



How do temporary repairs contribute to the safe and reliable operation of the Crude Distillation Unit?

BSc Mechanical Engineering – Year 3

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2.0 Executive Summary

It had been identified that the CDU is an ageing unit with a number of failures and potential failures. These have been addressed through a temporary repair philosophy. It was decided that this report was focused on researching how these repair affect the safety and reliability of the CDU.

Research was conducted through a temporary repair database, benchmarking and case studies. From this research it was evident temporary repairs contributed to the availability metrics, which in turn increased reliability of the CDU.

Costs were also included in this research, whereby it was found that vast savings were made when a temporary repair was fitted in place of a permanent repair through a unit shutdown. Safety issues were considered in line with the Valero risk matrix.

It has been concluded that by fitting a temporary repair, a succession of related factors have affected positively to contribute to a more reliable, safe and economical CDU. To put this in simple terms:

Less downtime = higher availability = increased reliability = reduced costs = less safety implications

Contents

1.0 Acknowledgements	1
2.0 Executive Summary	2
3.0 Tables of Figures	4
4.0 Abbreviations	4
5.0 Introduction	5
5.1 Valero Energy	5
5.1.1 Pembroke Refinery	5
6.0 Literature Review	6
6.1 What are Temporary Repairs and why are they used?	6
6.2 Types of Temporary Repairs.....	7
6.3 Process Safety	8
6.4 Crude Distillation Unit (CDU).....	8
6.5 What is the Problem?	10
6.6 Research Types.....	10
6.6.1 Research Onion	10
6.6.2 Quantitative Method	11
6.2.3 Temporary Repair Register	12
6.2.4 Solomon Index / Benchmarking.....	13
6.2.5 Case Studies	14
7.0 Research.....	15
7.1 Temporary Repairs on Pembroke Refinery (CDU).....	15
7.1.2 ASME PCC-2: Repair of Pressure Equipment and Piping	16
7.2 CDU Reliability.....	16
7.2.1 Reliability and Availability	17
7.3 Safety Implications	20
7.3.1 Risk Assessment Requirements	20
7.3.2 Generic Risk Assessment for a Unit Shutdown	20
7.3.5 Installation Safety	22
8.0 Results.....	25
8.1 Analysis of Temporary Repairs	25
8.2 Cost Implications	26
8.3 Crude Overhead Line – Case Study	26
8.3.1 Implementation of Temporary Repairs.....	27
8.3.2 Welded Repair Option	30
8.3.4 Recommendations	30
9.0 Discussion.....	31
9.1 Cost.....	31
9.2 Safety.....	31
9.3 Reliability	32
10.0 Conclusion	32
10.1 Recommendations	34

11.0 References	35
13.0 Appendices	38

2.0 Tables of Figures

Figure 3; Composite Rap (www.belzona.com)	8
Figure 4: CDU Process (www.ou.edu).....	9
Figure 5: Saunders Research Onion	10
Figure 6: Open Temp Repairs by Year.....	15
Figure 7: Closed Temp Repairs by Year.....	15
Figure 8: Refining Reliability 2019 Overall	19
Figure 9: Refining Reliability ex TAR	19
Figure 10: CDU Exclusion Zone	21
Figure 11: Mechanical Contractor RAMS.....	24
Figure 12: Cumulative Temp Repairs	25
Figure 14: Composite Wrap Installed.....	28
Figure 15: Composite Wrap Installed.....	28
Figure 16: Clamp Fabrication	29
Figure 17: Clamp Fabrication	29

4.0 Abbreviations

CDU – Crude Distillation Unit

VLO – Valero

ASME – American Society of Mechanical Engineers

C&O – Cracking and Olefins

CUI – Corrosion under insulation

IAN – Inspection Advice Note

RAMS – Risk Assessment Method Statement

VDU – Vacuum Distillation Unit

API – American Petroleum Institute

5.0 Introduction

5.1 Valero Energy

“Valero is the world’s largest independent petroleum refiner” (www.valero.com, 2019). Valero is an international manufacturer and marketer of fuels for transportation industry and other petroleum products. Worldwide, Valero operates 15 major oil refineries with headquarters based in San Antonio, Texas. Valero employs approximately 10,000 direct

employees and has assets in the region of \$50.2 billion. The

company is also ranked number 24 on the Fortune 500 list. From all refineries, Valero operates at a combined throughput capacity of 3.1 million barrels per day.

5.1.1 Pembroke Refinery

Valero acquired Pembroke Refinery in 2011; this was Valero’s entry into the European refining market. The refinery is situated on the River Cleddau, which gives a logistical advantage with regards to product and material transportation. The refinery is one of the most complex in Europe, with products such as gasoline, diesel, kerosene and liquefied petroleum gas. The refinery has a throughput capacity of approximately 270,000 barrels per day. The process units are split into two refinery sections; Cracking and olefins and Refining.



Figure 1; Valero Operations

6.0 Literature Review

According to a report by the US Department of Energy, *“there were over 1700 refinery shutdowns from 2009 to 2012 with 46% of them were caused by mechanical breakdowns, 23% by maintenance, 19% by electrical disruptions and power failures, and 12% by other causes such as fire accidents. The duration of a shutdown can range from a couple of hours to weeks, with 92% of them being unplanned.”* (US Department of Energy, March 2007).

Obviously any unplanned shutdown can be detrimental to production on any refinery. Given that 46% of these were caused by a mechanical breakdown it must be investigated

6.1 What are Temporary Repairs and why are they used?

A temporary repair forms part of Asset Integrity Management (AIM). According to (www.inspectioneering.com, 2019) *“AIM is a standard of operating that aims to protect equipment, health, safety and the environment”*. AIM looks at the entire infrastructure of the asset from conception, to design and engineering, construction and operation. It also includes the replacement or in this instance repair when necessary.

For a refinery to be profitable, it must be reliable. This means that the equipment availability must be or as close to 100% as possible (excluding planned outages). Simply, if the equipment is not operating the refinery loses money. Hence, why maintenance through AIM is required. It is very important to understand that not all items of equipment can be taken offline for maintenance without any loss of production. This is when a temporary repair would be utilised. A temporary repair is a form of maintenance that meets industry standards (ASME PCC2) that will not affect reliability or production. It is best practise to remove these temporary repairs and replace with permanent solutions during planned maintenance events – this way refinery metrics will not be affected.

When we consider maintenance, there are generally three types;

- Preventative
- Predictive
- Corrective

Temporary repairs are only used for maintenance that falls under the predictive and corrective category. Predictive maintenance refers to the probability of failure. Through inspection methods potential failures can be spotted and then rectified through the

planning and implementation of a temporary repair. A number of factors such as logistics, material types and operating conditions would stipulate the repair method. Each repair must meet specific repair codes and standards.

Corrective would be when a loss of containment has occurred. This simply means that a leak has occurred. This would constitute as a safety or environmental incident.

6.2 Types of Temporary Repairs

There are two main types of temporary repairs used at Pembroke Refinery, and for the purposes of this research, only these two types will be considered.

Box Clamp – This is a mechanical device specifically engineered to process conditions to contain a failure. The clamp is bolted together around the pipe, valve or component and injected with a resin to prevent any product escaping. These can range in size, weight and complexity depending upon the failure. These can range in cost from simple ‘off the shelf’ designs to specifically engineered complex designs.

