

Mathew Rowlands Major Project

by Mathew Rowlands

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Reducing Lost Production from Process Control Valves

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Major Project

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DOW RESTRICTED

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Abstract

This report details the findings from an investigation into the lost production from PV358 and PV345 process control valves. The report sets out the aims and objectives of the investigation. The history of the valve and failure data is used throughout the report. The root cause of the valves failures is identified as: failure to contain process material due to insufficient atmospheric seal caused by undermining or collapse of the seal mechanism. Possible solutions are proposed using research and data to justify their consideration. The solution chosen is to: replace the current four-inch Everlasting valve with a two-inch Everlasting valve. This solution is compared against the aims and objectives of the project and achieves them all. All calculations and considerations are made to the change in process operating conditions that the proposed solution would cause. The necessary stages of implementation and execution of the solution is stated. To support the findings of this study the installation of an orifice plate is recommended. A timeline and method for implementation is also proposed. The solution proposed in this report could prevent \$500,000 - \$750,000 (US) of lost production within four years of implementation.

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Introduction

Problem Statement

The Dow Chemical Company Barry site has two consistently unreliable valves responsible for causing lost production (Lovett, 2019). The valves are PV358 and PV345. They are process control valves that regulate the flow of silicone powder fed from hoppers into a carrier gas line. Both valves are identical and perform the same function in parallel with each other.

The problem to address is the lost production time that is caused by an unexpected mechanical failure from the valves. Reducing the rate of mechanical failure from these valves will increase the sites production reliability.

The investigation is important to reduce lost production for the Barry site and consequently increase profit. It will also highlight the safety benefits that accompany improved reliability, such as reduced unplanned emissions of silicone powder and Methyl Chloride gas. Emissions such as these are reported to the Natural Resource Wales. Safety and reliability are both fundamental values at the Dow Chemical Barry Site and the Dow corporate vision.

Past investigations into this problem have been conducted by the Facilities Engineers working at Dow Chemical Barry Site (Dow Corning, 2013). Their aim was to standardise the rebuild of the valves so that fewer variables would be present, successively allowing the root cause of the valves unreliability to be identified. This was achieved through creating maintenance procedure MP91 for the valve service. This procedure details all the steps that are required to successfully dismantle, rebuild and test the valve. In addition to producing a maintenance procedure it was identified that training is required before technicians can rebuild the valves. From standardisation of valve rebuilds, common failure mechanisms were identified. Mechanical solutions were applied to these failure mechanisms; consequently, improving the reliability of the valve (Dow Chemical, 2019). However, this was not enough to prevent all mechanical failures that result in lost production. This investigation commences from June 2015 after these improvements were implemented.

Process Overview

Dow Chemical Barry site manufactures silicone-based products and intermediates from raw elemental silicone lump material. The raw product is ground, chemically reacted and distilled to make silicon-based fluids, gums, rubbers and specialty polymers (Dow, 2019). These products are sold to customers as constituents to their products. Silicon-based materials are used in a variety of products ranging from

personal care, to automotive, sealants, protective coatings, lubrication and adhesives. The Barry site also provides other Dow sites with basic silicone polymers for downstream processes. PV358 and PV345 feed

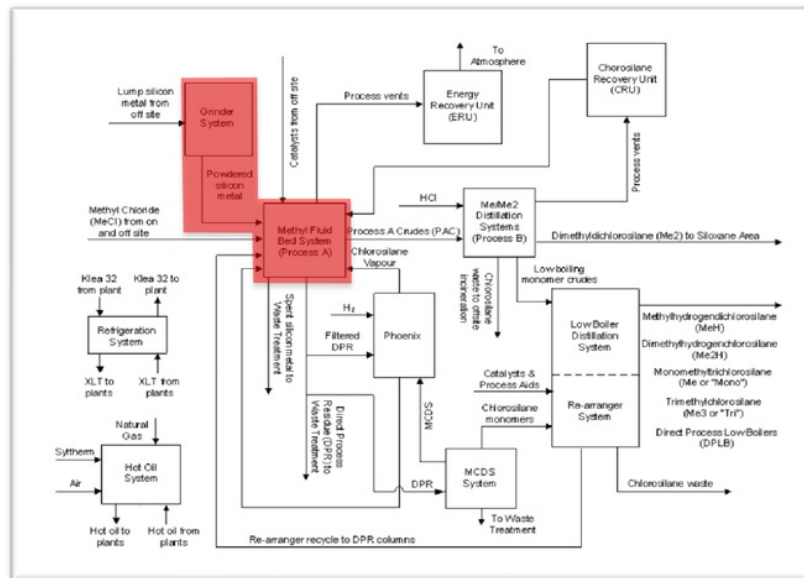


Figure 1- Silicone manufacturing process flow overview (Dow, 2013)

powder Silicone metal from the grinder system to the Methyl Fluid Bed Reactor seen highlighted in Figure1.

This subject has been chosen for the investigation due to the impact it has on the maintenance team as well as production. Technicians perform maintenance on these valves that include disassembly, cleaning, fault finding, repair, component replacement, rebuild and testing. Maintenance Technicians are also involved in the replacement of the valves when an unexpected failure occurs. Work Activity Coordinators have identified PV358 and PV345 as requiring a large amount of maintenance resource; this, in turn, led to this investigation into the production implications of the valves unreliability (Low, 2019). The maintenance work process is detailed in Figure 2.



Figure 2- Reliability Maintenance Work Process (RMWP) (Dow, 2013)

Project Aims and Objectives

The aim of the project is to reduce the lost production from silicone feed valves PV358 and PV345. The following objectives should be met whilst achieving this aim:

- To improve the production reliability of the site
- To prevent fugitive emissions
- To improve the mechanical reliability of the valves

The objectives help to guide the project. Improving the sites production reliability should be considered at all times; proposals from this study will have to meet this objective to be considered for implementation by the Dow Chemical Company.

Preventing fugitive emissions is an essential safety objective of this project. The frequency and consequences of fugitive emissions should be reduced. The environmental impact of the plants production is monitored by Natural Resource Wales and can result in fines, imprisonment and plant closure. Fugitive emissions also affect the way in which maintenance can be executed this should be considered during the investigation.

The mechanical reliability of the valves should be improved as an objective. Since production reliability can be improved through installation of a duty standby; however, this will not improve the mechanical reliability. Mechanical reliability and production reliability are not always directly connected.

Since June 2015 PV358 and PV345 have incurred eight failures resulting in 19 hours of lost production with a consequence of \$500,000 - \$750,000 (US) lost profit (Lovett, 2019). The project aims and objectives are designed to reduce this figure.

Dissertation Structure

The first chapter describes the existing valves PV358 and PV345, it discusses the following topics: manufacturer, application, valve reliability, safety factors, maintenance, root cause, modifications, and costs.

When discussing the section on the manufacturer; the history and background of the manufacturer are described. This section includes the design specification, the physical characteristics and how the valve mechanically operates.

Chapter one continues to describe the application of the valves; identifying their location on site, their function within production, the process medium, control loop, and frequency of operation.

When discussing the reliability of the valve, the failure data is considered including; the difference between planned and unplanned changeouts, the different conditions that allow a valve to be changed without production consequences, the time it takes to change a valve and the costs associated with valve replacements are included in this section.

The safety considerations of the valve include; chemical exposure during maintenance, emission data, and classifications. This section describes maintenance of the valves including the planned maintenance duration to change out the valve. It also includes the time it takes to service removed valves; along with a brief description of the steps required to overhaul the valve and the procedure is detailed within.

When discussing the root cause of valve failures, failure data is provided and the failure modes are discussed using historical data and technical findings to identify the root cause of the failures. When discussing the modifications that have previously been made the failure mode is referenced to justify the modifications. Failure data is then shown to display the quantifiable improvement the design changes have made to the reliability of the valve.

Finally, chapter one describes all financial aspects related to the valves. The cost of downtime is discussed and the comparison from when a valve is changed as preventative maintenance compared to a reactive breakdown. The labour costs for the valve changeout are also discussed. The cost to service the valve is identified; including labour costs, new parts, and component refurbishment. The value of spare parts held in maintenance stores to facilitate a valve service is also stated. These total costs are then compared to the cost of a new valve and downtime.

The second chapter identifies the solutions available to reduce the lost production from silicone feed valves PV358 and PV345. Throughout this chapter, all possible solutions are evaluated against the aims of the project. Evaluating the possible solutions against the aims is a simple way to establish the relevance of the solution.

The solutions discussed in this chapter include; mechanical improvements to eliminate the root cause of the valve failure, possible condition monitoring that could be applied to the valves, improving the maintenance efficiency for a valve change out, and using an alternative model of valve. The possible alternative models of valve include; ball, pinch, dome, and knife. The current applications of these valves are discussed and their strengths and weaknesses for the proposed application. Changing the 4" Everlasting valve model to a 2" model is also considered as it is used on similar duties and could be considered more reliable.

The third chapter details further information on the 2" Everlasting valve. The reliability of a 2" Everlasting valve is discussed. Describing their current use on site and how this compares to the function of PV358 and PV345. The reliability data is then compared for the 2" and 4" Everlasting valves. The different design characteristics of the 2" and 4" Everlasting valves are deliberated. The differences are compared to establish if mechanical reliability could be related to these variations.

Chapter three then goes on to describe the 2" valve flow rate compared to the flow rate of the current 4" Everlasting valve. Poiseuille's law is used to calculate flow differences between the two models. The calculated flow rates are discussed and how changing the operating times can maintain the feed requirements. The rate of actuation is discussed and possible correlation to increased lifespan from decreased actuations.

The fourth chapter evaluates the potential solutions provided. It compares each solution to the aims and objectives of the project. This comparison enables the solutions to be compared on their effectiveness to meet the projects target. The best solution is then identified and justified using the data and facts collected in the study. These data and facts are also compared to the current PV358 and PV345.

The fifth chapter identifies how to implement the installation of the chosen solution. This includes pipework modifications, documentation updates, spare stock and Planned Preventative Maintenance Strategy (PPM).

The sixth chapter concludes the findings of the report. It compares the chosen solution to the projects aims to critically asses if it meets the objectives of the project. It also details other benefits that could be seen from implementing the chosen solution. The chapter is summarized with a review of the project.

The seventh chapter describes the recommendations of the study. It details all endorsements that the study has made and how they can reduce the lost production from silicone feed valves PV358 and PV345. The chapter also recommends a method to validate the findings of the study that can be installed as future work.

Timescales

The only limitation to the study is duration. The Dow Chemical Barry Site supports the investigation and will review findings with the intent of implementation. This support allows access to historical failure data and process information that will form a statistical basis for the recommendations made in this study. The deadline for the interim oral examination is November 9th, 2018. From this deadline all major tasks identified that require completion are detailed in Table 1. This includes the final dissertation and poster submission on April 30th, 2019. The final oral examination deadline is May 7th, 2019. Table 1 indicates the

intention to complete all work by March 22nd, 2019. This is due to additional work and university commitments.

Table 1- Gantt chart of planned and actual tasks including deadlines

Task	Time	14-Dec	28-Dec	11-Jan	25-Jan	08-Feb	22-Feb	08-Mar	22-Mar	05-Apr	19-Apr	30-Apr	07-May
Collect comprehensive reliability data	Planned												
	Actual												
Examine current actuation rate of 2" valve	Planned												
	Actual												
Spares investigation and planning	Planned												
	Actual												
Collect data on time taken to changeout valves	Planned												
	Actual												
Collect service time data	Planned												
	Actual												
Identify valve weights	Planned												
	Actual												
Design pipework modifications	Planned												
	Actual												
Written dissertation	Planned												
	Actual												
Oral Presentation preparation	Planned												
	Actual												
Poster presentation	Planned												
	Actual												

Data Analysis

The quality of the data analyzed in the study should be considered. Historical data used for this study is collected in SAP Enterprise Resource Planning (ERP) Software. The quality of data outputted is reliant on the data inputted. Historical SAP data used in this study includes valve failure data, time to complete work and costs associated.

The SAP data used for the valves failures is established from Work Orders generated against each specific valve. Work Orders are automatically generated through the Planned Preventative Maintenance (PPM) process to initiate a planned valve change. For unplanned valve changeouts the Work Orders are generated by the Plant Operators. In some occasions, more than one Plant Operator may raise a Work Order for the same failure. It is also possible that no Work Orders are created. This would commonly be due to the urgency of a valve change, production loss and financial implications of a valve failure. This lack of

discipline with data entry can lead to discrepancies in data. Data discrepancies can also be caused if an automatic PPM work order is created shortly after an unplanned valve failure; the PPM Work Order may not be completed to prevent unnecessary duplicate work. Another form of data imprecision is present when a Work Order is raised for preventative work on a valve such as lubrication or a limit check. The work escalates to become a valve replacement without detail present in the Work Order. To eliminate poor quality data; all data collected was filtered to only include Work Orders that had a material movement of a complete spare valve charged against the Work Order. This eliminates any work orders that had no valve changeout completed. However, any valve changes completed without a Work Order would not be captured in the data.

SAP data is also used to calculate the working hours charged to the Work Orders by the Technicians. This can provide data for the time taken to complete a valve replacement and service. However, this data is not consistently recorded throughout the Work Orders. Therefore, it cannot be considered accurate for the study. Therefore, to gain data on time taken to change out a valve, a manual form was issued with the Work Orders for the duration of this study. This method only provides data for the last nine months. The data is a primary source of information that can be considered accurate due to its consistency. However, an improvement would be to continue to collect data to further substantiate the data detailed in this report.

The data in SAP of the time taken to service the valves has been entered inconsistently; therefore, the planned allocation of hours is used. The planned allocation of hours is accurate as inaccuracies have consequence in maintenance scheduling; therefore, they are regularly reviewed and updated.

SAP data is also used to identify the costs of components. The cost charged to Dow for every purchase for each component is available. This information provides accurate and reliable data for the report. The data is used to compare the cost of valve rebuild between the 2" and 4" models.

SAP data is also used to identify the lead time for components. The predicted lead time is stored in SAP from when the original quote was raised. The actual lead time is also stored from the last time the product was ordered. The data used in this report is the most conservative of these two times. This is to ensure the worst-case scenario is always applied when proposing a volume of stock to store on site.

PI ProcessBook is an information infrastructure system and data historian that continuously collates live data from process instrumentation. This primary data is accurate and reliable as the instrumentation is checked and calibrated to comply with safety and trading standards. The live data is used to track pressure used to calculate flow rates for the valves. The data is also used to track opening and closing times for the valves.

Reference Appraisal

A variety of sources are used throughout this study for data collection, information and justification. Peer reviewed journals are used as a reference for information on maintenance practices and material studies. Literature available from the Everlasting Valve Company is used for data and information on the products they supply. This includes data on valve sizes and operating parameters.

Many references are made to the Dow Chemical, formally Dow Corning. Information is taken from procedures and standards that the study has to comply with. This helps to structure the study, as Dow Chemical can be considered as the client and the standards can be used as design specifications. All Dow Chemical references are unpublished and are internal restricted documents.

Legal bodies and Government organisations are frequently referenced. This is to ensure the study complies with all the legal requirements to allow the site to operate. These are key references of primary sources of information.

When primary sources are not available within Dow Chemical resources, email correspondence is used to gather information. Many references to emails are used from Subject Matter Experts (SME) within the Dow Chemical organization.

Pictures have been used as a primary source of information. They are used to show aspects of the valves that are unique to Dow Chemical Barry site.

Current PV358 and PV345

Manufacturer

PV358 and PV345 are rotating disk valves manufactured by the Everlasting Valve Company; it is claimed the valve 'remains the toughest, longest lasting, best-performing valve on the market today' (Everlastingvalveusa, 2016). The Everlasting valve is manufactured in New Jersey USA and has been developed for over one hundred years through numerous models. The valve is designed for application in industries such as power generation, cement, petroleum, and chemical. In chemical industries it is explicitly designed for applications such as; reactor charging, equalizing and discharge, chlorinator feed and discharge, sand and catalyst separation. Figure 1.1 shows a fully refurbished Everlasting valve ready for installation.

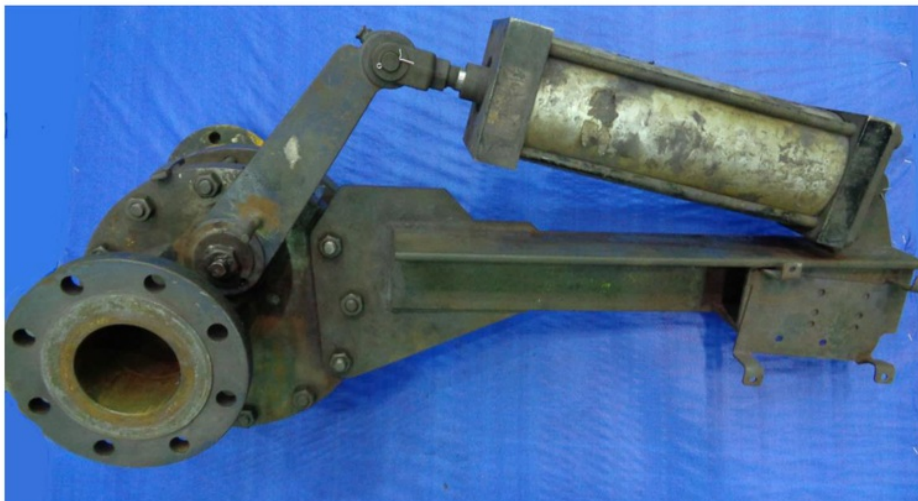


Figure 1.1 - Refurbished Everlasting Valve Ready for Installation

The valve is a 4"NB (Nominal Bore), inline, pneumatically actuating valve with flanged connections. The valve complies with the ASME B16.5 (The American Society of Mechanical Engineers, 2003). The valve has a carbon steel body compatible with process chemistry and 150# flanges to comply with the Dow Corning Pipe Standard PS27W (Dow Corning, 2010). These standards are essential so that the site meets Health and Safety Executive requirements as set out in the Control of Major Accident Hazards Regulations 1999 (Health and Safety Executive, 1999).

