University of Southern Queensland

Faculty of Engineering & Surveying

On-Line Equipment Condition Monitoring Based Maintenance

A dissertation submitted by

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in fulfilment of the requirements of

ENG4112 Research Project

towards the degree of

Bachelor of Engineering Mechanical

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Abstract

Incitec Pivot Limited's (IPL) Southern Cross Operations (SCO) operates an integrated mining and processing complex at Phosphate Hill and Mt Isa, producing one million tonnes of high analysis fertiliser per annum.

Working with the Southern Cross Operation Engineering Alliance in Townsville a research project was undertaken for the client; IPL. Several options were presented that were motivated by product improvement opportunities; it was negotiated with USQ and IPL that the topic of On-line Equipment Condition Monitoring Based Maintenance be investigated.

SCO are continually striving to identify improvement opportunities for efficiency, reliability, quality and productivity. By recognizing production constraints and other areas where improvements can be made, recommendations are put forward based on analysis of operational data and the use of information management systems.

The following project aims to improve the reliability and performance of centrifugal pumps in the Phosphoric Acid Plant by fully utilizing the existing process monitoring instrumentation. Through monitoring the process it is hoped that key indicators of pump failure can be derived and passed on as an automatic maintenance notification.

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ENG4111/2 *Research Project*

Limitations of Use

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Andrew Mitchell

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Signature

Date

Acknowledgments

The author would like to thank those people, who through their efforts and contributions enabled the completion of this project. Family and friends for encouragement and patience.

Andrew Mitchell

University of Southern Queensland
October 2007

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Chapter 1

Introduction

1.1 Background

The SCO facilities process phosphate rock which is mined from the Phosphate Hill resource and with the production of ammonia from natural gas, sulphuric acid from copper smelter gases, manufactures phosphoric acid and high analysis ammonium phosphate fertilizer for domestic and export markets. Phosphate Hill is approximately 150km south of Mount Isa in Queensland.

At this location there are two billion tonnes of phosphate rock including mining reserves of 103 million tonnes, some 2.2 million tonnes rock is mined per year. The operation produces about 0.8 to 1 million tonnes of diammonium phosphate (DAP) and monoammonium phosphate (MAP) - about the size of the Australian market and around 2 % of world production.

1.2 Project Aims

This project aims to use the process history monitoring system at Phosphate Hill to monitor and report operating parameters that provide a direct measurement of a centrifugal slurry pumps condition. This information is to be automatically communicated to SAP where maintenance tasks can be triggered if key condition parameters are exceeded.

1.3 Specific Objectives

1. Identify the critical equipment developing high maintenance costs that will benefit from online performance monitoring.

2. Identify the existing instrumentation on the equipment, determine the best candidate from assessing both maintenance costs and existing instrumentation.

3. Research methods of assessing the condition of equipment and the key indicators of failure.

4. Determine operating parameters of the chosen equipment through the plant history data and operating manuals.

5. Determine set point values that can be measured by the instruments and trigger an alarm signal once these set points are breached

6. Manage the timely replacement of pumps to achieve full component life without adversely affecting the process.

1.4 Consequential Effects & Risk Assessment

Undertaking any project there are always consequential effects and risks associated with achieving the desired outcome. The research part of the project had very minimal consequences and risks however it is important to identify issues that may arise if the project is taken into the next phase of actually implementing a new maintenance strategy.

1.4.1 Risk Assessment

Safety Inductions at Phosphate Hill outline all the hazards and the safety requirements that must be adhered to whilst on site. This includes notifying operators that work is being conducted in the area and that all Personal Protective Equipment (PPE) is worn. Being well informed on the requirements it then comes down to identifying the hazards associated with the particular task that has to be carried out.

As mentioned field test will be taken within the Phosphoric Acid Plant. This has been negotiated with the Production Superintendent and agreed on a process that should have minimal impact on production.

1.4.2 Consequential effects

Consequential effects can be broken down into the following areas:

- Safety
- Environment
- Ethics
- Economics

Safety

SCO's aim is to remove or control hazards so as to eliminate injuries to people. Facilities and maintenance activities are to comply with relevant statutory requirements and regulations, international and national standards, and codes of practice. It is expected that all personnel adopt safe work practices and contribute to the creation of a safe workplace.

Environment

SCO's approach is to to remove or control hazards to eliminate damage to the environment. Facilities and maintenance comply with relevant statutory requirements and regulations, international and national standards and codes of practice. SCO expects that all personnel adopt environmentally sound work practices and contribute to the creation of a healthy environment.

Ethics

The main ethical issues associated with the project relates to the safety and environmental issues raised in the previous two points. Neglecting either of these would constitute a breach of the ethics of the Institution of Engineers.

Economics

This project is taken within a chemical plant that has high production rates, any recommendation to change the maintenance strategy may have great economical benefits. However if the any recommendation is taken and it has an adverse effect, the operation could sustain considerable losses.

1.5 Resources & Timelines

It was specified by site that there would be no additional equipment or resources allocated to the project. All necessary information is to be accessed through Southern Cross Operations' Information Management System. Most of the information can been collected over the computer network and with the some field test conducted, accuracy should be achieved

From here it comes down to sorting through the material, improving accuracy, and discussing the findings with maintenance personnel. Some further trials may be needed and as time permits, implement the system.

With just over 8 months of project time, It is hoped that all necessary calculation and findings can be finalized before the end of October so adequate time be allocated to assembling the final dissertation.

1.6 Conclusion

There are basically two main parts to this project:

1. Identify centrifugal slurry pump failure characteristics using on-line process monitoring instruments.
2. Develop a reliable on-line condition monitoring based maintenance system for the centrifugal slurry pumps

It is anticipated that further instrumentation and capital will be required to implement the on-line condition monitoring based maintenance system. This is outside the scope of the project which aims to utilize the existing instrumentation. The dissertation will hopefully capture the information necessary to implement the system and outline the benefits to IPL.

Chapter 2

Production Chain

2.1 Overview

The SCO operation can be broken down into the following key areas at Phosphate Hill, Mount Isa and Townsville.

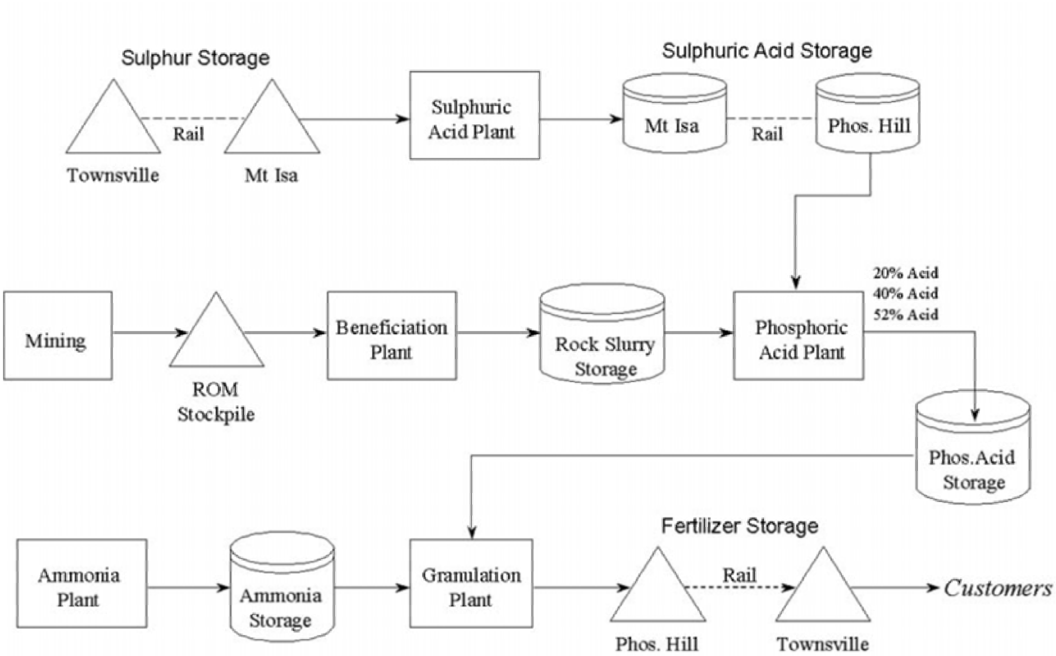

Figure 2.1: SCF Production Chain.

2.2 Mining

Phosphate Rock is mined at Phosphate Hill using conventional mining methods. Excavators are used to remove the overburden and to load the phosphate rock into dump trucks. The ore is transported by the dump trucks to the Run of Mine (ROM) pad to be stock piled. Loaders are then used to load the stockpiled rock into the ROM which delivers the rock by conveyor to the beneficiation plant.

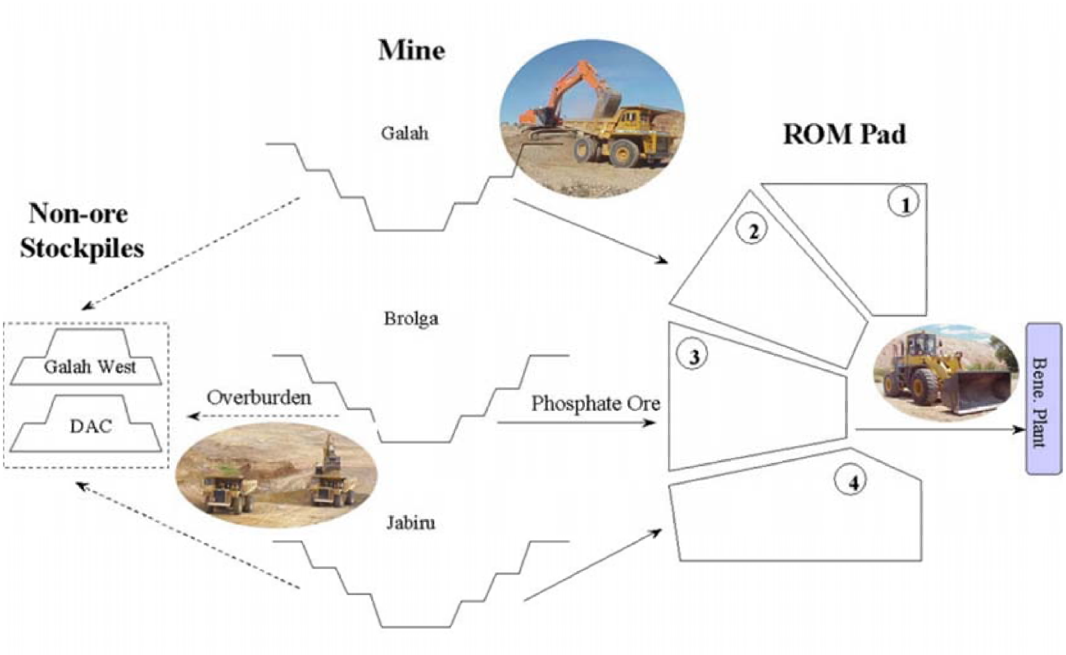

Figure 2.2: Mining process.

2.3 Beneficiation Plant

Here the rock is crushed, clay is washed out, and the clean rock is ground as slurry in a ball mill. The ground rock is thickened and stored in large tanks; it is then conveyed to the Phosphoric Acid Plant for processing.

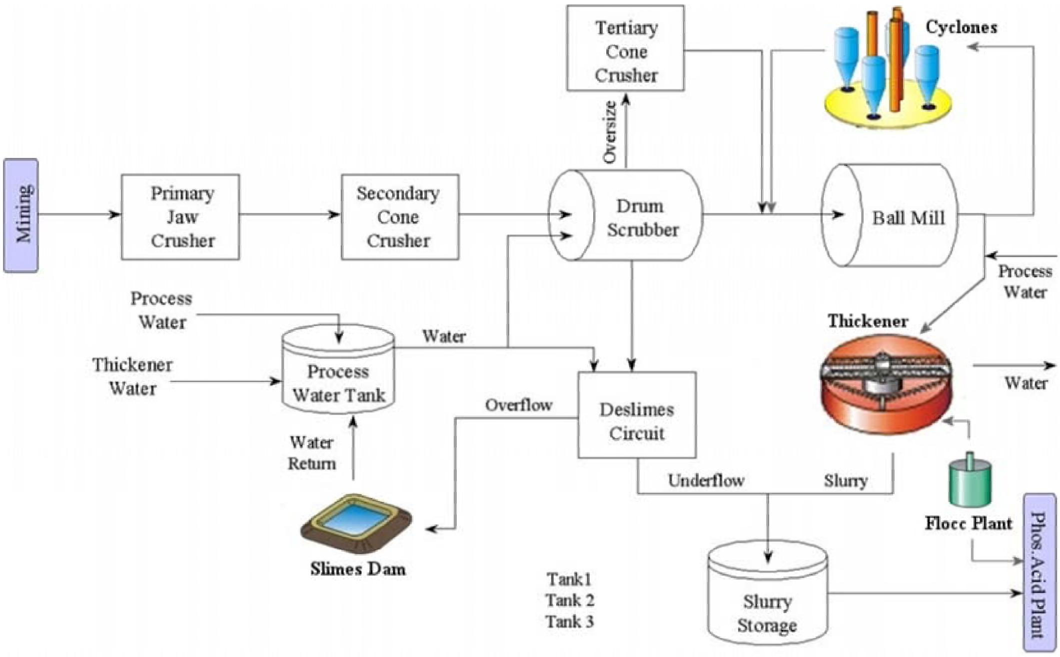

Figure 2.3: Beneficiation process.

2.4 Phosphoric Acid Plant

The Phosphoric Acid Plant (PAP) is the largest of its kind in the world; it has the capacity to produce phosphoric acid at a rate of 1,500 tonnes per day. Phosphoric Acid is produced by combining the phosphate slurry from the Beneficiation Plant with water and sulphuric acid produced at the Mount Isa Sulphuric Acid Plant.

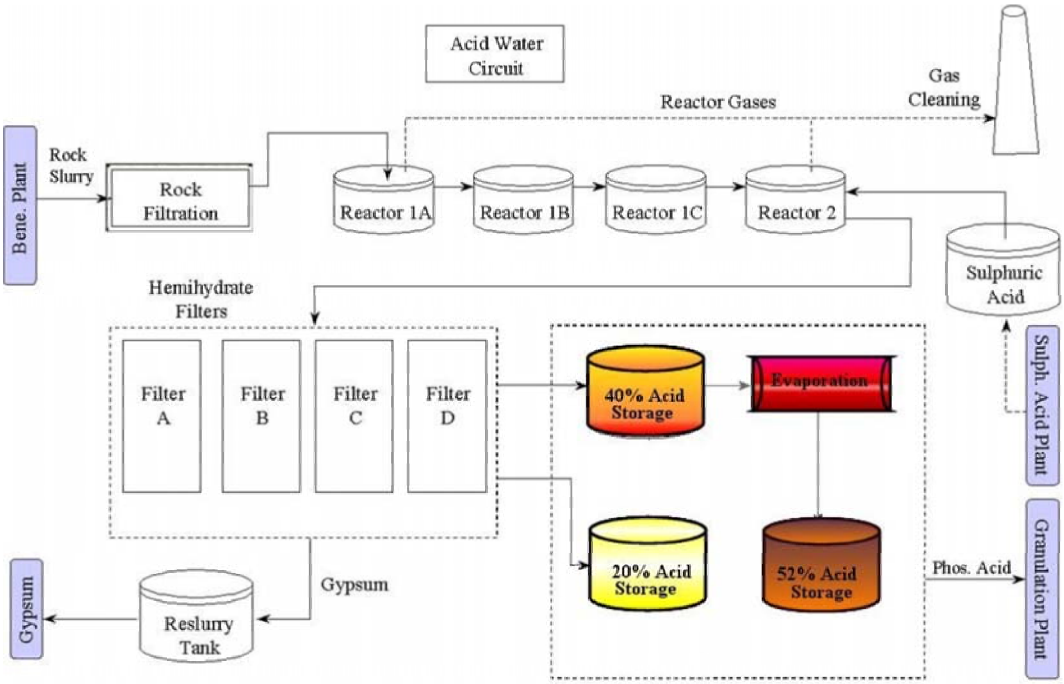

Figure 2.4: Phosphoric Acid process.

2.5 Gypsum

The Phosphoric Acid Plant produces a waste, hemihydrate solid (gypsum). The gypsum and any undissolved rock is separated from the phosphorous containing solution (known as phosphoric acid) by four belt filters. It is then sent out to be stacked where the acid waste water is retrieved.