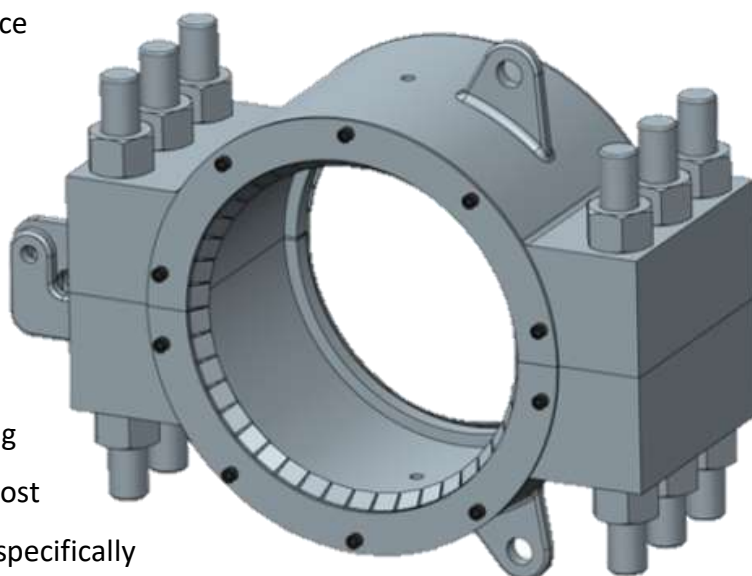


Figure 2: Box Clamp (www.hydratight.com)

Composite Wrap – A composite wrap consists of a thin material such as carbon fibre or glass wrapped around / over the component to build the component integrity and restore to withstand process conditions. Layer upon layer is applied with a resin used to bond and harden the wrap. Again, these can vary in complexity and are specifically engineered based on conditions such as temperature and pressure.



Figure 3; Composite Rap (www.belzona.com)

6.3 Process Safety

According to (www.iogp.org, 2019) *“Process safety is a disciplined framework for managing the integrity of operating systems and processes that handle hazardous substances.”*

In simple terms, what this means is keeping the product inside the pipe or piece of equipment. Obviously this is a major factor with regards to health, safety and the environment and is the driving force behind the implementation of temporary repairs.

Installing a temporary repair due to a process safety incident would mean a component or piece of equipment has failed. This has the potential of affect unit downtime, increase costs and most importantly cause a higher risk to personnel and the environment.

6.4 Crude Distillation Unit (CDU)

A crude distillation unit (CDU) is one of the primary units found on a refinery. The objective of this unit is to separate the crude mixture into several fractions such as gas oil, naphtha, kerosene and diesel. The basic process can be shown in the figure below;

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?

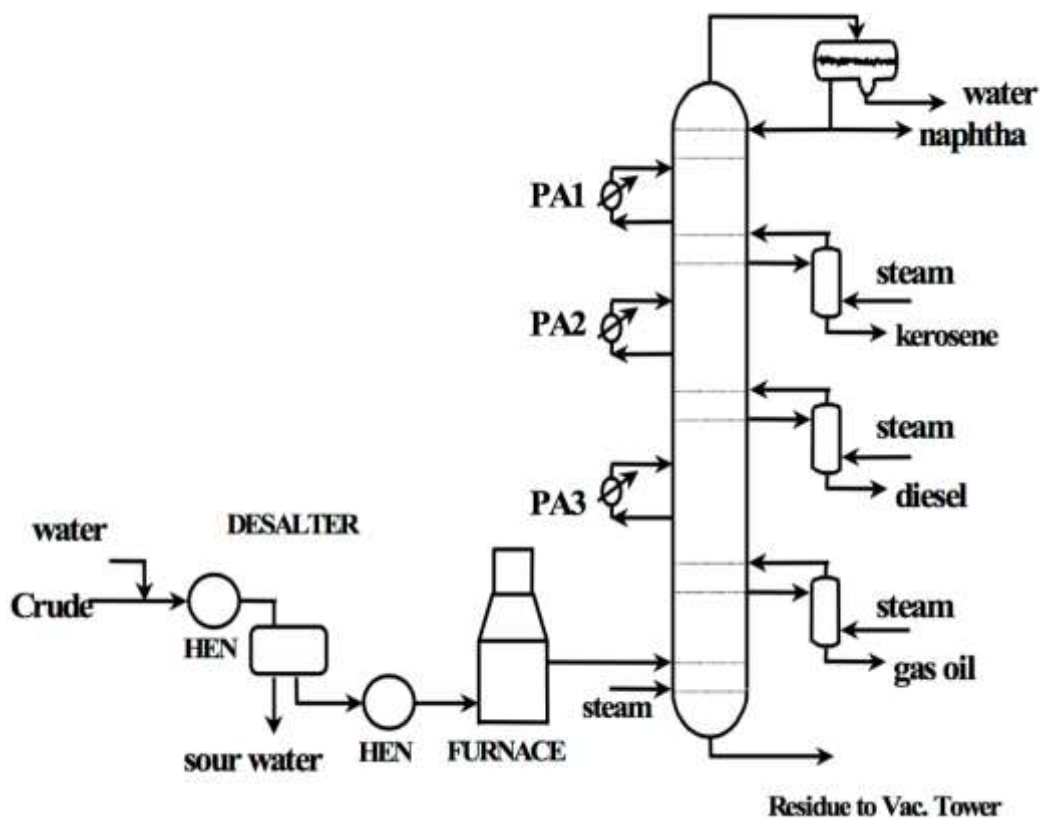


Figure 4: CDU Process (www.ou.edu)

Prior to fractionation, the salt must also be removed from the crude oil by using a desalter. The oil can then be heated and fractionated using an atmospheric distillation tower. As this is a high complexity unit with multiple products and dependant units, it is the backbone of the refinery so reliability is paramount.

This unit was commissioned at Pembroke Refinery in 1964. Therefore this unit has potential for equipment failures on a regular basis due to age related corrosion through 24-hour operation. Not only does the age cause concern for temporary repairs, but also planned maintenance event intervals have been extended from 6 to 10 years. This means that major, high impact pieces of equipment have no internal maintenance performed for 10 years; in addition to this the equipment is run for an extra 4 years non-stop. Varying Crude feeds can also cause accelerated internal corrosion. Being the primary unit, it must deal with these varying crude qualities without any treatment. When these critical items of equipment cannot have maintenance performed of them, many of the inlet and outlet pipelines cannot be maintained, instead they can only be inspected and monitored.

For these reasons, this report and dissertation will focus on this process unit.

6.5 What is the Problem?

As identified above, the CDU is an ageing process unit with reduced inspection periods run 24/7, 365 days per year. This means there is a greater need for temporary repairs to ensure the unit safety and reliability. It must be asked;

- Is this operating / maintenance philosophy correct?
- Are temporary repairs responsible for the safe and reliable operation of the unit?

What would the implications be if an effective temporary repair programme were not implemented?

6.6 Research Types

6.6.1 Research Onion

In order to assist in the research stages, the Saunders Research Onion can be used;

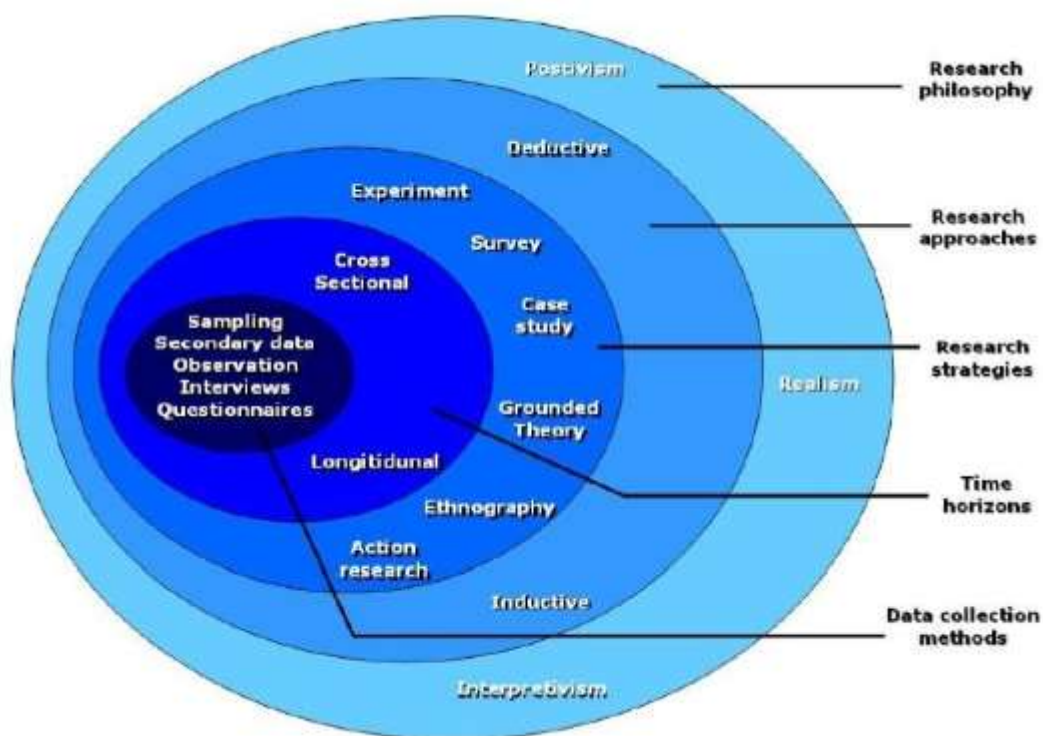


Figure 5: Saunders Research Onion

To use this method, you must work from the outer later inwards. By doing this, it has been described by (Tonuchi Joseph. E, 2019) as *“an effective progression though which a research methodology can be designed”*.