The valves are pneumatically driven with 5 bar(g) compressed air through a double acting actuator. The actuator is connected by a lever arm to the shaft of the valve. The shaft converts the linear drive of the actuator into rotational motion. At the opposite end of the shaft, there is a lever arm. The lever arm rotates through 45 degrees with every actuation and back on the reverse stroke. The lever arm has a sealing disk at the opposite end to the shaft. The length of the lever arm dictates the radius of the arc along which the sealing disk rotates. This allows the disk to cover and seal the pipe orifice when in the desired closed position and be removed entirely

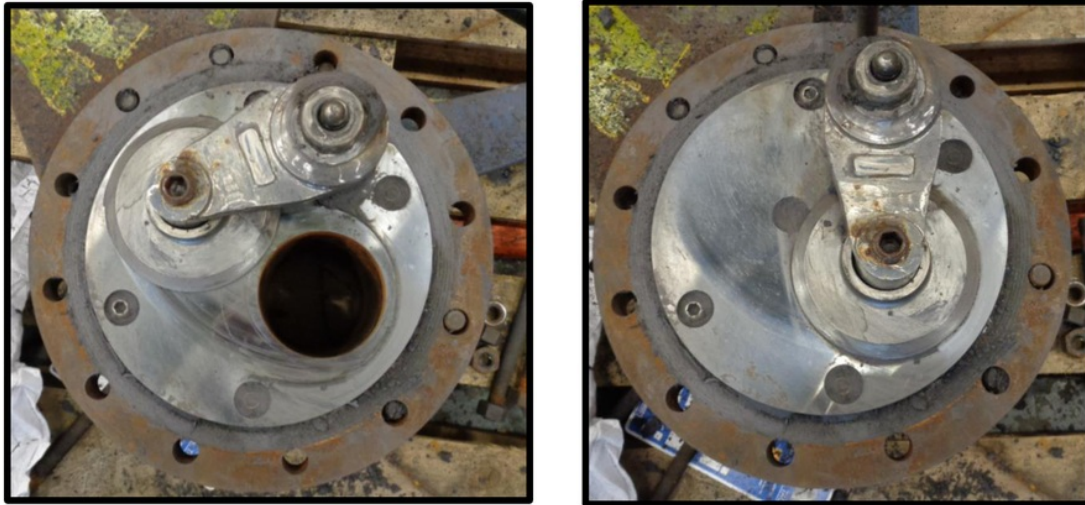


Figure 1.2 Everlasting valve dismantled in open and closed position, respectively

from the flow of material when in the open position. The open and closed positions are shown in Figure 1.2.

The Everlasting valve has a unique self-lapping mechanism that helps it maintain an operational seal when processing abrasive materials. The seal disk is not constrained radially to the lever arm, it is held in place through a tensioned spring normal to the sealing face. This allows the seal disk to freely rotate 45 degrees with every actuation; this is shown in Figure 1.3 below.

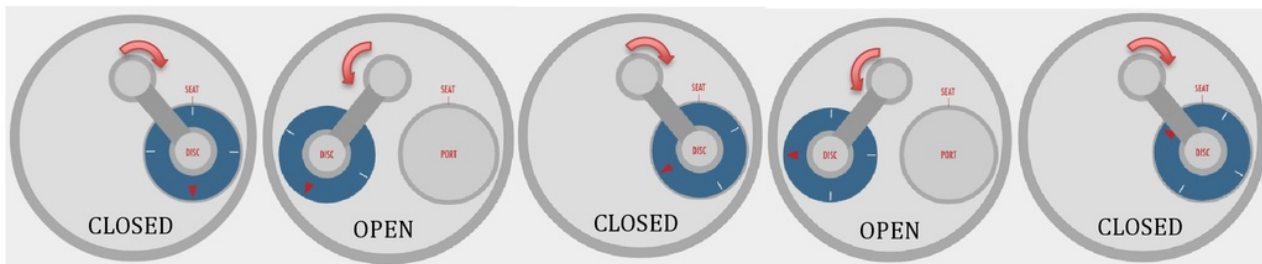


Figure 1.3- Diagram of seal disk rotating as valve actuates (Everlastingvalvesusa, 2016)

The natural rotation of the seal disk ensures wear is distributed evenly on the disk and seal plate. The rotation helps the disk lap into the seal plate over time. This rotation is unique to the Everlasting valve as most valve types lose sealing ability over time.

Application

The two valves are located on W930 plant as part of the fluid bed reactor feed process. PV358 and PV345 are process control valves. They are not isolation valves and have no critical safety function. The valves control the feed rate of silicon powder from hoppers 1208 and 1209 into a fluid bed reactor.

The valves work in tandem; PV358 operates for approximately four hours emptying the silicone powder from 1209 hopper into the Methyl Chloride feed line below. Once 1209 hopper is empty, PV345 on 1208 hopper starts feeding the reactor. This sequence allows 1209 hopper to refill. This process continually repeats to meet the silicon feed requirements of the fluid bed reactor. Figure 1.4 displays this repetition, as the graphs indicate the valves open and closed position when feeding the reactor.

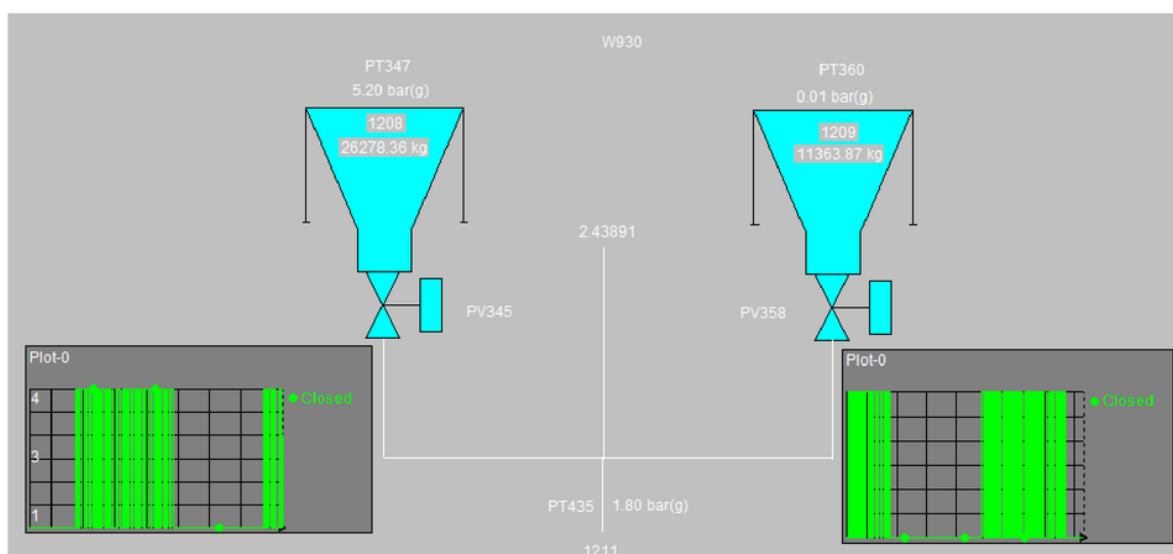


Figure 1.4- Process Illustration of PV345 and PV358 Operation over a ten hour period (Dow Chemical, 2019)

The process material is silicon powder. The silicon lump metal (raw material) arrives on site and is ground into a fine powder by another site production process. This powder is held in a large storage hopper; it is then transferred using differential pressure into the offline hopper 1208 or

1209. Silicon is an elemental metal with a Mohs hardness rating of 6.5 (Technical Data for Silicone, 2019). When pressurized in powder form the silicone becomes fluidized and is extremely abrasive.

Constant Nitrogen pressure is applied to the hoppers when they are offloading averaging about 5.2 Bar(g) (Dow Chemical,2019), this keeps the hoppers inert and fluidizes the powder. Beneath the hoppers is a common feed line, this links the two silicone hoppers as well as numerous other hoppers to the fluid bed reactor shown in Figure 1.5. Methyl Chloride is used as a carrier gas in the feed line; differential pressure transports material from the hoppers that feed into the reactor. The pressure in the Methyl Chloride feed line fluctuates when materials are added into the line from the various hoppers.

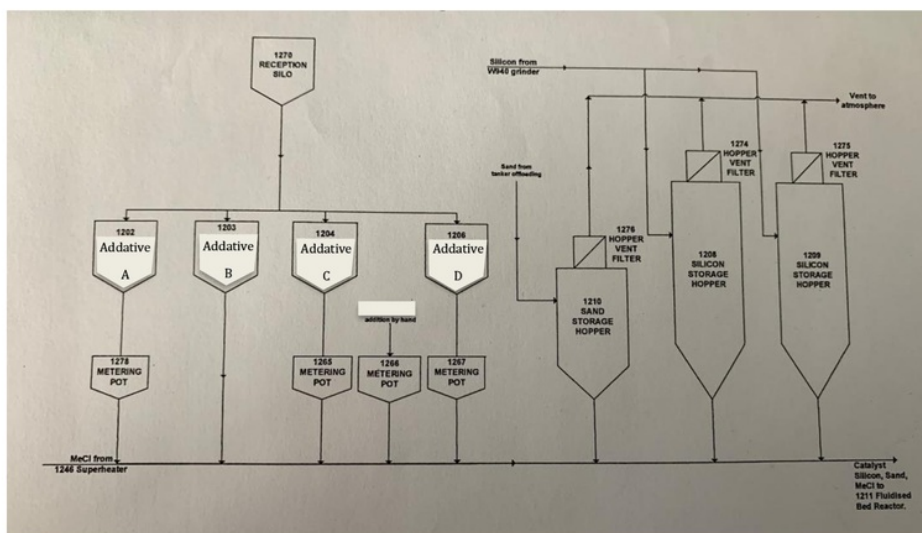


Figure 1.5 – Process illustration of hoppers that feed into the MeCl feed line (Dow, 2013)

The valves and reactor form a closed loop control system. The weight of the fluid bed reactor is the input and output controlling the operation of PV358 and PV345. Pressure instruments installed at varying heights on the side of the reactor are used to calculate the weight and volume of the material inside. The pressure instruments are the feedback elements of the control loop. If the reactor weight is below its set point it requires more silicon powder, PV358 or PV345 are opened to load the reactor. The valves are the controller in the control system. The system set up is detailed in Figure 1.6.

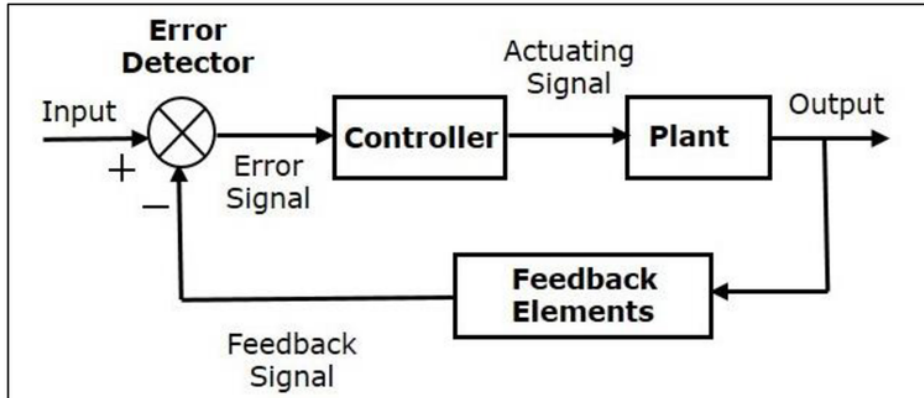


Figure 1.6 – Reactor control loop system

When operating the valves have a set maximum open time of 2 seconds, and a set minimum closed limit of 8 seconds. Taking data from an optimal and average production rate from 23/11/2018 08:39:53 for 24 hours the average open time was 1.961 seconds and the average closed time was 8.03 seconds for the valves (Dow Chemical, 2019). Therefore, the valve actuates 360 times an hour, this data is representative when the valve is operating during the production cycle.

Valve Reliability

Currently, each valve has a scheduled sixteen-week predictive planned maintenance (PPM) change out. Although, the valves can fail before their scheduled change out. There are two possible failure effects for control valves. PV358 and PV345 have a consistent failure mode of inadequate process containment as opposed to process control issues.

Spent bed feedback is a production phase during the fluid bed reaction cycle. “Spent bed feedback occurs approximately once every seventy-two hours for about a twelve-hour period” (Evans, 2019) these periods depend on the size of the planned production run. Spent bed feedback does not require any silicone powder to be fed into the reactor. Therefore, PV358 and PV345 can be isolated from the live production. This phase of operation provides an opportunity for maintenance that will not affect production.

Since June 2015 PV358 and PV345 have incurred eight failures resulting in 19 hours of lost production (Lovett, 2019). In addition to this, the valves have been removed eighteen times as predictive intervention to valve failure (Appendix 1.1). Planned predictive change of out the valves do not affect production as they can be scheduled for spent bed feedback.

If a valve experiences an unexpected failure the impact to production can only be minimized through transferring from the opposite silicone feed hopper. A silicone hopper can only feed for an average of four hours, this is currently insufficient to perform a valve change out. Therefore, spent bed feedback is initiated early, this cuts short the production run. Spent bed feedback is a fixed duration. Production runs can be cut short but require the same spent bed feedback phase; therefore, the production rate decreases.

As well as scheduling a planned changeout so production is not impacted, there are many additional benefits to planning the valve change. A planned job is the safest way to execute maintenance (Little, 2002). There are many tasks to facilitate the installation of the valve. A benefit from a planned valve change out is the necessary resource and paperwork can be aligned to the job before execution.

Once it has been identified that a valve requires changing, the following tasks need to take place:

- Enter a SAP work order to document the maintenance and costs
- Apply process isolations and prepare the line for maintenance
- Identify new valve in stores and check out of inventory and record material movement
- Transport the new valve to W930 plant from stores
- Complete permits to work and associated paperwork
- Remove machinery guard
- Remove instrumentation
- Remove and replace the valve
- Replace instrumentation
- Replace machinery guard
- Sign off permits and complete Return To Operation (RTO) paperwork
- Remove process isolations and leak test

(Appendix 1.2)

From data taken from four valve replacements it takes an average time of 6.37 hours to complete this work (Appendix 1.2). A benefit of completing the work in a planned manner allows the Technicians and Operators know who is working on the job, therefore coordination between tasks becomes simple. In a breakdown scenario, the Technicians and Operators often need to be taken from other work they are completing.

Due to poor reliability of the valves, the Barry site currently holds four fully rebuilt valves on stock to cover PV345 and PV358, as well as a large quantity of spare parts (Appendix 1.6). The parts are purchased from Everlasting Valve Company Inc based in New Jersey America, this results in a long lead time for parts. With poor reliability and long lead times, inventory strategies such as Just In Time (JIT) are not viable (Byung-Cheon and Myoung-Ju, 2018). Reliability improvements would allow inventory strategies such as JIT to be considered.

Safety Factors

Many safety aspects benefit from improving the reliability of the Everlasting valves. Increasing the duration between valve replacements would reduce the frequency in which the maintenance technicians are exposed to the hazards associated with valve changeouts.

One such hazard is Methyl Chloride gas. The gas may be present in the body of the valve or pipeline once isolated; therefore, maintenance personnel may become exposed to this hazard. The gas is visually undetectable, scentless and causes anesthesia. The Health and Safety Executive EH40 Workplace Exposure Limits (Health and Safety Executive, 2005) defines acceptable exposure limits to Methyl Chloride gas (Chloromethane) as 50ppm (parts per million), this is further reduced by Dow Chemical Standards to 25ppm.

When the possibility of exposure to Methyl Chloride occurs, the standard of Personal Protective Equipment (PPE) worn by the maintenance technicians includes Breathing Apparatus (BA) and chemical resistant suit. This is a Barry site standard established upon recommendations from the Health and Safety Executive.

When a valve fails unexpectedly there is often a fugative emission of Silicone powder and Methyl Chloride gas. Constant Air Monitoring (CAM) identifies the atmospheric release of Methyl Chloride gas to the Panel Operators and sounds a plant alarm to start an evacuation. The CAM is set to alarm at 25ppm of Methyl Chloride in the air. The Emergency Action Plans (EAP) are then followed to control and diagnose the cause of the release. This system is in place as a control measure to reduce the risk of exposure of Methyl Chloride to personnel.

Emissions of Silicon powder and Methyl Chloride gas also have an environmental impact. Fugitive emissions have to be recorded for Silicone powder if there is a visible release; and for Methyl

Chloride combined emissions of above sixty tonnes per year legally have to be reported to Natural Resource Wales (Phillips, 2019).

The manual handling of the valve is another hazard that could be reduced by improving the reliability of the valve. The 4" Everlasting valve weighs 112.42kg (Appendix 1.3), this means it has to be transported by pallet with a forklift truck to W930 plant. During installation, the valve is lifted onto the raised platform over the handrail using a forklift truck with an extendable lifting arm. Although the forklift truck supports the weight of the valve; it still requires some manual adjusting to position it correctly to align with the pipework.

Maintenance

The Everlasting valves sixteen-week maintenance plan is based on historical failure data and wear characteristics seen in Figure 1.7. The schedule is set so that PV358 is removed approximately halfway through PV345's change out schedule. This schedule provides time for spares to arrive and a valve overhaul to occur.

Everlasting valves that are removed from service are decontaminated of all hazardous substances before they are overhauled. The scheduled service is planned for two technicians over three days, during which the valve is dismantled and the cause of its failure identified. Reusable and serviceable parts are cleaned. The lever arm and seal plate are sent offsite for refurbishment. The remaining parts are considered to be wear parts and are routinely changed for new.

The valve is built to the specifications in MP091 (Dow Corning, 2015). MP091 is a maintenance procedure based on the manufacturer's recommendations and the Dow Chemical standards. This procedure was produced to help improve the repeatability of the service and rebuild of the valve. This procedure has increased the quality of the rebuilds, this has reduced failure mode variables and should help determine the root cause of repeated valve failures.

