215	0.51	0.705	1.05	0.205
Date	2012/01/06																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	8.14	8	8.76	9	8.885	9.685	9.11	10.955	9.365	9.73	9.24	9.24	10.22	11.44	11.8	9.27	9.85	9.69	9.355	9.785	10.29	10.94	9.54	8.17
Moving Range	2.025	0.14	0.76	0.24	0.115	0.8	0.575	1.845	1.59	0.365	0.49	0	0.98	1.22	0.36	2.53	0.58	0.16	0.335	0.43	0.505	0.65	1.4	1.37
Date	2012/01/07																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	8.415	9.605	8.915	9.31	8.32	8.61	9.665	10.835	10.595	11.915	10.99	11.035	11.005	11.14	11.65	10.395	10.34	11.205	10.16	9.305	10.2	11.345	10.45	11.45
Moving Range	0.245	1.19	0.69	0.395	0.99	0.29	1.055	1.17	0.24	1.32	0.925	0.045	0.03	0.135	0.51	1.255	0.055	0.865	1.045	0.855	0.895	1.145	0.895	1
Date	2012/01/08																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	7.96	8.325	8.8	8.71	8.045	7.955	8.915	11.35	9.165	8.03	10.395	11.775	10.66	9.415	10.65	10.15	10.6	10.6	9.45	10.85	10.72	10.395	10.395	10.065
Moving Range	3.49	0.365	0.475	0.09	0.665	0.09	0.96	2.435	2.185	1.135	2.365	1.38	1.115	1.245	1.235	0.5	0.45	0	1.15	1.4	0.13	0.325	0	0.33

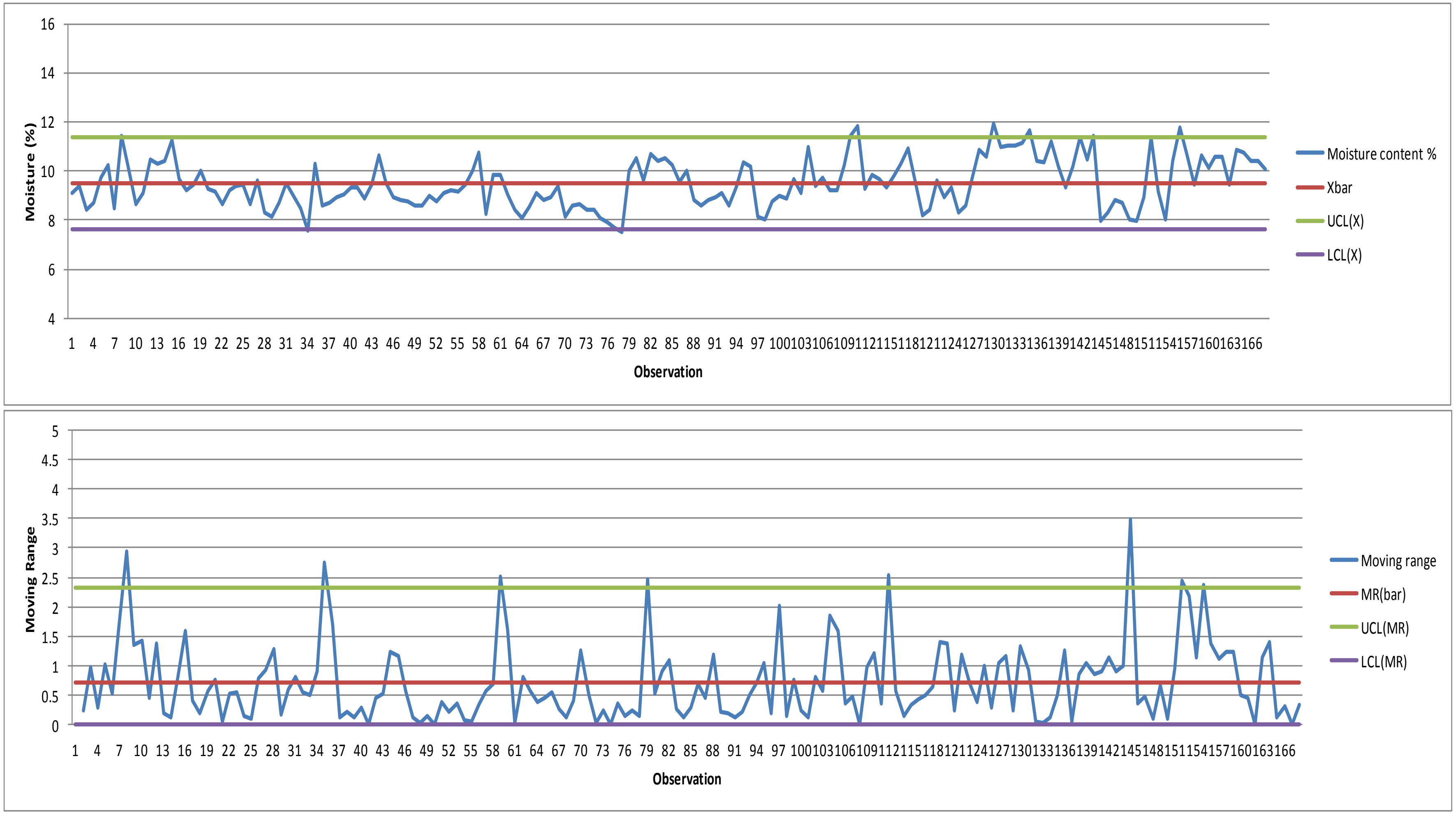
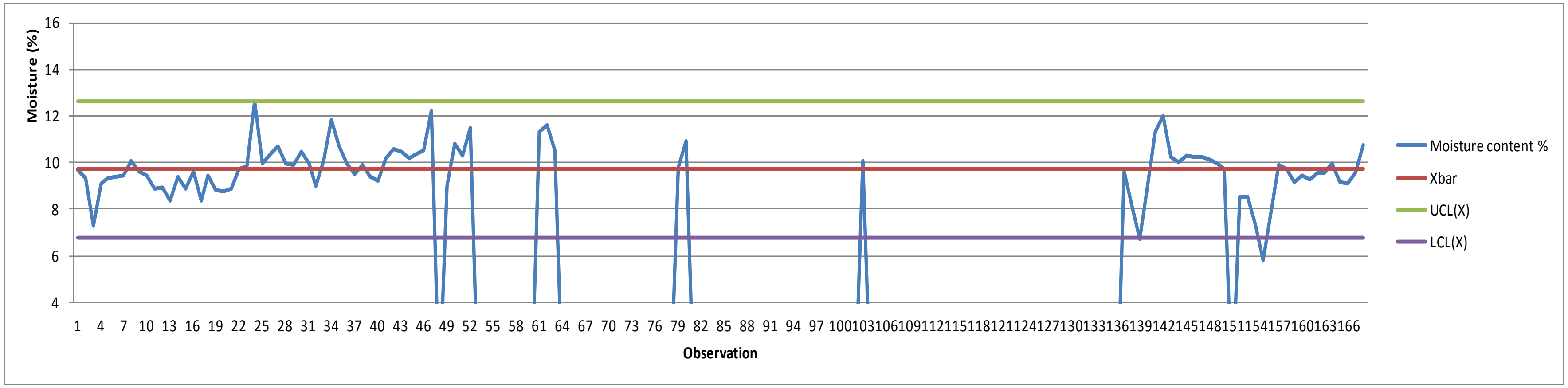