Philosophy – Epistemology is utilised to find the scientific research to provide the research without doubt. Essentially it is fact gathering.

Approach – This layer is based upon pre-existing theorems. From this the formulation of your own hypothesis can start from your understanding of the problem. It is also possible, at this stage to create your own theory through an inductive approach.

Strategy – this sets out how the work is to be researched. This can be through an experimental way – creating a process. Or through surveys or case studies.

Choice – A mono method is required for gathering one type of data. Either qualitative or quantitative. However, it is possible to use a mixed method to create one precise set of data.

Time – This refers to the time period the research will be conducted over and analysed.

6.6.2 Quantitative Method

According to (K. Hammarberg, M Kirkman, 2016) *“quantitative research methods are appropriate when ‘factual’ data are required to answer the research question”*. This can be related to the data required to undertake the research on temporary repairs on the CDU unit. The primary data collated must be factual in order to get a true representation. By using this method it will eliminate people’s opinions, experiences and views. This will ensure the hypothesis is clear and unambiguous.

With regards to quantitative research there are four main categories:

- Nominal – ‘naming’ things does this. In this instance it can be applied to the temporary repairs register. It can be observed that there are “X” amount of temporary repairs and observing their specific details. This directly applies to the research needed to retrieve the required data sets.
- Ordinal – done by placing things in order. This does not apply to the data required. For example; you would order the finishers in a race 1st, 2nd 3rd etc.
- Interval – this quantifies the gap between two measurements or scored. This method can be utilised when analysing primary data collected through the nominal method. Once the data has been recorded with associated information in the temporary repairs register, it would be possible to collate the intervals between

repairs and relate them between periods of planned maintenance. For example; higher rate of repairs 3 years after a planned events compared to 1 year after an event.

- Ratio – this uses a ratio scale for comparison. This would mean a 0 score means the absence of something. This can be compared to the Solomon index. Whereby refineries are ranked based on performance data. The data is normalised then ranked based on the outcome.

6.2.3 Temporary Repair Register

In order to understand the refinery's current status with regards to temporary repairs on the CDU, all available data must be collated, filtered and analysed. Data for each individual temporary repair is recorded within the temporary repair register/database. However, a report must be created to retrieve the required data for the Crude Unit. The data is a collation over a number of years and is a HSE requirement to record each repair. This data can then be used to critically analyse at a higher level the impact these temporary repairs have on the refinery. It will also allow any 'out of the ordinary' repairs to be flagged up. For example; repairs that are drastically more expensive or the type of repair being undertaken. This can also add justification for any case studies that may be included in the dissertation at a later date.

The major benefit by using this register it that the data associated with each repair is quantitative. There is a traceable history and the information fields for each repair is the same for each entry. This makes the information comparable and variables can be linked to form a hypothesis.

Each repair follows a design code or standard, therefore there is no disputation over the method used or the data collated. This means that the data is reliable and consistent. Although there is a standard (ASME PCC2) to follow, there may be anomalies from time to time due to the standard of information entered. Sometime not all information is available due to the age of the refinery; this is when problems may occur, as the data entered could be qualitative. For example, no available information process conditions of a line. A time served process engineer may know from experience the process conditions, but no supporting documentation.

Not only should live data be considered, but also historical data sets for repairs that have been completed and closed out. It will then be possible to draw relationships between the rate of failures and repairs over a prolonged period of time. This relates to the types of quantitative data mentioned above. By having these two sets of primary data, a number of methods can be used to analyse and draw conclusions.

6.2.4 Solomon Index / Benchmarking

Benchmarking is an important factor in understanding a refinery's competitiveness in an ever-changing market. According to (www.solomononline.com, 2019) *"85% of the world's refining capacity relies on Solomon's Fuel Study – year after year"*.

This provides an insight into key performance related factors by utilising gap analysis data and comparing other refineries to develop effective data driven strategic plans. Solomon displays this performance related data in quartiles. An upper quartile would reference good performance compared to other refineries, whereas a lower quartile would be a poorer performance.

The benefit of using a benchmarking method such as Solomon is that it normalises data sets from a wide range of refineries. This method is known as Comparative Performance Analysis (CPA).

By using this secondary data it would be possible to create a direct relationship between certain elements and the primary data from the temporary repairs database. This relationship would be able to highlight how the refineries' temporary repairs can affect its competitiveness.

As this data is available from previous years, it would be beneficial to compare certain measurements against analysed factors available from the temporary repair database. Ratios can then be calculated which will provide a reliable statistic for evaluation to help draw a hypothesis.

6.2.4.1 Limitations of Benchmarking

Although it is very important to benchmark, benchmarking only occurs at a high level. It would be beneficial to compare other refineries' equivalent data. But, not all refineries are 'like for like'. It would be possible to compare over the Valero spectrum, but then each refinery or specifically Crude Unit has a different design, capacity, age, operating strategy

and maintenance plan. Not only this, a refinery based in Canada would have many more temporary repairs due to the colder climate during winter months, compared to a refinery in Texas or the UK. As mentioned above, data is normalised but only at a high level for comparison.

Solomon index also does not show the justification behind the statistics. For example, a refinery with a lower quartile ranking on equipment availability may not be due to a temporary repair related incident. Whereas a refinery with a top quartile ranking for equipment availability may be due to the implementation of effective temporary repairs. Essentially it is hard to compare the finer detail unless you have the raw data to analyse.

6.2.5 Case Studies

Analysing case studies would also be beneficial research to consider for the purposes of a hypothesis. It would be advised that a high impact repair should be considered. A case study that would have a vast impact on Pembroke Refinery from a commercial, operational, health and safety and environmental stance would draw in depth conclusions. Only through in depth analysis from research conducted on the temporary repair database could a suitable case study be chosen.

(Helena Harrison, 2017) describes a case study as “an effective methodology to investigate and understand complex issues in real world settings”. This method of research would be suited to historical data gathered. Any conclusions drawn from the case study can then be used to study the current live data and contribute to a potential hypothesis. This way lessons learnt can be implemented to make recommendations and improve unit reliability.

Through researching temporary repair case studies, it is clear that qualitative data may be used. Although much of the data will be quantitative, sources such as emails and reports may help analysis and to draw conclusions. This related back to the research onion whereby a mixed approach is possible.

7.0 Research

7.1 Temporary Repairs on Pembroke Refinery (CDU)

As previously mentioned, Pembroke Refinery holds a temporary repairs database. This database has been utilised to produce a report detailing all live and closed temporary repairs on specific units. Please refer to appendix “Temporary Repairs Report” for the full detail of these reports.