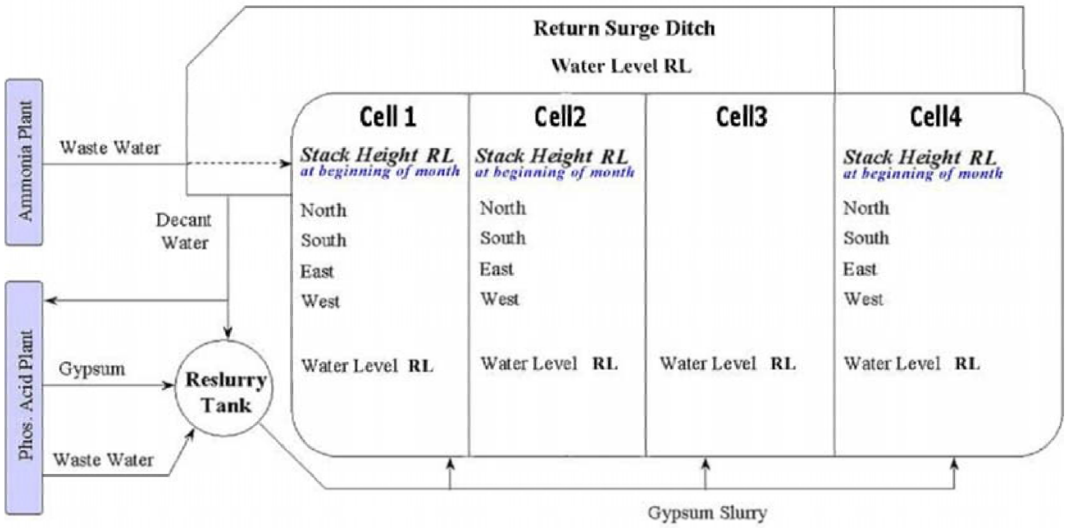

Figure 2.5: Gypsum and Acid Water Recovery Process

2.6 Ammonia Plant

The Ammonia Plant combines hydrogen extracted from natural gas and nitrogen from air to form ammonia which is combined with phosphoric acid in the Granulation Plant. The hydrogen is generated from the natural gas by catalytic reaction with steam. The resulting hydrogen rich gas is purified by pressure swing adsorption. Nitrogen is cryogenically separated from air. The nitrogen and hydrogen are compressed and reacted to form ammonia. The ammonia is removed by refrigeration and the un-reacted nitrogen and hydrogen recirculated. The ammonia is then used as one of the feed stocks to the Granulation Plant. (SCO 2001)

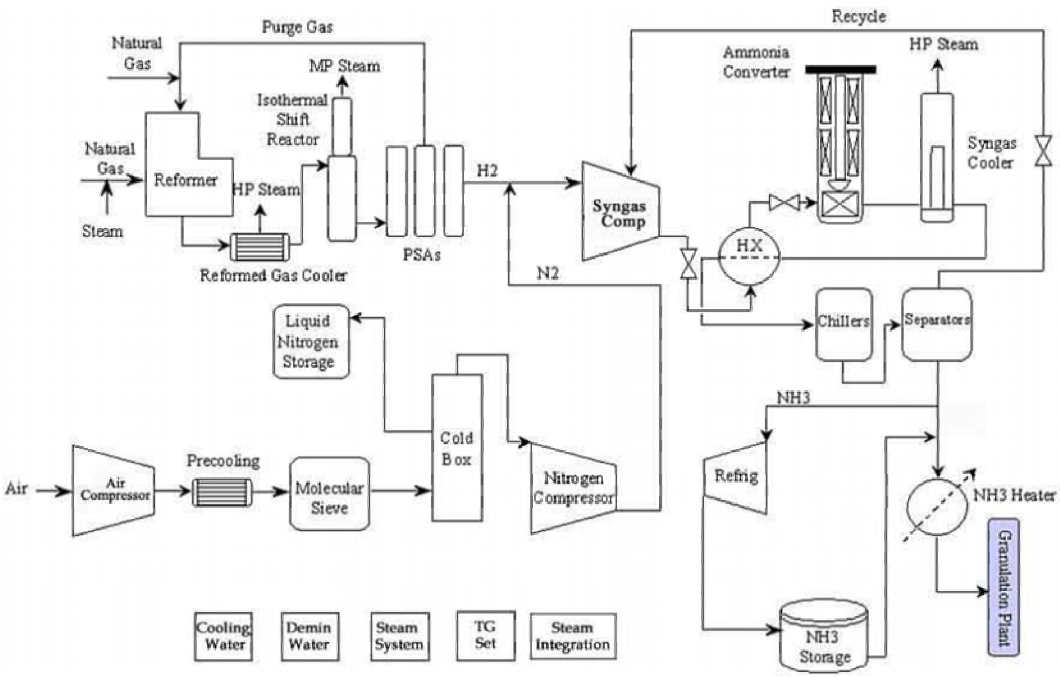

Figure 2.6: Ammonia

2.7 Sulphuric Acid Plant

The Sulphuric Acid Plant at Mount Isa sits adjacent to Xstrata's Copper Smelter. Acid is produced by collecting the gas, cleaning using a quench tower and radial flow scrubbers, and then converted to liquid sulphuric acid. The liquid acid is railed to Phosphate Hill where it is combined with the phosphate slurry to form phosphoric acid. The Sulphuric Acid Plant has a maximum capacity 4200 tonnes per day.

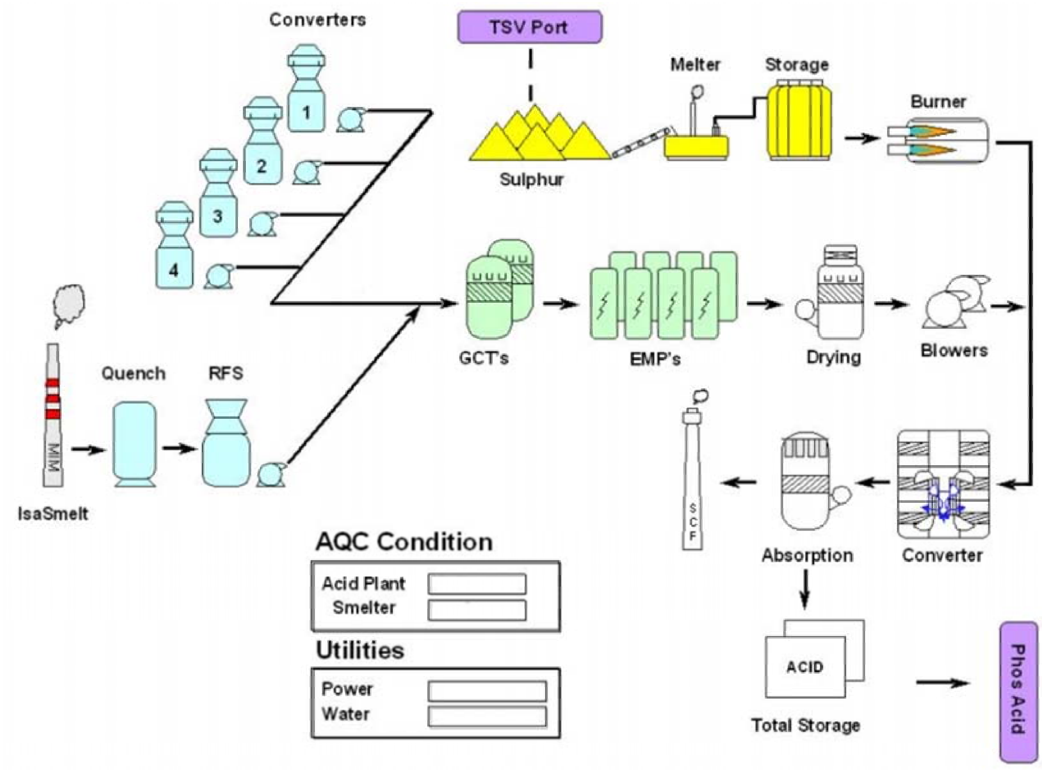

Figure 2.7: Sulphuric Acid Process

2.8 Granulation Plant

The Granulation Plant handles the final phase of fertiliser production. Phosphoric acid and liquid ammonia are combined to form ammonium phosphate slurry which is pumped into the granulator to produce fertiliser granules. The granules are dried, screened and coated before being railed to Townsville.

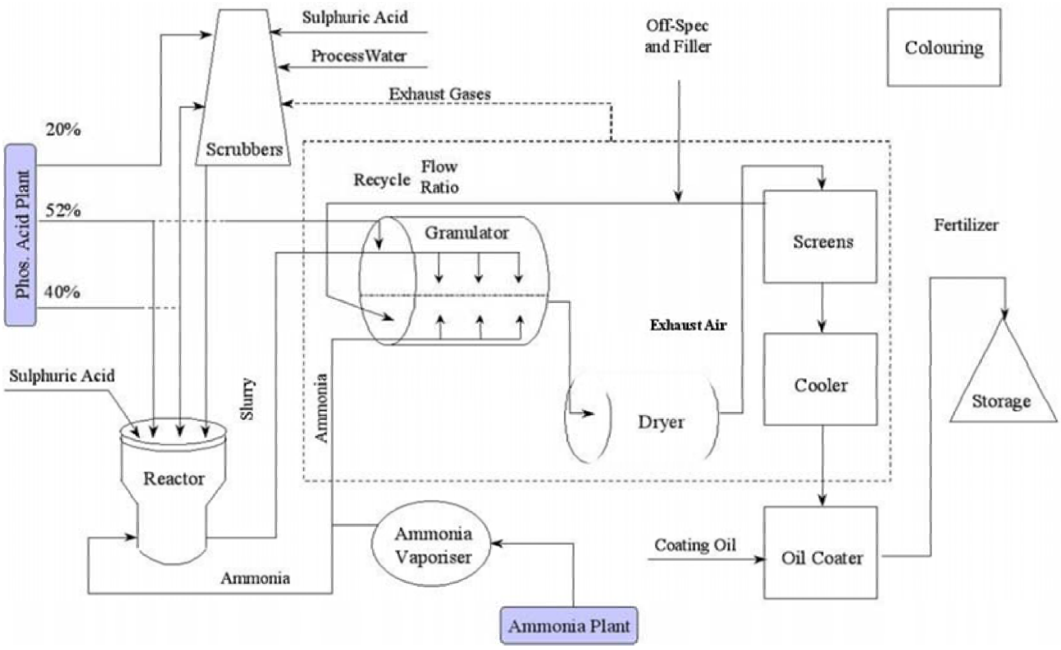

Figure 2.8: Granulation Process

2.9 Port Facility Townsville

The Townsville Port Facility consists of a storage shed catering to 90,000 tonnes of fertiliser and 10,000 tonnes of sulphur pastilles; rail transfer stations for transit of both fertiliser and sulphur; and a fully enclosed conveyor system to transport fertiliser to and from the rail transfer stations and to ships in port.

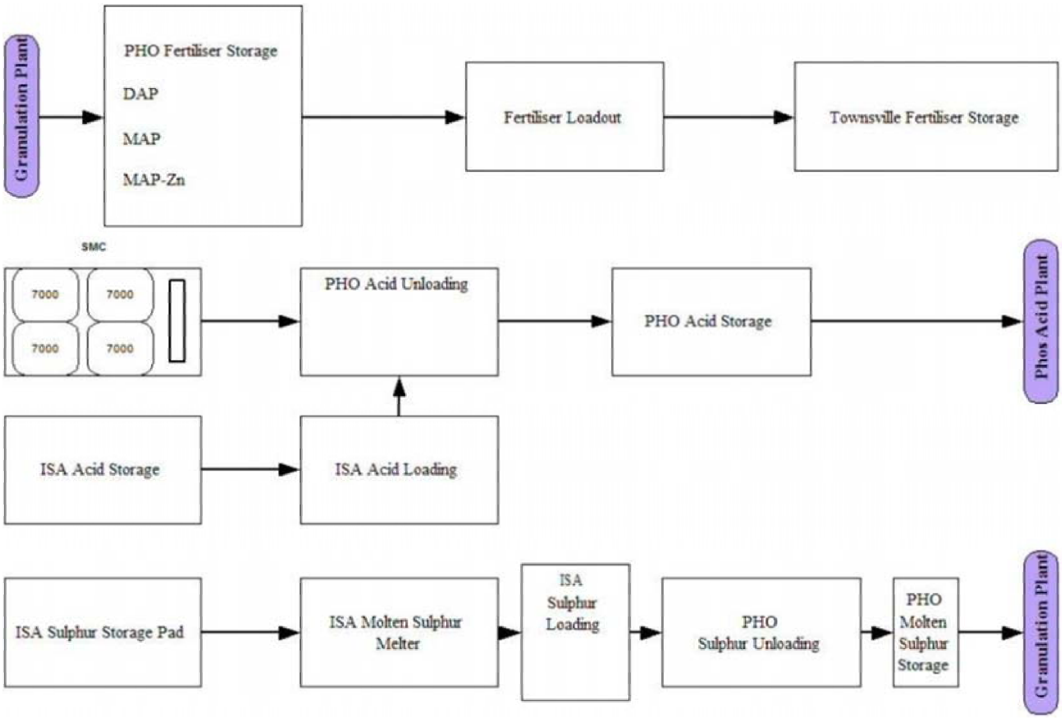

Figure 2.9: Townsville Port Operation

Chapter 3

Maintenance

3.1 Maintenance

3.1.1 Overview

Maintenance can be broken down into two categories; corrective maintenance and preventive maintenance. Corrective maintenance (CM), also known as reactive maintenance, is performed when action is required to restore the functional capabilities of failed equipment or systems. As the action is triggered by the unscheduled event of equipment failure it is considered a reactive approach to maintenance, this kind of policy usually generates high costs due to the following reasons:

- the expense of restoring equipment to a working state under crisis situation;
- the resultant damage and hazards caused by the failure;
- the loss of production.

Preventive maintenance (PM) is the approach taken to avoid these losses. This usually takes the form of equipment overhaul or item replacement at fixed intervals. This practice is known as time directed (TD) maintenance. When only TD maintenance is performed opportunities for enhancement of the PM programme is minimized. The reasons for performing PM tasks need to be recognized in order for a PM programme to reach its full potential. These reasons are:

- to prevent failure;
- to detect the onset of failure;
- to discover hidden failure.

As mentioned the most common type of PM task is time directed (TD). A TD task requires an intrusion into the equipment, thereby rendering it out of service until the task is completed. The trade off between replacing a part too early and thereby wasting money in terms of component life versus leaving it late and risking failure requires careful consideration.

The next type and preferred PM task is condition-based maintenance (CBM), which is also known as on-condition maintenance, condition-directed maintenance, or predictive maintenance. CBM is designed to detect the onset of a failure, this is by measuring some parameter over time where it has been established that the parameter correlates with incipient failure conditions. CBM is similar to TD maintenance in that the task is performed at preset intervals. However the actual preventive action is taken only when it is believed that an incipient failure has been detected.

Another important PM task that is often overlooked is the failure-finding (FF) task. In the typical operation of a plant there are many backup systems, emergency systems, and infrequently used equipment that can hide many potential hidden failures. These hidden failures can lead to operational surprises that can set up a chain of events which lead to larger scale problems within the plant if gone undetected. It is imperative to exercise a prescheduled option to check all equipment systems are in proper working order.

The final PM task to be discussed here which is not to be confused with corrective maintenance requires a deliberate decision to allow an equipment to operate until it fails with no preventive maintenance of any kind being performed, this is known as Run-To-Failure (RTF). There are some instances where no action is more cost beneficial then performing preventive maintenance. In these situations, the component or system is designed to run until failure at which point a new unit is installed. This maximizes the usage of the item and minimizes costs due to premature change out. If the failure has no affect on other items, the item is not classed as critical, there are no supply delays and the installation of a new item is quick, then operating until failure may be acceptable. Alternatively, if back-up machinery is available the item can continue until failure. With a standby machine, failures will not usually affect production. Components will then achieve their maximum life and the company will save money by ensuring there is no premature replacement.

Regardless of the amount of preventive maintenance procedures performed, corrective maintenance will still be required. Failures will happen as machinery ages or due to unforeseen accidents, however the goal is to reduce its occurrence to rare occasions by implementing more accurate methods of assessing equipment/system condition.

3.1.2 SCO Approach

The production capacity of facilities at SCO is dependant upon the effectiveness of maintenance which is a significant component of the cost of production. Maintenance performance directly influences the capital invested in income producing plant. The purpose of maintenance at SCO is defined as follows:

Purpose of maintenance
"Ensure the Planned Performance and Integrity of the Company's Income Producing Plant, at the lowest practical cost". (SCO 2004)

The role of the Maintenance Department at SCO is to ensure that the required plant performance is available to enable the production plan to be achieved in a cost effective manner. They are also responsible for the critical review of equipment performance and the improvement of the availability and capability of the equipment up to the requirements of the business plan.