Once the valve is built, it is pressure tested. The valve is pressurized with five bar(g) of compressed air which is sealed inside its body. A thirty-minute pressure containment drop test takes place where the procedure specifies that no more than half a bar should be lost in this time. This test confirms the integrity of the valve seals and body before use.

Establishing the Root Cause of Failure

Damage found to the valve after a failure occurs is entered by Technicians in to the SAP database as part of Technical Findings once the rebuild is complete (Appendix 1.5). These Technical Findings detail components that the Technician identifies as a contributing to the valve's failure. A damage code is entered which identifies what damage classification has occurred. A text item is also entered to add further detail to the code. From the details entered, in every case, the seal is recorded as a failed part. In most cases, there is wear on the shaft. This wear is usually the cause of the seal failure as the Silicone powder abrasively wears the shaft undermining the seal packing causing a leak path to atmosphere. An example of such shaft wear that undermines the seals, shown in Figure 1.7.

The area in Figure 1.7 denoted as A is the location of the bearing bush on the shaft. Area B shows the location of gland packing on the shaft. Wear is present in both these areas. This wear is repeatedly the cause of failures detailed in the Technical Findings (Appendix 1.5) Further images of wear in this location are shown in Appendix 1.4.

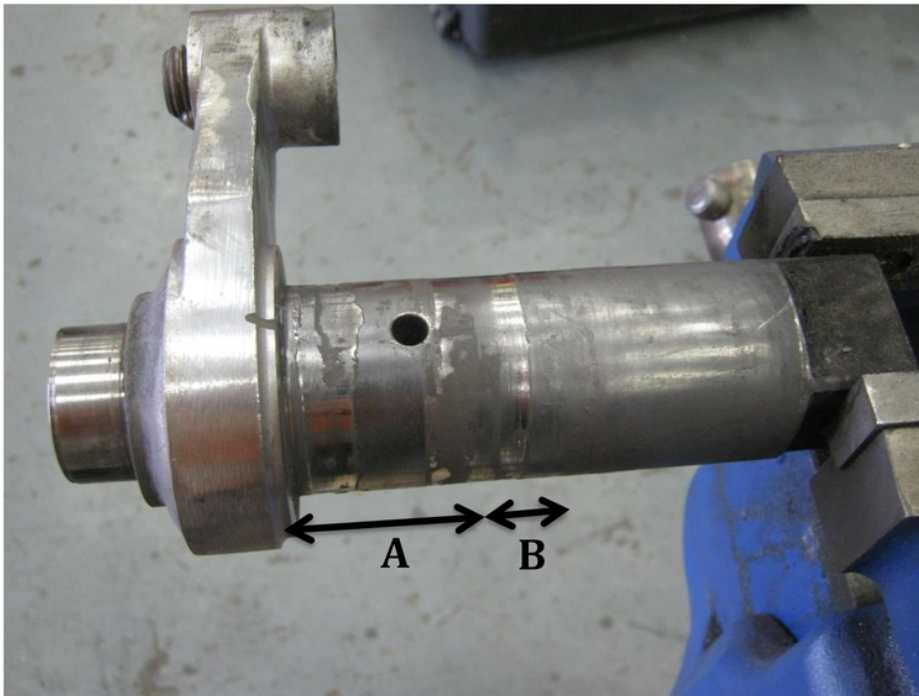


Figure 1.7- Wear on the Everlasting valve shaft

Modifications

The root cause of failure has previously been identified as shaft wear undermining the seal. Changes have been made to address this failure mechanism. Previous improvements modified the standard Everlasting valve to; incorporate an LSE scraper seal, wear resistant coating on the shaft and a lubrication application. These changes can be seen in Figure 1.8.

The LSE scraper seal replaced the previous graphite rope packing. The original packing had four rings of graphite rope that were packed inside the valve body and around the shaft. A gland follower secured the layers of packing in place with a spring cage on top. The tension from the spring cage compressed the layers of rope packing axially and forced them to expand radially, creating a seal between the shaft and the valve body.

The LSE scraper seal is housed in the same position on the shaft as the previous rope seals. The LSE scraper is made from four PTFE rings. The rings consist of an LSE scraper, a spacer, a second LSE scraper, and an energizing ring. The orientation of the seals is detailed in Figure 1.9. The seal is energized with nitrogen directly on the spacer ring. This nitrogen causes the two LSE scrapers to inflate. The nitrogen also passes across the sealing face creating a positive pressure seal helping to purge silicone powder away from the sealing area.

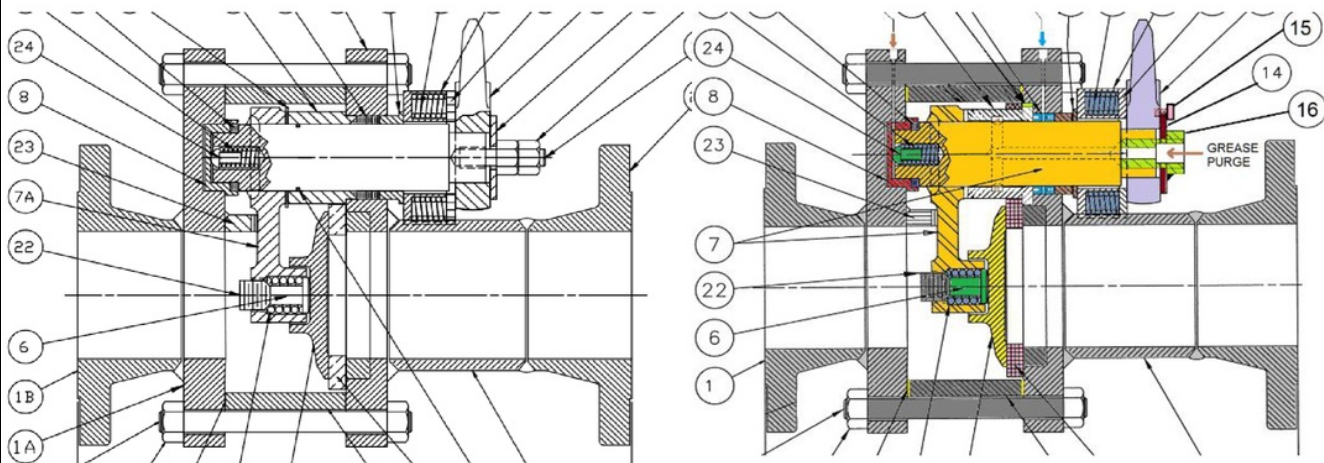


Figure 1.8 – Previous unmodified Everlasting valve and valve with modifications, respectively (Everlasting Valve Company, 1997)

The LSE scraper system has a sealing advantage over the graphite rope packing system because the nitrogen purge continually forces the LSE scraper to expand. Whereas previously, if the spring

tension had fully compressed the graphite rope, it was unable to expand further to seal any potential leak paths on the shaft caused by the abrasive Silicon powder.

The second modification applied to the 4" Everlasting valve was the application of a hard coating to the shaft. This coating was implemented to reduce the wear on the shaft from the abrasive Silicon powder. The original material for the shaft was 17-4 PH SS (stainless steel 630); this is considerably softer than silicone powder as displayed in Table 1.1. Two different spray coatings have been separately tested on the shaft; these were Chrome Oxide and Tungsten Carbide. Both of these spray coatings are harder than Silicon powder. Both coatings were trialed multiple times for PV358 and PV345.

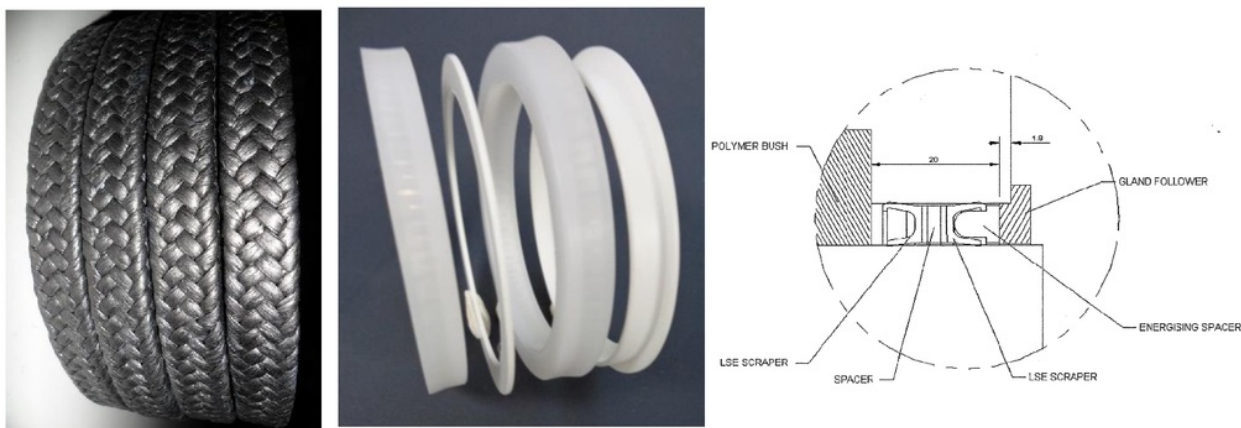


Figure 1.9- The Original Graphite Rope Packing, LSE Scraper and Scraper Orientation, respectively (Lanson Polymers, 2015)

The testing of these spray coatings typically gave the valve greater wear resistance and a longer lifespan. However, some catastrophic failures were seen. These failures were due to the spray coat becoming undermined. Once undermined, the coating would rapidly flake off up to 5mm² at a time, providing a large leak path to atmosphere. It is concluded that although the coating provided better wear resistance, its bonding to the shaft was insufficient to prevent catastrophic failures.

The next shaft coating trialed was Stellite 6b weld overlay. Once the weld overlay is applied to the shaft, the surface is ground back to dimensional tolerance. Weld overlay is fixed to the shaft through fusion, a chemical bonding that is much stronger than spray coating. When tested these shafts still received wear from Silicone powder abrasion, but with significant improvement from the original stainless steel 630.

Table 1.1 – Hardness comparison of shaft materials (Technical Data for Silicone, 2019)(Memsnet,2019)and(Azom, 2001)

Material	Hardness Rockwell A	Mohs (hm)	Vickers kg/mm/mm
Silicon		7	982
17-4 PH SS	38		382
Chrome Oxide		8.5	
Tungsten Carbide	90	9	1300
Stellite 6b	70		635

A further change implemented at this time was the application of lubrication to the shaft. The lubrication has two functions; firstly to apply a positive purge of grease along the shaft. The grease would displace from lubrication channels machined in to the shaft and into the valve body away from the seal. This lubrication would prevent the Silicon powder from entering the faces between the shaft and the bearing as well as the seal. Preventing the Silicon powder from entering the areas where it could undermine the seal was the primary objective of the grease. An additional benefit of the grease is lubrication of the shaft and bearing.

These changes improved the reliability of the valve mostly through trial and error (Dow Chemical, 2019). This was costly to plant production; however, the desired results were provided. In June 2015 the reliability of the valve was seen to increase. This is evident from the planned maintenance change out of PV358 and PV345 becoming extended from twelve to sixteen weeks. All reliability data collected in this study starts from this date to ensure data from the less reliable valve design are not included.

Costs

The maintenance department charges the plant and hourly rate of £75 (Low, 2019). For two Technicians to service the valve over three days costs a total of £3,600. During the service the single-use parts are discarded and replaced; this costs a total of £4,581.69 (Appendix 1.6).

The lever arm shaft and seal plate are sent off-site for refurbishment. The lever arm shaft has a new Stellite 6b weld overlay applied and surface ground back to dimensional tolerance, this costs £220 per unit. The seal plate, also made from Stellite 6b; it is ground entirely flat again so that it

seals correctly for its next installation, this costs £260.50 per unit. This is a substantial saving as a new seal plate costs £6,649 (Dow Chemical, 2019).

These figures make the total cost for valve refurbishment £8,662.19. The current total value of stock held is £45,239 (Appendix 1.6). The large inventory of spare parts is required due to the poor reliability of the valve.

The costs of maintenance are relatively insignificant in comparison to the cost of lost production. Eight failures have cost \$500,000 - \$750,000 (US) lost profit since June 2015 (Lovett, 2019).

Potential Solutions

Summary

Many potential solutions should be investigated to reduce the lost production from silicon feed valves PV358 and PV345. The projects aims should be considered when identifying the solutions:

- To improve the production reliability of the site
- To prevent fugitive emissions
- To improve the mechanical reliability of the valves

This ensures the solutions meet the targets of the study. Potential solutions investigated are; mechanical improvements to the valve's components to eliminate the root cause of failure, applying condition monitoring to the valve to better predict failure, improve the efficiency in which a valve is changed out, and use an alternative model of valve. These considerations are shown in Figure 2.1 as an Ishikawa diagram (fishbone), this cause and effect analysis can be used to start such processes as Six Sigma and Failure Mode and Effects Analysis (Spencer, 2015).

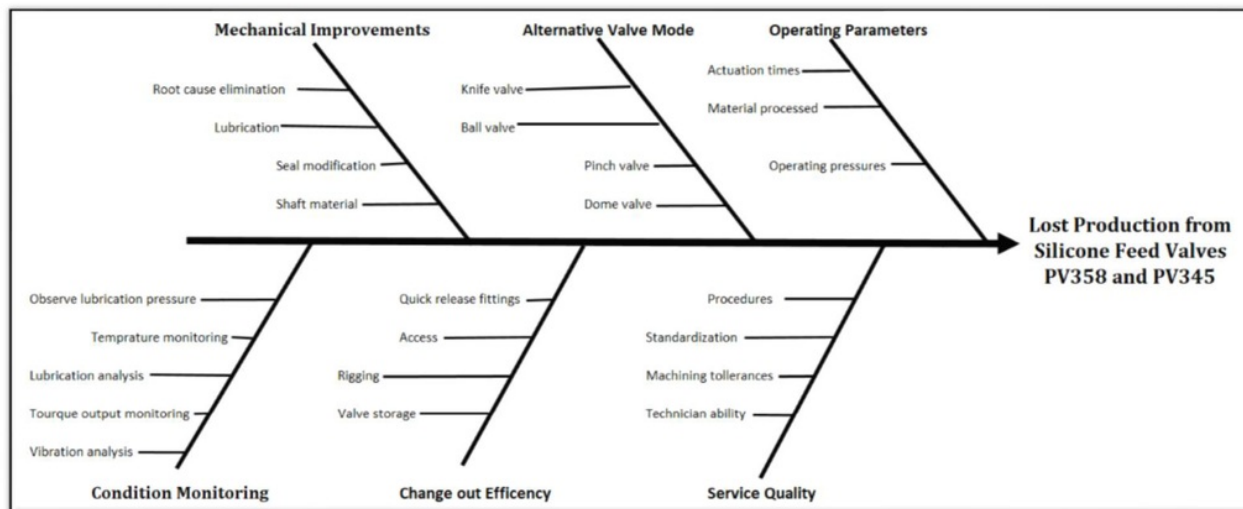


Figure 2.1- Ishikawa diagram displaying considerations to lost production

Mechanical Improvements to the Valve

There are potential mechanical improvements that could be made to the valve to remove the root cause of the failure. Such improvements would continue from work already completed in June 2015. These include seal improvements and further lubrication improvements.

A dust seal could be applied to the bearing to help prevent further ingress of Silicon powder. This would reduce the abrasion on the shaft and increase the valves lifespan. Another possible sealing solution could be an atmospheric seal. A second LSE scraper could be applied as a secondary containment mechanism to prevent an emission.

Modifications could be made to the lubrication system, allowing it to apply grease more evenly across the bearing face. In addition to this, the type of grease could be changed. Currently the grease is able to mix with the Silicon powder, this forms an abrasive paste. This paste accelerates abrasion of the shaft. The paste can also cause the lubrication channels to block and prevent fresh grease from entering the valve. This has not been found to cause a failure but is a contributing factor to accelerated wear. It is unknown why in some failures the pressure of the grease is insufficient to prevent Silicon powder ingress from the valve's body into the bearing. The bearing is where the grease and powder mix to form an abrasive paste.

Implementing mechanical improvements to remove the root cause of the valves failure would improve the sites production reliability; prevent unplanned emissions; and improve the valves mechanical reliability. This would be an ideal solution; however, many improvements have already been made in this area and did not eliminate the root cause. All potential solutions would have to be trialed and would have a cost to production if a failure occurred.

Condition Monitoring

A method of accurately monitoring the condition of the valve could help predict failures; allowing the valve to be changed preventatively before a failure and emission occurs. The only method to currently predict the failure of the valve is on the lubrication system.

The grease lubrication is charged through a pressurized automatic lubrication system (auto-luber). The auto-luber is set to empty the stored grease over a period of two weeks. The grease is injected in shots; these shots show a noticeable rise on the inline pressure gauge. The pressure decreases again as the grease dissipates into the valve. If the grease channel blocks as a result of forming a paste with Silicon powder; the grease is unable to dissipate and the pressure keeps rising. This continual rise in pressure on the gauge could be considered as an early indication of valve failure. This method is currently used and has resulted in the valves removal eighteen times as predictive intervention to the valves failure (Appendix 1.1).

Grease enters the valve through channel in the center of the shaft. Two adjacent channels allow the grease to exit the shaft and into the bearing. From the bearing, the grease can purge towards the valve internals or through the seals; this is indicated in Figure 2.2 with red arrows. If the grease purges into the valve internals, positive pressure is intended to prevent Silicon powder from entering the shaft and bearing area. If the grease purges out towards the seals, it can pass through the seals. This is due to the higher pressure of the grease compared to the nitrogen purge of the LSE scrapers. The grease exits the valve and builds up externally on the end of the shaft; as seen in Figure 2.3. The external buildup of grease could be sampled; as a method of condition monitoring. If Silicon powder is present in the grease it could be an indication of valve wear and potential failure.