Figure 21: Moisture content January 2012 - 1st week

Table 10: Moisture content January 2012 - 2nd week

X and MR chart - Phosphate moisture content			
Section	Filtration	Duration	2012/01/16 - 2012/01/22
Process	Belt filter discharge		

Date	2012/01/16																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	9.685	9.305	7.305	9.085	9.335	9.36	9.435	10.065	9.605	9.45	8.885	8.91	8.38	9.38	8.86	9.62	8.385	9.415	8.83	8.765	8.865	9.71	9.83	12.595
Moving Range		0.38	2	1.78	0.25	0.025	0.075	0.63	0.46	0.155	0.565	0.025	0.53	1	0.52	0.76	1.235	1.03	0.585	0.065	0.1	0.845	0.12	2.765
Date	2012/01/17																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	9.97	10.33	10.67	9.95	9.9	10.45	9.925	9.01	10.08	11.815	10.71	9.96	9.49	9.885	9.38	9.225	10.19	10.56	10.46	10.19	10.37	10.54	12.23	0
Moving Range	2.625	0.36	0.34	0.72	0.05	0.55	0.525	0.915	1.07	1.735	1.105	0.75	0.47	0.395	0.505	0.155	0.965	0.37	0.1	0.27	0.18	0.17	1.69	12.23
Date	2012/01/18																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	9	10.8	10.27	11.51	0	0	0	0	0	0	0	0	11.3	11.59	10.54	0	0	0	0	0	0	0	0	0
Moving Range	9	1.8	0.53	1.24	11.51	0	0	0	0	0	0	0	11.3	0.29	1.05	10.54	0	0	0	0	0	0	0	0
Date	2012/01/19																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	0	0	0	0	0	0	9.78	10.92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moving Range	0	0	0	0	0	0	9.78	1.14	10.92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Date	2012/01/20																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	0	0	0	0	0	0	10.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moving Range	0	0	0	0	0	0	10.06	10.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Date	2012/01/21																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.59	8.16	6.73	9.01	11.29	11.97	10.23	10
Moving Range	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.59	1.43	1.43	2.28	2.28	0.68	1.74	0.23
Date	2012/01/22																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	10.27	10.21	10.21	10.15	9.96	9.7	0	8.51	8.51	7.32	5.82	7.86	9.89	9.73	9.14	9.46	9.285	9.565	9.58	9.95	9.185	9.08	9.545	10.73
Moving Range	0.27	0.06	0	0.06	0.19	0.26	9.7	8.51	0	1.19	1.5	2.04	2.03	0.16	0.59	0.32	0.175	0.28	0.015	0.37	0.765	0.105	0.465	1.185



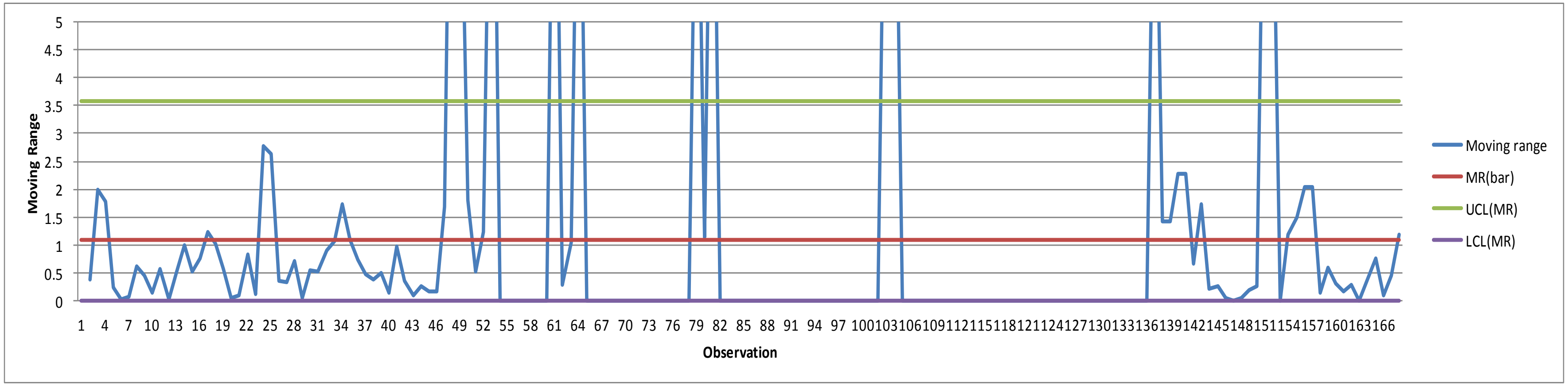
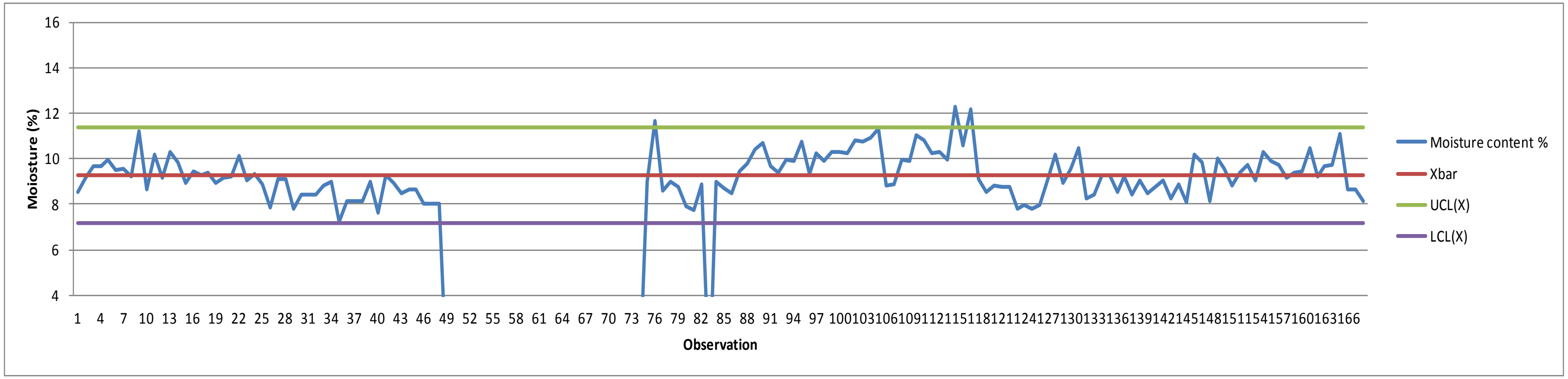