Wherever practical and cost effective, preference is given to adopting equipment maintenance strategies that are proactive and planned. The aim is to prevent in service failure of equipment, or to limit the consequences of in service failures. The preferred hierarchy of equipment maintenance strategies are:

- design out the failure mechanism
- monitor the condition or performance of equipment to detect early signs of deterioration and act to repair before failure occurs
- where equipment service life is consistent, repair or replace equipment at a defined point in its expected service life
- implement measures (such as stand-by equipment) to remove or reduce the consequences of failure, or
- Operate equipment to failure.

Preventative maintenance strategies have been developed for all equipment based on the Reliability Centered Maintenance (RCM) methodology.

3.1.3 Reliability Centered Maintenance (RCM)

Reliability-Centered Maintenance (RCM) is a structured methodology for determining the maintenance requirement of any physical asset in its operating context. The primary objective of RCM is to preserve system function (Moubray 1990). Maintenance tasks which are not cost effective in preserving system function should be eliminated. The RCM methodology is developed on the basis of the following concepts (Smith & G.Hinchcliffe 2003):

- Preserve functions.
- Identify failure modes that can defeat the functions.
- Prioritize function need (via failure modes).
- Select applicable and effective PM tasks for the high priority failure modes.

The RCM methodology uses a systematic technique to rank the criticality of failure modes and provides guidelines for the selection of applicable PM tasks that are most cost-effective in preserving system function. A PM task is applicable when it can accomplish one of the three objectives of performing PM, prevent failure, detect the onset of failure, or discover hidden failure. The RCM methodology will form the basis of the analysis in this project and its merits expanded upon further in the final dissertation.

3.2 SCO Maintenance Performance Management

The purpose of maintenance is to achieve the best balance between equipment throughput, life and costs. The following model illustrates how the elements of a maintenance management system interact.

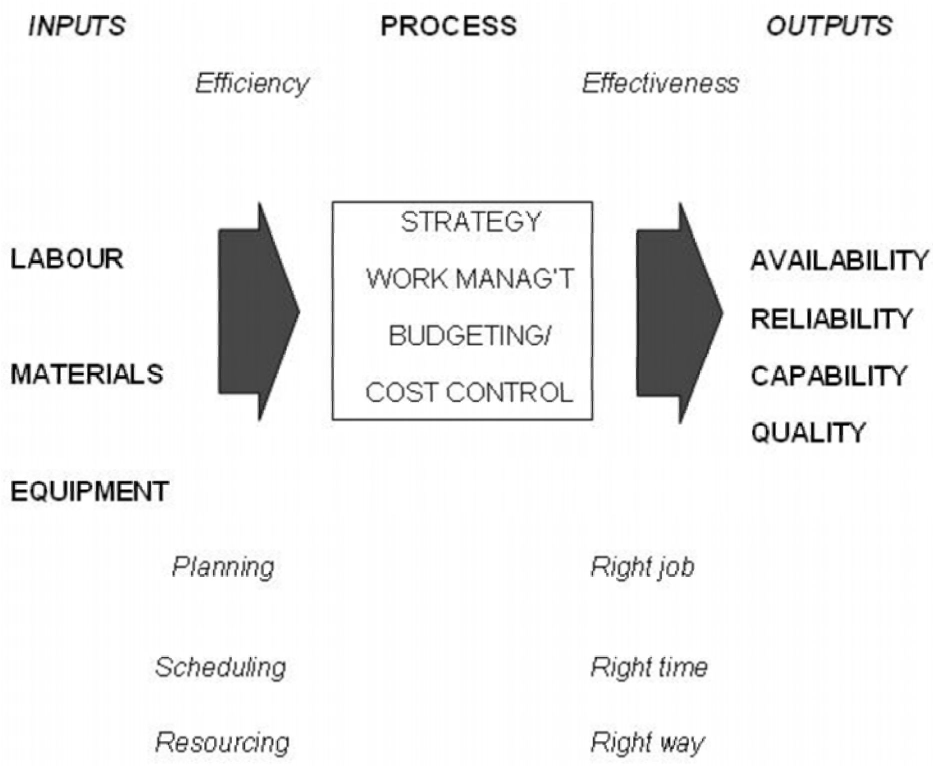

Figure 3.1: Maintenance Management Model.
(SCO 2004)

3.2.1 Plant Performance

The outputs of maintenance at SCO has three relevant dimensions.

- Availability
- Reliability
- Capability

These measures reveal a unique dimension of the impact of maintenance performance, and no single measure is sufficient to provide a full understanding of performance. However, the relative significance of the four performance dimensions will vary for some plants and processes. The benefits of measuring each dimension need to be weighed for each case.

A fifth parameter, utilisation, is not a measure of maintenance performance itself, but important in understanding the significance of the level of plant availability. For this reason utilisation is reported along with availability

Availability/Utilisation

Availability is a measure of the percentage of time in which plant could be operated.

$$\frac{Calendar\,Time - Maintenance\,Downtime}{Calendar\,Time}\,x\,100 \tag{3.1}$$

Maintenance Downtime is the time that equipment is not capable of operation due to it being assessed, serviced, repaired or tested by maintenance, and the time equipment is out of service awaiting availability of maintenance personnel or facilities, excluding time awaiting return to operation after maintenance. Maintenance Downtime includes both unplanned and planned maintenance and is accrued whether the equipment is needed for operation or not.

Utilisation is a measure of the percentage of time in which plant is actually operated.

$$\frac{Operating\,Time}{Calendar\,Time}\,x\,100 \tag{3.2}$$

Periods when plant is not operated due to meal breaks, shift changes, non-working shifts, etc. are recorded as non-utilised time. The following is reported.

- Equipment Identity.
- Reason not available/utilised.
- Period not available/utilised

Reliability

Reliability is a measure of the probability that a system or piece of equipment will perform its function for a prescribed duration of time. The following is recorded

- Number and Duration of failures per month

Any unscheduled maintenance activity, irrespective of whether or not it causes equipment downtime is recorded. The cumulative impact of numerous malfunctions can exceed the impact of one significant shutdown. Hence, all instances of the failure or malfunction of equipment shall be recorded. This is to include those instances where the selected maintenance strategy is to operate equipment to failure. Reliability is a measure of the frequency of equipment failure or malfunction.

Capability

Capability Loss is the measure of the extent of limitations to process throughput.

$$= \textit{Throughput Restriction x Duration}$$

Capability Loss can occur due to many causes, including both maintenance and operation influences.

Instance of capability loss are recorded along with the:

- Equipment Identity
- Reason for Restriction
- Size of the capacity restriction
- Duration of restriction

Reporting

The maintenance impact on plant performance is measured for each of the three dimensions that are relevant to the area of plant being analysed. The purpose of the analysis is to determine opportunities for improvement and pursued through modification of operating practices, maintenance practices or plant design. To enable areas of recurring losses to be identified and corrected, records detail the specific cause and duration of each instance where a plant item is not performing well.

3.2.2 Maintenance process KPI

The in-process measures in the Maintenance Management Model are determined directly from the execution of maintenance work. The current performance levels of plant are dependent on the quality and timeliness of maintenance work completed in the past. The future performance levels of plant are dependent on the correct and timely execution of all the maintenance work now. The correct maintenance work can be done at the right time, but done inefficiently. The efficiency of maintenance resource use is dependent on the level and quality of work planning and scheduling, and the flexibility of resourcing strategies.

Maintenance Process KPIs indicate:

- The degree to which the work necessary to ensure the ongoing performance and integrity of plant is correctly completed, in a timely manner
- The degree of prior planning, scheduling and resourcing of work - factors which effect the efficiency of maintenance and hence maintenance cost

Planning and Scheduling Review Meetings are held to ensure a uniform and managed approach to the review of planning, scheduling, and work execution performance, and to identify, record and report progress on improvement projects. The object of the meetings are for each Area Management Group to use the standard in-process KPIs to review actual performance against targeted performance. Monthly meetings identify projects or behavioural changes which are to be undertaken to address the gaps. These projects or changes are recorded, prioritised, actions assigned and timeframes agreed. The meeting shall also review the progress of previously identified projects and actions to ensure closure is being achieved.

3.2.3 Cost KPI

The inputs to the maintenance process are the labour, materials and equipment used in the management and execution of maintenance work. The quantities consumed, and the unit cost of the resources determines the direct cost of maintenance. The unit costs of maintenance resources are determined by the resourcing and logistics strategies set in place. The consumption of resources is determined by; the design of the plant, the performance required of the plant, the maintenance strategies in place to achieve that performance, and the efficiency of the management processes for maintenance. Measures of maintenance inputs are not very useful as a control tool. However, when analysed properly they assist in determining whether performance targets, strategies, or management processes should be analysed for cost improvement opportunities.

3.2.4 Overall Maintenance KPI

Overview

To provide an indicator of overall maintenance impact on production performance, it is necessary to construct a measure that combines the impacts of availability and capability losses on a collection of processing activities. Production losses caused by poor reliability are often not easily quantifiable; it is assumed that reliability losses will be reflected as lost availability or capability. Combining these measures across a range of processes can produce an indication of maintenance outcome trends, but removes the ability to directly identify the nature and extent of the opportunities to improve performance, to identify these opportunities the individual process performance KPIs need to be analysed.

The overall indicator of maintenance performance impact is the Maintenance Performance Index, the sum of the maintenance induced production losses, normalised to the targeted Maximum Sustainable Production Rates (MSPRs). MSPR is defined as the highest average rate for five continuous days

Maintenance policy decisions related to the repair and/or replacement of equipment impact on both the direct maintenance cost of an operation, and on the operating charges derived from the depreciation of expenditure for sustaining capital. To provide an overall indicator of maintenance policy and performance impacts on the total cost of operations, a cost measure combining both the direct maintenance costs and the costs of sustaining capital depreciation is desirable.

The overall indicator of maintenance cost impact shall be the Maintenance Cost Index - direct maintenance costs (plus sustaining capital depreciation charges), normalised to the actual process throughput.

Maintenance Performance Index (MPI)

The Maintenance Performance Index shall be calculated from the availability and maintenance induced losses in capability for each of the process areas where availability, capability losses are measured. The unit of measure shall be Tonnes Lost. The MPI shall be normalised to the sum of the process area targeted Maximum Sustainable Production Rates (MSPRs).

$$= \frac{Total\, Tonnes\, Lost}{Sum\, of\, MSPRs} \tag{3.3}$$

Maintenance Cost Index

The Maintenance Cost Index shall be calculated from

$$= \frac{maintenance\, costs + sustaining\, capital\, depreciation\, charges}{tonnes\, MAP + DAP} \tag{3.4}$$

The Maintenance Cost Index and Maintenance Performance Index is reported on a monthly basis in the form of a line graph of the rolling 12 month figure. The report period shall be the twenty four months up to and including the current reporting month.

3.2.5 Summary

The measured response to maintenance improvements are usually delayed, it may be some time before any real benefit can be recognized. It can be months or years between the change in maintenance processes or effort is made, and the result of that change becomes evident in some of the outcome measures.

Chapter 4

Information Management

4.1 Introduction

In any maintenance regime the information pertaining to a piece of equipment or system is important in the assessment of the health and future maintainability. Considerable time and effort can be saved if the information can be easily accessed and drawn on when required.

The objective of the Information Management System at SCO is to provide an easily accessible, reliable source of plant real-time and historical data. This data is used by technicians and managers to troubleshoot optimize and report on actuals against key performance indicators. The system achieves this by:

- Providing access to accurate, reliable and complete plant and laboratory data to all personnel.
- Enabling sophisticated analysis of data via a customised suite of software tools.
- Performing real-time calculations on data to enable plant performance with regard to quality and budget to be known at all times.
- Transfer of data to Enterprise Resource Planning (SAP).

4.2 Enterprise Resource Planning (SAP)

The SAP enterprise system acts as the critical support system across the company. Its integration of commercial, production, and support processes rapidly and reliably informs and enables enterprise-wide planning, execution and reporting.

With respect to maintenance, the integration of scheduling, maintenance spares and all costs through a specific work order number allows tracking of expenditure through different budgets allowing monitoring and even control of expenditure. Subject to predefined access authority, this information can be accessed by all of the system's users.

In simple terms, the technology of enterprise information systems can be thought of with two main operational features.

1. Single, shared information repository for all company commercial and operations information including
   - Equipment history.
   - Spares/inventory records.
   - Automated PM work orders.
   - Corrective maintenance requests and records.
   - Failure analysis records.
2. Transaction processing, business-related exchanges such as:
   - Issuing invoices for sales to customers.
   - Making payments to suppliers.
   - Reordering critical consumables.

4.3 DOCS Open

DOCS Open is the document management system used by SCO. All Microsoft Office documents are filed in the operations library and all the CAD drawings are filed in the technical library. Both libraries are accessed through the DOCS Open interface which searches and retrieves the document. The goal of the computerized document management is to capture and share unstructured corporate information resources while making them more secure, accessible, retrievable and interchangeable.

4.4 Plant Information Management System

The Plant Information Management System (PIMS) collects all data measured and output by the Distributed Control System (DCS) through a Tag, a unique series of numbers and letters corresponding to the area, system, instrument code and equipment number. Information collected may be flow, temperature, level, valve position and motor status depending on the instrument connected to the piece of equipment being monitored. PIMS scans the DCS at set intervals using "Data Collectors", in most cases every 60 seconds. The "Data Collectors" then transfer this information to the Plant Historian Database (PHD) as raw data, where it is available for analysis using on line calculations and desktop software tools. These calculations are primarily used for production reporting and include values such as monthly production, recoveries, and utilisations. The calculated values are then validated and sent to SAP, where it is used in Production Planning, Plant Maintenance and Quality Management modules. The Uniformance desktop tools such as PHD trend and Excel companion allow data from the PHD to be viewed retrieved and analysed by personnel.

4.5 Uniformance Desktop Tools

Uniformance is the software suite installed on all PCs at SCO to access PHD data.

4.5.1 Process Trend

Process trend is a charting and analysis tool that allows viewing of data in several different formats including:

- Statistical Analysis
- Regression analysis
- Power Spectrum
- Statistical Process Control (SPC)

Process Tend allows the trending and analysis of up to eight tags per chart. Up to ten trend analysis windows can be displayed at any one time. A key feature of the application is the ability to trend tags for different time spans.

4.5.2 Excel Companion

The Microsoft Excel workbook companion allows PHD data to be easily retrieved and displayed in an Excel Workbook. There are two main types of data retrieval:

- PHD Data - interpolated/resampled data
- PHD Raw Data - actual values stored in PHD

Data retrieved from PHD can then be trended using normal Excel charting functions.

4.5.3 ModTag

ModTag allows for quick and easy retrieval of both PHD data and tag definition data. A number of data sampling and data reduction methods are available including:

- Average
- Delta
- Standard Deviation
- Regression

The application can also perform unit conversion.

4.5.4 Tag Explorer

Tag Explorer provides a Microsoft Windows Explorer type interface for viewing tag names and descriptions. PHD automatically organizes tags into standard directories. A filter function is used to support searches by both tag name and description. Tag names can be dragged and dropped into other Uniformance desktop applications for data retrieval.

Chapter 5

Slurry Pumping Theory

5.1 Pumps

A pump is a device used to move liquids or slurries. A pump moves liquids from lower pressure to higher pressure, and overcomes this difference in pressure by adding energy to the system.

Pumps fall into two major groups: rotodynamic pumps and positive displacement pumps. Their names describe the method for moving a fluid. Rotodynamic pumps are based on bladed impellors which rotate within the fluid to impart a tangential acceleration to the fluid and a consequent increase in the energy of the fluid. The purpose of the pump is to convert this energy into pressure energy of the fluid to be used in the associated piping system.

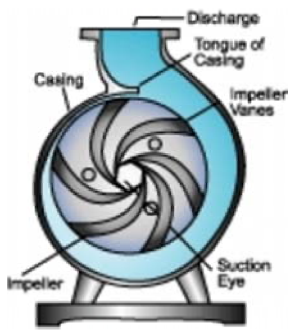

Figure 5.1: Centrifugal Pump Cross Section.

5.2 Centrifugal Pumps

A centrifugal pump is a machine which moves liquid by accelerating it radially outward in a rotating impeller to a surrounding housing or casing. (Rogers 2002)

Typically, a rotating impeller increases the velocity of the fluid. The casing, or volute, of the pump then acts to convert this increased velocity into an increase in pressure. So if the mechanical energy is converted into a pressure head by centripetal force, the pump is classified as centrifugal.