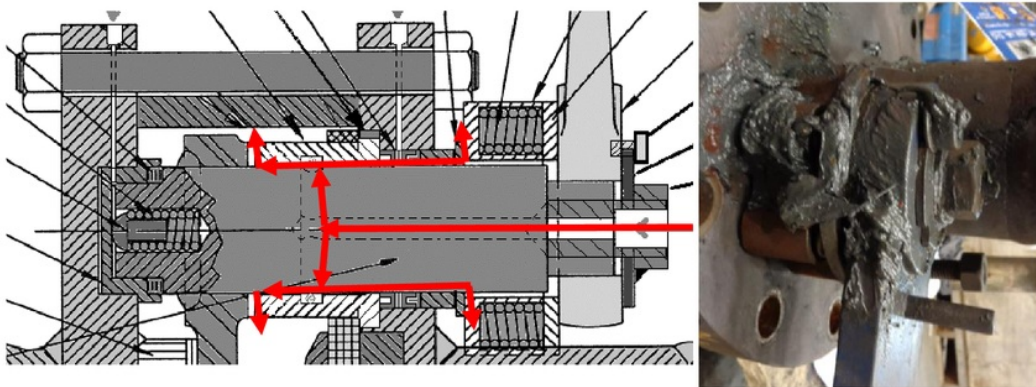


Figure 2.2 – Diagram of grease flow. Figure 2.3 – Image of grease that has purged out of the valve

Application of further condition monitoring could be applied to the valve such as temperature and vibration monitoring. The deterioration of the valves condition may increase the temperature inside the valve or cause small vibrations from increased friction. These monitoring techniques could be applied, and over time data may show trends that could indicate a failure.

Another potential method of condition monitoring could be to calculate the torque that is used to actuate the valve. If the torque increases it could be an indication of the grease becoming contaminated with the Silicon powder, this may cause increased friction and resistance.

Applying condition monitoring to the valve could prevent fugitive emissions and improve the sites production reliability. However, it would not improve the valves mechanical reliability. PV358 and PV345 would be changed out in the same frequency, exposing the maintenance Technicians to the associated hazards with the same frequency. The cost of maintenance would not change. It would also take an extended period to build a reliable database to predict valve failures. There may also be no correlation with heat or vibration to the failure of the valve.

Improve Maintenance Efficiency

Improving the maintenance efficiency for a valve changeout would increase the sites production reliability as it would reduce the downtime required to complete the maintenance. If the maintenance is completed in less than four hours after a valve failure it may not have any effect on production as the standby hopper may be able to feed for this whole time (if the standby hopper is full when the failure occurs).

The current average time to replace a 4" Everlasting valve is 6.37 hours (Table 2.1). To reduce this to less than four hours requires streamlining. Possible studies such as Six Sigma, Kaizen, SMED or Lean may be useful to make this task as efficient as possible (Dao, Basten and Hartmann, 2018).

Table 2.1- Times taken to complete the tasks required to change out PV345 and PV 358 (Appendix 1.2)

Task	Time Taken to Complete Task in Each Valve Changeout (min)				Average Time (min)
	21/1/19	9/10/18	15/2/19	31/8/18	
Enter a SAP work order to document the maintenance	15	15	30	30	22.5
Apply process isolations and prepare line for maintenance	60	60	30	60	52.5
Identify new valve in stores and check out	5	30	30	30	23.75
Transport valve to W930	30	30	30	30	30
Complete permits to work and associated paperwork	30	60	30	60	45
Remove machinery guard	30	30	30	30	30
Remove instrumentation	X	30	30	30	30
Remove and replace valve	60	60	60	60	60
Replace instrumentation	X	30	30	30	30
Replace machinery guard	30	30	30	30	30
Sign off permits and complete Return To Operation (RTO) paperwork	30	10	30	30	25
Remove process isolations and leak test	60	45	35	30	42.5

There are many possible ways to improve the maintenance efficiency: better access, simpler rigging, quick release fittings and storing the valve on the plant.

Better access to the valve would allow hands-on maintenance to be executed quicker. Currently, a machine guard has to be removed to complete the maintenance seen in Figure 2.4. This guard could be simplified or replaced with an interlocking gate that complies with BS EN ISO 12100:2010 (British Standards Institution, 2010). Currently removal and reinstallation of the guard takes a total average time of one hour, this could be completely eliminated with an interlock gate. The area around the valve is small and overcrowded making some of the valves flange bolts hard to access. The platform could be extended, and all auxillary instrumentation could be relocated to a different area that does not limit access. This improvement cannot be quantified with the current data provided.



Figure 2.4 – Machine guarding in place around PV345

Currently, the valve is removed and replaced using a forklift and extending arm, it can be awkward to align the new valve with the limited control of a forklift truck. Installation of a lifting beam with a beam trolley would allow the valve to be lifted and traversed with a chain-block. This rigging equipment could be installed precisely, so that pipe alignment is achieved efficiently for every installation. This improvement cannot be quantified with the current data provided.

Quick release fittings on the actuator air supply, nitrogen supply to the LSE scraper and grease supply to the shaft would make the valve change quicker. All these fittings are currently threaded and would be more efficient to remove and replace with quick release fittings. Currently removal and reinstallation of the instrumentation is completed by an Instrument Technician; with quick release fittings the Mechanical Technician could complete this task in tandem with the valve removal. The total average time taken to remove and replace the instrumentation is one hour; this could be completely eliminated with quick release fittings.

Currently, the spare valves are kept in a stores warehouse approximately half a kilometer from W930. Outside regular working hours this warehouse requires the Shift Manager to attend in order to access. The valve then has to be transported to W930 on a pallet with a forklift truck. The same forklift truck then has to have the extendable arm installed. These tasks currently take an average time of fifty-three minutes. Storage of a spare valve on W930 would eliminate all of these steps and the resulting time incurred. The spare valve would be replaced after the maintenance was complete.

The discussed solutions can accumulatively reduce the maintenance duration by two hours and fifty-three minutes (on current average duration for tasks completed). This would result in an overall duration to complete a valve change as four hours and thirteen minutes. If the time to complete a valve changeout could be reduced to below four hours this would improve the production reliability of the site, as feeds could continue from the opposite hopper whilst maintenance is completed. However, it would not improve the mechanical reliability of the valves or prevent fugitive emissions. PV358 and PV345 would be changed out just as regularly, exposing the maintenance technicians to the same number of exposures to associated hazards, and the cost of maintenance would not change.

Alternative Valve Models

An alternative valve model could improve the production reliability of the site; prevent unplanned emissions; and improve the valves mechanical reliability. There are many different valve designs available, identifying a valve that can operate effectively in the process conditions, and also meet the safety

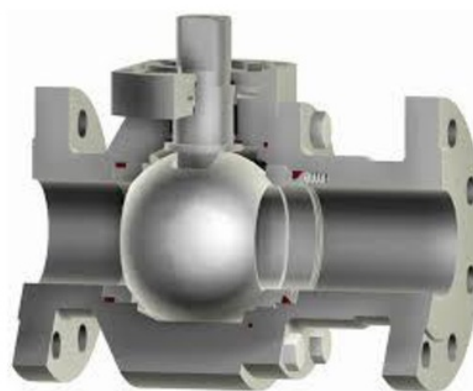


Figure 2.5- Cross-section of a Perrin Ball Valve (Perrin Ball Valves, 2018)

standards set out in Control of Major Accident Hazards Regulations 1999 (COMAH) and Dow Chemicals standards is necessary.

Typical process control valves are ball valves; brands commonly used throughout Dow Chemical are Argus and Perrin. Figure 2.5 shows a 70-S model of Perrin ball valve. These models of valve have a ball that when open rotates against its seats to align its orifice with the flow of the pipe. When the valve closes, the ball rotates, removing the orifice from the flow and creating a seal on its circumference with its metal seats. When used with abrasive materials these valves do not seal well. The failure to seal is caused from the balls rotation, it drags residual abrasive material across the sealing faces of the ball and seats. This action can quickly wear away the seats causing a leak path. However, this leak is internal and only affects the function of the valve. This failure rarely results in atmospheric emission. Ball valves would be an inappropriate replacement for the Everlasting valves in the use of process control. This is because of the high frequency in which they actuate would quickly cause an internal leak path preventing the valve from operating effectively.



Figure 2.6- Cross-section of a Clyde Dome Valve
(Macawber, 2019)



Figure 2.7 – Cross-section of a Pinch Valve (Pinch-valve, 2018)

Another model of valve used on the site is a Dome valve shown in Figure 2.6. The Dome valves are most commonly used in applications with abrasive powder materials. The Dome valve has a similar operation to a ball valve although its ball is cut away. Unlike the ball valves, the dome valve does not have metal seats, it has a sealing bladder. After the dome rotates into the closed position the bladder inflates forming a tight seal. This sealing method is an advantage over the ball valve as the dome does not carry abrasive material across the sealing face when it rotates. However, the dome valve is suited to applications with a low actuation frequency due to the

bladder material. The bladder is manufactured from Viton rubber a soft, durable material that allows it to inflate, it can puncture easily with high actuations (David Gardellin, 2010). Similarly to the ball valve, the failure is internal and only affects the performance of the valve with no atmospheric emission from this type of failure.

Another type of valve commonly used on Silicon powder duty is a pinch valve. A pinch valve has a boot (rubber lining) that contains the process material. The boot is compressed with a t-bar to close the valve. The t-bar can be closed manually through the use of a lead screw as seen in Figure 2.7. In actuated applications a bladder and spring mechanism is employed. The rubber lining provides sufficient wear resistance to contain the Silicon powder and can maintain its integrity through a high volume of actuations. However, a pinch valve takes a long time to compress the boot making it inadequate for precision process control.

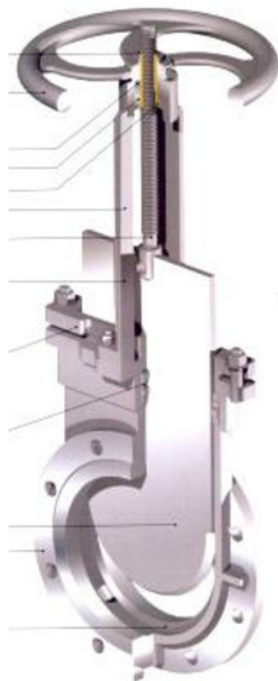


Figure 2.8 – Cross-section of a knife valve (Aquaval.net, 2018)

A knife valve is another universal design used in Silicon powder operations seen in Figure 2.8. A knife valve is a model of gate valve, the knife opens and closes adjacent to the flow of material. The knife valve has a large plate (knife) typically made of hardened material such as Stellite 6b that closes the valve and seals against two seats. Similarly to the ball valve when the knife closes it drags residual abrasive material across the sealing faces of the seats. This action can cause leak paths but is more abrasion resistant due to the material of the knife. The knife valve has a graphite rope packed gland; this seal prevents atmospheric release. The gland seal has a large surface area because it has to seal around the parameter of the knife. In Ball, Dome and Everlasting valves the atmospheric gland packing only has to seal around the circumference of the drive shaft. This large packing area is a weak point in the knife valve and when it actuates the packing is disturbed. This packing arrangement is a frequent failure of the valve, it can result in an atmospheric release of process material. Therefore, the knife valve is not suitable for high actuation applications.

The Ball, Dome, Pinch and Knife valves all have their limitations and should be compared to each other and the Everlasting valve to see which would be most suited to the application. This

comparison has been completed by the Everlasting Valve Company on its website and displayed in Table 2.2.

*Table 2.2 – Common problems found with valves and the design solutions implemented by Everlasting Valve Ltd
(Everlastingvalveusa, 2016)*

Problem	Common Valve Weaknesses	Everlasting Solution	Result
Seats wear out	Sealing surfaces always meet at the same point (1 to 4)	Rotating disc/self-lapping	Seats wear in, seal improves with use
Leak rate limits exceeded soon after installation	Tight shut-off only at time of installation (1 to 4)	Rotating disc/self-lapping metal to metal seats	Tight shut-off is maintained long after installation
Media build-up, drags across seats	Ineffective seat cleaning (1 to 4)	Sharp edge, shearing disc against flat metal seat	Media build-up sheared from sealing surfaces
Flow causes erosion across seating surfaces	Narrow seat band in line with flow (1,2,3)	Wide seat band perpendicular to flow	Erosion in flow path does not affect sealing ability
Loss of product through packing gland or top seal	Stem scores packaging or vulnerable "O" ring (1 to 4)	Spring loaded packing and non-rising rotating stem	Reduced maintenance hours, efficient operation
Thermal lock-up	Intolerance to different expansion rates (1 to 4)	Disc drive to disc is spring loaded	Constant yield to thermal stress and shock
Excessive pressure drop and reduced flow	Flow path restricted when valve is open (1,2,3)	Full port flow	No obstruction to flow, downsizing possible

(1) Ball Valve (reduced port) (2) Plug Valve (3) Butterfly Valve (4) Gate Valve

Table 2.2 shows a list of common problems found with different valve designs when used on abrasive material. It describes the solutions that Everlasting Valve Company have designed to overcome these problems. However, none of these solutions resolve the issue of a high rate of actuation that PV358 and PV345 require. Other smaller Everlasting valves on site do not suffer from the same failure modes as the 4" models used for PV358 and PV345. Differences in the reliable 2" Everlasting valves are compared with the unreliable 4" Everlasting valves to see if a solution can be identified and replicated for PV358 and PV345, this is done in Chapter Three.

2" Everlasting valve

Reliability of a 2" Everlasting Valve

Four 2" Everlasting valves are used on the Barry site in two different locations. KV 159 and KV 156 on W714 plant have an identical duty to PV358 and PV345: processing Silicone powder into a Methyl Chloride feed line to a fluid bed reactor. KV 206 and KV 215 on W348 plant operate on a similar duty feeding Silicone powder into a Chlorosiline feed line to a fluid bed reactor. The 2" valves are used due to the feed line size they are situated on. These valves are much more reliable compared to the 4" Everlasting valves used for PV358 and PV345; demonstrated in Table 3.1 from data collected since June 2015 (Appendix 1.1, 3.1 and 3.2).

Table 3.1- Work orders processed for maintenance comparing the 4" and the 2" Everlasting valves

	W930 (4")	W714 (2")	W348 (2")
Work Orders	93	21	18
Priority 1's	26	9	2

The number of work orders for each location indicates the planned valve change outs that has occurred on the valves. The Priority 1 work orders indicate when a valve has failed unexpectedly, and a reactive valve change out has been required. This data indicates the 2" Everlasting valves are more reliable than the 4" Everlasting valves. This is represented in the preventative maintenance plan for a 2" valve, which has a yearly change out; compared with the sixteen-weekly change out for a 4" Everlasting valve.

Differences in design

There are design differences between the 4" and 2" Everlasting valves; these variations could impact on the valve's reliability, full assembly drawings shown in Appendix 3.3 and 3.4. The main differences between the two valve models are; the 2" model has an internal bearing seal, and how tension is maintained on the seal packing.

The 2" Everlasting valve has a graphite rope seal set into a shoulder of the bearing bush, this is not present in the 4" model. This rope seal may reduce Silicon powder ingress into the bearing. This ingress will cause shaft wear and ultimately a failure. The 4" valve has been redesigned to prevent this failure mode. A positive pressure displacement of grease is used in an attempt to prevent the silicone powder ingressing to the bearing and shaft.

The 2" Everlasting valve does not have a spring cage to maintain tension to the seal packing. Eight Belleville washers are used in a series stack to tension the gland follower (Centuryspring, 2018). The 4" valve has a spring cage with six individual springs inside, this applies tension to the gland follower. The Belleville washers may be able to maintain tension better than the spring cage when the packing wears or loosens.

In addition to these differences, the 2" valve is unmodified from the manufacturer's original design. Therefore there it has no lubrication method. It also has the original graphite rope seal packing and no LSE scrapers. The lever arm shaft is constructed from its original material 17-4 PH Stainless Steel.

Design or Size Change

The change in model design takes place at a three-inch sized valve. Valves sized one to three-inch nominal bore have the same design; in four inches and above the change in design is implemented. The changes in design could be the difference between the excellent reliability of the 2" Everlasting valve on the Barry site and the poor reliability of the 4" model. The reason for the design change is unknown. The 4" Everlasting valve was originally fitted to keep continuous pipe diameter for the whole of the carrier gas line. This is now known to be unnecessary (Preese, 2019).

These design changes could be made to the 4" Everlasting valve to help eliminate the root cause of failure. However, all the work to modify the valve would have to be done in house, as the parts would be non-standard items from the supplier. To change the 4" valve to have the same design as the 2" but on a larger scale could increase the valves reliability. To do this the majority of the 4" parts would stay the same (or revert to the manufacturer's original design, pre Dow modification). The exception to this would be the Belville washers. They would require design to

fit the 4" shaft and to ensure they apply the appropriate tension to the gland follower. The bearing would also have to be re-designed to incorporate the additional bearing packing.

This method would make the valves bespoke, this could cause the supply to become unreliable or expensive. Any machining completed in house could produce out of tolerance components. There would not be accountability to supplier for variations of the valve. The valves may also no longer comply with American Petroleum Institute (API) standards that we abide by on site.

Alternatively, a 2" Everlasting valve could be used for PV358 and PV345. The diameter change has to be investigated to see what effect it would have on process flow rate. If the change in flow rate is too dissimilar for the 2" and 4" models, a 3" valve could be considered as it has the same design as the 2" but with a compromise to the flow rate.

Valve flow rates

Poiseuille's law applies to a volume of fluid with isenergetic flow through a line with a change in pressure at each end. It applies to the application of the Everlasting valves on site. Poiseuille's law states:

$$Q = \frac{\Delta P \pi r^4}{8L\mu}$$

This shows that the volumetric flow rate is proportional to the change in pressure and its fourth power to its radius, and inversely proportional to the length and viscosity of the fluid (Lust, 2007).