Figure 22: Moisture content January 2012 - 2nd week

Table 11: Moisture content March 2012 - 1st week

X and MR chart - Phosphate moisture content			
Section	Filtration	Duration	2012/03/05 - 2012/03/11
Process	Belt filter discharge	Spec limit (tLtb)	7%

Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	8.51	9.185	9.675	9.645	9.965	9.52	9.565	9.19	11.21	8.655	10.2	9.15	10.285	9.84	8.925	9.45	9.3	9.4	8.945	9.175	9.2	10.14	9.055	9.315
Moving Range		0.675	0.49	0.03	0.32	0.445	0.045	0.375	2.02	2.555	1.545	1.05	1.135	0.445	0.915	0.525	0.15	0.1	0.455	0.23	0.025	0.94	1.085	0.26
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	8.895	7.84	9.09	9.085	7.815	8.425	8.4	8.4	8.8	8.97	7.25	8.15	8.16	8.14	9	7.6	9.3	8.95	8.45	8.64	8.64	8	8	8
Moving Range	0.42	1.055	1.25	0.005	1.27	0.61	0.025	0	0.4	0.17	1.72	0.9	0.01	0.02	0.86	1.4	1.7	0.35	0.5	0.19	0	0.64	0	0
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moving Range	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	0	0	9	11.64	8.6	8.97	8.77	7.9	7.72	8.9	0	9	8.68	8.48	9.47	9.805	10.41	10.675	9.65	9.4	9.96	9.87	10.745	9.305
Moving Range	0	0	9	2.64	3.04	0.37	0.2	0.87	0.18	1.18	8.9	9	0.32	0.2	0.99	0.335	0.605	0.265	1.025	0.25	0.56	0.09	0.875	1.44
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	10.25	9.915	10.275	10.275	10.225	10.79	10.74	10.895	11.32	8.845	8.9	9.955	9.915	11.015	10.815	10.215	10.315	9.98	12.265	10.6	12.19	9.12	8.555	8.815
Moving Range	0.945	0.335	0.36	0	0.05	0.565	0.05	0.155	0.425	2.475	0.055	1.055	0.04	1.1	0.2	0.6	0.1	0.335	2.285	1.665	1.59	3.07	0.565	0.26
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	8.745	8.745	7.775	7.955	7.785	7.945	9.035	10.175	8.94	9.53	10.44	8.27	8.41	9.26	9.255	8.55	9.24	8.415	9.02	8.465	8.745	9.06	8.275	8.875
Moving Range	0.07	0	0.97	0.18	0.17	0.16	1.09	1.14	1.235	0.59	0.91	2.17	0.14	0.85	0.005	0.705	0.69	0.825	0.605	0.555	0.28	0.315	0.785	0.6
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	8.055	10.165	9.825	8.125	10.01	9.565	8.845	9.405	9.74	9.02	10.29	9.885	9.73	9.165	9.4	9.455	10.44	9.23	9.66	9.705	11.085	8.65	8.625	8.12
Moving Range	0.82	2.11	0.34	1.7	1.885	0.445	0.72	0.56	0.335	0.72	1.27	0.405	0.155	0.565	0.235	0.055	0.985	1.21	0.43	0.045	1.38	2.435	0.025	0.505