In order to provide reliable efficient operation the pump must be operated correctly and preferably as close as possible to the Best Efficiency Point (BEP - the point where efficiency is at its highest).

At this point the flow through the impeller is smoothest and losses are at a minimum. Away from this point the efficiency reduces. It reduces because the flow no longer travels through the pump in a smooth fashion. The flow becomes turbulent and liquid recirculates within the pump. The following curve describes the operating parameters of the centrifugal pump.

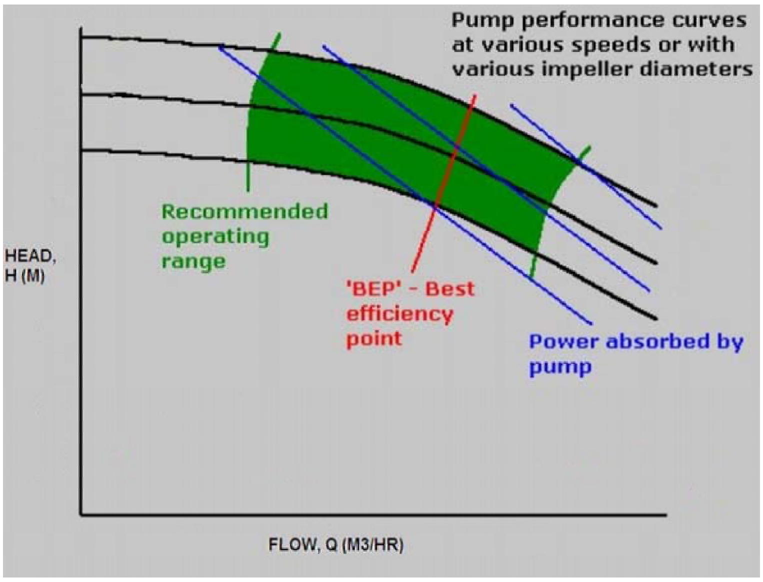

Figure 5.2: Centrifugal Pump Curve.

5.3 Slurry Pumping Fundamentals

A slurry can be defined as a thick suspension of solids in a liquid. The solid is generally suspended in water so that it can be rapidly pumped to another location for further processing. Slurry properties add complexity to the calculation of the BEP for a particular pumping system.

Water flowing through a pipe changes velocity; and velocity head when pipe diameters change. When velocity head increases (or decreases), it proportionally decreases (or increases) the static head in accordance with Bernouillis theorem. This exchange between the two types of energy, kinetic and potential, would go on forever if it were not for friction, which gradually converts to thermal energy.

When there are solid particles in a flowing slurry, water flows faster than the solids, the solids only move when drag forces, generated by the faster water, overcome gravity forces. The average velocity of the slurry then is somewhere between the velocity of water and that of the solids.

If there was a solid particle of a certain volume and an equal volume of water being accelerated through they would both gain kinetic energy while passing through the impeller. When they leave the impeller and enter the volute, the liquid slows down and converts its velocity to pressure. The solid particle on the other hand continues traveling until it hits the wall of the volute, or other particles, and expends its energy in collisions, friction and erosion. Of the total slurry, only the water part generates discharge head in the pump, the solids are not contributing anything.

There is therefore a loss of head per unit mass flow and an extra expenditure of power when pumping solids in comparison to pumping water alone. The magnitude of this loss depends on the actual amount of water displaced by the solids, i.e. concentration, sizing and specific gravity of the solids in the slurry as well as on the size of the pump.

5.4 Slurry Pump Externals

Slurry pump casings always have larger distances between the impeller and the cutwater tongue to ensure free passage of large solid particles in the slurry and to reduce wear. For this reason there is always a considerable amount of recirculation inside a slurry pump casing under a variety of operating conditions.

An important feature of slurry pumps is the provision for axial adjustment between the impeller and the adjoining throatbush seal face. This can be achieved either by axial movement of the shaft, bearing assembly and impeller in the pump or by axial adjustment of the throatbush. Either method assists in maintaining pump performance as the inner component parts wear.

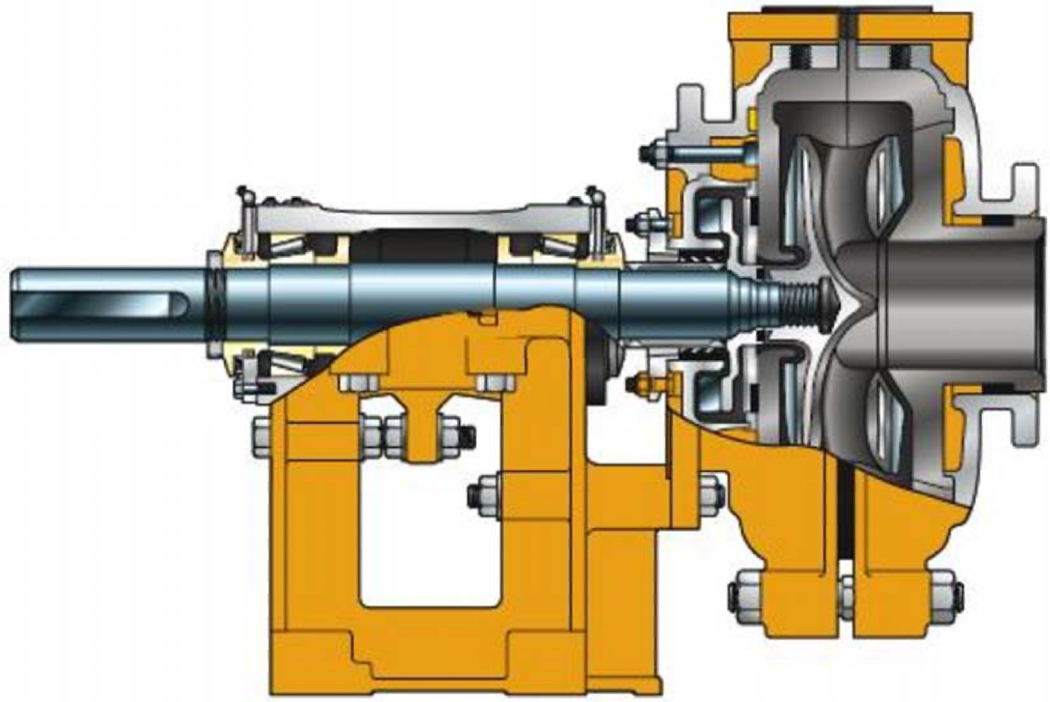

Figure 5.3: Centrifugal Slurry Pump Partial Section.

(Grzina 2002)

5.5 Slurry Pump Internals

Unlined metal pump casings, or shells, are usually made of hard alloys to resist erosion, or of wear resistant steel so that they can have their worn areas repaired by laying weld down to replace the lost metal. The liners can be made of virtually any material which resists erosion. Rubber or more generally elastomer impellers and liners are used in pumping small solids, this can be used if the rubber is compatible with the slurry. Larger particles tend to damage impellers and liners by impact and cutting action. For such particles the impellers and liners are mostly made of hard alloys and polyurethanes.

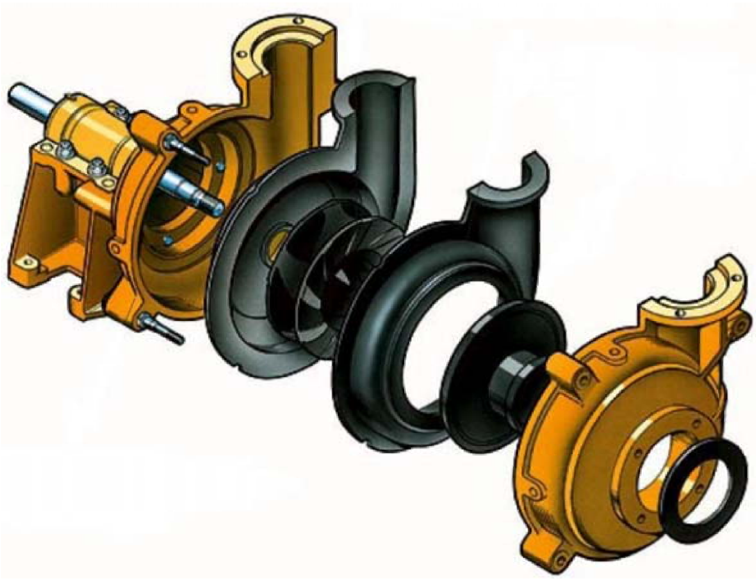

Figure 5.4: Slurry Pump Lined with Rubber.
(Grzina 2002)

Traditionally centrifugal slurry pumps have been belt-driven and a change in operation is achieved by a change in sheave ratio to give the rotational speed required. Alternatively the centrifugal pump can be run by variable speed driven (VSD) motors or variable frequency controllers. These arrangements are used to compensate for wear and in situations where flow conditions fluctuate. Pump speed or flow must be controlled either manually or automatically to compensate for impeller wear and in some cases the scale build up in the pipe which increases system resistance.

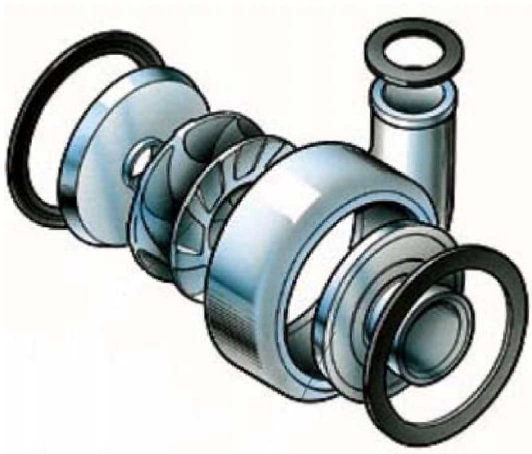

Figure 5.5: Metal Liner.
(Grzina 2002)

5.6 Mining Applications

These applications usually require very large pumps that are subjected to high levels of wear and different types as oulined below

- Gouging abrasion occurs when coarse, angular particles tear fragments of the wearing surface.
- Grinding wear of fine particles crushing between two surfaces in close proximity, such as at the clearances between the impeller and the front and back wear plates, or the casing itself.
- Erosion abrasion caused by the impact of solid particles on the wearing surface. Tough materials of construction are necessary in most of these applications and include metal liners and/or wear plates with Ni-Hard and heat-treated high chrome iron.
- Corrosion caused by the deterioration of essential properties in a material due to reactions with its fluid. Corrosion can be concentrated locally to form a pit or crack, or it can extend across a wide area to produce general deterioration

5.7 Pump Speed & Wear

The centrifugal pump has four operating parameters flow rate, head, power and pump speed. The first three parameters are closely related to the forth, speed. The following explanation shows the relationship, point 1 on Fig.5.6 is along the best efficiency line of a 6/4 pump, here we have Q1, H1, eff and N1. Assume that the system resistance curve coincides with the pump BEP line and then double pump speed to N2, to get point 2 on the BEP line. This yields a corresponding new set of values: Q2, H2 and eff. If fluid being pumped has an SG=1 the calculated absorbed powers are Pi1 and Pi2 respectively. A different value of SG would change the values of Pi2 and Pi1 but not their ratio.

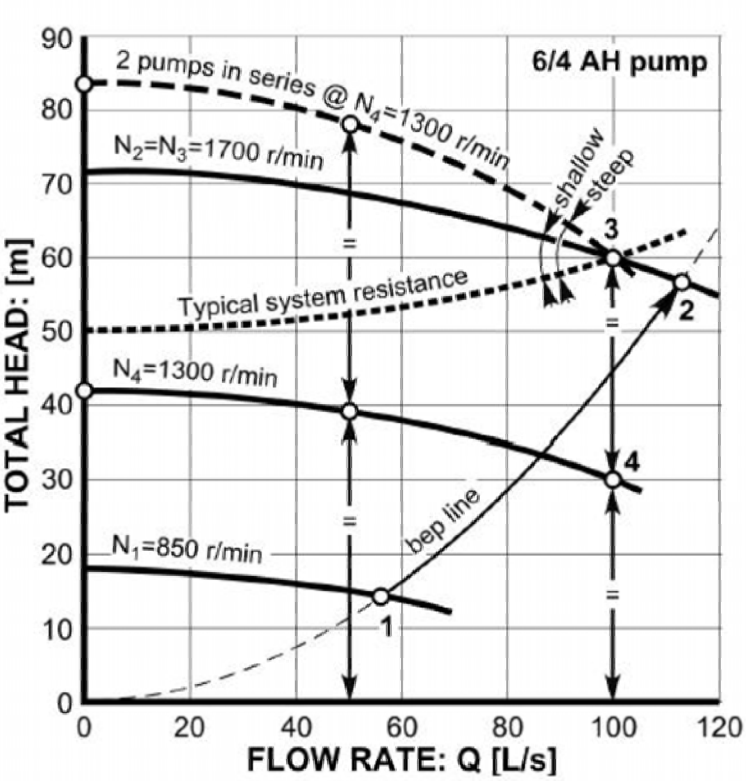

Figure 5.6: Graphic representation of affinity laws and series pumping.

(Grzina 2002)

All these values are listed in Figure 5.7. Efficiencies eff1=eff2=70%. As can be

Point	N (r/min)	Q (L/s)	H (m)	Pi (kW)
1	850	56	14.2	14.5
2	1700	112	56.8	116
Ratio (2/1)	2	2	$4 = 2^2$	$8 = 2^3$

Figure 5.7: Pump performance at two speeds.

readily seen from the tabulation, the values at point 2 can be calculated from the values at point 1 and from the speed ratios by means of the following well known basic affinity laws: Note that the same relationships are valid for speed

$$Q_2 = Q_1(N_2/N_1) \quad \text{or} \quad N_2 = N_1(Q_2/Q_1)$$

$$H_2 = H_1(N_2/N_1)^2 \quad \text{or} \quad N_2 = N_1\sqrt{(H_2/H_1)}$$

$$Pi_2 = Pi_1(N_2/N_1)^3 \quad \text{or} \quad N_2 = N_1\sqrt[3]{(Pi_2/Pi_1)}$$

Figure 5.8: Affinity law equations.

reductions. The simple point here is that flow rate through the pump is directly proportional to pump speed, head to speed squared and power to speed cubed. Generally speaking if the pump speed is doubled, the flow rate through the pump is doubled. At the same time the generated head increases four times and power consumption eight times. This large power increment is transferred from the impeller to the slurry i.e. to the water and the solids by the impeller vanes. The solids in the slurry cause internal pump wear and it is therefore expected such eight-fold power increment would produce a proportionate increase in wear. The internal pump wear can vary considerably between overhauls, even in one pump on the same duty, wear at two speeds is approximately proportional to the ratio of the speeds raised to the power of 3, or a little less. The actual value depends on the relative hardness of the pump wearing parts and the solids pumped (Grzina 2002).

5.8 Summary

When designing a pumping system it is most important to calculate the system resistance and then select the pump so that the pump will work within the BEP range for that pump. The problems encountered when operating off design are summarised as follows (Rogers 2002):

- discharge recirculation
- suction recirculation
- increased radial and axial loads
- fluid temperature rise

These problems will cause the following:

- increased vibration
- poor mechanical seal life
- poor bearing life
- reduced impeller life
- early pump failure

When a pump fails, the root cause is rarely obvious. A thorough review of both the pump and the entire system is required in order to get to the root cause of the problem.

Chapter 6

Method of Analysis

6.1 Introduction

Recirculation Slurry Pump, PC2505 (Figure 6.1), in the Phosphoric Acid Plant was identified by the Maintenance Superintendent as a piece of equipment that could benefit greatly from on-line condition monitoring based maintenance. The slurry pumped travels through the Recirculation line in view Figure 6.2.

The project started with a detailed search using the information management system at SCO to gather operational data on the pump. With the aid of drawings, operating manuals and data sheets; the instruments controlling the process were identified. In collaboration with production staff the operating parameters were established.

Figure 6.1: Recirculation Slurry Pump (PC2505-Spare).

Figure 6.2: Phosphoric Acid Plant Reactors.

6.2 System Description

The Hemihydrate (HH) process is used to produce phosphoric acid by reacting phosphate rock with concentrated sulphuric acid under the following carefully controlled process conditions. The hemihydrate terminology refers to the production of calcium sulphate (phosphogypsum) (Kato 1998).

The success of the process depends on the satisfactory growth of uniform crystals with a high filtration and washing rate. The properties of the crystals are determined by the free sulphate level, P_2O_5 concentration and temperature; it is therefore critical that these parameters be closely monitored during plant operation.