The data deduced from these reports have been collated to produce the following;

	Total	Open	
		Temp Box	Temp Wrap
2019	21	12	9
2018	28	15	13
2017	16	12	4
2016	26	25	1
2015	20	17	3
2014	6	4	2
2013	31	26	5
2012	5	5	0

Figure 6: Open Temp Repairs by Year

As you can see from the figure above, temporary repairs are steadily increasing. These repairs would constitute from failures or potential failures that have occurred and unable to complete a permanent repair due to unit production. For example, in 2019 a total of 21 repairs were installed. That would potentially mean 21 instances whereby unit production would be stopped or reduced to implement a permanent repair.

	Total	Closed	
		Temp Box	Temp Wrap
2019	23	18	5
2018	5	5	0
2017	5	5	0
2016	1	1	0
2015	0	0	0
2014	0	0	0
2013	0	0	0
2012	0	0	0

Figure 7: Closed Temp Repairs by Year

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?

Closed repairs occur when previously installed temporary repairs have an opportunity to be permanently repaired. This can happen for a number of reasons;

- Shipping movements / oil planning windows
- Planned maintenance on the same prepped equipment by operations
- Other maintenance / upgrades allows isolation of the temporary repair.

As an old unit, you would expect temporary repairs to increase each year, however certain factors can increase the requirement for temporary repairs. As you can see the highest number of repairs occurs in 2018. This is due to the severe cold weather that occurred in the first quarter of the year. Many utility lines froze and expanded during low temperatures causing multiple failures.

An increased number of repairs can also be caused by over pressuring systems or increasing heat too fast. These can cause failures that will require a temporary repair. Historically, these can happen when starting process unit up too fast. Usually done, as there is a rush to achieve on spec product as soon as possible. However, operating procedures now dictate in detail the start up tasks and timings.

7.1.2 ASME PCC-2: Repair of Pressure Equipment and Piping

ASME PCC-2 is a repair code, which has been developed under accredited procedures for the American National Standards. This has become the accepted standard for mechanical repairs on pressure equipment since 1993. As these standards are for repair, they only apply post construction, unlike the API codes.

As stated under (ASME PCC-2, 2006) *“The methods provided in this Standard address the repair of components when the repair is deemed necessary based on inspection assessment”*. Therefore it must be deemed by an inspection authority as a repair necessary. In terms of Valero’s processes, this would come in the form of an Inspection Advice Note (IAN).

7.2 CDU Reliability

According to (Torbjörn Idhammar, 2020) *“The goal for any plant is to increase overall production reliability, meaning the maximization of output with current resources by reducing waste in equipment reliability and process reliability”*.

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?

When considering this statement, temporary repairs must be taken into account to understand Pembroke Refinery's position on reliability. In order to increase production and reduce waste the operating time must be maximised through SMART maintenance systems such as the temporary repair philosophy.

By implementing temporary repairs and a proactive maintenance philosophy, downtime can be decreased which in turn will reduce waste.

Fitting a clamp or composite wrap and eliminating the need for unit downtime produce little to no waste. If equipment or a unit requires a shutdown, product is wasted when reducing temperatures and pressures, as this product is not to specification. This also applies when starting the unit back up. Only when a product is to specification there will be no waste.

In addition to this, when a failure occurs that a temporary repair may have prevented, it is possible for a break in containment. This is when the physical product is lost from the process and can cause an environmental issue. As described under section 7.3.4, a break of containment can result in thousands of litres of product being lost.

7.2.1 Reliability and Availability

The amount of time equipment is operating can directly affect the performance of the CDU. Availability is a metric used to quantify the reliability of a unit. Availability quantifies the probability that the unit is in good working order. Obviously this metric can be directly related to the success of temporary repairs implemented to ensure the unit is running correctly.

In order to characterise asset availability, the downtime of an asset needs to be taken onto consideration. As a result of implementing a temporary repair online compared to an offline permanent repair, higher unit availability will be achieved.

Intuitively, it can be said that availability and reliability are analogous. If the CDU operates without equipment failures, it would be expected that the availability would increase. Obviously inevitable downtime will occur on some equipment due to planned maintenance such as PM's and statutory inspections.

Defining the availability of the CDU can be done so by being expressed as a percentage of the actual operating time. This percentage is calculated using the following formula;

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?

$$\text{Availability (\%)} = \left(\frac{\text{Actual Operational Time (hours)}}{\text{Total time (hours)}} \right) \times 100$$

Actual operational time can be determined by taking planned and unplanned downtime and deducting this from the total time. Or expressed as the overall formula below;

$$\text{Availability (\%)} = \left(\frac{\text{Total Time} - (\text{unplanned} + \text{planned maintenance})(\text{hours})}{\text{Total time (hours)}} \right) \times 100$$

From this formula, it is recognisable that reducing equipment downtime will increase overall availability. As shown under the research of the temporary repairs carried out, it can be seen that 21 temporary repairs were installed in 2019.

A direct relationship can be drawn between this statistic and the availability of the CDU. In the figure below, the availability is shown per each month of 2019. The target availability is shown as 97.2%. It can be seen at during Q1 of 2019 these metrics were not met. This is due to a planned outage event of process units; therefore it doesn't shown a true representation.

Figure 9 has been introduced to show a representation of availability when these outage events are excluded from the metrics. As you can see, these targets are hit for 91% of 2019. It can be argued that if these 21 temporary repairs were instead, a permanent repair that caused downtime, these metrics would be further reduced having an effect on cost, availability, reliability and safety.

Referring to the literature review conducted, it was mentioned that benchmarking marking against other refineries would provide insight into the performance of the refinery. As you can see from figure 8 below, the upper quartile (red line) is the target for availability. As you can see the results vary month on month, this would be dependent on the equipment downtime or maintenance being carried out.

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?