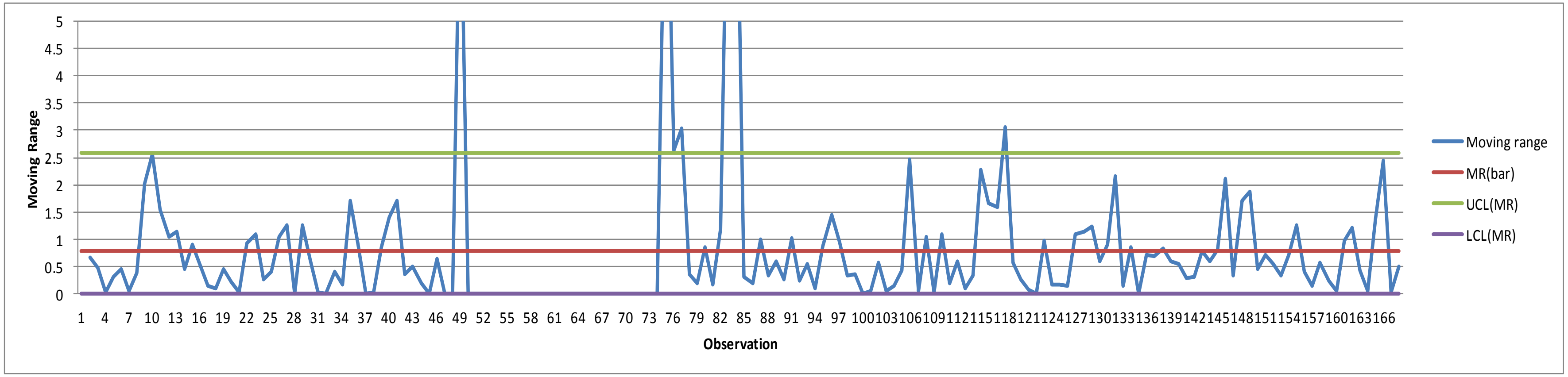
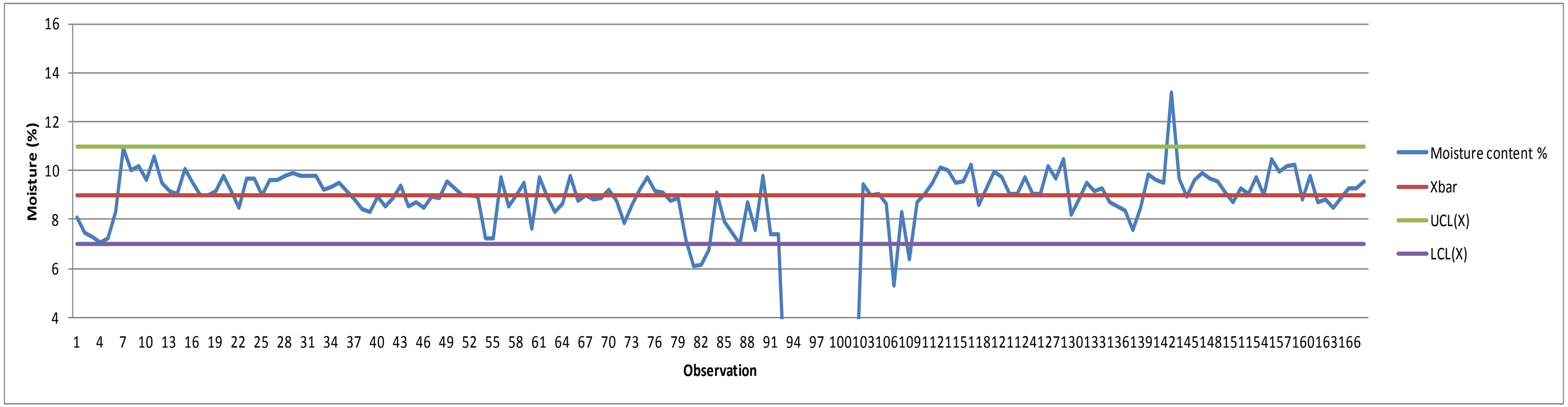


Figure 23: Moisture content March 2012 - 2nd week

Table 12: Moisture content March 2012 - 2nd week

X and MR chart - Phosphate moisture content			
Section	Filtration	Duration	2012/03/12- 2012/03/18
Process	Belt filter discharge	Spec limit (tLtb)	7%

Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	8.075	7.435	7.285	7.03	7.215	8.305	10.9	10.035	10.19	9.615	10.57	9.49	9.14	9.05	10.095	9.515	8.98	8.965	9.155	9.765	9.17	8.5	9.65	9.65
Moving Range		0.64	0.15	0.255	0.185	1.09	2.595	0.865	0.155	0.575	0.955	1.08	0.35	0.09	1.045	0.58	0.535	0.015	0.19	0.61	0.595	0.67	1.15	0
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	9	9.605	9.64	9.795	9.91	9.765	9.8	9.76	9.2	9.32	9.5	9.13	8.815	8.42	8.33	8.93	8.54	8.9	9.385	8.515	8.715	8.475	8.95	8.85
Moving Range	0.65	0.605	0.035	0.155	0.115	0.145	0.035	0.04	0.56	0.12	0.18	0.37	0.315	0.395	0.09	0.6	0.39	0.36	0.485	0.87	0.2	0.24	0.475	0.1
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	9.53	9.25	8.975	8.985	8.955	7.23	7.205	9.7	8.53	9.005	9.495	7.645	9.7	8.925	8.32	8.675	9.81	8.785	8.98	8.82	8.9	9.2	8.75	7.85
Moving Range	0.68	0.28	0.275	0.01	0.03	1.725	0.025	2.495	1.17	0.475	0.49	1.85	2.055	0.775	0.605	0.355	1.135	1.025	0.195	0.16	0.08	0.3	0.45	0.9
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	8.6	9.2	9.7	9.15	9.12	8.76	8.88	7.18	6.11	6.15	6.77	9.12	7.89	7.45	7.01	8.7	7.56	9.77	7.41	7.39	0	0	0	0
Moving Range	0.75	0.6	0.5	0.55	0.03	0.36	0.12	1.7	1.07	0.04	0.62	2.35	1.23	0.44	0.44	1.69	1.14	2.21	2.36	0.02	7.39	0	0	0
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	0	0	0	0	0	0	9.43	8.96	9.05	8.64	5.31	8.31	6.39	8.68	9.05	9.48	10.145	9.99	9.525	9.57	10.25	8.6	9.3	9.95
Moving Range	0	0	0	0	0	0	9.43	0.47	0.09	0.41	3.33	3	1.92	2.29	0.37	0.43	0.665	0.155	0.465	0.045	0.68	1.65	0.7	0.65
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	9.75	9.05	9.05	9.75	9.03	9.055	10.18	9.655	10.47	8.21	8.835	9.51	9.15	9.3	8.69	8.505	8.38	7.555	8.47	9.835	9.6	9.5	13.2	9.65
Moving Range	0.2	0.7	0	0.7	0.72	0.025	1.125	0.525	0.815	2.26	0.625	0.675	0.36	0.15	0.61	0.185	0.125	0.825	0.915	1.365	0.235	0.1	3.7	3.55
Date																								
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Moisture(%)	8.95	9.6	9.9	9.65	9.54	9.1	8.69	9.26	9.07	9.74	9.005	10.47	9.925	10.175	10.24	8.8	9.78	8.71	8.84	8.465	8.85	9.3	9.25	9.55
Moving Range	0.7	0.65	0.3	0.25	0.11	0.44	0.41	0.57	0.19	0.67	0.735	1.465	0.545	0.25	0.065	1.44	0.98	1.07	0.13	0.375	0.385	0.45	0.05	0.3