The hemihydrate reaction system consists of four cylindrical tanks of equal volume and dimension. The first three (RA2501, RA2502 and RA2503) comprise Reactor 1 whilst the fourth is Reactor 2 (RA2504). The recycle slurry is pumped from Reactor 2 through a flow meter to Rector 1A. The flow is automatically controlled by adjustment of the set point on the controller to the desired value. The recycle flow is calculated from the rate of sulphate to calcium oxide feeds to Reactor 1A.

Reactor 1 has been designed as three separate tanks (1A, 1B and 1C) to enhance the release of gas produced by the reaction of rock and acid, thereby improving process control. Phosphate rock is discharged from the rock conveyor through a chute (CH2501) into Reactor 1A (RA2501), while 98.5% sulphuric acid is fed to Reactor 2 (RA2504) through the acid mixers (TK2503/2504). Reaction slurry overflows from Reactors 1A to 1B to 1C to 2 (RA2501 to RA2502 to RA2503 to RA2504).

From Reactor 2 (RA2504) part of the slurry is pumped by the Flash Cooler Slurry Pumps (PC2506/2507) to the Flash Coolers (HE2501/2502) which maintains the temperature of the slurry in the hemihydrate reaction system at 96 - 100C. The slurry from the Flash Coolers (HE2501/2502) is returned to Reactor 2 (RA2504).

The flow of recycled slurry to Reactor 1A is supplied by the Recirculation Pump (PC2505) and controlled so that only 40% of the total CaO fed to Reactor 1A is precipitated. The free sulphate level in Reactor 2 (RA2504) liquid phase is controlled at around 2.0%. The gaseous discharge from the Flash Coolers (HE2501/2502) passes to the Flash Cooler Condensers (HE2503/2504) where they are condensed with acid water.

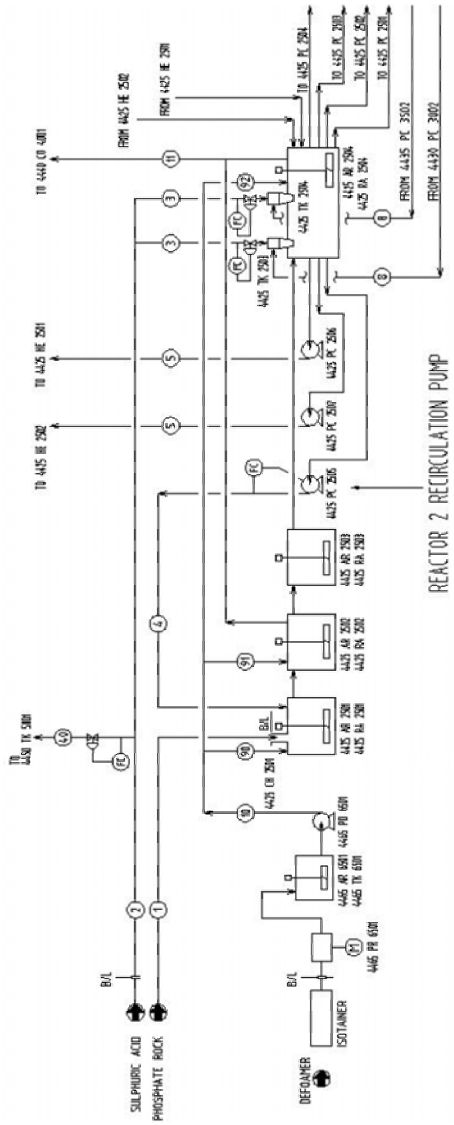

Figure 6.3: Phos Acid Process Flow Diagram

6.3 Maintenance Analysis

The HH process requires close monitoring and generates high cost if failure occurs. The Recirc Pump is a Warman 500STL it is the largest pump on the final Reactor in the first major chemical process on site. The Recirc pump controls the whole reaction process; loss of this pump means the process is no longer under control. This leaves limited operating time, so when the plant goes down it cost approximately $24 800 per hour.

SAP Plant Maintenance Module has an output equipment tree of drop down menus that allows the maintenance team to log and retrieve all tasks and costs associated with the piece of equipment. The maintenance history on the Recirc pump dates back 9 years to 1999 the commissioning of the plant. This history includes the work type, equipment number, task definition, cost and status (i.e. planned, unplanned, Emergency shutdown.)

For easy access the SAP data was exported to Excel, during this process fields were created, with the aid of filters was possible to attach costs with tasks and arrange by dates. The task definitions were then identified and compared with cost; the high cost tasks were identified as being pump change out and pump rebuild. Under another field it was possible to sort by work type which helped determine the dates of when the actions where taken and the costs involved. It was noted that there are two 500STL's, one in operation and a spare rebuilt awaiting failure on the other. A time line was then constructed to cross check the dates and track the movements of the two pumps.

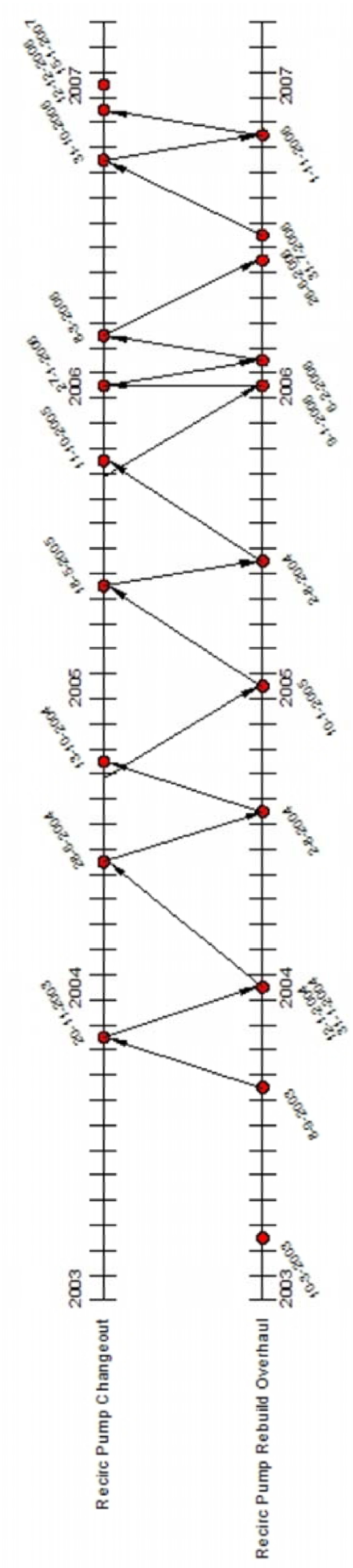

Figure 6.4: Pump Change Out Timeline

6.4 Maintenance Costs

It was difficult to exactly track the movement of the pump with the non-uniform one line descriptions being entered into SAP. The cost were hard to gauge with the same maintenance activity costs; varying by tens of thousand of dollars.

The pump change outs were sometimes performed under emergency where the plant had to be shutdown. In these cases the change out costs were a lot higher and harder to quantify. The average cost over the periods outlined in the time line was $45 000 with the highest at $70 000. With prior planning the pump can be changed out during a planned shutdown, as was the case with the most recent change out below.

Time	Short Text	User Status	Cost
14 August 2007	Change Out Pump	Planned	$25 396

The average cost of rebuilding the pump during the period of the time line was approximately $38 000 with the highest at $94 000. During this period impeller material and liners changed, these changes in consumables and lead times associated with them made rebuild costs fluctuate. The most recent rebuild costs have been added below.

Time	Short Text	User Status	Cost
19 August 2007	Rebuild Recirc Pump	Planned	$89 663

If the pump is out of action for too long the reaction process is interrupted which means it can take a considerable length of time to get temperature and levels back to full operation. Loss of reaction in the past has cost up to $500 000.

With the varying high costs associated with the pump it seemed improvements could reap reasonable reward.

6.5 System Analysis

At this stage the project scope was locked in as it was anticipated that there could be a successful outcome, research into maintenance and in particular SCO's maintenance and reliability strategies were reviewed. Parallel to this, information was being gathered from the on-line library DOCS-Open to find any process descriptions, procedures, pump and instrument data sheets etc. relating to the HH process.

Process & Instrument Diagram (P&ID) 44-B-3021 (Appendix B) was used to analyse the system. From the P&ID the pumps equipment tag number was confirmed along with the instruments associated with it. Armed with this information and a sound understanding of the process, equipment and control method was formed, this ensured the correct instruments would be monitored and accurate methods of analysis used.

With the instrument tag numbers identified for the Recirc pump it was possible to go into Uniformance Desktop Tools Tag Explorer and confirm the tag numbers and their descriptions. Knowing the 10 dates that the pump was changed out on over the last 4 years, Excel Companion was used to retrieve tag values for the 5 days leading up to the change out and the 5 days after the change out. It was hoped that tag values would give an indication of failure. It was clear that the pump did stop during these periods and that failure was occurring at different speeds and under differing process variables. Some instruments were not working on these occasions, which indicated that instrument reliability is an issue. The exercise proved that data collection was possible and that there was a method to analyse the data.

6.6 Pump Analysis

The Recirculation Slurry pump is driven by a 220 kW variable speed drive (VSD) though a pulley gear reduction onto the pump. The VSD is controlled by the output of the flow meter which is continually changing speeds to maintain the required flow rate. The flow rate is set by chemical test which indicate the recirculation volume required to balance tank properties.

The original instrument, the magnetic flow meter failed at the start of 2006 which meant in the last 12 months the process was being manually controlled by the operator, by changing pump speed so the desired properties in each tank could be balanced. Due to the fact that chemical test were taken every 4 hours, there tended to be overshoot with the properties which meant it took some time, even days to reach steady state.

In May 2007 a new flow meter was installed and brought into operation. The SonarTrac flow monitoring system is an external, non-intrusive style flow sensor that utilizes patented array processing techniques to take low frequency acoustics from the turbulent flow along with pipe wall strain measurements to generate an accurate value for flow. There was some discrepancies between the magnetic flow meter value and the SonarTrac, field test were undertaken to adjust the process to accept the SonarTRAC flow reading.

Another change in late 2006 was the upgrade of impeller material. The original material C26 was being corroded and eroded at a rapid rate. The new material A53 has higher corrosion resistant properties which gave it better properties to combat corrosion.

6.7 Summary

With the material changes and instrument problems it seemed futile to base any judgements on the historical data.

Chapter 7

Analysis of Results

7.1 Computer Monitored Results

A CAD drawing was produced to clearly show the overall layout,along with the elevation of tanks and piping (Appendix B). Warman Software wsCat 3.2 along with the pumps data sheet were used to plot the system resistance curve along with the 500ST-L pump speeds (Appendix C). The system resistance and speed curves were then plotted in Excel (Fig 7.1).

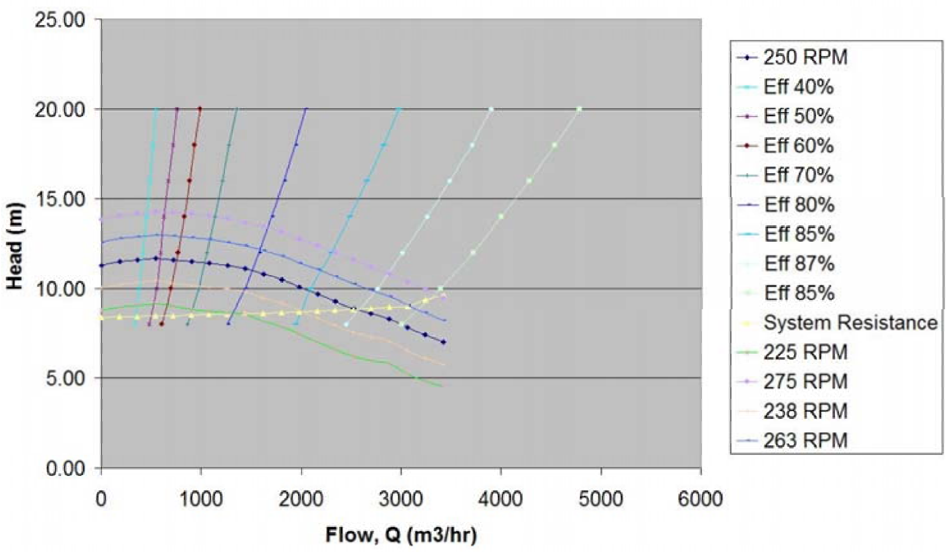

Figure 7.1: Warman 500ST-L Pump Curve

Where the speed curves crossed the system resistance curve a theoretical value of speed for a given flow was established. Although this may not have been 100% correct it represented a base line that could be carried through each passing month so the deviation could be quickly identified.

An Excel Companion spread sheet was created to accept the tag value data, for a small example see (Appendix D). The first column is the data from the flow meter (44FIC25003.PV), the second column is the data from the speed controller feedback(44FIC25003.MV/100). The speed control value was converted to a real time speed value(((44FIC25003.MV/100)*50*120/8)*0.38). A breakdown of this equation is the fraction of 50Hz multiplied by a constant 120 divided the 8 pole motor multiplied by the pulley gear reduction. It is understood that .PV indicates that flow, is the process variable, related to the feed to Reactor 1 A. The tag ending in .MV indicates it is a manipulating process variable, feedback to reach the target flow. These two tags were monitored through the months of May, June, July, August and September.

The following graph (Fig 7.2) takes actual speed and flow values (blue) every 5 minutes form 6am 27 May 2007 to 6am 1 June 2007. The pink line is the theoretical value of speed for a given flow, this represents ideal performance. The following months actuals were plotted against the theoretical in order to see how the relationship changed over time.