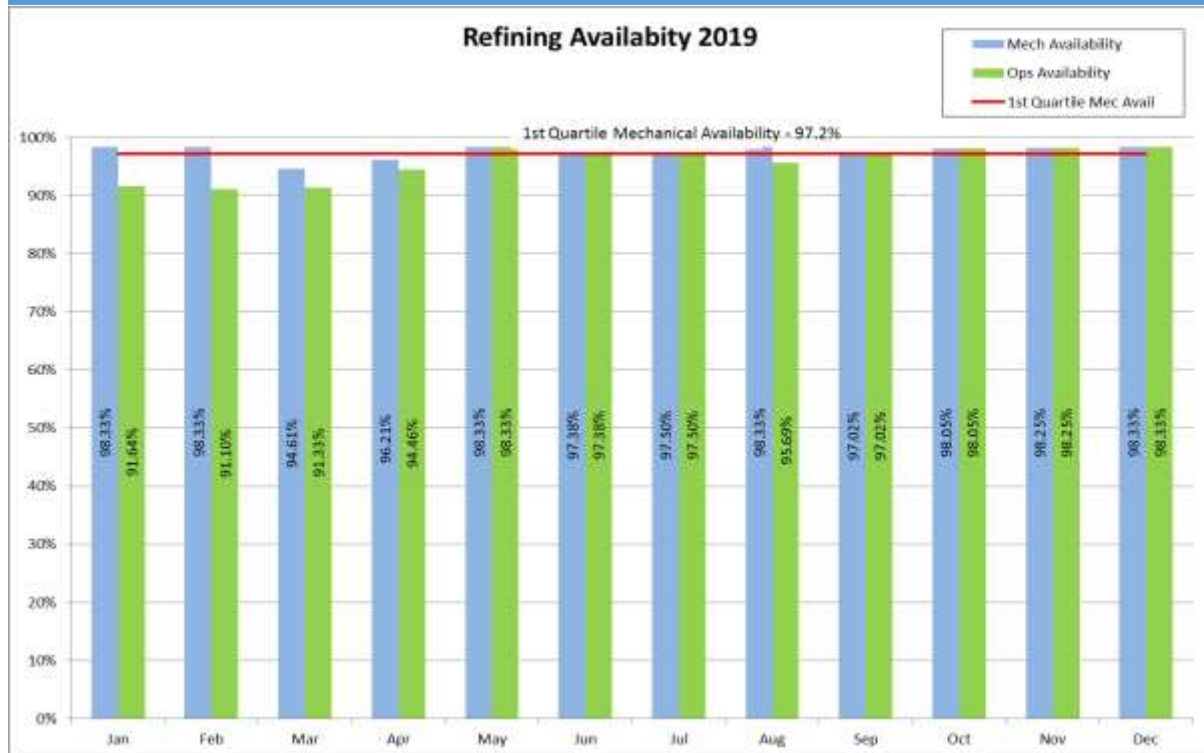


Figure 8: Refining Reliability 2019 Overall

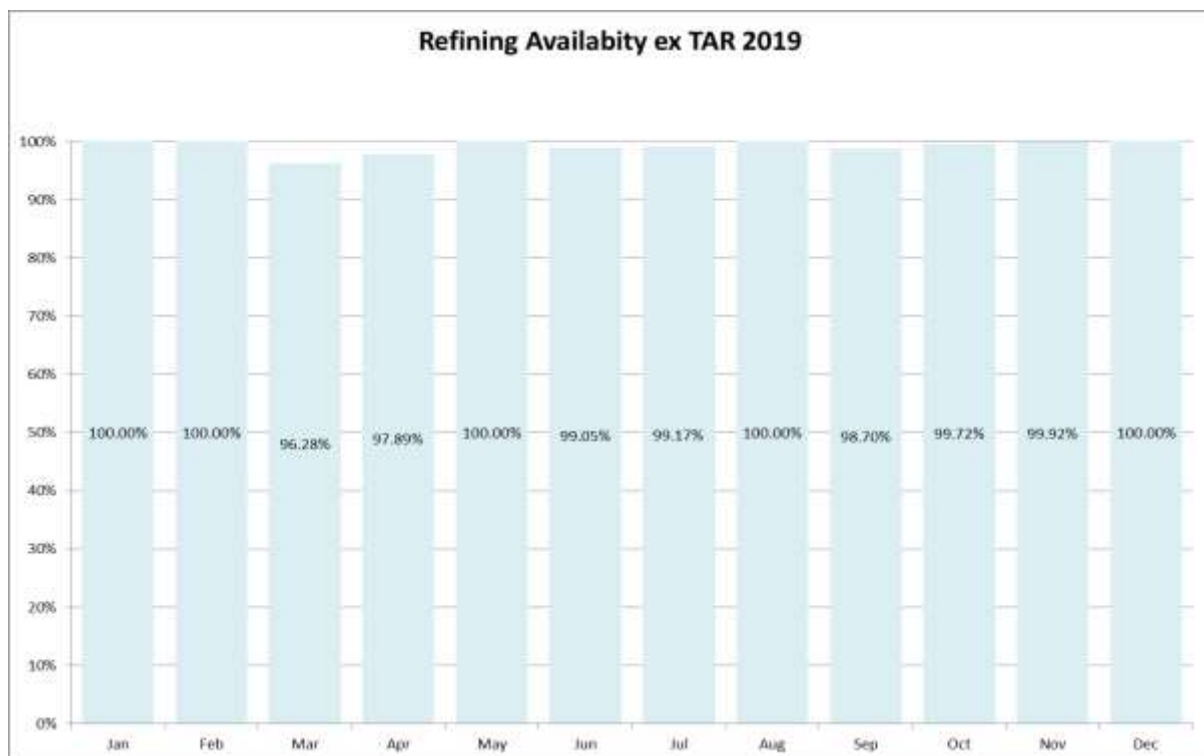


Figure 9: Refining Reliability ex TAR

7.3 Safety Implications

7.3.1 Risk Assessment Requirements

According to (hse.gov.uk, 2001) *“for all repairs, the operator needs to perform a structured risk assessment that includes the consideration of all of the potential future damage or deterioration mechanisms. The output from this risk assessment will typically be the specification of the necessary inspection and testing activities, and associated periodicities, to ensure continuing fitness for purpose.”*

This would typically mean that a reliability engineer, whereby the design and operating conditions are taken into consideration to approve the correct repair, must complete a review of the proposed temporary repair.

7.3.2 Generic Risk Assessment for a Unit Shutdown

To highlight the risks associated with shutting down the CDU to implement permanent repairs, a risk assessment has been completed in order to understand how these can affect safety and reliability issues.

7.3.2.1 Exclusion Zones

As highlighted under the risk assessment mentioned in section 7.3.2, a shutdown to implement a permanent repair involves the requirement for an exclusion zone when shutting down or starting up the process unit.

The reasoning behind an exclusion zone is to restrict all non-essential personnel, work and equipment from the area. Only essential personnel are to enter the exclusion zone, these are functions that are essential to the safe shutdown or start up of the unit. During these times only critical maintenance can be performed within this zone. This maintenance is only for work directly affecting the unit shutdown or start up.

As you can see from the table below, the exclusion zone consists of two areas and can be broken zone for both shutdown and start up;

	Shutdown	Start Up
LEVEL 2	Starts: At the point when the process unit decreased feed rate, pressure and temperature Ends: When the significant hazards identified (due to high energy) with unit shutdown have been removed.	Starts: When significant identified hazards are introduced due to high energy. Ends: When all identified areas of the process unit are stable and a minimum operating conditions as declared by operations coordinator.

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?

LEVEL 1	Starts: Level 1 starts once all Level 2 activities are complete. Ends: The shutdown is essentially complete, most energy has been removed although hydrocarbons remain in the system and continued removal required. Operations coordinator removes the requirement for exclusion zones. Permits to work on the unit commence.	Starts: Once all maintenance work has been complete. Introduction of hydrocarbons, temperature and pressure to rise as part of start up. Ends: When introduction of higher temperatures and pressures commences.
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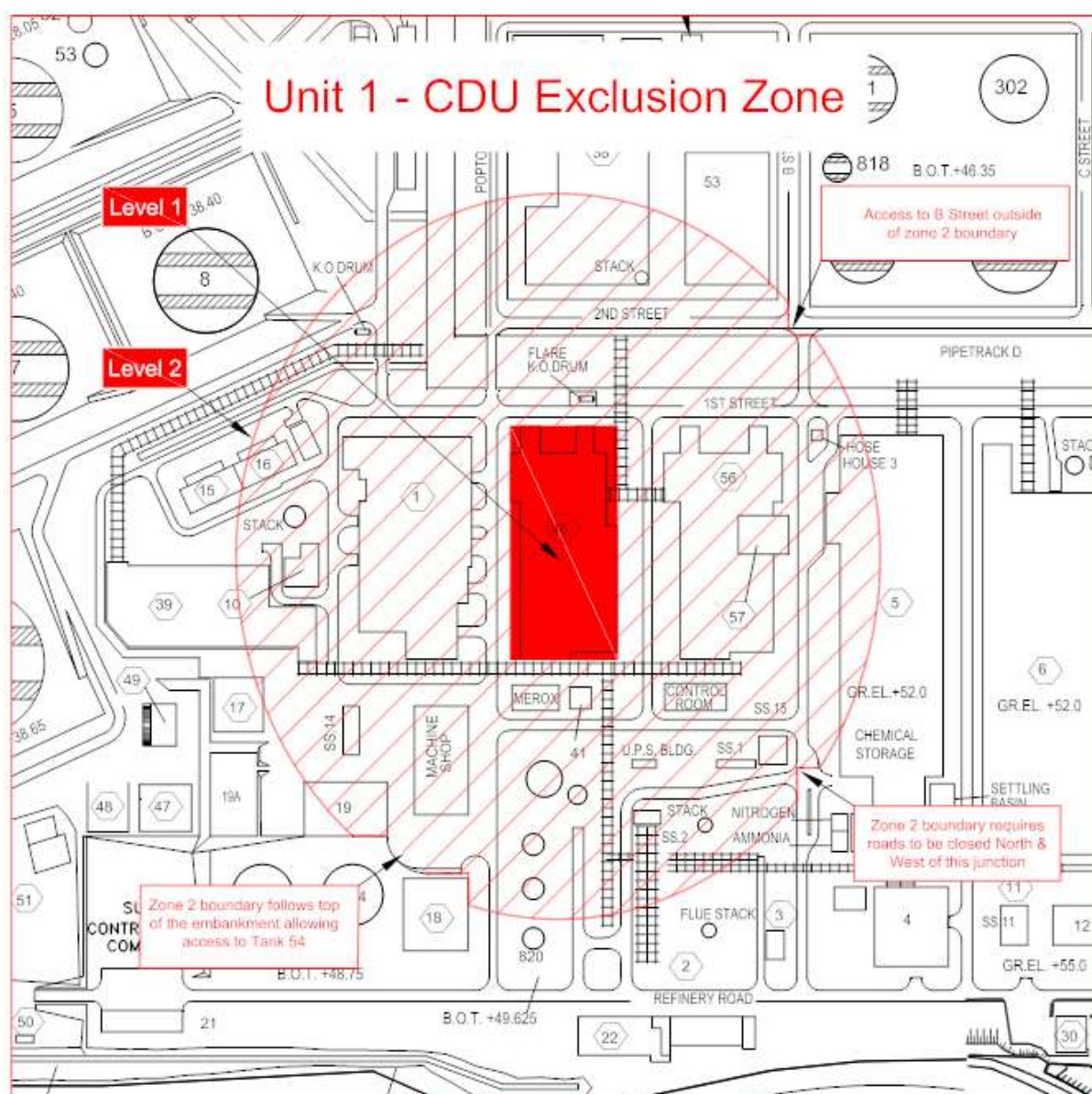