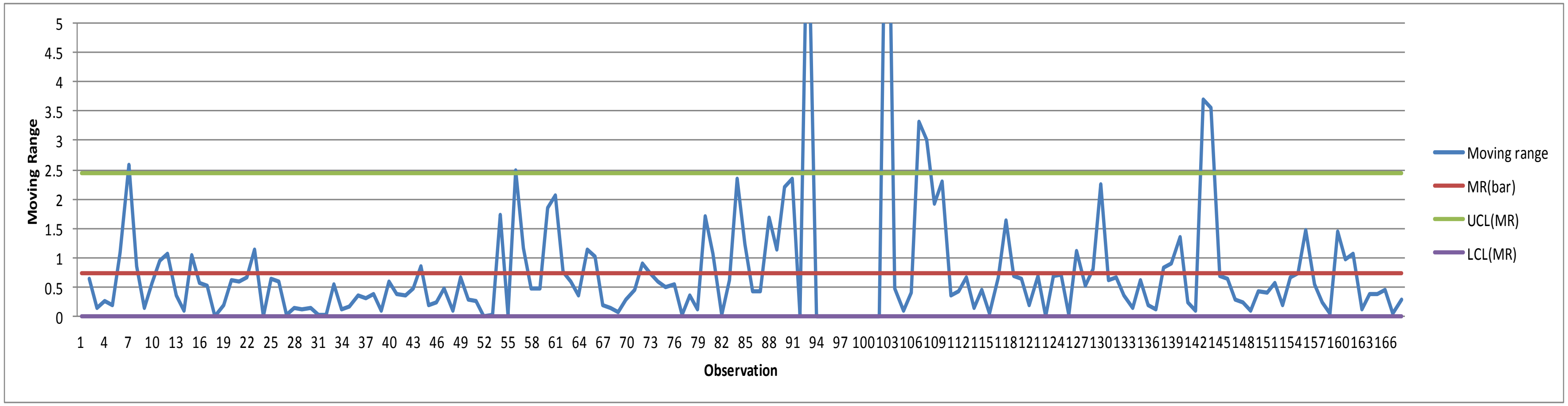


Figure 24: Moisture content March 2012 - 2nd week

Table 13: Pulp densities March 2012 - 1st week

X and MR chart - Pulp density			
Section	Filtration	Duration	2012/03/05 - 2012/03/11
Process	Thickeners		

Date	2012/03/05																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Pulp density	1932.33		1696.33	1648	1838.67	1768.33	1692.33	1837	1772.33	1772.67	1806.33	1828.33	1792.33	1779.33	1931	1813.67	1874	1913.33	1933.67	1885.67	1882.33	1842.33	1895.67	1865.33
Moving Range				48.3333	190.667	70.3333	76	144.667	64.6667	0.33333	33.6667	22	36	13	151.667	117.333	60.3333	39.3333	20.3333	48	3.33333	40	53.3333	30.3333
Date	2012/03/06																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Pulp density	1877	1982.33	1950.33	1821.67	1732	1794.33	1651.33	1607.33	1788	1886.67	1836	1751	1836.67	1765.33	1607.33	1801.33	1681.67	1813.67	1683.67	1575.67	1763.33	1427.67	1282.67	1002.67
Moving Range	11.6667	105.333	32	128.667	89.6667	62.3333	143	44	180.667	98.6667	50.6667	85	85.6667	71.3333	158	194	119.667	132	130	108	187.667	335.667	145	280
Date	2012/03/07																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Pulp density	1003.67	1003.33	1003.67	1003.33	1003	1003	1002.33	1003.33		1002.33	1002.33	1003.33	1003.33	1003	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Moving Range	1	0.33333	0.33333	0.33333	0.33333	0	0.66667	1			0	1	0	0.33333	3	0	0	0	0	0	0	0	0	0
Date	2012/03/08																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Pulp density	1000	1033.67	1251.67	1402.33	1565	1562.33	1526.33	1665.67	1879	1537.33	1626.33	1515.33	1663.33	1688.67	1838.67	1889.67	1659.67	1717.33	1729	1768.67	1447.67	1536.33	1496.67	1841.33
Moving Range	0	33.6667	218	150.667	162.667	2.66667	36	139.333	213.333	341.667	89	111	148	25.3333	150	51	230	57.6667	11.6667	39.6667	321	88.6667	39.6667	344.667
Date	2012/03/09																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Pulp density	1931.33	1849.67	1843.67	1862.33	1858	1781	1841.67	1688.33	1725.67	1679.67	1769.67	1720	1457	1398	1497.67	1397.67	1426	1424.67	1467.67	1616.33	1893	1880	1834.67	1850.67
Moving Range	90	81.6667	6	18.6667	4.33333	77	60.6667	153.333	37.3333	46	90	49.6667	263	59	99.6667	100	28.3333	1.33333	43	148.667	276.667	13	45.3333	16
Date	2012/03/10																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Pulp density	1903	1900.33	1904.33	1892.67	1810	1860.33	1842.67	1784	1856.33	1739	1737	1796.33	1793.33	1825	1924	1933.33	1934	1906	1804.33	1957	1956.33	1946.33	1935	1936
Moving Range	52.3333	2.66667	4	11.6667	82.6667	50.3333	17.6667	58.6667	72.3333	117.333	2	59.3333	3	31.6667	99	9.33333	0.66667	28	101.667	152.667	0.66667	10	11.3333	1
Date	2012/03/11																							
Time	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
Pulp density	1940.67	1981	1859.67	1865	1947.67	1898	1834.67	1901.33	1894.33			1888	1924	1849.67	1750.67	1842.33	1929.33	1874	1908.33	1880.33	1866.33	1930.67	1926.33	1876
Moving Range	4.66667	40.3333	121.333	5.33333	82.6667	49.6667	63.3333	66.6667	7				36	74.3333	99	91.6667	87	55.3333	34.3333	28	14	64.3333	4.33333	50.3333