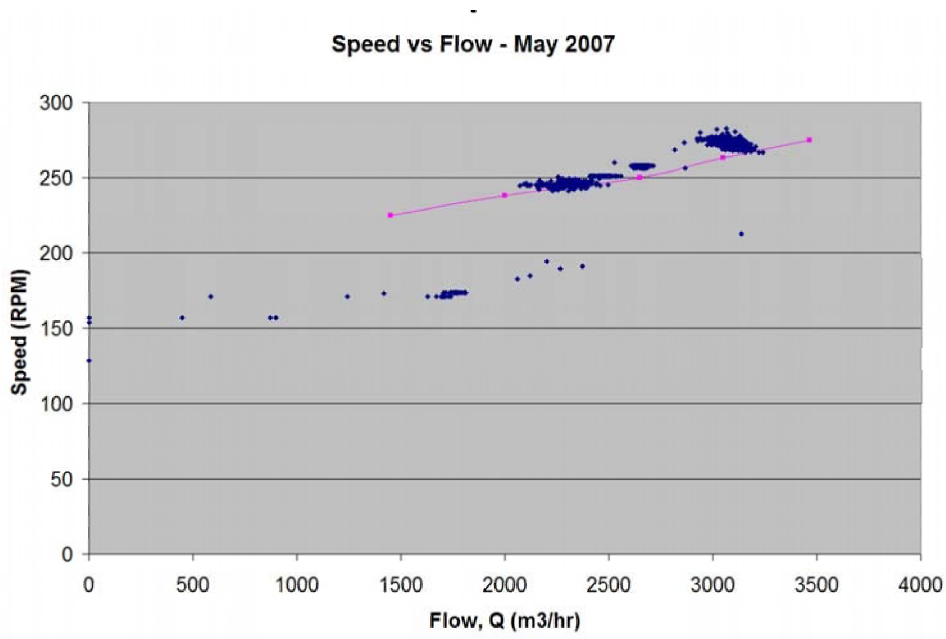

Figure 7.2: Speed vs Flow May 2007

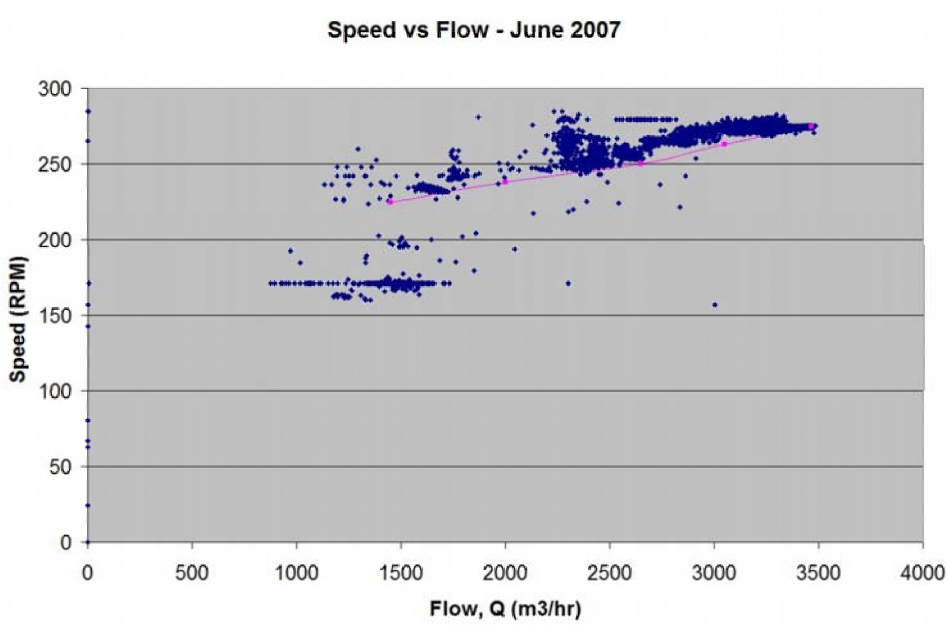

Figure 7.3: Speed vs Flow June 2007

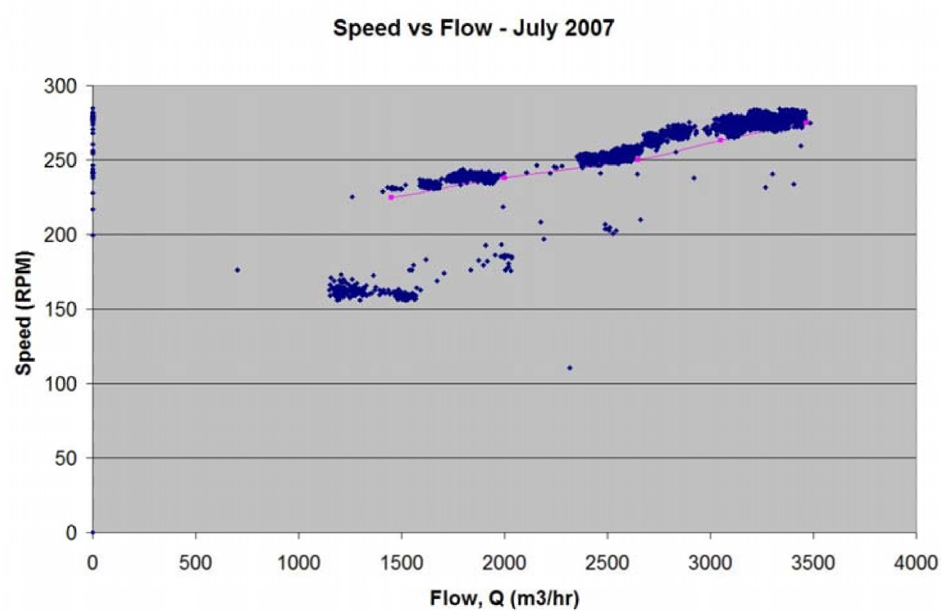

Figure 7.4: Speed vs Flow July 2007

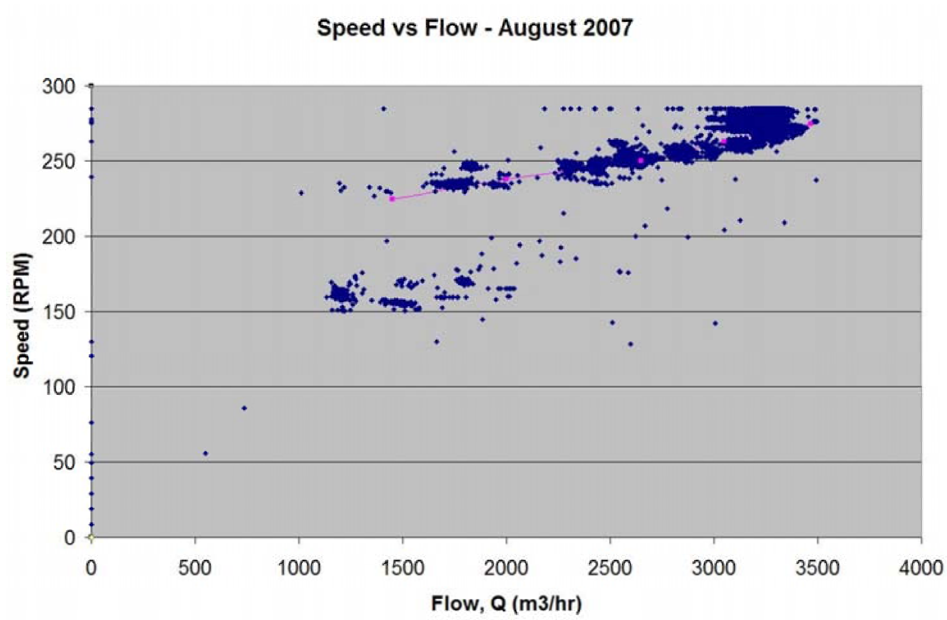

Figure 7.5: Speed vs Flow August 2007

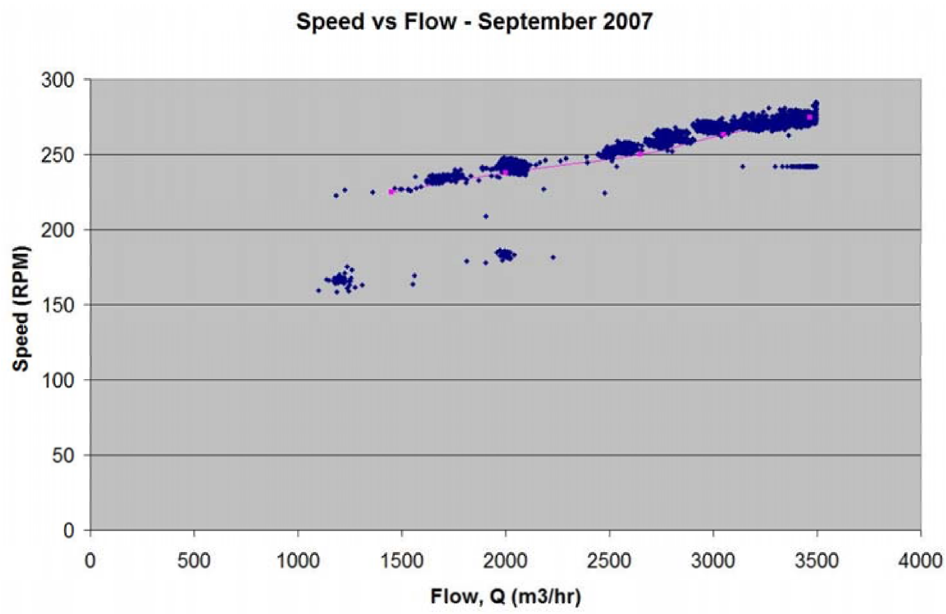

Figure 7.6: Speed vs Flow September 2007

Referring to monthly plots it can be seen that the actual speed flow values (blue) moved further in an increasing y position from the theoretical values (pink). From the plots it is clear to see that as time passes there is a higher speed required to achieve a given flow.

Mid way through the month of August the pump was changed out, it can be interpreted from the August plot where the actual (blue) drifts below the theoretical (pink). This indicates that performance has improved dramatically.

What also can be seen plots, particularly in June and also in August the speed reaches a maximum of 285 RPM which is as fast as the speed controller will let the motor run. So as the pump wears and due to the capped speed, the pump may never reach a given flow.

A monthly average of speed control feedback was plotted against time to show how the speed increased with time. A general trend line was plotted to show how the speed increased exponentially over the months of monitoring.

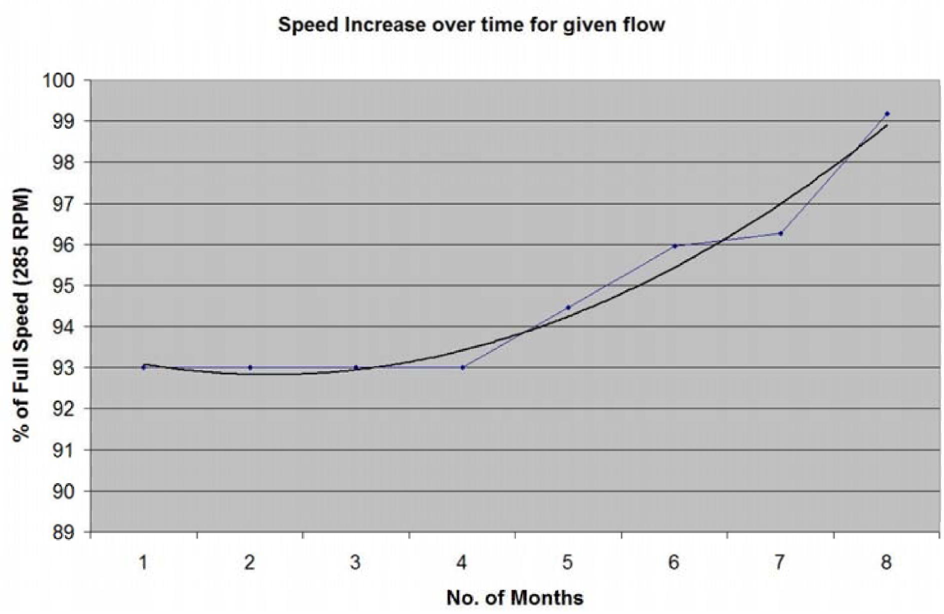

Figure 7.7: Speed Increase Over Time

From analyzing the data it became apparent that the tank level was a major process variable that would effect the pump's flow - speed relationship. If the level in the tank was high the speed would decrease for a given flow at a lower tank level. Holding the tank level relatively constant and taking approximately ten rows of data a quick assessment of the effects could be made, see (Appendix D).

The data prior to the change out and after was filtered according to the target level 75%. By gathering data on the 16/08/2007 after the Recirc pump had been changed out and the process back under control it was possible to create a speed flow relationship for the pump in a newly rebuilt condition.

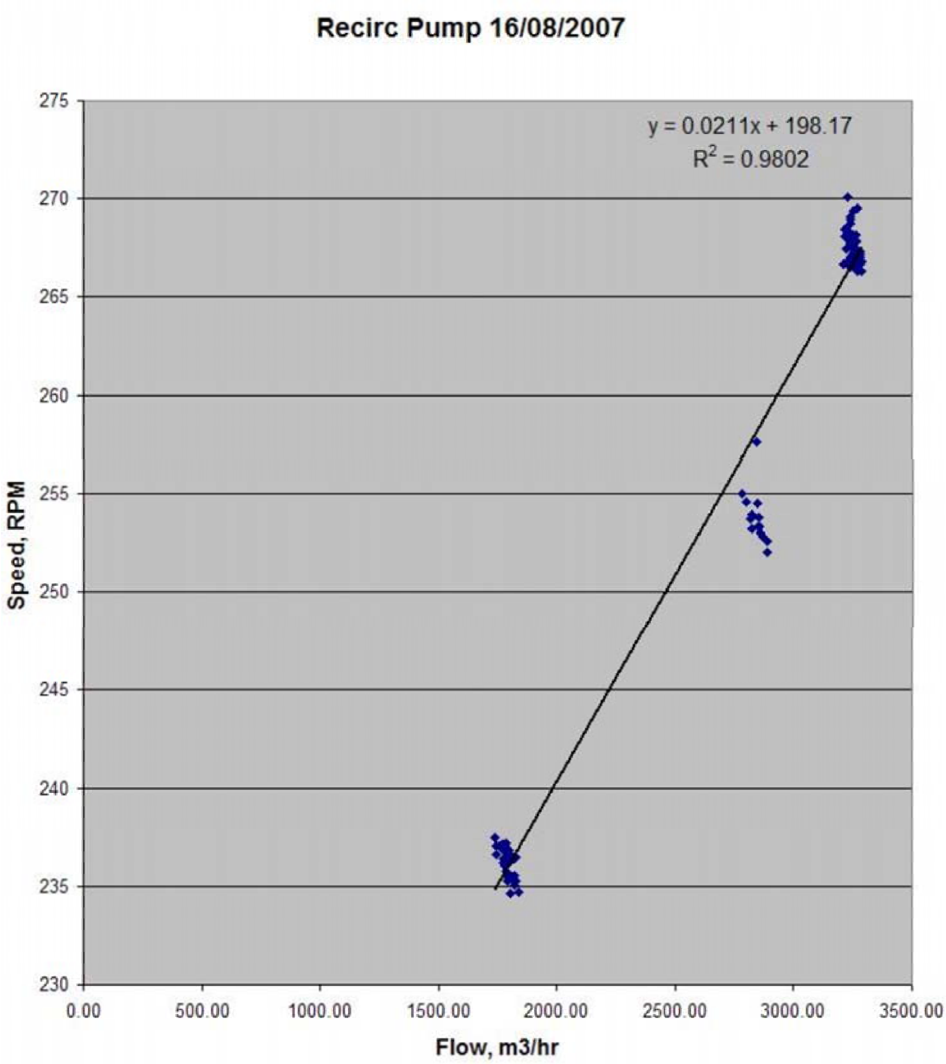

Figure 7.8: Speed vs Flow of Rebuilt Pump

With trend line placed over the real time data, along with the equation it was clear there was a linear relationship. Displaying the $R^2 = 0.9802$ it confirmed the correlation was strong.

$$Speed = 0.0211(Flow) + 198.17 \tag{7.1}$$

By locating a flow in the period 16-17 when the level in the tank is between 74% & 76%. A check on the speed can be made to see how closely it matches the trend line equation.

Time Stamp	44FIC25003.PV	44FIC25003.MV	Speed	44LI25001.PV
16 August 2007 2:25AM	3272	93.88	267.58	75.34

For the given flow using equation 7.1 the theoretical speed is 267.2092 RPM, The actual is saying 267.58 RPM again confirming the relationship.

Prior to the pump change out an equivalent flow was sort when the level in the tank ranged between 74% & 76%. This flow was then used to calculate the theoretical speed from equation 7.1.

Time Stamp	44FIC25003.PV	44FIC25003.MV	Speed	44LI25001.PV
13 August 2007 11:40AM	3274	99.17	282.65	74.52

For the given flow the trend speed is 267.26 RPM, The actual is saying 282.65 RPM so the pump prior to change out is running at higher speed for a given flow.

The motor is running at 99.17% of 285RPM before the change out, when it should only actually run at 93.88% full of full speed in the rebuilt condition. Approx. 5% higher.

7.2 Discussion

It was clear after the calculations that the speed controller - 44FIC25003.MV would be the key indicator of the pumps condition. The real time data and the theoretical line proved that there was a linear relationship.

The current draw 4425PC2505.FV, (Appendix D), is calculated from a full load current of 303 Amps, this was an opinion on site and not confirmed. A quick check was performed using the Warman Software (Appendix C) for clear water and multiplying by the S.G. of Phosphoric Acid, the full load seemed reasonable enough to proceed.

By scanning the data and finding very low fluctuations in current it was considered difficult to use as a key indicator. There is also the fact that is inaccuracy in the power factor and motor efficiency, this makes it a drawback by not giving a true indication of current draw.

7.3 Condition Monitored Results

When 4425PC2505 is considered to have reached a point of failure it is changed out with the another rebuilt pump. The failed pump is in turn stripped immediately and rebuilt. It is sealed and placed on a pallet ready for the next change out.

After the pump was changed out in August the failed pump was stripped, the impeller was quickly sent away for inspection and testing. The following photos show the results of the wear on the recirculation pump's impeller.

Figure 7.9: Wear on face and leading edges, suction side

Figure 7.10: Eroded suction side impeller vane

Figure 7.11: Erosion on exit of impeller vane, discharge

Figure 7.12: Metal loss on cutting edges, suction side

Figure 7.13: Close up of metal loss

Figure 7.14: Loss in effective vane surface

Figure 7.15: New Impeller in stock

Figure 7.16: Discharge profile of the New Impeller

7.4 Summary

The first six photos in the previous section, refer Figure 7.9 to 7.13, display a deeply eroded impeller, by inspection it would seem like there is severe metal loss on the fluid cutting edges when compared to the new impeller in stock, refer Figure 7.15 & 7.16.

The outside diameter of 1040mm on the worn impeller had been reduced to approximately 1037 - 1039. Where more dramatic effects are found are the 310mm width of the impeller being reduced to 292 - 296mm. The 14 - 18mm of wear increases the clearance on the suction side of the impeller.

This clearance can be closed up by moving the throat bush into towards the impeller. However this wear also increases the clearance on the back face of the impeller this cannot be adjusted and the increase in recirculation wear escalates.

The effective surface area of the vanes of the old impeller have been reduced (refer Figure 7.10), decreasing the impeller's ability to catch the fluid on suction side of the pump, this inefficiency would result in the increased speeds witnessed in the computer monitored results.