Figure 10: CDU Exclusion Zone

As shown above, the requirement for exclusion zones is mainly due to the removal or introduction of high energy through temperature and pressure. As an aging unit, the CDU is

susceptible to the failure of pressure equipment and components when pressure and temperature is removed or introduced. These can cause entirely new issues. If the unit is pressured up too quickly or too much heat introduced in a short space of time, multiple failures can happen and the entire process to repair these failures would have to start again. Alternatively, these failures often have temporary repairs fitted to get the unit back into production. Again, another reason how temporary repairs contribute to a reliable unit.

7.3.4 Environmental Impact

An environmental incident may occur when a pipe or piece of equipment fails. Temporary repairs can avoid these scenarios by utilising inspection findings. If a section of line is below T-min (minimum allowable wall thickness) then it is possible to install a temporary repair to mitigate the risk of failure.

From an article by the (www.bbc.co.uk, 2019) *“Two fuel pipelines shut at Valero's Milford Haven refinery”*.

In this instance, two failures occurred on the fuel oil pipelines located on the jetty areas of the refinery. These failures occurred due to CUI (corrosion under insulation). Corrosion in this scenario can be easily addressed by implementing a temporary repair. However, these thinned areas of pipe must be identified. These two failures could have been avoided if a suitable temporary repair was implemented. This event also ended in a recordable environmental incident, meaning a full investigation is required and possible fines or penalties incurred.

Not only do these events damage the refineries' reputation it can cause harm to the environment (air, sound, water & ground). In this instance 10,000 litres of fuel oil were leaked into the Cleddau River with large clean up costs and the need for two lines to be repaired offline this was avoidable if a temporary repair was used upfront.

7.3.5 Installation Safety

As with any maintenance work, safety implications apply. The safety of the personnel undertaking the installation must be fully trained and competent in the task. The installation risks identified must be outweighed by the mitigation achieved by the temporary repair.

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?

According to (hse.gov.uk, 2020) *“analysis of data from recent years indicates that 25-30% of manufacturing industry fatalities in Great Britain were related to maintenance activity.”*

Due to this it is evident control measures must be in place to undertake the task. When considering the two types of maintenance;

- Preventive or proactive
- Corrective or reactive

Different risks arise when fitting temporary repairs based on the type of maintenance being carried out. Obviously preventive maintenance carries less risk. These can be classed as section of a pipeline that has been identified through routine inspection to be thinned, therefore a clamp or wrap can be fitted to ensure the integrity of the component.

The Health and Safety Executive (hse.gov.uk, 2020) states that *“carrying out unforeseen repairs on workplace facilities or equipment after sudden breakage or failure. This is usually more hazardous than scheduled maintenance.”*

These repairs would be classed as a break in containment such as the crude overhead line whereby a failure has occurred. The personnel undertaking the maintenance are then subjected to potential process conditions.

These risks are controlled by a number of measures. All risks are identified through the contract companies' risk assessment and a method statement detailing the potential hazards, safety measures and how the associated tasks will be carried out. Please refer to these specific RAMS under the appendices.

In addition to RAMS, every task must have a valid permit to work. These are issued by the unit operator, which gives the contractor permission to undertake each task associated with the job. The permit details all tools required and the PPE needed. Please refer to the appendices for the permit associated with the CDU overhead line.

In addition to fitting the clamp, mechanical assistance is also required. There tasks cover all other aspects of the job. Please see figure 11 below, which details these tasks.

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?

-  20-MS-004 Working at Height.doc
-  20-MS-005A Crane Lifting Over Live Plant.doc
-  20-MS-008 Cold Cutting.doc
-  20-MS-013 Manual Handling & Lifting.doc
-  20-MS-056 use of hand tools.doc
-  20-RA-004 Working at Height.doc
-  20-RA-005A Crane Lifting Procedure Over Live Plant.doc
-  20-RA-008 Cold Cutting.doc
-  20-RA-013 Manual Lifting & Handling.doc
-  20-RA-056 use of hand tools.doc

Figure 11: Mechanical Contractor RAMS

8.0 Results

8.1 Analysis of Temporary Repairs

From the data collected through the temporary repair register it can be seen that the amount of open temporary repairs rises as the duration from the previous turnaround increases. As you can see from 2012, 153 temporary repairs have been installed.

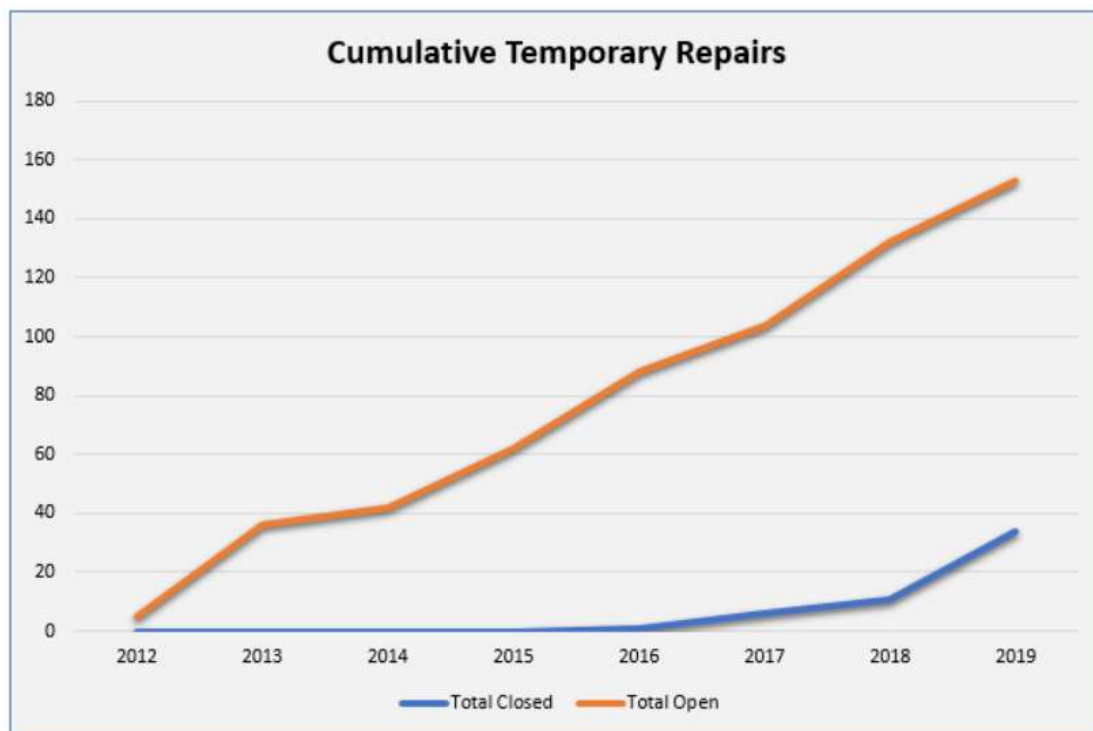


Figure 12: Cumulative Temp Repairs

This data would correlate with the Valero guidance that all temporary repairs are to be removed and replaced with permanent solutions. This is matched by (hse.go.uk, 2001) whereby it states;

“For safety critical piping systems the repair philosophy should whenever possible be;

- *Replace like for like*
- *Temporary repair until replacement can be carried out*
- *Permanent repair only where replacement is not practical”*

Again, this would relate back to the question asked during the literature review;

Is this maintenance philosophy correct?