Table 3.2- Comparison of 4" and 2" flow characteristics

Measurement	Symbol	4" Valve	2" Valve
Volumetric Flow Rate	Q	Unknown	Unknown
Change in Pressure	ΔP	Same	Same
Radius	r	2r	r
Length	L	Same	Same
Viscosity	μ	Same	Same

Table 3.2 shows the comparison of the 4" and 2" Everlasting valves application concerning Poiseuille's law. Therefore, all variables stay the same except the radius. The radius for a 4" valve

is twice the size of a 2" valve; therefore, the volumetric flow rate would be 16 times faster ($2r^4$) for a 4" valve than a 2" valve.

The reactor feed rate must be maintained. Therefore a 2" Everlasting valve would reduce the volumetric feed rate by 16 times of the current volumetric feed rate; this would be insufficient to appropriately meet the reactor feed requirements. To counteract this, the valve can remain in the open position longer providing an equal volumetric flow rate per unit time with the 4" valve.

Opening times

Currently, PV358 and PV345 in the 4" Everlasting model are set to open for 2 seconds and close for 8 seconds. If the 2" Everlasting valve was used it would decrease the volumetric flow rate by 16 times; therefore, the valve would have to be open for 16 times longer. To maintain equal volumetric flow rate per unit time the 2" model would have an open time of 32 seconds and a closed time of 8 seconds.

Table 3.3 – Comparison of Set Open and Set Closed Times for 2" Everlasting valves on site (Appendix 3.5, 3.6, 3.7 and 3.8)

	Set Open Time (seconds)	Set Closed Time (seconds)
KV 159 (W714)	3	10
KV 156 (W714)	3	10
KV 206 (W348)	4	40
KV 215 (W348)	4	40

Table 3.3 shows the set open and closed times for existing 2" Everlasting valves on site. This shows that the 2" Everlasting valves are typically open longer than the 4" Everlasting valves. This could also have a benefit on valve wear rate as fewer actuations could increase the valves lifespan.

Table 3.4 – Comparison of time taken for valves to cycle 1000 times

	Time to complete one actuation cycle	Time taken to actuate 1000 cycles
Current 4" PV358 and PV345 (W930)	10 seconds	2.7 hours
Proposed 2" PV358 and PV345 (W930)	40 seconds	11.1 hours
KV 159 and KV 516 (W714)	13 seconds	3.6 hours
KV 206 and KV 215 (W348)	44 seconds	12.2 hours

Table 3.4 shows that the proposed 2" valve would have a similar actuation cycle to KV 206 and KV 215 on W348, which are the most reliable Everlasting valves on site as shown in Table 3.1. The decreased rate of actuation may have an additional reliability improvement as indicated by this data. Therefore, this is another justification to propose the use of a 2" Everlasting valve for PV358 and PV345.

Although a 2" Everlasting valve could maintain an equal volumetric flow rate per unit time to the 4" model, consideration should be given for the application of silicone powder into the reactor. A more continuous feed with a lower rate of volumetric flow as proposed with the 2" valve would not affect the process reaction (Preese, 2019). Furthermore a 2" Everlasting valve is used on the same application in Dow Chemical Zhangjiagang China (Ming, 2019) and Dow Chemical Carrollton USA (King, 2019).

Solutions

Solution Choice

From the different solutions provided there are many options available to reduce the lost production from silicon feed valves PV358 and PV345. Some of the options could be combined to make the optimal solution. Consideration for the objectives of the project should be accounted for when choosing the solution:

- To improve the production reliability of the site
- To prevent fugitive emissions
- To improve the mechanical reliability of the valves

Using the projects objectives to identify if the solution meets the targets of the study. Potential solutions investigated are, mechanical improvements to the components of the valve to eliminate the root cause of failure, applying condition monitoring to the valve to better predict failure; improve the efficiency in which a valve is changed out, or to use an alternative model of valve.

Table 4.1 – Comparing possible solutions against project objectives

Solutions	Objectives		
	To improve the production reliability of the site	To prevent fugitive emissions	To improve the mechanical reliability of the valves
Mechanical solutions to eliminate the root cause of failure	✓	✓	✓
Apply condition monitoring to valve	✓	✓	
Improve maintenance efficiency	✓		
Replace with ball valve			
Replace with pinch valve			
Replace with dome valve		✓	
Replace with knife valve			
Replace with 2" Everlasting valve	✓	✓	✓

Table 4.1 shows that the only proposed solutions that achieve all three of the aims of the project are; mechanical solutions to eliminate the root cause of failure, and replace PV358 and PV345 with 2" Everlasting valves.

Implementing potential mechanical improvements to remove the root cause of the valves failure has already been attempted and did not eliminate the root cause. All potential solutions would have to be trialed. Trials would have a cost to production if repeated failures occur.

Replacing the 4" Everlasting valve with a 2" model has data and calculations to justify its recommendation. This data would be critical in gaining agreement to implement this solution on site.

Justification

The 2" Everlasting valve has historical data to show it fails on average 2.7 times a year compared to 13.2 times a year for a 4" Everlasting valve (Table 3.1). The change in valve size would be an excellent reliability improvement.

Using a 2" Everlasting valve for PV358 and PV345 would provide the valve a 40 second cycle time compared to the current cycle time of 10 seconds of the 4" Everlasting valve. A cycle rate of four times less than the current valve could decrease the wear rate by up to four times.

The 2" Everlasting valve is installed on four other locations on site. The 4" Everlasting valve is only used for PV358 and PV345, changing to a 2" model would help standardize valve models on site. Standardization helps with familiarization which in turn improves build quality. Another benefit of standardization is the utilization of common part spares. This standardization would mean the uneconomical £45,239 of shelved spare stock for the 4" valve would be redundant (Appendix 1.6). The 2" valve parts stock required to service the valves would be shared for all six locations. A proposal for the volume of service parts should be considered as the spares requirement may increase.

The 2" Everlasting valve weighs 42.52kg compared to the 4" model which weighs 112.42kg (Appendix 4.1). The overall dimensions of the valve are also smaller as demonstrated in Figure 4.1. The proposed size reduction is most relevant for installation; the 2" valve would be easier to

install and have less manual handling considerations for the technicians making the installation. Changing from a 4" to a 2" Everlasting valve would make the valve changeout a safer to complete.

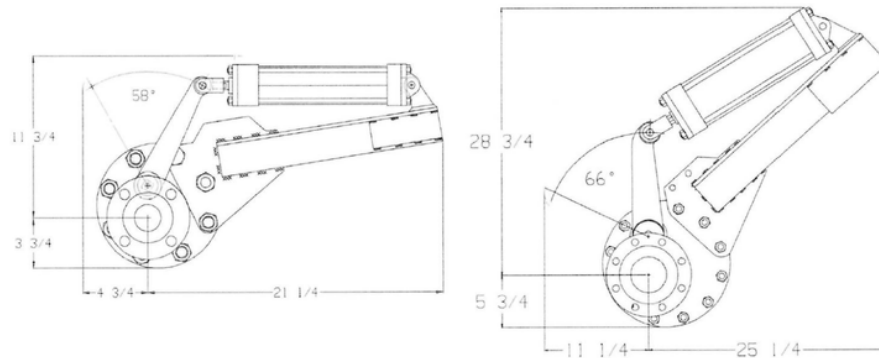


Figure 4.1 – Dimensions for 2" (left) and 4" (right) Everlasting valves in inches (Everlasting Valve Company, 1997)

The average time taken to change out PV358 and PV345 is 6.37 hours (Appendix 1.2). Compared to the average 4.5 hours taken to change a 2" Everlasting valve (Appendix 4.2). This time difference is critical in a scenario of unexpected failure where maintenance has a direct result on lost production time. This also reduces the maintenance resource required when the valve is changed.

The time planned for two technicians to complete a full service of a 4" Everlasting valve is 32 hours (Dow Chemical, 2019). This time is compared to the 16 hours for one technician to service of a 2" Everlasting valve. The maintenance department charges £75 per man per hour (Low, 2019). This incurs a cost of £4,800 for a 4" valve and £1,200 for a 2" valve service. The cost of components to refurbish a 2" valve is £4176.56 (Appendix 4.3) compared to £5,062.19 (Appendix 1.6) for the 4" Everlasting valve. This makes a full-service cost for a 4" valve £8,662.19 and £5,376.56 for a 2" model. This provides additional financial support for changing PV358 and PV345 to a 2" Everlasting valve

The possible reliability improvements for changing PV358 and PV345 to a 2" Everlasting valve is suitable justification to implement the proposed change. The maintenance cost savings are an additional benefit to changing PV358 and PV345 to a 2" Everlasting valve but do not compare to the cost of \$500,000 - \$750,000 (US) lost profit seen since June 2015 (Lovett, 2019).

Implementation

To change PV358 and PV345 to a 2" Everlasting valve practical implications should be considered; these include pipework modifications, load supports, machinery guarding, paperwork, spare replacement valves, valve part stock quantities and a planned predictive maintenance strategy.

Pipework and Installation

To change PV358 and PV345 to a 2" Everlasting valve model the existing pipework has to be changed. The current pipework is 4" 150# schedule 80 satisfying Dow pipe specification PS27W. This pipe specification will still have to be adhered to. To facilitate the installation of the 2" Everlasting valve the line diameter would have to be reduced. Ideally, these reducers would be flanged and incorporated into the space left by the 4" valve, this prevents cutting and welding a process line. A second option is to weld the reducers in-line to incorporate the 2" valve. Figure 5.1 details the exiting pipework as well as the two proposed pipework modifications.

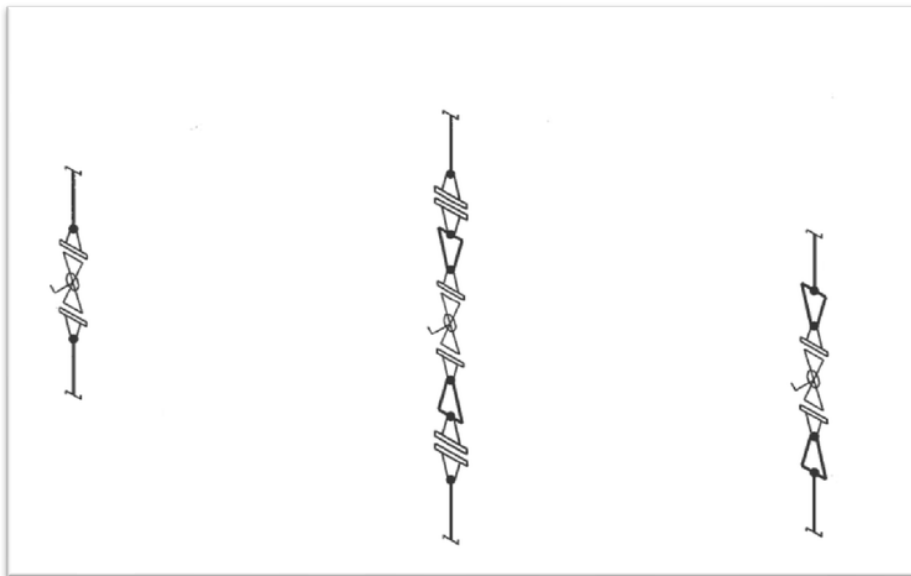


Figure 5.1 – Existing, Preferred and Second Choice Valve Installation respectively (Appendix 5.1)

Table 5.1 – Component dimensions and weights (Pipedata Pro 9.3, 2019) (Appendix 5.2)

Component	Length	Weight
4" Everlasting Valve	16" (406.4mm)	112.42kg
2" Everlasting Valve	12.5" (317.5mm)	45.52kg
4" NB WeldNeck Flange 150#	44mm	8.98kg
2" NB WeldNeck Flange 150#	64mm	3.04kg
4" x 2" Buttwelded Concentric Reducer	102mm	2.27kg

Table 5.1 shows the total length of two flanged reducers and the 2" valve is 737.5mm; there is only 406.4mm of available space from the removed 4" Everlasting valve. Therefore, the reducers would have to be welded inline. For this solution, the pipe would have to be cut and prepped with a remaining space of 649.5 mm. This would accommodate the reducers, flanges and new valve. As the weight of the complete new installation is 56.14kg compared to 112.42kg of the existing valve no further considerations would be required to load supports.

In addition to pipework modifications the nitrogen pipework and lubrication system installed as previous modifications can be removed. To complete this the appropriate paperwork should be updated including existing P+ID shown in Figure 5.2.

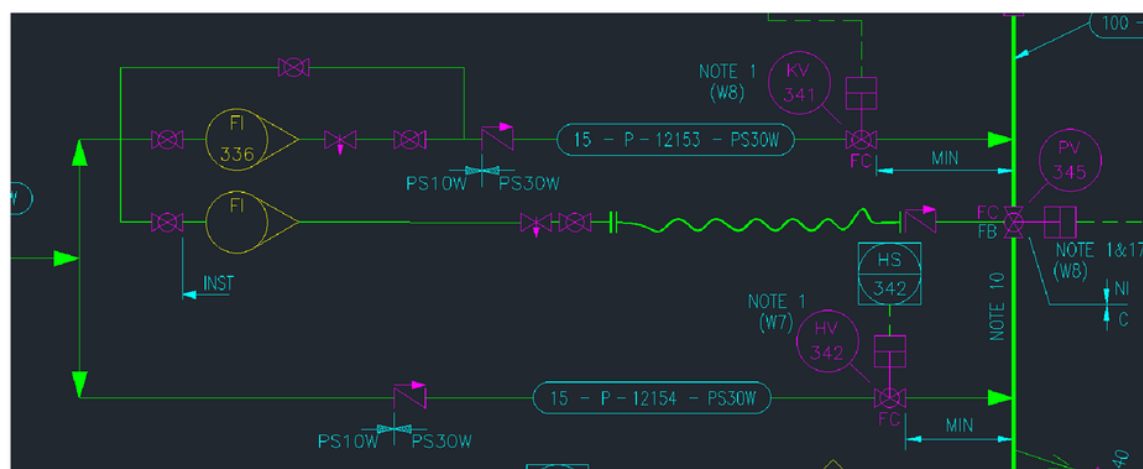


Figure 5.2 – Existing P+ID for PV345 that would have to be updated to implement installation (Dow Corning Limited, 2016)

Spares

Consideration for the spare inventory should be taken when changing PV358 and PV345 to a 2" Everlasting valve model. Currently, there are four 2" Everlasting valves operating on site with two completely built stock spares. To increase the number of operating valves, consideration should be given to the volume of stocked spare valves. A proportional increase would provide three spare valves. This stock might be unnecessary if the valves Planned Predictive Maintenance (PPM) is scheduled correctly.

Currently, the 2" Everlasting valves are changed out on a one-year PPM schedule. This schedule is supported by technical findings that identify minimal wear on critical components after a one-year cycle. All serviceable parts are replaced regardless of condition to return the valve to 'as new condition'. This strategy is implemented to ensure that another one-year cycle would be completed.

Exceptions to a one-year changeout occur when the valve fails unexpectedly. The months between valve failures are plotted in Figure 5.3. This clearly shows a similarity to the Weibull Bathtub Curve Figure 5.4. The Weibull curve is a lifetime model that identifies infant mortality, normal life and wear out time for plant assets (Montoya, Diaz-Frances, and Figueroa, 2019). Sondalini (2019) states "The presence of infant mortality indicates poor training, lack of procedures and poor-quality control". Infant mortality indicated in Figure 5.3 should be addressed in addition to changing PV358 and PV345 to a 2" Everlasting valve model to help increase reliability.

To successfully change PV358 and PV345 to a 2" Everlasting valve the pipework modifications, load supports, paperwork, spare replacement valves, valve part stock quantities, and PPM strategy should be implemented.

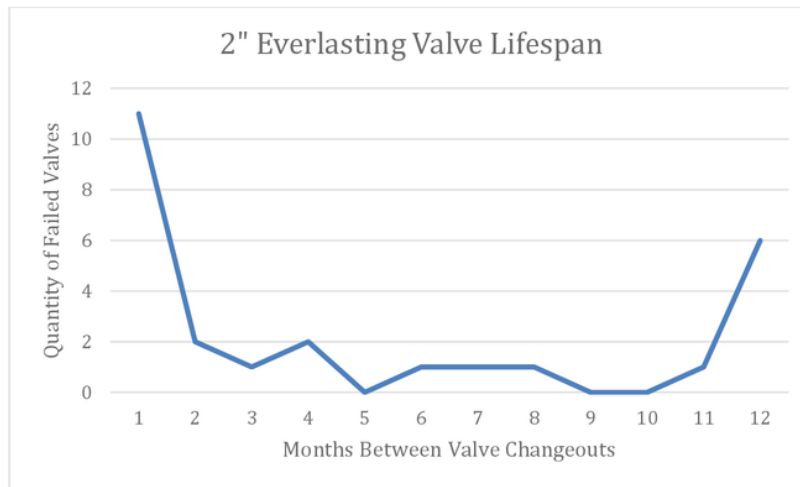


Figure 5.3 – 2" Everlasting valve failures

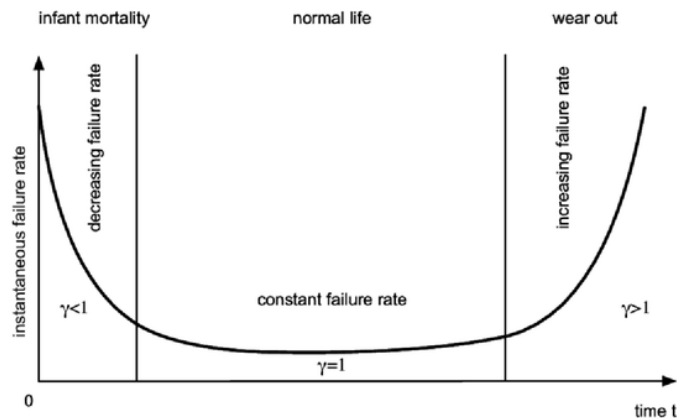


Figure 5.4 – Weibull Bathtub Curve (Miller, et al., 2016)

The PPM strategy should not consider infant mortality as it is not a suitable solution. Alternative solutions should be found to address the infant mortality as previously indicated by Sondalini (2019). The Weibull Bathtub Curve supports the yearly changeout strategy. This approach would be sufficient to prevent 'wear out' failures of the 2" Everlasting valves. However, consideration should be given to always have a minimum of one complete valve on stock as contingency for an unplanned failure. The stock level is essential given the cost of downtime for PV358 and PV345. Table 5.2 shows a proposal for PPM valve changeout.