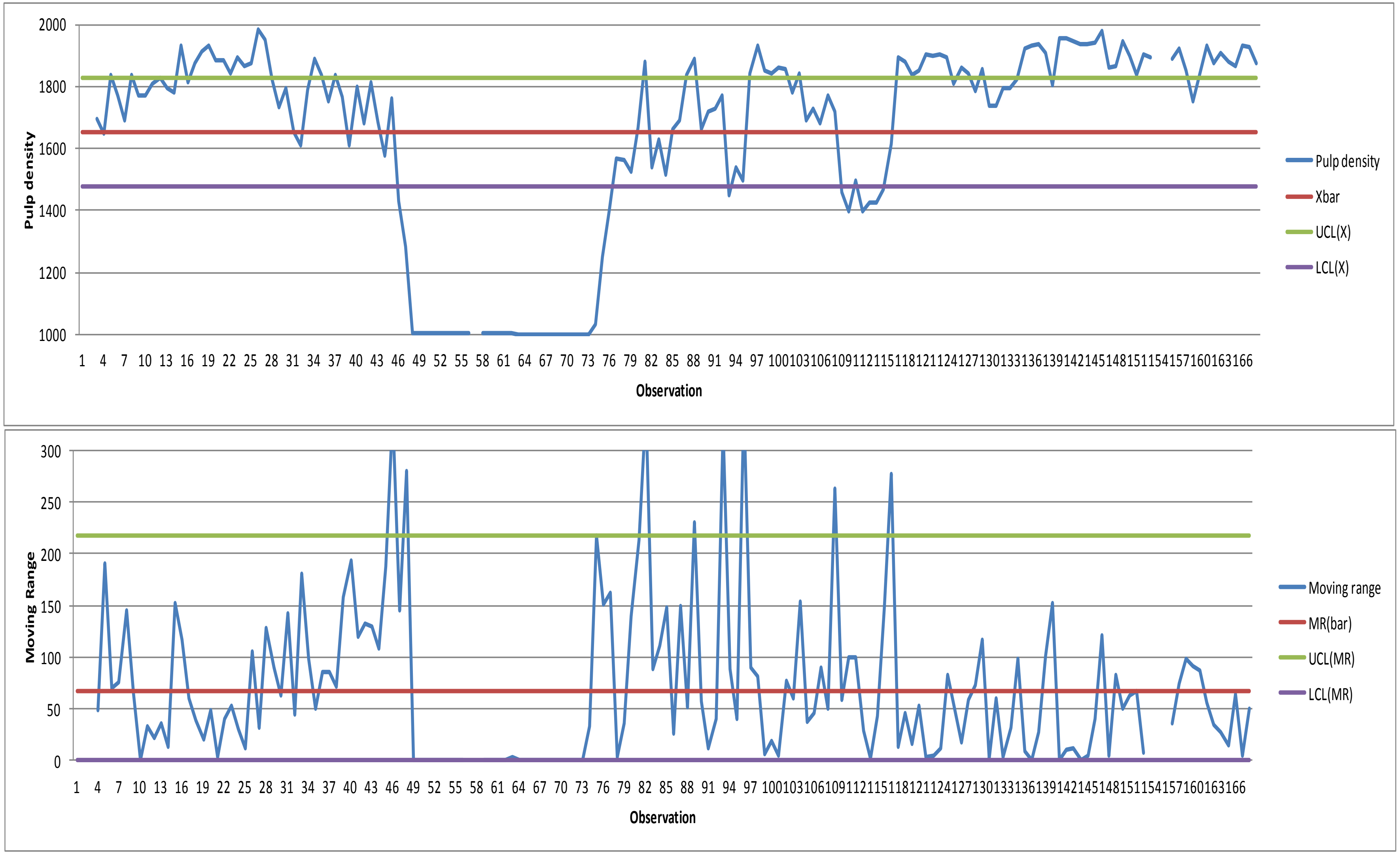


Figure 25: Pulp densities March 2012 - 1st week

Observations

During the observation periods and the daily inspections it had become apparent that irregularities in plant operation and maintenance issues are not addressed or even noticed. Very few of the irregularities in plant operation and maintenance issues were addressed during the investigation.

Operation irregularities and maintenance issues:

- Vacuum box drain pipes not connected and lying on transporter belt.
- Overflow drain pipes not connected, overflow concentrate spilled and not captured into the system.
- Barometric seal tanks which are not cleaned.
- Barometric seal tank drain valve not functioning.
- Pressure gauges which are dirty or painted over, which are not legible.
- Transporter belt curbing is cracked and there are sections of curbing missing as well.
- The carry-over of liquid and dissolved solids can occur if the filtrate pumps are not in good working condition.

The photo on the left shows the pressure gauge on the filter manifold of Filter 13 which is painted red and cannot be read.

The photo on the right shows sludge that has gathered in the barometric seal tank, the sludge was taken no more than 10 cm below the water level; this indicates that the barometric leg had been submerged in about 30 cm of sludge and this had been the case for more than two weeks of operation.

This photo shows the drain vacuum box drain pipe which is disconnected and lying on top of the moving transport belt.

The lack of control measures regarding the moisture and thickness of the cake creates the possibility for irregularities in the operation of the plant to go undetected.

Downstream effects of high moisture content product

The section directly downstream from filtration is the Drying section. The Drying section utilizes ovens to bake/dry the phosphate to a moisture content of 1.5%. The driers are fed with the product discharged at filtration. Product with moisture content in the region of 11% should be avoided as this has the following effects:

- Choking of chutes, which stops production to be cleaned
- Transfer between conveyors is made difficult because of product sticking
- Wet stockpiles collapsing rendering conveyor system useless
- The stockpile reclaimers are overworked and this causes breakages

The production impact as can be seen from Table 14: Drying capacity vs Feed moisture content is a real concern that should is overlooked at times by the Filtration section. The values relating to a 75 % drier capacity will be referenced as that is a realistic and very achievable target.

The 8.5 % moisture content goal equates to a production capacity of 2 745 288 tons P2O5/ year. The Filtration section has produced product averaging at a moisture content of around 9% which will give you production capacity of 2 325 960 tons P2O5/ year. The loss in production capacity due to the inefficient operation at the Filtration section is about 425 000 tons P2O5/ year.

Foskor has expanded their open-pit mine and they are estimating a yearly production figure well above the attainable production capacity of 2 745 tons P2O5/ year.

The financial impact in terms of lost sales for the year caused by the Filtration section's inefficiency can be estimated with a sales price of around $185/ton to be $78 500 000.