If a large amount of temporary repairs are present on the operating unit; does this warrant a stop in production to shutdown and make permanent solutions rather than wait for planned events that can be seen to have further durations between downtime intervals.

8.2 Cost Implications

Obviously the costing element contributes to the decision of which repair method to use. From research conducted under section 7.0, the costings of each temporary repair have been collated. This means that the total cost of installing temporary repairs on the CDU unit since 2012 can be analysed.

In align with the Valero Risk Assessment Matrix (PP-PEM-JBA-0008), the business loss element can be referenced to show that each potential repair may have resulted in a loss of between \$1mm - \$10mm. Obviously this depends upon the extent of the repair in question i.e. the schedule of the repair (downtime) and the cost of the permanent repair in terms of equipment and labour. From both the temporary repair costs and potential costs a relationship can be drawn between the two.

Total number of open temporary repairs: 153

Total cost of implementation of repairs: £4,234,630

Average cost of each repair: £27,677

To compare these a conversion rate from (www.xe.com, 2020) has been used of 0.81.

Potential business loss: £810,000 - £8,100,000.

This means each temporary repair install has the potential to save Valero between £782,323 - £8,072,323.

Obviously this is only an average. Larger repairs wouldn't have such great savings and identified under the case study of the CDU overhead line.

The main saving being the requirement to not shut the CDU down, meaning no loss of production occurs.

8.3 Crude Overhead Line – Case Study

According to a study by (Brian Chambers, 2011) *"refinery operators face substantial risk of corrosion damage in both the atmospheric unit and the vacuum unit. The atmospheric unit,*

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?

also called the crude distillation unit (CDU), is often exposed to increased levels of chlorides and sulfur species, leading to substantial corrosion issues related to the species that manifest in crude overhead operations.”

The case study in questions relates specifically to this reference, whereby a tee section of the crude overhead line has been subjected to internal corrosion. The failure has also been accelerated by the operating conditions of the CDU. Increased throughput production means increased product velocity. Pairing this with the internal corrosion, a combination of corrosion erosion is responsible for the failure.

The failure occurred on a 30 inch tee section of the crude overhead line, which is a draw off of the Crude Distillation Column. The line is relatively low pressure of approximately 3.3 bar and a design temperature of 150 degrees (actual temperature 110 degrees).

The failure was spotted by an operator who noticed product dripping from the section of line.

8.3.1 Implementation of Temporary Repairs

Due to the nature of the failure (leak location, pipe size and configuration, service, metallurgy), it was deemed that in the first instance a composite wrap must be attempted to temporarily repair the leak. This is due to the manufacture durations of the clamp required. A 30inch clamp to fit around the tee section requires multiple measurements (due to expansion and contraction of the line) engineering supports and a design scaffold. Attempting a repair through the composite wrap method would buy time for the manufacture and mitigate the leaking line. If the composite wrap sealed the leak, the requirement for the clamp would be removed.



Figure 13: Example of Internal Corrosion

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?

8.3.1.1 Composite Wrap

Once inspection reports for the landing points were produced, the carbon fibre wrap could be applied. Multiple layers were applied to restore integrity. However, the failure worsened over time as unit throughout was not altered. Therefore this was only a stopgap while the clamp was in manufacture.



Figure 14: Composite Wrap Installed



Figure 15: Composite Wrap Installed

8.3.1.2 Clamp

Figures 16 and 17 show the fabrication of the clamp by TEAM industrial services. Specifically designed to suit the process conditions and 3D scanned at the job site to ensure the correct fitment.

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?



Figure 16: Clamp Fabrication



Figure 17: Clamp Fabrication

8.3.1.3 Planning

Planning and

scheduling of the installation has been run through the refinery maintenance schedule, whereby resources are utilised from on site services. Resources are planned on a weekly basis for each activity. Below in figure 18, it details how the resources are planned for each operation and any required support services such as standby men for heat monitoring or scaffolding requirements.

Order	PM02 5602531	ALTRAD 0152 1-O-1112-3118-30-NL, 1-C-1 O					
Sys.Status	TECO	GMPS	MANC	PRC	SETC	PC	
HeaderData	Operations	Components	Costs	Partner	Objects	Additional Data	Location
Op...	SOp	W...	Plant	Co...	S...	Operation short text	LT- W.. Un N... Dur. Un C.
0010	OP	FL25	PM01	C		ALTRAD 0152 RAP: 20159852 SS	0.0HR 0 0.0HR Ma
0020	OC	FL25	PM01	C		CARRY OUT FURTHER CLOCKSPRING REPAIR	...0HR 2 8.5HR Ca
0020 0010 01-	FL25	PM01	C			ASSIST WITH CLOCK SPRING REPAIR	8.5HR 1 8.5HR Ca
0030	OC	FL25	PM01	C		CARRY OUT CLOCKSPRING REPAIR	...0HR 2 8.5HR Ca
0030 0010 01-	FL25	PM01	C			ASSIST CLOCKSPRING	8.5HR 1 8.5HR Ca
0040	OC	FL25	PM01	C		CARRY OUT CLOCKSPRING REPAIR	...0HR 2 8.5HR Ca
0040 0010 01-	FL25	PM01	C			ASSIST CLOCKSPRING	8.5HR 1 8.5HR Ca
0050	SC	FL25	PM01	C		ERECT SCAFFOLD 19-BOM-****	...0HR 6 8.5HR Ca
0050 0010 3B	FL25	PM01	C			HEAT STRESS MONITOR	8.5HR 1 8.5HR Ca
0051	SC	FL25	PM01	C		ERECT SCAFFOLD 19-BOM-****	...0HR 6 8.5HR Ca
0051 0010 3B	FL25	PM01	C			HEAT STRESS MONITOR	8.5HR 1 8.5HR Ca
0052	SC	FL25	PM01	C		ERECT SCAFFOLD 19-BOM-****	...0HR 6 8.5HR Ca
0052 0010 3B	FL25	PM01	C			HEAT STRESS MONITOR	8.5HR 1 8.5HR Ca
0053	SC	FL25	PM01	C		ERECT SCAFFOLD 19-BOM-****	...0HR 6 8.5HR Ca
0053 0010 3B	FL25	PM01	C			HEAT STRESS MONITOR	8.5HR 1 8.5HR Ca
0054	SC	FL25	PM01	C		ERECT SCAFFOLD 19-BOM-****	...0HR 6 8.5HR Ca
0054 0010 3B	FL25	PM01	C			HEAT STRESS MONITOR	8.5HR 1 8.5HR Ca
0055	SC	FL25	PM01	C		ERECT SCAFFOLD 19-BOM-****	...0HR 6 8.5HR Ca
0055 0010 3B	FL25	PM01	C			HEAT STRESS MONITOR	8.5HR 1 8.5HR Ca
0100	OP	FL25	PM01	X		LAG	0.0HR 0 0.0HR Ca
0300	01-	FL25	PM01	C		REMOVE SMALL BORE PIPEWORK	6.0HR 2 3.0HR Ca
0310	01-	FL25	PM01	C		RELOCATE CORROSION BOX	6.0HR 2 3.0HR Ca
0340	01-	FL25	PM01	C		COLD CUT SHOE / SUPPORTS AS REQUIRED	...0HR 2 8.5HR Ca
0340 0010 T50	FL25	PM01	C			CRANE ASSIST	3.0HR 1 3.0HR Ca
0340 0020 3B	FL25	PM01	C			HEAT STRESS MONITORING	8.5HR 1 8.5HR Ca
0340 0030 3C	FL25	PM01	C			SCAFF MODS IF REQUIRED	9.0HR 3 3.0HR Ca
0345	01-	FL25	PM01	C		STEEL WORK MODS TO TOP PLATFORM	...0HR 2 8.5HR Ca
0345 0010 T50	FL25	PM01	C			CRANE ASSIST	3.0HR 1 3.0HR Ca
0345 0020 3B	FL25	PM01	C			HEAT STRESS MONITORING	8.5HR 1 8.5HR Ca