Table 5.2 Proposed PPM valve changeout for 2" Everlasting valves. Changeout (C), Overhaul (O)

Valve	Date last changed	Proposed changeout (C) and overhaul (O) month											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
KV215	28/11/2018											C	O
KV206	11/02/2018	C	O										
KV159	06/02/2018			C	O								
KV156	13/06/2018					C	O						
PV345	N/A							C	O				
PV358	N/A									C	O		
Remaining stock of completely built valves		1	2	1	2	1	2	1	2	1	2	1	2

For the proposed PPM schedule to work the valve service must be completed within the following month of a valve changeout. This discipline will prevent the valve stock from falling below one. Ensuring the valve is serviced within a week of the valve changeout is a realistic additional improvement. A justification for a quicker valve servicing is the historical data for 'infant mortality'.

Another consideration when choosing a PPM strategy is the lead time for parts. Table 5.3 displays the lead time for parts (Dow Chemical, 2019). The lead times dictate the proposed stock levels. This proposal would allow for two unplanned failures in consecutive months in addition to the PPM changeout before the stock level of components reaches zero. If this scenario occurs, the stock would be replenished within a maximum of 83 days since the first failure. Since June 2015 the average rate of valve changeout has been 32 days with only eleven completed as an unplanned failure (Table.3.1). However, those eleven failures have been completed within one month of the valves installation as shown in Figure 5.3.

Table 5.3 – 2" Everlasting valve consumable parts lead times

Consumable Spare Components	Lead Time (Days)	Proposed Minimum Stock Held
10080031917 Valve Seat; DISC; 50 MM L	76	4
10080043990 Pump Disc; VALVE	21	2
10080012618 Valve Repair Kit; 50 MM	76	4
31010149054 DISC SPRING SPACER ITEM 10	28	2
31010149055 DISC SPRING SETSCREW ITEM 9	28	2
10080043288 Valve Lever; ARM	83	4
10080041764 Valve Bearing; BONNET DISC; 50 MM	60	3
31010223772 SPACER,CARBON STEEL	28	2
10080044772 Valve Collar; POST DISC; 50 MM	76	4
10080044213 Valve Gland; DISC VALVE	76	4
10080036392 Valve Spring; SET; DISC; 50 MM	28	2
31010149056 GLAND SPRING WASHER ITEM 27	76	4
31010149126 POST WASHER ITEM 18	76	4
31010149125 POST GLAND NUT ITEM 19	28	2
31010149124 POST GLAND STUD ITEM 20	28	2
10080001517 Equipment Gasket; BODY; 50 MM	60	3
31010223771 O-RING,70MM X 3MM,BUNA-N	60	3
31010085752 WASHER THRUST DISC VALVE 50NB	76	4
10080024156 Valve Packing; DISC; 50 MM	76	4

Appendices

Appendix 1.1 – PV358 and PV345 breakdowns June 2015 – February 2019 (Dow Chemical,2019)

Date	Notification Number	Work Order Number	Priority	Equipment Number	Description	Function Location	Equipment
29.08.2015	1001177119	20010596651	1	102768832	Replace PV358 on 1209	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
23.01.2016	10010994286	20010346782	1	102768832	please replace PV358	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
11.05.2016	10011555582	20010548120	1	102768832	Please trouble shoot PV358	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
11.05.2016	10011651695	20010570790	1	102768832	REPLACE PV-358 EVERLASTING VALVE	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
12.05.2016	10011768976		1	102768832	replace PV358 on 1209	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
27.03.2017	10010931859	20010284420	1	102768832	Repair linkage on PV358 limits	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
01.05.2017	10011066206	20010418584	1	102768832	Please reattach PD358 limit arm.	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
08.12.2017	10012004045	20010766361	1	102768832	Repair limits guide arm on PV-358	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
10.12.2017	10012005508	20010767848	1	102768832	w930 pv358*	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
10.02.2018	10012399982	20011149945	1	102768832	Bladder failure on PV385 (1209 hopper)	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
10.02.2018	10012420865	20011170789	1	102768832	Please disconnect actuator on PV358	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
11.02.2018	10012979220	20011728755	1	102768832	replace PV358 on 1209	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
28.06.2018	10013745859		1	102768832	replace leaking everlasting valve PV358	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
30.08.2018	10013958809	20012640811	1	102768832	replace 1209 base PV358	H510-00W930-000002-A3-0358930-PV	EVERLASTING VALVE
07.08.2015	10011747375	20010591988	1	102758126	Check PV 345	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE
29.02.2016	10011113173	20010447208	1	102758126	REPLACE PD345, online valve has failed.	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE
24.03.2016	10011174303	20010464901	1	102758126	1208 PV345 failed - powder release.	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE
27.07.2016	10011398460		1	102758126	PV345 everlast on 1208 not opening	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE
11.10.2016	10010921269	20010273882	1	102758126	PV345 on 1208	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE
16.11.2016	10011100767	20010442486	1	102758126	replace pv 345 on 1208	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE
20.12.2017	10012028916	20010782887	1	102758126	Please change PD345	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE
10.02.2018	10012529544	20011279484	1	102758126	Pv345 everlasting (1208) replace	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE
10.02.2018	10012596611	20011346442	1	102758126	Change out KV345	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE
12.02.2018	10013252313	20012001701	1	102758126	PV345 everlast on 1208 not opening	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE
21.07.2018	10013812149	20012507463	1	102758126	replace failed PD345	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE
09.10.2018	10014078643	20012745993	1	102758126	REPLACE 1208 EVERLASTING PV345	H510-00W930-000002-A3-0345930-PV	EVERLASTING VALVE

W930 Everlasting Valve Change out Timings

Date: 21/1/14

Task	Person(s) Completed by	Trade/Role	Start Time	End Time
Enter a SAP work order to document the maintenance	~~L. Brooks~~ M. Williams ~~D. Addis~~	~~Mech Tech~~ WAC ~~Mech Tech~~	8.30	8.45
Apply process isolations and prepare line for maintenance	J. SAMUEL	OPERATIONS	09:30	10:30
Identify new valve in stores and check out	Jason	Storeman	9am	9.05
Transport valve to W930	R. Cawston B. Ashford ~~W. Williams~~	Riggers	10:30	11:00
Complete permits to work and associated paperwork	L. Brooks D. Addis S. Harris	Mech Tech Mech Tech elec Tech	11:00	11:30
Remove machinery guard	L. Brooks D. Addis	Mech Tech Mech Tech	11:30	12:00
Remove instrumentation	S. Harris	elec Tech		
Remove and replace valve	L. Brooks Riggers D. Addis	Mech Tech Rigger Mech Tech.	12:00	13:00
Replace instrumentation	S. ~~Williams~~ Harris	elec Tech.		
Replace machinery guard	S. Harris L. Brooks D. Addis	elec Tech Mech Tech Mech Tech.	13:00	13:30
Sign off permits and complete Return To Operation (RTO) paperwork	L. Brooks D. Addis	Mech Tech Mech Tech	13:30	14:00
Remove process isolations and leak test	A. Williams ~~operator~~ D. Gentle	operator.	14:00	15:00

DOW RESTRICTED

W930 Everlasting Valve Change out Timings

Date: 9/10/18

Task	Person(s) Completed by	Trade/Role	Start Time	End Time
Enter a SAP work order to document the maintenance	R. BURGONE	WORK ACTIVITY COORDINATOR	18:50	19:05
Apply process isolations and prepare line for maintenance	B. WEEKLEY	OPERATOR	20:00	21:00
Identify new valve in stores and check out	A Rowles	Mech	20:00	20:30
Transport valve to W930	A Rowles	Mech	20:30	21:00
Complete permits to work and associated paperwork	A Rowles J Morgan	Mech	21:00	22:00
Remove machinery guard	A Rowles	Mech	22:00	22:30
Remove instrumentation	M. Perry	E / I	22:30	23:00
Remove and replace valve	A Rowles J Morgan	Mech	23:00	00:00
Replace instrumentation	M. Perry	E / I	00:00	00:30
Replace machinery guard	A Rowles J Morgan	Mech	00:30	01:00
Sign off permits and complete Return To Operation (RTO) paperwork	J Morgan	Mech	01:00	01:10
Remove process isolations and leak test	B. WEEKLEY	OPERATOR	01:15	02:00

DOW RESTRICTED

W930 Everlasting Valve Change out Timings

Date: 15/2/19

Task	Person(s) Completed by	Trade/Role	Start Time	End Time
Enter a SAP work order to document the maintenance	D. Smith	GATEKEEPER	13:00	13:30
Apply process isolations and prepare line for maintenance	A. lester	Operator	13:30	14:30
Identify new valve in stores and check out	D. ADOZS	MECH TECH	13:30	14:00
Transport valve to W930	D. ADOZS	MECH TECH	14:00	14:30
Complete permits to work and associated paperwork	D. ADOZS	MECH TECH	14:30	15:00
Remove machinery guard	D. ADOZS	MECH TECH	15:00	15:30
Remove instrumentation	A. GAMBLING ~~D. ADOZS~~	E-I Tech ~~MECH TECH~~	15:30	16:00
Remove and replace valve	D. ADOZS	MECH TECH	15:30	16:30
Replace instrumentation	A. GAMBLING	E-I tech	16:30	17:00
Replace machinery guard	D. ADOZS	MECH TECH	16:30	17:00
Sign off permits and complete Return To Operation (RTO) paperwork	D. ADOZS	MECH TECH	17:30	18:00.
Remove process isolations and leak test	A. lester	Operator	18:10	18:45

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W930 Everlasting Valve Change out Timings

Date: 31/8/18

Task	Person(s) Completed by	Trade/Role	Start Time	End Time
Enter a SAP work order to document the maintenance	Mat	WAC	9.00	9.30
Apply process isolations and prepare line for maintenance	~~SAP~~ STEVE	OPP	10	11
Identify new valve in stores and check out	PHIL	MECH	10. am.	10. 30 am
Transport valve to W930	PHIL	MECH.	10.30 am	11. 00 am
Complete permits to work and associated paperwork	PHIL	MECH.	11. 00 am	12. 00 am
Remove machinery guard	PHIL	MECH.	12. 00 am	12. 30 pm.
Remove instrumentation	GARETH	E/I	12:30	1:00 pm
Remove and replace valve	PHIL	MECH.	1. 00 pm	2. 00 pm
Replace instrumentation	Mat	G+I	1.30 pm	2 pm
Replace machinery guard	PHIL	MECH.	2. 00 pm	2. 30 pm
Sign off permits and complete Return To Operation (RTO) paperwork	PHIL	MECH.	2.30 pm	3. 00 pm
Remove process isolations and leak test	STEVE	OPP	3.30	4

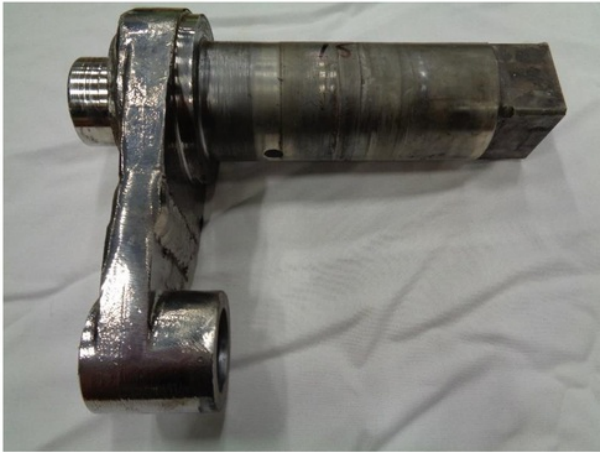
DOW RESTRICTED

Appendix 1.3 – Weight of 4" Everlasting valve before installation



Appendix 1.4 – Wear on lever arm shaft that causes valve failures





Appendix 1.5 – Technical Findings, Parts failed data, June 2015 – February 2019 (Dow Chemical,2019)

Work Order	Header Data	No	Object Part	Damage Code	Damage	Text	No	Object Part	Damage Code	Damage	Text
20010634393	service everlasting valve	1	Seal	D235	Failure	seal leaking	2	Shaft	D235	Failure	Collapsed seal
20010448693	REFURBISH FAILED EVERLASTING VALVE	1	Seal	D235	Failure	Broken seal	2	Shaft	D222	Wear	worn shaft
20010840673	W/S SERVICE REMOVED EVERLASTING VALVE	1	Seal	D235	Failure	damaged	2	Shaft	D222	Wear	erosion
20011027160	(W/S) 1208 SERVICE EVERLASTING VALVE (6M)	1	Seal	D222	Wear	Shaft worn	2	Shaft	D222	Wear	failed shaft
20011054181	1208 W/S SERVICE EVERLASTING VALVE (3M)	1	Seal	D235	Failure	failed	2	Shaft	D222	Wear	shaft worn
20011181807	(W/S)1208 SERVICE EVERLASTING VALVE (3M)	1	Seal	D235	Failure	seal failed wear	2	Shaft	D235	Failure	shaft worn
20011331115	1208 SERVICE EVERLASTING VALVE (6M)	1	Shaft	D222	Wear	erosion	2	Seal	D235	Failure	seal undermined
20011340969	(W/S)1208 SERVICE EVERLASTING VALVE (3M)	1	Seal	D235	Failure	blocked seal	2	Shaft	D235	Failure	Failure worn
20011354904	(W/S) Service everlasting valve	1	Shaft	D222	Wear	wear	2	Seal	D222	Wear	leak
20011375156	1208 SERVICE EVERLASTING VALVE W/S (3M)	1	Seal	D235	Failure	seal undermined	2	Shaft	D235	Failure	Seal undermined
20011381527	1208 SERVICE EVERLASTING VALVE W/S (3M)	1	Seal	D235	Failure	SEAL WORN	2	Shaft	D222	Wear	WEAR
20011384645	1208 W/S SERVICE EVERLASTING VALVE (3M)	1	Seal	D222	Wear	failed seal	2	Shaft	D222	Wear	erosion
20011386160	1208 SERVICE EVERLASTING VALVE (6M)	1	Seal	D235	Failure	wear under seal	2	Shaft	D222	Wear	wear
20012508586	(W/S) @ REBUILD SPARE EVERLASTING	1	Seal	D222	Wear	seal leaking	2	Shaft	D222	Wear	leaking seal
20012747446	(W/S) SERVICE 4" EVERLASTING VALVE	1	Seal	D235	Failure	not holding	2	Shaft	D222	Wear	wear on shaft
20012747445	(W/S) SERVICE 4" EVERLASTING VALVE	1	Seal	D222	Wear	failed seal	2	Shaft	D222	Wear	coating damaged
20010589803	1209 W/S SERVICE EVERLASTING VALVE (16W)	1	Shaft	D222	Wear	wear on shaft	2	Seal	D235	Failure	loss of containment
20010293569	service everlasting valve	1	Seal	D235	Failure	failed seal	2	Shaft	D222	Wear	shaft wear
20010957293	W930 EVERLASTING VALVE SERVICE (16W)	1	Seal	D235	Failure	Failed	2	Shaft	D222	Wear	failed
20010959944	(W/S)W930 EVERLASTING VALVE SERVICE(16W)	1	Seal	D235	Failure	failure on seal	2	Shaft	D222	Wear	worn shaft
20010965570	1209 W/S SERVICE EVERLASTING VALVES	1	Shaft	D222	Wear	wear on shaft	2	Seal	D235	Failure	wear on shaft
20010986850	(W/S) SERVICE EVERLASTING VALVE	1	Seal	D235	Failure	failure on seal	2	Shaft	D222	Wear	Wear
20011160215	(W/S) EVERLASTING VALVE SERVICE (16W)	1	Seal	D222	Wear	wear on seal	2	Shaft	D235	Failure	wear along shaft
20011200870	W930 EVERLASTING VALVE SERVICE (16W)	1	Seal	D235	Failure	Failed	2	Shaft	D222	Wear	gouging
20011207029	(W/S) SERVICE EVERLASTING VALVE	1	Shaft	D222	Wear	wear on shaft	2	Seal	D235	Failure	undetermined
20011240977	1209 W/S SERVICE EVERLASTING VALVE (16W)	1	Seal	D222	Wear	wear on seal	2	Shaft	D222	Wear	wear
20011280958	1209 W/S SERVICE EVERLASTING VALVE	1	Seal	D235	Failure	seal leaking	2	Shaft	D222	Wear	seal undermined
20011317967	(W/S) SERVICE EVERLASTING VALVE	1	Seal	D235	Failure	failure on seal	2	Shaft	D222	Wear	seal undermined
20011328919	(W/S) SERVICE VALVE	1	Seal	D222	Wear	wear on seal	2	Shaft	D222	Wear	wear
20011337150	1209 W/S SERVICE EVERLASTING VALVE (16W)	1	Seal	D235	Failure	failure on seal	2	Shaft	D222	Wear	leaking seal
20011351972	1209 W/S SERVICE EVERLASTING VALVE (16W)	1	Shaft	D222	Wear	wear on shaft	2	Seal	D235	Failure	failed shaft
20011907343	W/S SERVICE FAILED EVERLASTING VALVE -	1	Seal	D222	Wear	seal leaking	2	Shaft	D222	Wear	leak
20012248474	(W/S) PV-358 SERVICE VALVE	1	Seal	D235	Failure	failure on seal	2	Shaft	D222	Wear	erosion

Appendix 1.6 – 4" Everlasting Valve Bill of Materials with Unit Costs, Stock Held and Service Quantity (Dow Chemical,2019)