Table 14: Drying capacity vs Feed moisture content

Actual - Drier Capacity 100 %									
		% Inlet Moisture		Drier 4	Drier 5	Drier 6	Drier 7	Drier 8	Total tons / Week
24h X 7days	168		9.0	10920	11760	15120	8400	13440	59640
Operating time per		AVERAGE	8.5	11760	12600	16968	13440	15624	70392
week at			8.0	12600	13440	18480	15456	16464	76440
100% availability			7.5	13440	15120	19656	16800	17808	82824
			7.0	13440	15120	20160	17472	20160	86352

Actual - Drier Capacity 80%									
		% Inlet Moisture		Drier 4	Drier 5	Drier 6	Drier 7	Drier 8	Total tons / Week
24h x 7days›	**134**		**9.0**	**8736**	**9408**	**12096**	**6720**	**10752**	**47712**
Operating time per		**AVERAGE**	**8.5**	**9408**	**10080**	**13574.4**	**10752**	**12499.2**	**56314**
week at			**8.0**	**10080**	**10752**	**14784**	**12364.8**	**13171.2**	**61152**
80% availability of			**7.5**	**10752**	**12096**	**15724.8**	**13440**	**14246.4**	**66259**
the Drying Plant			**7.0**	**10752**	**12096**	**16128**	**13977.6**	**16128**	**69082**

Thus:	**Total drying capacity**	**@ average inlet moisture content of 9.0%**	**80% Availability**	**t / year**	**2 481 024**
	Total drying capacity	**@ average inlet moisture content of 8.5%**	**80% Availability**	**t / year**	**2 928 307**
	Total drying capacity	**@ average inlet moisture content of 8.0%**	**80% Availability**	**t / year**	**3 179 904**

Actual - Drier Capacity 75%									
		% Inlet Moisture		Drier 4	Drier 5	Drier 6	Drier 7	Drier 8	Total tons / Week
24h x 7days›	**126**		**9.0**	**8190**	**8820**	**11340**	**6300**	**10080**	**44730**
Operating time per		**AVERAGE**	**8.5**	**8820**	**9450**	**12726**	**10080**	**11718**	**52794**
week at			**8.0**	**9450**	**10080**	**13860**	**11592**	**12348**	**57330**
75% availability of			**7.5**	**10080**	**11340**	**14742**	**12600**	**13356**	**62118**
the Drying Plant			**7.0**	**10080**	**11340**	**15120**	**13104**	**15120**	**64764**

Thus:	**Total drying capacity**	**@ average inlet moisture content of 9.0%**	**75% Availability**	**t / year**	**2 325 960**
	Total drying capacity	**@ average inlet moisture content of 8.5%**	**75% Availability**	**t / year**	**2 745 288**
	Total drying capacity	**@ average inlet moisture content of 8.0%**	**75% Availability**	**t / year**	**2 981 160**

Proposed Implementations

The current means of measuring moisture content of the belt filter's discharge is too inefficient for the means of process control. The current measurement is a mixture of the discharge of four different filters each running at different parameters. The moisture content that is obtained from these readings cannot be used with confidence as a process control and analysis variable.

The horizontal belt filter can be fitted with an online real time moisture analyzer, which measures the moisture content and filter cake thickness of the product discharged by each filter individually by means of a non destructive microwave operated process. The catalogue for the moisture analyzer is in the appendix. This is the only product currently available that can do these measurements non-destructively. The data provided by the moisture analyzer will be of a lot more use for process control and analysis.

The use of the current process measurements for moisture content, might at times cause stratification on the control charts, because of the sampling that is done from more than one subgroup.

Conclusion

The investigation has revealed a number of issues that contribute to the failure of the Filtration section in meeting their 8.5% moisture content goal for discharged product. The most evident of the identified issues were that of plant operation and maintenance.

The data analysis and process control studies had shown periods where they had come close to achieving their moisture content goal of 8.5%. These periods were however the same periods that they had operated the plant within the design specifications or very close to it.

It is thus recommended that the improvement effort of the Filtration section should commence with the personnel issues within operations and maintenance; this should be in the form of a process of accountability of the responsible employee. The sampling methods used for the control of the operation of the plant should also be addressed as the current method provides output data with a low degree of traceability. The plant and its components can be upgraded after this initial improvement effort if better performance is still desired.

References

Wills, BA, *Wills' mineral processing technology,* 7th edn, Butterworth-Heinemann, Linacre house, Jordan hill, Oxford, UK.

Gitlow, HS, Oppenheim, AJ, Oppenheim, R & Levine, DM 2005, *Quality Management*, 3rd edn, McGraw-Hill, New York.

Foskor Phalaborwa 2010, Theory/operation of wet concentration and handling, 3rd edn, Phalaborwa.

Moistscan online moisture analysis, <http://www.moistscan.com/ma600hbf.htm>.

Appendix

Shift operation and maintenance checklist

	Completed		
	Yes	No	Remarks
Check job cards: completed and outstanding			
Inspect completed job card's repairs or installations			
Clean barometric seal tank			
Inspect instrumentation			
Visual plant inspection			
Pipes			
Holes			
Flanges			
Vacuum pumps			
Holes			
Flanges			
Seals			
Motor v-belts			
Discharge manifold: Carry over			
Cloth condition			
Blinding			
Wear			
Transporter belt			
Drain holes			
Grooves			
Curbing			
Vacuum box			
Vacuum pipes			
Holes			
Fittings			
Belt feed dam area			
Curtain			
Overflow			
Chokes			
Pipes			
Holes			
Fittings			
Belt alignment			
Vacuum readings - Assess difference (Pump and Filter manifold)			

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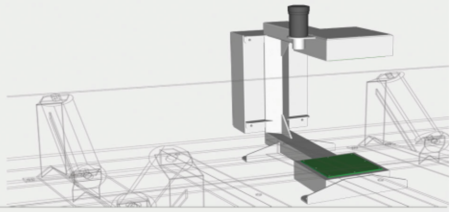
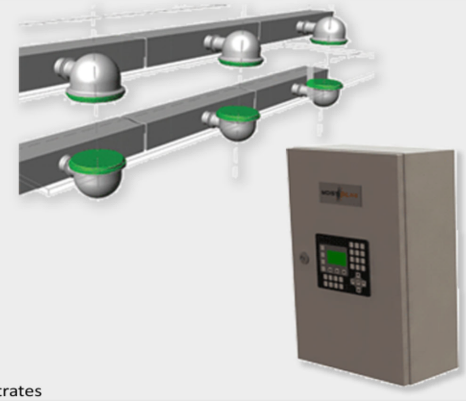


MoistScan® MA-600HBF
Horizontal Belt Filter Moisture Analyser

General Description



The MositScan® MA-600HBF is custom designed for accurate analysis of filter cake moisture on a horizontal belt filter. The MA-600HBF standard configuration employs 3 sensors – one located 1 meter (3.3 feet) from each side of the filter bed and 1 in the centre. Data from the MA-600HBF is typically used to control the vacuum pressure or belt speed, the objective of which is to ensure that the moisture of the filter cake is maintained within set point limits.