There is the possibility that the impeller was capable of reaching the necessary flow if the pump was able to run fast enough. It may be possible to increase the set point frequency to 52Hz which would give the pump the ability to run up 313RPM extending the service life of the impeller.

The pump's design allows it run at faster speeds so that's not a limiting factor, the questions could be raised to whether the impeller is in a failed state. Wear occurs at an exponential rate so it gets very risky to push past the existing set points. More work would be needed in order to bring confidence to such a call.

Chapter 8

Conclusion

8.1 Final Remarks

There was much learnt about the system through the data collection process refinements were possible when commissioning the SonarTRAC flow meter. This further improved the performance of the pump by giving back automatic control of the pump speed, the chemical level results showed that there was less fluctuations. This in turn means the pump was running at more constant speed instead of ramping up and down to cater for the overshoot and lag in the tanks levels.

Due to time constraints and inexperience no alarming method was implemented. It is envisaged that a count on the number of times 44FIC25003.MV exceeds the value 98% be taken. Another threshold would be set up on the percentage of the day that the tag exceeds 98%. This would take out any instantaneous erroroneous data triggering the alarm. If the threshold for the day is exceeded a maintenance request could be raised on the daily SAP exports.

There are are numerous reasons for the pump not to reach a given flow. There can be blockages in the pipe, scale build up in the line which increases the system resistance and at the same time decreases the pumps capability to deliver a prescribed flow under capped speeds. Having suction and discharge pressure would give the actual system resistance, which is increasing as the scale in the line builds up.

The current monitoring method does not differentiate between wear and system resistance increases. Increased speed requirement is a combination of both, the aid of a pressure differential would help diagnose problems in the system. However more instruments would not necessarily bring any cost saving benefits.

A closer relationship between 44FIC25003.MV and the condition of the impeller needs to be established, as more reliable historical data is compiled greater confidence can be achieved when making the call on when to change the pump out.

Although no exact value of condition can be interpreted from the results at this stage, confidence has been gained when judging the timing of the pump change out, taking into account the planned shutdowns.

Close to a record length of impeller service life was achieved, the new impeller has proven to be effective. Given seven weeks between opportunities and knowing the condition after approximately 35 weeks of service, to try for an extra 20% service life seemed a risk not worth taking. The right timing for pump change out was made, no unnecessary downtime was caused by the pump change out.

8.2 Future Work

The concept of an alarming system will most likely be developed with the improved monitoring methods developed in this project. In cases where there are more significant advantages, time and money may be allocated to fund such a project.

References

Grzina, Roudnev, B. (2002), *Weir Slurry Pumping Manual*.

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Rogers, G. (2002), *Pumping Fundamentals Course Notes*.

SCO (2001), ‘Staff orientation program’.

SCO (2004), *Maintenance Management Manual*.

Smith, A. M. & G.Hinchcliffe (2003), *RCM Gateway to World Class Maintenance*, Elsevier Butterworth-Heinemann.

Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **ANDREW MITCHELL**

TOPIC: ON-LINE EQUIPMENT CONDITION MONITORING BASED MAINTENANCE

SUPERVISOR: Mr Robert Fulcher

SITE SUPERVISOR: Mr Greg McCubben

PROJECT AIM: This project aims to use the process history monitoring systems at Phosphate Hill to monitor and report operating parameters that provide a direct measurement of equipment condition. This information is to be automatically communicated to SAP where maintenance tasks can be automatically triggered if key condition parameters are exceeded.

SPONSORSHIP: Incitec Pivot, Southern Cross Fertilisers.

PROGRAMME: Issue B, 06 March 2007

1. Describe and explain the operation of the process plant under review including current maintenance practices and problems therein.
2. Research best practice in online condition monitoring and maintenance task initiation.
3. Review existing instrumentation capabilities and limitations.
4. Determine equipment candidates for on-line condition based maintenance.
5. Implement simple system and test to prove effectiveness.
6. Write project dissertation

As time permits:

7. Report on implementation of new on-line condition based system(s).

AGREED: (Student) (Supervisor)

9/3/07 12/3/07

19-3-07

Figure A.1: Project Specification Rev B

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **ANDREW MITCHELL**

TOPIC: ON-LINE EQUIPMENT CONDITION MONITORING BASED MAINTENANCE

SUPERVISOR: Mr. Robert Fulcher

SITE SUPERVISOR: Greg McCubben

PROJECT AIM: This project aims to use the process history monitoring systems at Phosphate Hill to monitor and report operating parameters that provide a direct measurement of equipment condition. This information is to be automatically communicated to SAP where maintenance tasks can be automatically triggered if key condition parameters are exceeded.

SPONSORSHIP: Incitec Pivot, Southern Cross Fertilisers.

PROGRAMME: Issue A, 20 February 2007

1. Research best practice in online condition monitoring and maintenance task initiation.
2. Review existing instrumentation capabilities and limitations.
3. Determine equipment candidates for on-line condition based maintenance.
4. Implement simple system and test to prove effectiveness.

As time permits:

5. Implement more complex system(s).
6. Provide detailed justification as time allows.

AGREED:

Andrew Mitchell (Student) R. Fulcher (Supervisor)

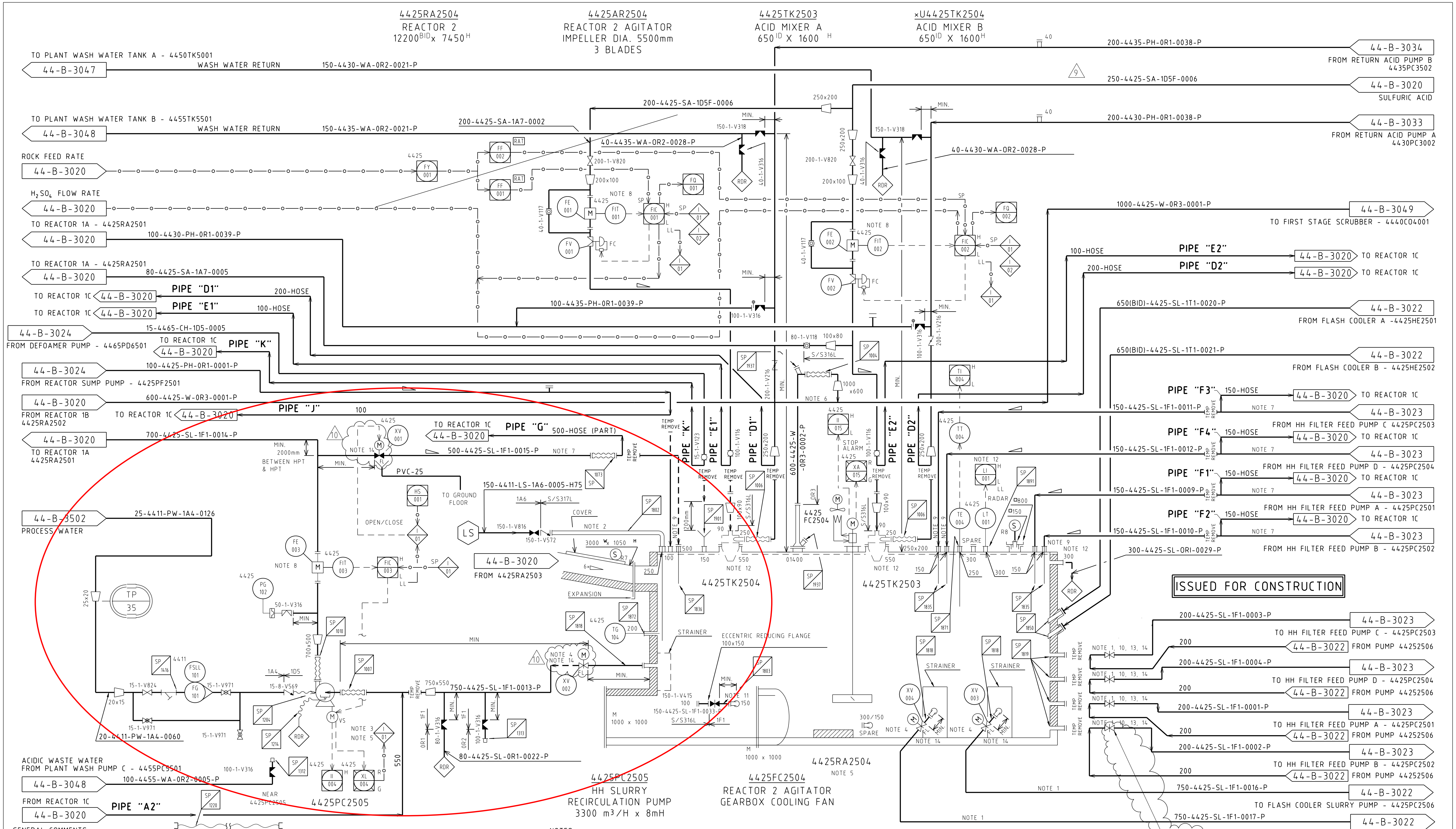
20/2/07 27/2/07.

Agreed. Assistant Examiner 2/3/07

Figure A.2: Project Specification Rev A

Appendix B

Drawings



GENERAL COMMENTS:

A. EXPANSION JOINT TO BE INSTALLED AS NECESSARY BY THERMAL CALCULATION DURING DETAILED ENGINEERING STAGE.

B. DRAIN AND VENT TO BE INSTALLED DEPENDING ON PIPING CONFIGULATION DURING DETAILED ENGINEERING STAGE.

C. STEAM TRAP TO BE CONSIDERED DURING DETAILED ENGINEERING STAGE ON STEAM LINE.

D. FOR ALL PUMPS FOR SLURRY AND ACID, SUCTION DRAIN TO BE TANGENTIAL. PLANT WASH TO BE VERTICAL FROM TOP OF SUCTION.

E. NOZZLE FOR PG CONNECTION TO BE PROVIDED UPWARD.

F. BLIND TO BE INSTALLED AT APPROPRIATE NOZZLES OF EQUIPMENT FOR MAINTENANCE.

G. SPLASH GUARD ON FLANGE TO BE PROVIDED FOR SULFURIC ACID PIPING.

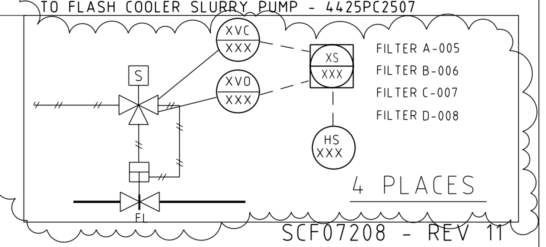
H. PUMP SUCTION LINE FOR PROCESS PUMPS TO BE PRACTICALLY MINIMUM LENGTH.

I. LINE WORK IN SLURRY SERVICE TO BE MINIMUM LENGTH BETWEEN VESSEL AND FIRST VALVE.

J. SLOPE( )MEANS THAT TO BE PRACTICALLY MAXIMUM SLOPE.

NOTES:

1. PUMP SUCTION LINE TO BE MINIMUM LENGTH.
2. REMOVABLE DIP PIPE (USED AT START-UP). AFTER REMOVAL OF PIPE, BLIND FLANGE TO BE PUT ON THE NOZZLE. DAVIT IS REQUIRED.
3. % HZ OR % SPEED INDICATION TO BE PROVIDED ON DCS FOR ALL VVVF PUMPS.
4. KNIFE GATE VALVE SHALL BE MOTOR OPERATED.
5. APPROPRIATE BUND IS REQUIRED AROUND REACTORS AND PUMPS.
6. FLANGES TO BE PROVIDED APPROPIATELY FOR REMOVAL OF PIPE SPOOLS.
7. PIPING TO MINIMIZE SYPHON EFFECT.
8. MAGNETIC FLOWMETER TO BE INSTALLED TO ENSURE FLOODED OPERATION.
9. SLEEVE PIPE IS TO BE PROVIDED. MATERIAL IS URANUS 52+ / SUS316L.
10. BOP OF SUCTION NOZZLE TO BE 1000mm FROM BOTTOM (ACID BRICK TOP SURFACE).
11. NOZZLE ON TANK IS 300.
12. TO BE TEMPORARILY RELOCATED TO REACTOR 1C
13. PNEUMATICALLY ACTUATED VALVE REFER "DWG 44-B-013861"
14. FLUSHING WATER REQUIRED TO VALVE BONNET, REFER "DWG 44-B-013864"



SCF07208 - REV 11

REVISIONS	NO.	DATE	DRN.	CHK.	DES.	D.A.	P.A.	REVISIONS	NO.	DATE	DRN.	CHK.	DES.	D.A.	P.A.
QF007208-DCS CONTROL TO VALVES ADDED	11	06.09.07	JP	DB	DB			FIELD VERIFIED	5	16/6/00	WMC				
VTM V/V FLUSHING WATER ADDED	10	20.05.07	PW					AS BUILT	4						
SULPHURIC ACID DELIVERY LINE REPLACE'T	9	11.05.05	FPD	PW	SJM			REVISED ISSUE	3	99/04/05	Y.K	T.N	Y.Y	Y.O	
REACTOR 2 BYPASS CONCEPT ADDED	8	18.04.05	JM	PW	TC			REVISED ISSUE	2	98/08/28	Y.K	A.I	Y.Y	Y.O	
ACTUATOR VENT VALVES ADDED 4 PLACES	7	12.10.01	PW	D.R.	D.R.		D.W.	REVISED ISSUE	1	98/06/17	Y.K	T.N	Y.Y	Y.O	
GLAND WATER REVISED AS BUILT	6	15/08/00	GB	BVH		BD	JK	FOR CONSTRUCTION	0	98/03/31	Y.K	A.I	Y.Y	Y.O	

REFERENCE DRAWINGS	NUMBER

SCALE		DATE
DRAWN	Y.Kato	97/11/25
CHECKED	Y.Yamazaki	97/11/25
DESIGNED		
DESIGN APP.	Y.Ogiwara	97/11/26
FPE APP.		
PROJECT APP.		

QUEENSLAND FERTILIZER PROJECT

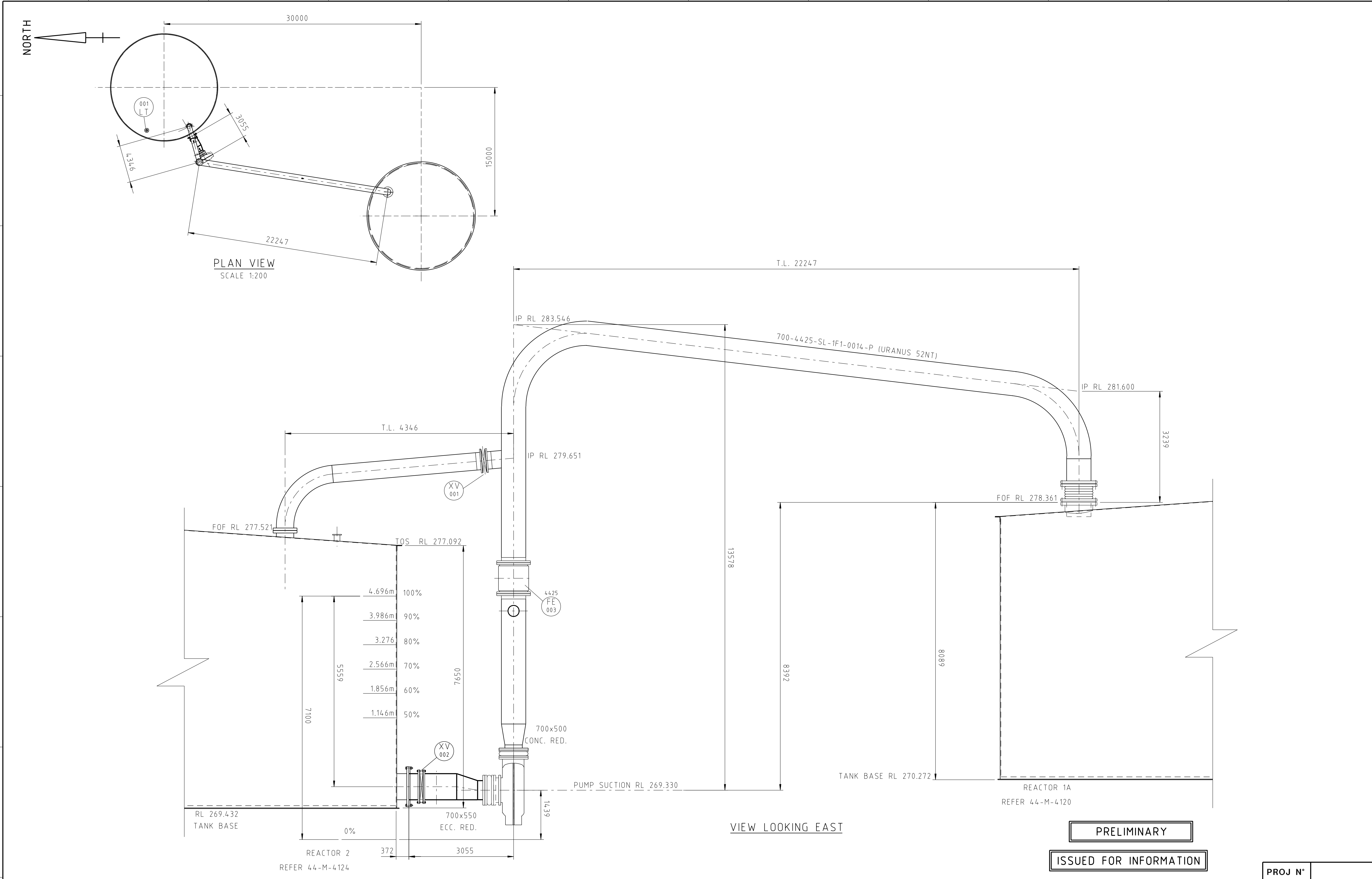
PHOSPHORIC ACID PLANT
HEMIHYDRATE REACTION 2
PIPING AND INSTRUMENT DIAGRAM SHT 2

WMC FERTILIZERS LTD.