Component	Quantity Replaced Every Refurbishment	Stock Held	Cost Per unit (£)
COMPLETE ACTUATED VALVE ASSEMBLY			
31010089389 VALVE DISC 100NB 150#			
E/I SPARE COMPONENTS			
Solenoid Valve; 5/2-WAY; 1/2 IN; NPT;		1	200
Module; 1-CHANNEL; 20 - 35 VDC; 24 V		3	134.05
Intrinsic Safety Barrier; 2-CHANNEL SHU		11	69.55
Solenoid Valve; 3/2-WAY; SS; -40 - 60		4	646.09
Electrical Box; SWITCH		1	145.6
SW PROX MAGNUM XT-90		2	39.34
MECH SPARE COMPONENTS			
LSE SCRAPER SEALS FOR PV-345 AND PV-358		13	69.48
Valve Ring; QUAD; 100 MM; 100 MM		8	3.6
Seal Set; VALVE		3	154.89
Spring; VALVE; 150 LB	1	4	154.96
BEARING 100NB 150#	1	4	225.11
Valve Gland; DISC VALVE		3	241.72
Valve Spring; RIVET; 100 MM; 150 LB		4	52.61
Valve Collar; 100 MM	1	4	88
Equipment Gasket; BODY; 100 MM; 150	1	2	81.04
Valve Spring; RIVET; 100 MM; 150 LB	1	3	169.49
Valve Packing; 100 MM		6	82.14
DISC 100NB 150	1	2	507.56
Valve Assembly; POST AND LEVER ARM;	1	3	1,025.50
SEAT PLATE DISC VALVE ITEM 8	1	8	2,219.05
SPRING CAGE FOR 4" EVERLASTING VALVE		3	46.5
GLAND SPRING WASHER FOR 4" EVERLASTING		4	50.47
POST WASHER FOR 4" EVERLASTING VALVES		3	5.1
WRENCH/ARM FOR 4" EVELASTING VALVES		3	254.16
BONNET ASSEMBLY		2	1,502.36
Valve Bonnet; ASSY		3	2,997.95
ACTUATOR SPARE COMPONENTS			
3/8" 1SN PNEUMATIC HOSE HOSE ASSEMBLY			
ROD CLEVIS FOR CYLINDER		1	79.5
Bolt Kit; EVERLASTING VALVE; 5 OFF BOL	1	2	110.98
RSJ-1/4" UNION FOR EVELASTING VALVE		4	40.31
Valve Repair Kit; 4 IN; PUSH ROD ASSY		2	135.12

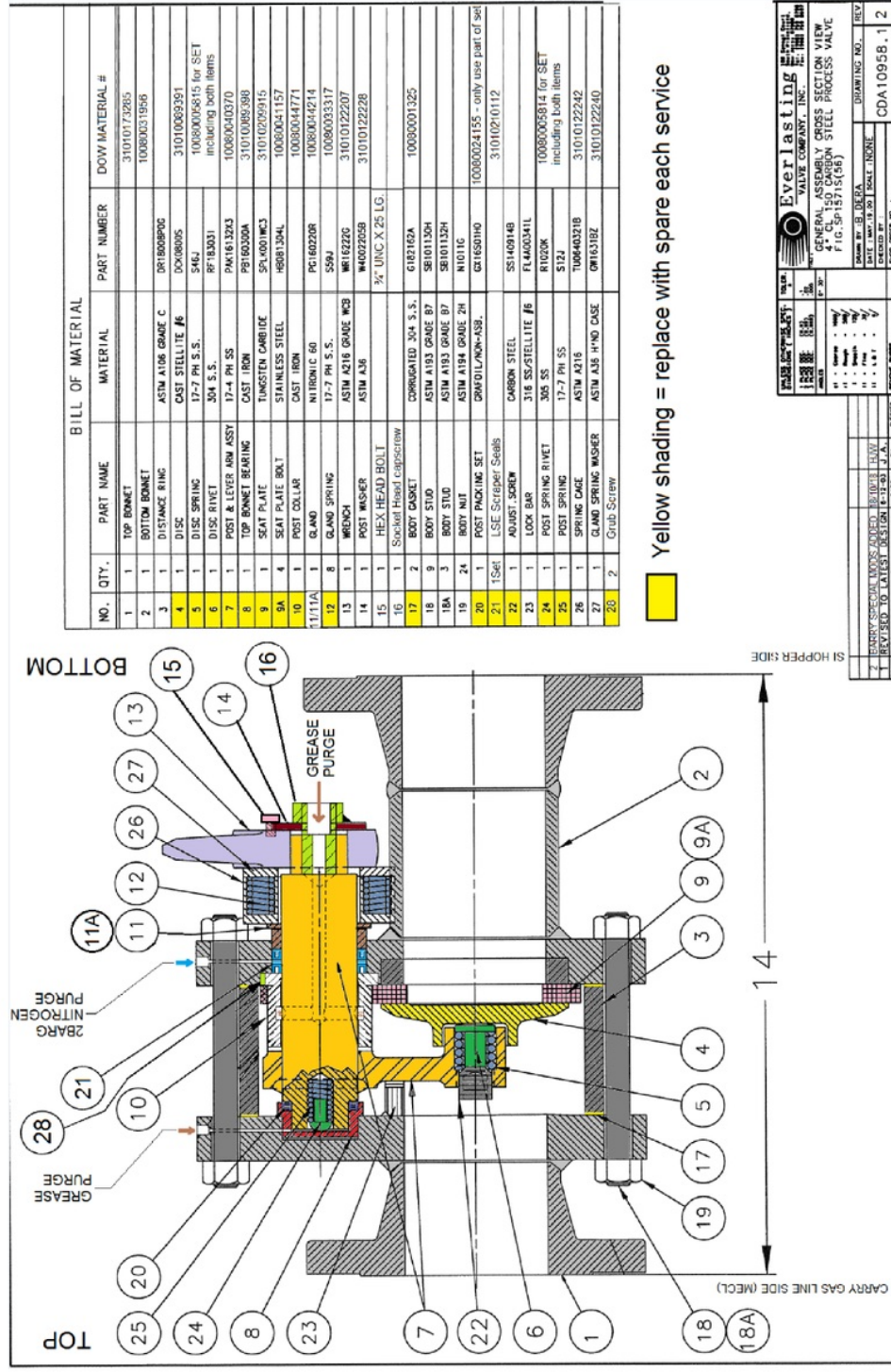
Appendix 3.1 – W930 KV206 and KV215 breakdowns June 2015 – February 2019 (Dow Chemical, 2019)

Date	Notification Number	Work Order Number	Priority	Equipment Number	Description	Function Location	Equipment
06.12.2015	10010932246	20010284698	3	102564890	@ (!) 1008 KV206 REPLACE VALVE (1Y)	HS10-00W348-000001-K-0206348-KV	EVERLASTING VALVE
12.06.2016	10011810875		4	102564890	Repair / Replace valve Please replace KV206 under 1008 hopper	HS10-00W348-000001-K-0206348-KV	EVERLASTING VALVE
28.10.2016	10011015314	20010367692	1	102564890		HS10-00W348-000001-K-0206348-KV	EVERLASTING VALVE
09.01.2017	10011855139	20010626441	3	102564890	REPLACE LEAKING VALVE	HS10-00W348-000001-K-0206348-KV	EVERLASTING VALVE
16.01.2018	10010874651	20010227305	3	102564890	1008 KV206 REPLACE VALVE (1Y)	HS10-00W348-000001-K-0206348-KV	EVERLASTING VALVE
11.02.2018	10012901773	20011651386	1	102564890	replace KV206	HS10-00W348-000001-K-0206348-KV	EVERLASTING VALVE
11.02.2018	10013205721	20011955152	4	102564890	Repair / Replace valve	HS10-00W348-000001-K-0206348-KV	EVERLASTING VALVE
28.11.2018	10014244971	20012895965	3	102564890	1008 KV206 REPLACE VALVE (1Y)	HS10-00W348-000001-K-0206348-KV	EVERLASTING VALVE
03.12.2015	10010899329	20010251915	3	102564834	@ (!) 1009 KV215 REPLACE VALVE (1Y)	HS10-00W348-000001-K-0215348-KV	EVERLASTING VALVE
06.11.2016	10011076625	20010428964	3	102564834	Repair leak on KV215	HS10-00W348-000001-K-0215348-KV	EVERLASTING VALVE
11.09.2017	10011400107		3	102564834	1009 KV215 REPLACE VALVE (1Y)	HS10-00W348-000001-K-0215348-KV	EVERLASTING VALVE
29.12.2016	10011609933		2	102564834	Leak on KV215 stem	HS10-00W348-000001-K-0215348-KV	EVERLASTING VALVE
06.02.2017	10011915564	20010684245	3	102564834	1009 KV215 REPLACE VALVE (1Y)	HS10-00W348-000001-K-0215348-KV	EVERLASTING VALVE
11.09.2017	10012135094	20010888279	3	102564834	1009 KV215 REPLACE VALVE (1Y)	HS10-00W348-000001-K-0215348-KV	EVERLASTING VALVE
06.02.2018	10012170265	20010922560	3	102564834	1009 KV215 REPLACE VALVE (1Y)	HS10-00W348-000001-K-0215348-KV	EVERLASTING VALVE
11.02.2018	10013213373	20011962853	3	102564834	@ (!) 1009 KV215 REPLACE VALVE (1Y) replace leaking KV-215 on W348	HS10-00W348-000001-K-0215348-KV	EVERLASTING VALVE
23.10.2018	10014119424		2	102564834	DUPLICATE	HS10-00W348-000001-K-0215348-KV	EVERLASTING VALVE
28.11.2018	10014245267	20012896261	3	102564834	1009 KV215 REPLACE VALVE (1Y)	HS10-00W348-000001-K-0215348-KV	EVERLASTING VALVE

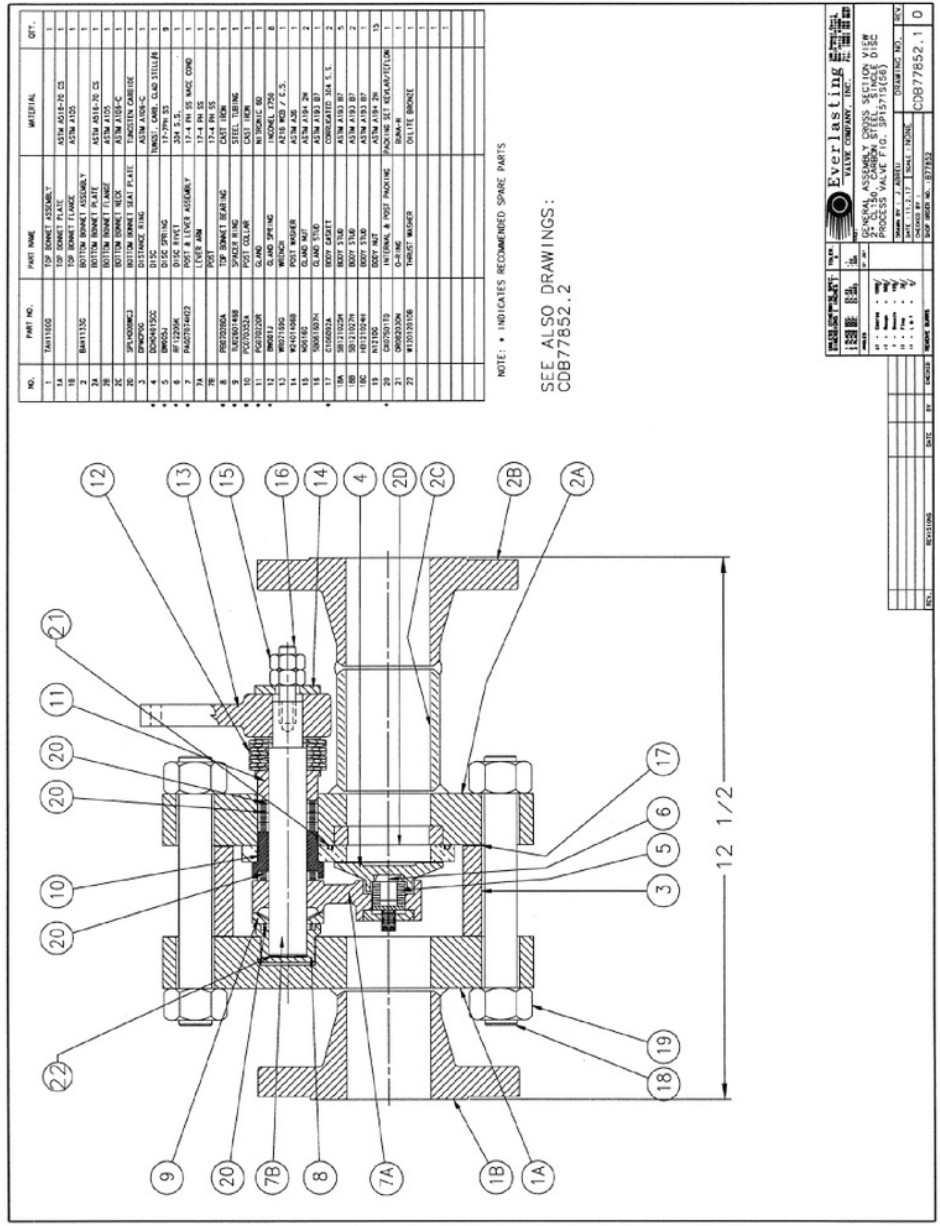
Appendix 3.2 – W930 KV206 and KV215 breakdowns June 2015 – February 2019 (Dow Chemical, 2019)

Date	Notification Number	Work Order Number	Priority	Equipment Number	Description	Function Location	Equipment
16.01.2018	10010875207	20010227812	3	102555112	106 KV159 REPLACE VALVE (1Y) (J)106 KV159 REPLACE EVERLASTING VLV(1Y)	HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
28.07.2015	10011639093	20010567882	3	102555112		HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
19.11.2017	10011650342		1	102555112	Please check KV159	HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
26.11.2017	10011669995		1	102555112	check KV-159 operation, valve sticking	HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
12.08.2016	10011917456	20010686154	3	102555112	106 KV159 REPLACE VALVE (1Y)	HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
17.09.2016	10011934386	20010702418	1	102555112	Replace KV159 at the base of 106	HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
02.01.2018	10012087058	20010840427	1	102555112	check operation of KV159 shuttle valve	HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
19.11.2017	10012147590	20010900700	1	102555112	Please check KV159	HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
06.02.2018	10012171422	20010923699	3	102555112	106 KV159 REPLACE VALVE (1Y)	HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
07.06.2018	10013674799	20012383567	3	102555112	106 KV159 REPLACE VALVE (1Y)	HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
25.07.2018	10013825467	20012519259	3	102555112	106 KV159 REPLACE VALVE (1Y)	HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
27.07.2018	10013836745	20012529728	1	102555112	Change out KV159 on 106 hopper	HS10-00W714-000002-A2-0159714-KV	EVERLASTING VALVE
28.07.2015	10011639094	20010567883	3	102555110	(J)108 KV156 REPLACE EVERLASTING VLV(1Y)	HS10-00W714-000002-A2-0156714-KV	EVERLASTING VALVE
16.08.2015	10011725880		1	102555110	kv156 under 108 hopper passing	HS10-00W714-000002-A2-0156714-KV	EVERLASTING VALVE
06.02.2017	10011925287	20010693439	1	102555110	Replace failed Everlasting valve	HS10-00W714-000002-A2-0156714-KV	EVERLASTING VALVE
01.02.2018	10012077147	20010830604	3	102555110	108 KV156 REPLACE VALVE (1Y)	HS10-00W714-000002-A2-0156714-KV	EVERLASTING VALVE
06.02.2018	10012171421	20010923698	3	102555110	108 KV156 REPLACE VALVE (1Y)	HS10-00W714-000002-A2-0156714-KV	EVERLASTING VALVE
11.02.2018	10012704806	20011454493	3	102555110	W714 EVERLASTING VALVES	HS10-00W714-000002-A2-0156714-KV	EVERLASTING VALVE
11.02.2018	10012835162	20011584777	1	102555110	kv156 under 108 hopper passing	HS10-00W714-000002-A2-0156714-KV	EVERLASTING VALVE
07.06.2018	10013674798	20012383566	3	102555110	108 KV156 REPLACE VALVE (1Y)	HS10-00W714-000002-A2-0156714-KV	EVERLASTING VALVE
13.06.2018	10013686943	20012394249	3	102555110	108 KV156 SERVICE VALVE (1Y)	HS10-00W714-000002-A2-0156714-KV	EVERLASTING VALVE

Appendix 3.3 – General Assembly Cross Section View 4" Everlasting Valve (Dow Chemical,2019)



Appendix 3.4 – General Assembly Cross Section View 2" Everlasting Valve Company,1997)



The screenshot displays a process control system (PCS) interface for 'REACTOR FEEDING FROM 106'. The interface is divided into several sections:

- Top Status Bar:**
 - Left: STEP: 4, FEEDING TO THE REACTOR, HOLD
 - Right: 14Sep16, Rev 2, W714_09
- Process Diagram:**
 - Tanks:** 104 (yellow), 106 (yellow), 5009 (yellow).
 - Valves:** KV252A2, KV251A2, KV250A2, KV253A2, KV159A2, KV250A2, KV255A2, KV256A2, KV259A2, KV268A2, KV269A2, KV276A2, KV294A2, KV278A2, KV297A2, KV261A2, KV262A2, KV263A2, KV264A2, KV265A2, KV266A2, KV267A2, KV268A2, KV269A2, KV270A2, KV271A2, KV272A2, KV273A2, KV274A2, KV275A2, KV276A2, KV277A2, KV278A2, KV279A2, KV280A2, KV281A2, KV282A2, KV283A2, KV284A2, KV285A2, KV286A2, KV287A2, KV288A2, KV289A2, KV290A2, KV291A2, KV292A2, KV293A2, KV294A2, KV295A2, KV296A2, KV297A2, KV298A2, KV299A2, KV300A2.
 - Pumps:** P161A2, P162A2, P163A2, P164A2, P165A2, P166A2, P167A2, P168A2, P169A2, P170A2, P171A2, P172A2, P173A2, P174A2, P175A2, P176A2, P177A2, P178A2, P179A2, P180A2, P181A2, P182A2, P183A2, P184A2, P185A2, P186A2, P187A2, P188A2, P189A2, P190A2, P191A2, P192A2, P193A2, P194A2, P195A2, P196A2, P197A2, P198A2, P199A2, P200A2.
 - Feed Streams:** F5173W, F164A2, F165A2, F166A2, F167A2, F168A2, F169A2, F170A2, F171A2, F172A2, F173A2, F174A2, F175A2, F176A2, F177A2, F178A2, F179A2, F180A2, F181A2, F182A2, F183A2, F184A2, F185A2, F186A2, F187A2, F188A2, F189A2, F190A2, F191A2, F192A2, F193A2, F194A2, F195A2, F196A2, F197A2, F198A2, F199A2, F200A2.
 - Control Elements:** ON-TIMER SECS 3.0, OFF-TIMER SECS 10, FEED MODE AUTO, FEED RAMP 140 ON, FEED RAMP 141 ON, ALM ACK.
- Data Tables:**
 - Table 1 (Top Left):**

F5173W	0.0000 kg/hr	FAIL5173W
--------	--------------	-----------
 - Table 2 (Middle Left):**

P161A2	4.47 barg	4.50 SPT
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 - Table 3 (Bottom Left):**

F164A2	801.16 kg/hr	800.00 SPT
--------	--------------	------------
 - Table 4 (Middle Right):**

F184A2	1217.68 kg/hr	840.00 SPT
--------	---------------	------------
 - Table 5 (Bottom Right):**

F163A2	12.01 Te/hr	12.00 SPT
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REACTOR FEEDING FROM 108

27Feb18 Rev 3 W714_1

STEP: 0 IDLE

TIME: 0.00 UNABLE TO RUN

START PERMs SEQ KEYS

ON-TIMER SECS 3.0

OFF-TIMER SECS 10

FEED MODE AUTC

ALM ACK

Process details and flow rates:

- Vessel 104: VENT FROM 101, VENT, KV257A2 OPEN, KV260A2 CLOSED, KV258A2 OPEN.
- Vessel 108: Si, KV254A2 OPEN, PSH185A2, PSL208A2, 0.0000 bar, 2.46 barg, KV156A2 CLOSED, KV255A2 CLOSED, FV164A2, 5.86 barg, KV268A2 CLOSED, FV163A2 C, 11.95 Te/hr, 12.00 SPT.
- Vessel 5009: LIC6153 FEED OFF, -424.44 m, KV627A2 OPEN, KV6630A2 CLOSED, TO I25, CISI TO I18, F184A2, 1217.68 kg/hr, 840.00 SPT, KV629A2 OPEN, Si RTN FROM I19, SB TO / FROM I09, KV627A2 OPEN, KV628A2 OPEN, 140 ON, 141 ON.