Callidan Instruments is the only company who manufactures a purpose-built online microwave moisture analyser for horizontal belt filters.

The MA-600HBF is suitable for use on:
- Copper concentrate
- Coal filter cake
- Iron ore concentrate
- Lead and Zinc concentrate
- Nickel concentrate
- Most metallic and non metallic mineral concentrates as well as organic concentrates

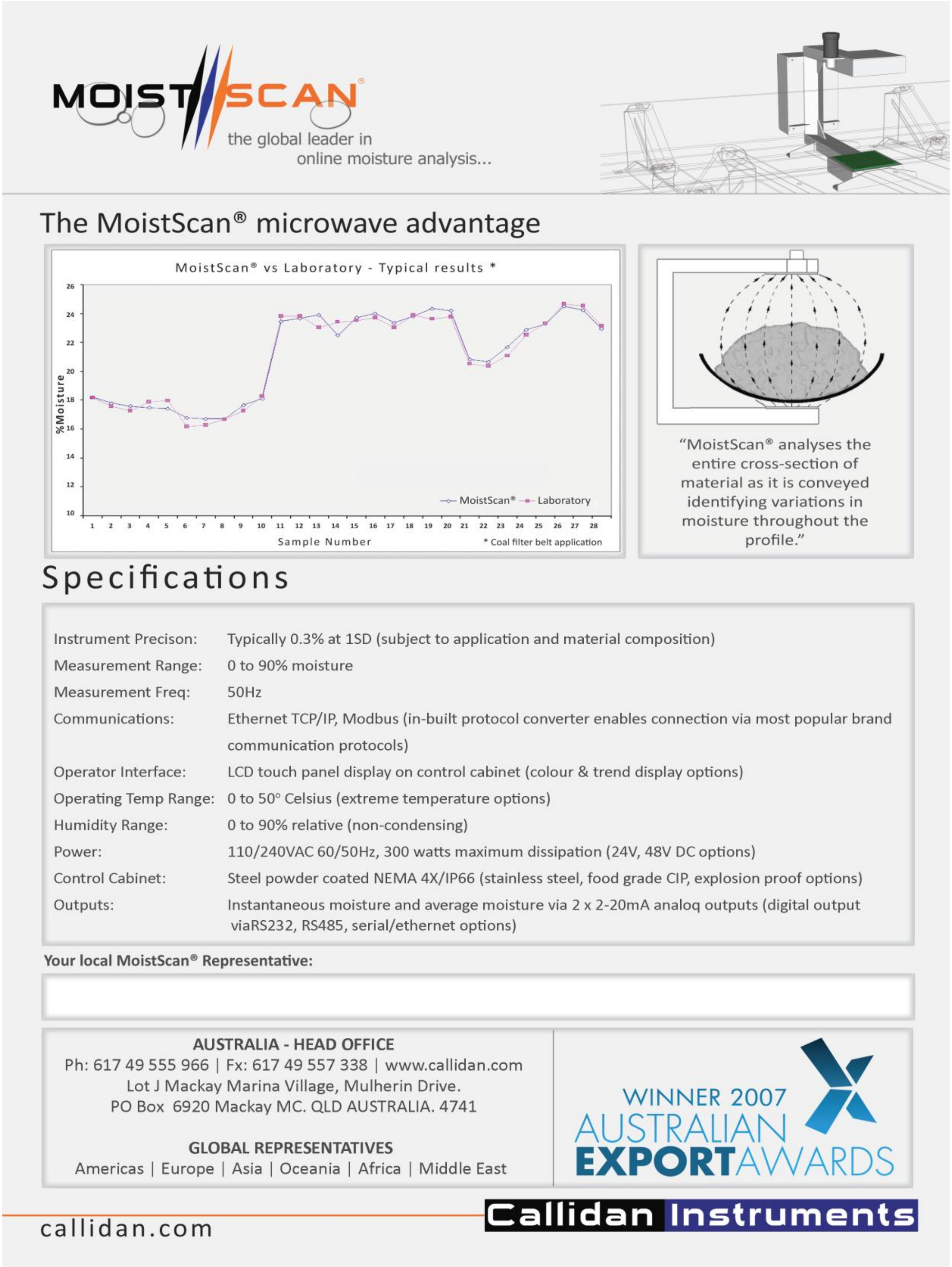
MINING | AGRICULTURE | CHEMICALS | BUILDING MATERIALS | FOOD | BIOFUELS

Benefits	Features
• Superior Precision and Accuracy	• Analyses 100% of the material on the conveyor from top to bottom. • Uses MoistScan®, the most widely used online microwave analysis technology on the market for measuring moisture in bulk materials.
• Mass compensation device not required	• Analyser operates independant of mass flow rate
• Non Contact	• No contact with the material being analysed
• Non Nucleonic	• No radioactive source is required
• Low Whole of Life Costs	• As no beltweigher or radioactive sources is required ongoing costs associated with servicing and regulatory compliance is minimal
• Seamless Plant Integration	• Wide range of communication options for transmitting data to Plant PLC
• Remote Access Calibration & Servicing	• Cost-effective remote communication access for periodic checking of calibration

callidan.com

Callidan Instruments

Moistscan online moisture analysis, <http://www.moistscan.com/ma600hbf.htm>.



MOIST SCAN

the global leader in online moisture analysis...

The MoistScan® microwave advantage

"MoistScan® analyses the entire cross-section of material as it is conveyed identifying variations in moisture throughout the profile."

Specifications

Instrument Precison:	Typically 0.3% at 1SD (subject to application and material composition)
Measurement Range:	0 to 90% moisture
Measurement Freq:	50Hz
Communications:	Ethernet TCP/IP, Modbus (in-built protocol converter enables connection via most popular brand communication protocols)
Operator Interface:	LCD touch panel display on control cabinet (colour & trend display options)
Operating Temp Range:	0 to 50° Celsius (extreme temperature options)
Humidity Range:	0 to 90% relative (non-condensing)
Power:	110/240VAC 60/50Hz, 300 watts maximum dissipation (24V, 48V DC options)
Control Cabinet:	Steel powder coated NEMA 4X/IP66 (stainless steel, food grade CIP, explosion proof options)
Outputs:	Instantaneous moisture and average moisture via 2 x 2-20mA analoq outputs (digital output viaRS232, RS485, serial/ethernet options)

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