NUMBER: 44-B-3021

REV: 11

A1



REVISIONS	NO.	DATE	DRN.	CHK.	DES.	ENG.	OPS.
ISSUED FOR INFORMATION	PB	01.08.07	AM				
ISSUED FOR APPROVAL	PA	14.05.07	AM				

REFERENCE DRAWINGS	NUMBER
PIPING SECTION 'D'	44-D-4120
PIPING ARRANGEMENT SHEET 1 OF 3	44-D-4034
PIPING SECTION 'E'	44-D-4116
PIPING GENERAL ARRANGEMENT SHEET 3 OF 3	44-D-4036
4425RA2504 NOZZLE ORIENTATION ARRANGEMENT	44-M-4124
DETAIL PLOT PLAN	44-M-4201

Incitec Pivot

	NAME	DATE
DRAWN	A.MITCHELL	01.08.07
CHECKED		
DESIGNED		
ENG. MGR.		
OPERAT'NS		
SCALE	1:50	U.N.O

Southern Cross Operations ABN 30 004 936 850

PHOS HILL - PHOSPHORIC ACID PLANT
HEMIHYDRATE - REACTORS
REACTOR TANK AREA
RECIRC. LINE ARRANGEMENT

PROJ N°

NUMBER: 44-D-013854

REV: PB

A1

I:\DOCSOPEN\WMCF_Technical\A_MITCHELL\px901_.DGN
01/08/2007
10:21

Appendix C

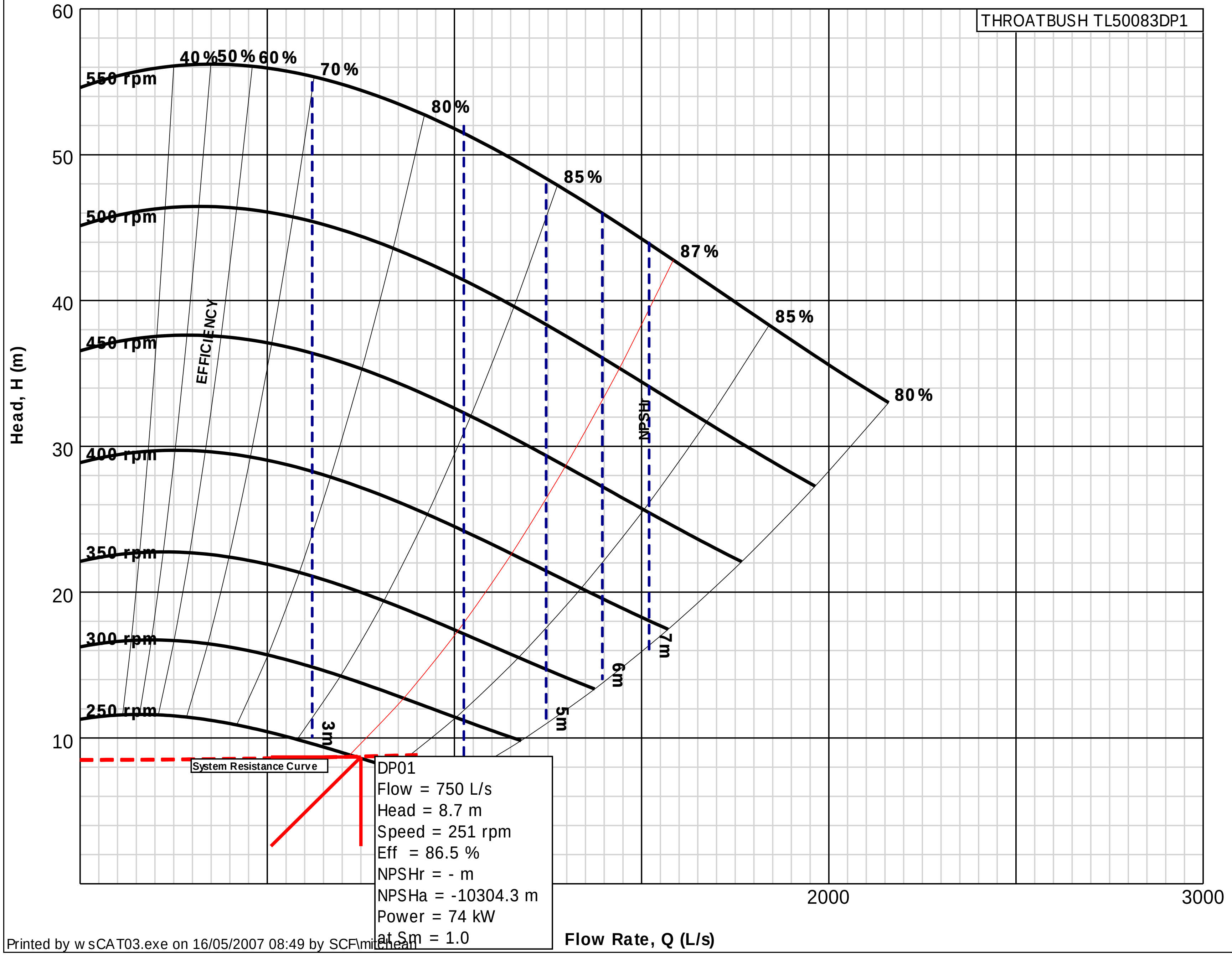
Warman 500ST-L Pump Curve

WARMAN®
Centrifugal Slurry Pumps

Horizontal Pump 500 L

Slurry Equipment Solutions
WEIR MINERALS

CURVE SHOWS APPROXIMATE PERFORMANCE FOR CLEAR WATER (International Test Standard ISO9906:1999 - Grade 2 unless otherwise specified). For media other than water, corrections must be made for density, viscosity and/or other effects of solids. WEIR MINERALS reserves the right to change pump performance and/or delete impellers without notice. Frame suitability must be checked for each duty and drive arrangement. Not all frame alternatives are necessarily available from each manufacturing centre.



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Pump	
Suction	550mm
Discharge	500mm
Impeller	
Vanes	5
Vane ø	1040mm
Type	Closed
Part No	**Material**
TL50147DP1	Metal
STL50147DP1	Metal
Frame (Rating - KW)	
SX	560
ST	560
TU	1200
Seal	
Gland Sealed Pump	
Liner (Norm Max r/min)	
Polymer	500
Metal	550
Curve	
Revision	2
Revision Notes	
MINIMUM PASSAGE SIZE CHANGED	
Reference	TEST 8, 8A, 8B
Last Issued	Mar 99
Issued	Mar 06

TYPICAL PUMP PERFORMANCE CURVE

WPA500A22/2

Appendix D

Sample Data Collection

	Flow (m3/hr)	Speed (% of Full speed)	Speed	Current (% of full load)	Power	Tank Level
	Raw	Raw	Calculated			
Timestamp	44FIC25003.PV - SnapShot	44FIC25003.MV - SnapShot	RPM	4425PC2505.FV - SnapShot	kW	44LI25001.PV - SnapShot
13/08/2007 10:40:00 AM	3232.33	99.96089935	284.8886	68.75585175	147.3	74.33265686
13/08/2007 10:45:00 AM	3326.67	99.26324463	282.9002	71.37460327	152.9103	74.33204651
13/08/2007 10:50:00 AM	3293.97	98.73190308	281.3859	67.125	143.8061	75.07279968
13/08/2007 10:55:00 AM	3329.01	98.44909668	280.5799	66.75	143.0027	75.14984894
13/08/2007 11:00:00 AM	3288.63	99.04299927	282.2725	67.74995422	145.145	75.11605072
13/08/2007 11:05:00 AM	3328.94	98.50195313	280.7306	69.25	148.3586	75.15890503
13/08/2007 11:10:00 AM	3294.40	98.8865509	281.8267	66.52929688	142.5299	75.07060242
13/08/2007 11:15:00 AM	3231.53	99.58189392	283.8084	67.99755096	145.6754	74.94824982
13/08/2007 11:20:00 AM	3367.02	98.57754517	280.946	69.75	149.4298	74.7980957
13/08/2007 11:25:00 AM	3310.16	98.86029816	281.7518	66.375	142.1993	74.75709534
13/08/2007 11:30:00 AM	3296.23	98.75015259	281.4379	67.75	145.1451	74.91220093
13/08/2007 11:35:00 AM	3324.23	98.71640015	281.3417	66.875	143.2705	74.59970093
13/08/2007 11:40:00 AM	3274.61	99.17489624	282.6485	67.84375	145.3459	74.52149963
13/08/2007 11:45:00 AM	3306.76	98.88310242	281.8168	67.625	144.8773	74.72360229
13/08/2007 11:50:00 AM	3275.02	100	285	71.61474609	153.4248	74.36399841
13/08/2007 11:55:00 AM	3288.71	99.75654602	284.3062	69.25004578	148.3587	74.09564972
13/08/2007 12:00:00 PM	3308.45	99.72460175	284.2151	68.75	147.2874	74.32374573
13/08/2007 12:05:00 PM	3305.85	99.78234863	284.3797	70.71875	151.5052	74.16725159
16/08/2007 1:40:00 AM	3247.45	95.61274719	272.4963	67.125	143.8061	74.03565216
16/08/2007 1:45:00 AM	3279.69	95.2105484	271.3501	67.38659668	144.3665	74.63285065
16/08/2007 1:50:00 AM	3281.18	95.25675201	271.4817	67.625	144.8773	74.20135498
16/08/2007 1:55:00 AM	3243.20	95.47109985	272.0926	67.5	144.6095	74.36064911
16/08/2007 2:00:00 AM	3234.89	95.57250214	272.3816	68	145.6807	74.43689728
16/08/2007 2:05:00 AM	3290.51	95.06445313	270.9337	68	145.6807	74.51425171
16/08/2007 2:10:00 AM	3287.69	94.27545166	268.685	67.85160065	145.3627	74.74720001
16/08/2007 2:15:00 AM	3233.56	94.38610077	269.0004	67.75	145.1451	74.86505127
16/08/2007 2:20:00 AM	3250.80	94.06310272	268.0798	67.25	144.0739	75.05944824
16/08/2007 2:25:00 AM	3272.00	93.8864975	267.5765	66.875	143.2705	75.34844971
16/08/2007 2:30:00 AM	3257.43	94.02349854	267.967	67.125	143.8061	75.37214661
16/08/2007 2:35:00 AM	3229.41	94.12405396	268.2536	67.25	144.0739	75.44979858
16/08/2007 2:40:00 AM	3218.53	94.06719971	268.0915	66.875	143.2705	75.76239777
16/08/2007 2:45:00 AM	3253.10	93.93470001	267.7139	66.95315552	143.4379	75.72070313
16/08/2007 2:50:00 AM	3239.63	94.12565613	268.2581	67	143.5383	75.76170349
16/08/2007 2:55:00 AM	3255.92	94.0203476	267.958	66.5	142.4671	75.64520264

24/07/2007 11:40:00 PM	3300.08	95.8451004	273.1585	67.125	143.8061	75.92839813
24/07/2007 11:45:00 PM	3298.15	96.0128479	273.6366	66.875	143.2705	75.57485199
24/07/2007 11:50:00 PM	3343.53	95.82315063	273.096	66.5	142.4671	75.61294556
24/07/2007 11:55:00 PM	3308.08	95.98910522	273.5689	67.25	144.0739	75.46089935
25/07/2007	3283.06	96.25889587	274.3379	66.49220276	142.4504	75.14735413
25/07/2007 12:05:00 AM	3296.90	96.33979797	274.5684	68	145.6807	75.06909943
25/07/2007 12:10:00 AM	3310.04	96.1411972	274.0024	68	145.6807	74.67980194
25/07/2007 12:15:00 AM	3301.23	96.47674561	274.9587	68	145.6807	74.54220581
25/07/2007 12:20:00 AM	3300.50	96.6085968	275.3345	68	145.6807	74.28894806
25/07/2007 12:25:00 AM	3348.97	96.24124908	274.2876	67.74900055	145.1429	74.09449768
25/07/2007 12:30:00 AM	3330.34	96.40635681	274.7581	68.12425232	145.9469	74.20869446
25/07/2007 12:35:00 AM	3291.90	96.57929993	275.251	67.5	144.6095	74.09545135
13/06/2007 12:55:00 AM	3277.42	95.96694946	273.5058	66.64039612	142.7679	75.47705078
13/06/2007 1:00:00 AM	3222.79	96.38619995	274.7007	67.67254639	144.9791	75.40190125
13/06/2007 1:05:00 AM	3244.96	96.42855072	274.8214	68.64059448	147.0531	75.26324463
13/06/2007 1:10:00 AM	3244.58	96.26854706	274.3654	67.58955383	144.8013	75.30090332
13/06/2007 1:15:00 AM	3297.75	96.21820068	274.2219	67.97544861	145.6281	75.04794312
13/06/2007 1:20:00 AM	3238.20	96.66435242	275.4934	69.19520569	148.2412	75.01025391
13/06/2007 1:25:00 AM	3259.77	96.50769806	275.0469	68.62020111	147.0094	74.81594849
13/06/2007 1:30:00 AM	3320.03	96.13339996	273.9802	67.54740143	144.711	74.58114624
13/06/2007 1:35:00 AM	3266.77	96.43989563	274.8537	68.49394989	146.7389	74.73684692
13/06/2007 1:40:00 AM	3246.39	96.67150116	275.5138	68.35585022	146.443	74.30905151
13/06/2007 1:45:00 AM	3255.33	96.60839844	275.3339	68.94454956	147.7042	74.38639832
13/06/2007 1:50:00 AM	3263.84	96.62080383	275.3693	68.89825439	147.6051	74.19114685
27/05/2007 2:15:00 PM	3119.98	95.12049866	271.0934	66.54309845	142.5595	74.54135132
27/05/2007 2:20:00 PM	3126.48	95.0658493	270.9377	66.52549744	142.5218	74.57029724
27/05/2007 2:25:00 PM	3133.37	94.89494324	270.4506	66.34065247	142.1257	74.84474945
27/05/2007 2:30:00 PM	3061.43	95.56999969	272.3745	67.32835388	144.2418	74.68890381
27/05/2007 2:35:00 PM	3063.79	95.52905273	272.2578	67.03265381	143.6083	74.65000153
27/05/2007 2:40:00 PM	3142.66	94.61070251	269.6405	66.40654755	142.2669	74.68495178
27/05/2007 2:45:00 PM	3045.18	95.88629913	273.276	66.01100159	141.4195	74.53504944
27/05/2007 2:50:00 PM	3183.12	94.47935486	269.2662	66.32725525	142.097	74.42445374
27/05/2007 2:55:00 PM	3053.41	95.48605347	272.1353	66.50640106	142.4808	74.38059998
27/05/2007 3:00:00 PM	3172.25	94.66470337	269.7944	67.06745148	143.6828	74.31324768
27/05/2007 3:05:00 PM	3049.33	95.64295197	272.5824	66.84519958	143.2067	74.37934875
27/05/2007 3:10:00 PM	3116.46	95.40840149	271.9139	67.322052	144.2283	74.26490021
27/05/2007 3:15:00 PM	3028.67	95.99739838	273.5926	67.23124695	144.0337	74.14794922