Appendix 3.7 – KV206 set ON OFF timer (Dow Chemical,2019)

TCS SEQUENCE 6 - FBR REACTOR FEEDING FROM HOPPER 1008

W348_SQ6

1008 SILICON HOPPER

INITIAL WEIGHT	24.82	Te
CURRENT WEIGHT	17.20	Te
AMOUNT FED TO FBR	7.62	Te
TRANSFER ON-TIME	3	Secs
TRANSFER OFF-TIME	30	Secs
AUTO/MANUAL FEED	A	

STEP 0 - IDLE STATE

CHECKING DATA ENTRY

STEP 1

PRESSURISE SILICON HOPPER 1008 WITH N2

STEP 2

OPENING SILICON BLOCK VALVE

STEP 3

FEED SILICON TO FBR - TIMED

STEP 4

STEP 5

MESSAGE	
ACTION	

START
ABORT
CONTINUE
QUIT

Appendix 3.8 – KV215 set ON OFF timer (Dow Chemical,2019)

TCS SEQUENCE 8 - FBR REACTOR FEEDING FROM HOPPER 1009

W348_SQ8

1009 SILICON HOPPER

INITIAL WEIGHT	25.97	Te
CURRENT WEIGHT	4.60	Te
AMOUNT FED TO FBR	20.69	Te
TRANSFER ON-TIME	4	Secs
TRANSFER OFF-TIME	40	Secs
AUTO/MANUAL FEED	A	

STEP 0 - IDLE STATE READY

STEP 1

STEP 2

STEP 3

STEP 4

STEP 5

MESSAGE	+2.0594395e+1 TONNES FED TO FBR
ACTION	

START
ABORT
CONTINUE
QUIT

Appendix 4.1 – Weight of 2" Everlasting valve before installation



2" Everlasting Valve Change out Timings

Date: 7/02/19

Task	Person(s) Completed by	Trade/Role	Start Time	End Time
Enter a SAP work order to document the maintenance	D. Lee	Gatekeeper	07.30	08.00
Apply process isolations and prepare line for maintenance	WASSAL	OPP	08.00	08.30
Identify new valve in stores and check out	G. RAFFAELLI	MECH FITTER/ MAINT	08.00	08.05
Transport valve to W930 714	RIGGING/FITTERS		08.15	08.30
Complete permits to work and associated paperwork	OPERATIONS + MECHANICAL TECH (G. RAFFAELLI)	OPS/MAINT	08.30	08.45
Remove machinery guard	MAINT TECH/ G. RAFFAELLI	MECH FITTER	08.45	09.00
Remove instrumentation	E/I TECH	E/I TECH	09.00	09.30
Remove and replace valve	G. RAFFAELLI/ MAINT TECH	MECH FITTER	09.30	10.15
Replace instrumentation	E/I TECH	E/I TECH	10.15	10.45
Replace machinery guard	G. RAFFAELLI/ MAINT TECH	MECH FITTER	10.45	11.15
Sign off permits and complete Return To Operation (RTO) paperwork	G. RAFFAELLI/ MAINT TECH	MECH FITTER	11.20	11.45
Remove process isolations and leak test	WASSAL	OPP	12.	12.30

DOW RESTRICTED

2" Everlasting Valve Change out Timings

Date: 17/12/19

Task	Person(s) Completed by	Trade/Role	Start Time	End Time
Enter a SAP work order to document the maintenance	M. Rowlands	WAC	7am	7.05
Apply process isolations and prepare line for maintenance	JAMES	OPP	7.00	8.00
Identify new valve in stores and check out	Susan	Stanner	7.00	7.15
Transport valve to W938 W7H	C Tombs	MECH	07.30	07.35
Complete permits to work and associated paperwork	C Tombs	MECH	07.35	08.00
Remove machinery guard	C Tombs	MECH	08.00	08.30
Remove instrumentation	N. Mortimore	E/I	08.00	08.30
Remove and replace valve	C Tombs	MECH	08.30	09.00
Replace instrumentation	N. Mortimore	E/I	09.00	09.15
Replace machinery guard	N. Mortimore	E/I	09.15	09.30
Sign off permits and complete Return To Operation (RTO) paperwork	C Tombs	MECH	10.00	10.05
Remove process isolations and leak test	JAMES	OPP	10.00	11.00

DOW RESTRICTED

Appendix 4.3 – Cost of parts replaced for 2” Everlasting valve service (Dow Chemical,2019)

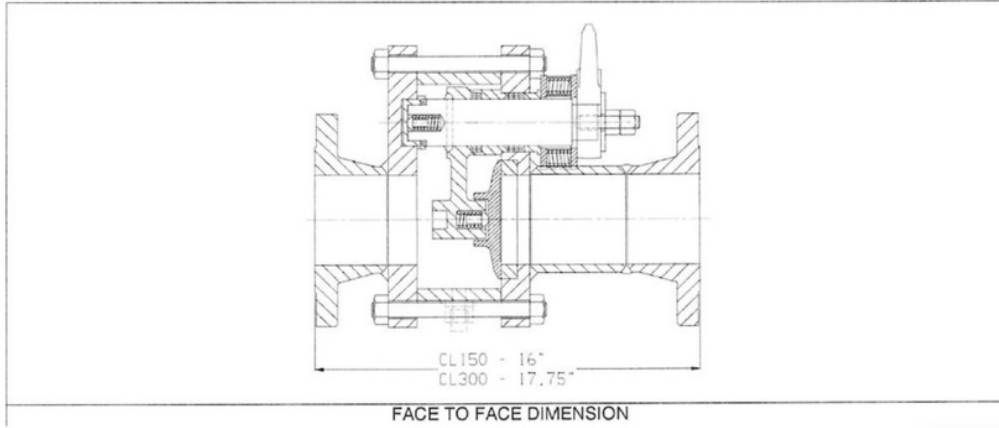
Component	Cost (£)
10080031917 Valve Seat; DISC; 50 MM L	1,654.00
10080043990 Pump Disc; VALVE L	301.69
10080012618 Valve Repair Kit; 50 MM L 1 EA	131.21
31010149054 DISC SPRING SPACER ITEM 10 L 1 EA	48.03
31010149055 DISC SPRING SETSCREW ITEM 9 L 1 EA	7.84
10080043288 Valve Lever; ARM L 1 EA	1,060.00
10080041764 Valve Bearing; BONNET DISC; 50 MM L 1 EA	152.00
31010223772 SPACER,CARBON STEEL L 1 EA	84.88
10080044772 Valve Collar; POST DISC; 50 MM L 1 EA	211.00
10080044213 Valve Gland; DISC VALVE L 1 EA	173.00
10080036392 Valve Spring; SET; DISC; 50 MM L 8 EA	118.00
31010149056 GLAND SPRING WASHER ITEM 27 L 1 EA	7.84
31010149126 POST WASHER ITEM 18 L 1 EA	7.83
31010149125 POST GLAND NUT ITEM 19 L 2 EA	3.92
31010149124 POST GLAND STUD ITEM 20 L 1 EA	2.35
10080001517 Equipment Gasket; BODY; 50 MM L 2 EA	120.00
31010223771 O-RING,70MM X 3MM,BUNA-N L 1 EA	18.00
31010085752 WASHER THRUST DISC VALVE 50NB EVERLA L 1 EA	28.00
10080024156 Valve Packing; DISC; 50 MM L 1 EA	47.00

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CLASS 150 & 300 VALVES

CL150
CL300 **4"**

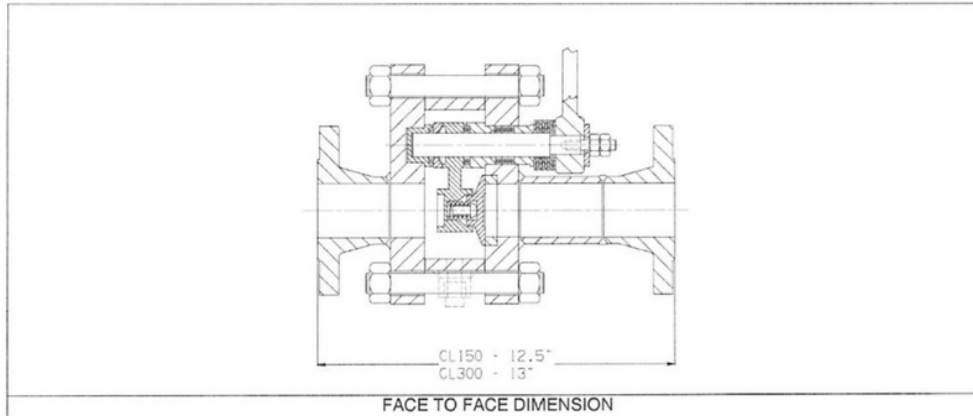
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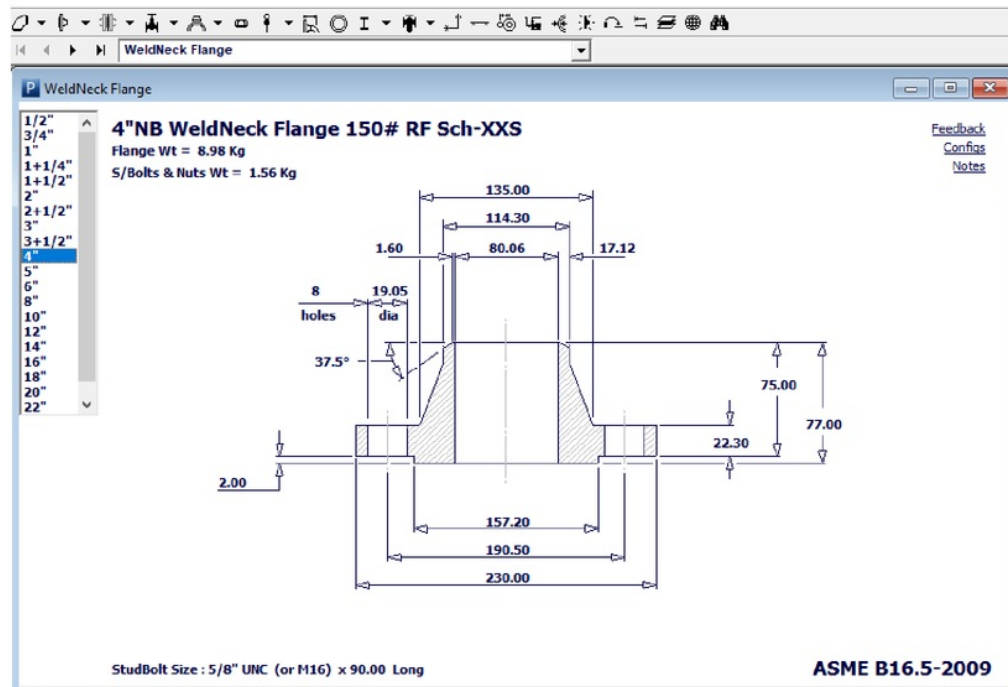
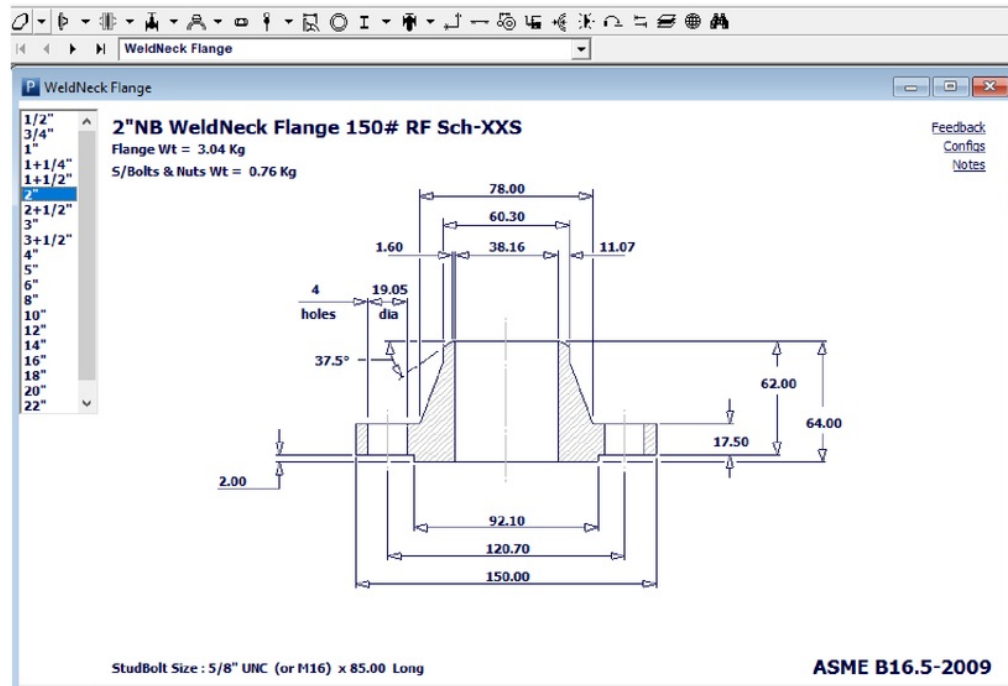
CLASS 150 & 300 VALVES

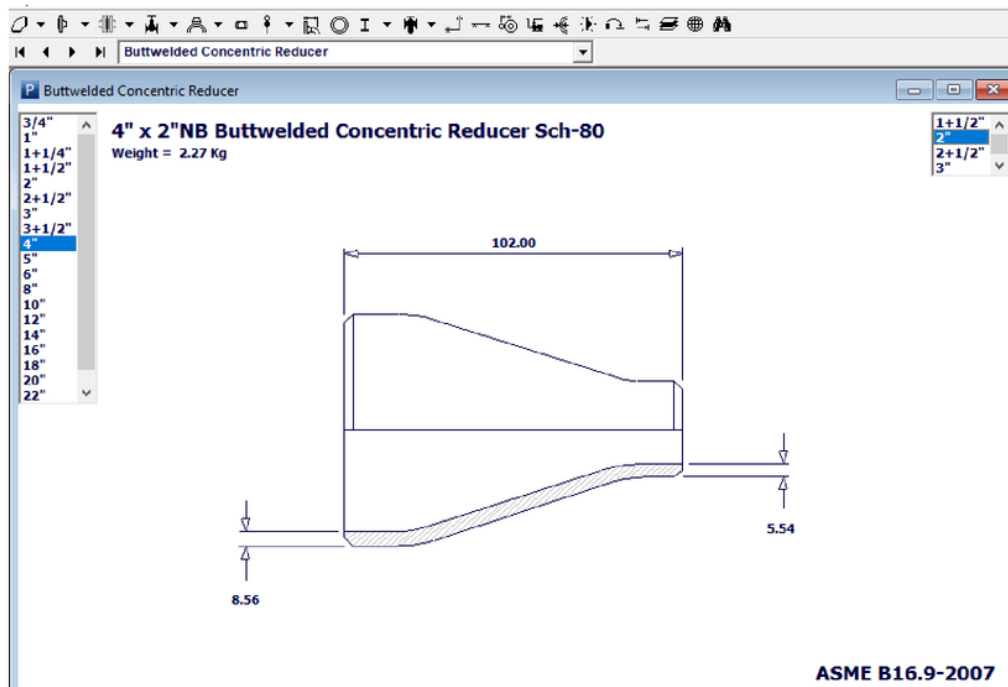
CL150
CL300 **2"**

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Appendix 5.2 – Pipe fittings dimensions (PipeDataPro, 2019)





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