Figure 18; SAP Schedule

8.3.2 Welded Repair Option

It would be possible to complete a welded repair to the corroded section of the CDU overhead line. This is stipulated under (API 510, 2014) *“Fillet welded patches may be used to make repairs to damaged, corroded, or eroded areas of pressure vessel components”*.

It also addresses the possibility of weld overlay. This would build up the failed and thinned area of the component and restore the integrity.

These repairs must also be in accordance with the relevant repair code. The repair code used is ASME PCC-2. This details the requirements for the repair and any design implications.

These repairs would reinstate the greater integrity to the component; however, compared to a mechanical clamp enclosure the installation has greater risks that can not be mitigated. Due to a leaked line, it would not be possible to preform a hot work task (welding). This is known as live line welding. In accordance with the Valero risk matrix (see appendix) this would be too greater risk wit little benefit compared to a mechanical enclosure.

8.3.4 Recommendations

Due to the failure mechanism of the overhead line, it would be recommended that an upgrade to the design and metallurgy be completed. Obviously a full engineering task would be required. The main recommendation would be to increase the diameter of the pipe. Currently 30inches, a larger diameter would decrease the corrosion erosion internally when high velocity product is causing turbulence, paired with the corrosion mechanism this turbulence accelerates failures. This is described by (www.nace.org, 2019) *“Erosion corrosion is an acceleration in the rate of corrosion attack in metal due to the relative motion of a corrosive fluid and a metal surface. The increased turbulence caused by pitting on the internal surfaces of a tube can result in rapidly increasing erosion rates and eventually a leak”*.

9.0 Discussion

9.1 Cost

As identified during the research of the impact temporary repairs have on cost implications it has been identified that there are significant savings made when a temporary repair is installed compared to a permanent repair due to equipment shutdown. These cost savings are made through the reduced repair time and better unit reliability. Reducing the repair time means that refinery resources are not absorbed into one repair, instead these can be utilised elsewhere on the CDU. This means focus can be aimed at other problem areas to ensure a reliable unit.

Although these savings are made, it must be asked if this is the correct decision to make. Should these repairs be made permanent?

(ASME-PCC2, 2006) states this is an acceptable practise using the term *“fitness for purpose”*. In conjunction with ASME-PCC2, (API510, 2014) states that *“for temporary repairs, approval by both the inspector and engineer is required”*. This would be signed confirmation on the IAN.

9.2 Safety

Highlighted under the risk assessment conducted it can be seen that the greatest risks are due to high energy due to high temperature and pressure when shutting down or starting up a unit. These risks outweigh the risks associated with fitting the repairs itself. The repairs are conducted by highly skilled labour with specific risk assessments and method statements.

It is often possible to reduce pressure / feed rate to fit these repairs which can reduce the hazards involved. Although this is a change to process conditions, it does not constitute as a shutdown. These scenarios are dictated by the lead operators and relayed to the maintenance teams to implementation can be made of the repair itself.

Although risks are eliminated on the day to day running of the CDU, a temporary repair can still pose a threat, hence why they are not classed as permanent. Regular inspection intervals are still required and a philosophy to change the temporary repair at the next opportunity is enforced. (ASME-PCC2, 2006) states that *“If the component is leaking or has*

the potential to leak during installation, and if the contents are hazardous, additional precautions should be taken and those pre-cautions should be addressed during the pre-job hazard review meeting". These risks will then be detailed under the specific risk assessment and mitigated accordingly.

9.3 Reliability

It must be highlighted that although an ageing unit, with high criticality to the refineries overall throughput and amount of time between shutdown intervals, the availability is calculated to be within the upper quartile. In order to improve this statistic, higher inspection rates of equipment must be implemented. This way, increased preventive maintenance can be performed and temporary repairs used to reinstate asset integrity. This would have a positive affect on the reliability of the unit by decreasing operational downtime.

10.0 Conclusion

From the research undertaken, it can be concluded that utilising temporary repairs impact a number of succession factors. The three main areas concerned with these factors are:

- Safety
- Reliability
- Cost

As highlighted in this report if a temporary repair is to be fitted it must be in compliance with repair codes that are in accordance with the construction codes to ensure the correct repair method is applied. If these codes and practises are followed correctly fitting temporary repairs can have a positive affect on the CDU.

Obviously the risks must be taken into consideration, but mitigated through safe working practises approved by the relevant governing bodies and Valero. From this mitigation the risks associated with the installation are outweighed by the risks of shutting down equipment to complete a permanent repair.

Not only can these be outweighed from a safety perspective, but inline with the risk matrix (refer to appendices) it can be justified from a cost perspective also, as shown under the cost breakdown of in this report. It is beneficial to minimise the amount of outages, the

HOW DO TEMPORARY REPAIRS CONTRIBUTE TO THE SAFE AND RELIABLE OPERATION OF THE CRUDE DISTILLATION UNIT?

repairs detailed on the database can be planned and scheduled accordingly for a unit shutdown when statutory inspections on other equipment is due. This way there is minimal disruption to unit operability to remove the temporary repair and install a permanent solution.

Due to the ageing Crude Distillation Unit, it is inevitable that the amount of temporary repairs will increase year on year, therefore the upkeep of the temporary repair database is imperative to the success of the maintenance programme at Pembroke Refinery. As the refinery ages and equipment run times extended, minimising downtime through temporary repairs to meet metrics such as the Solomon index will provide an insight into refineries' competitiveness within the market.

The benefits from installing temporary repairs can be shown by a sequence of contributing factors:

1. Temporary repairs installed & recorded
2. Unit downtime reduced and risks mitigated
3. Reduced downtime results in higher unit availability
4. Higher availability mean increased reliability and unit operability
5. Increased reliability reduces costs. Maintenance budget can be spent on critical equipment to improve refinery efficiency and any unplanned maintenance.
6. More money in the budget for critical maintenance means a safer working environment
7. Metrics such as Solomon index are in upper quartile and competitiveness within the refinery market is increased.

Less downtime = higher availability = increased reliability = reduced costs = less safety implications

In summary, temporary repairs contribute to safer, reliable and more economical process units to help become a competitive business and secure the future of the refinery.

10.1 Recommendations

It would be recommended that similar research be carried out across other process units. This would give a better indication on the refineries overall status with regards to temporary repairs and how they affect availability and reliability of that unit. Additionally, it would be beneficial to complete case studies of further temporary repairs (large and small) across all process units.

It would also be of interest to compare the availability metrics of newer process units to those older such as the CDU, along with the number and types of temporary repairs installed. Other, non-critical units may also have better isolation designs which would allow equipment to be taken offline safely and with little disruption of unit operability, this may also be a contributing factor to the overall Solomon index ratings.

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13.0 Appendices

Valero Risk Assessment Matrix

Unit Shutdown / Start-up Risk Assessment

MECH QA/QC Overhead Line

TRA-3701 Injected enclosure installation

Overheads Clamp EMOC Hazard Review

TRP-3701 Injected enclosure installation

Temporary Repairs Report