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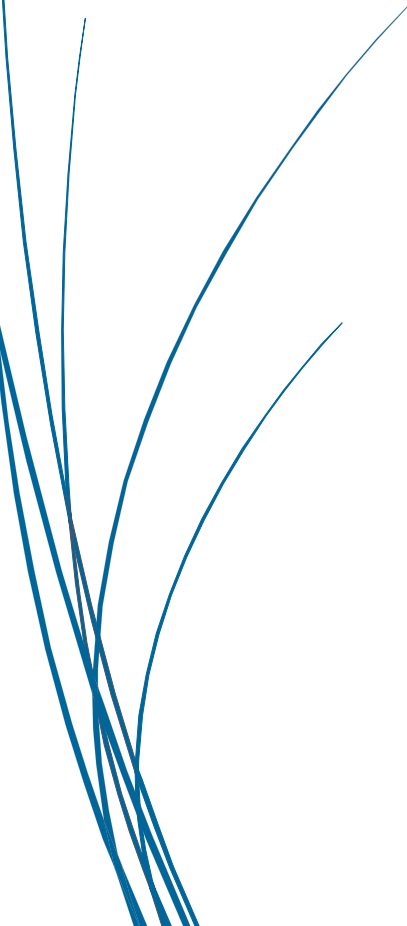
An Investigation into The Pembroke Refinery Fluid Catalyst Cracking Unit Feed Optimisation Project

Project Dissertation M6X00417

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Declaration of Authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed.....

Date.....

Acknowledgements

Firstly, I would like to thank Arnaud Marotin and Rob Goodson; not only for their guidance in writing this dissertation, but also for their lectures over the course of this degree which have been a key influence - as have lectures provided by Kelvin Lake, Andrew Thorn, Marie Pitson and Greg Owen.

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I would also like to thank my eldest daughter, Alana, and my son, Travis, for understanding that this sacrifice of my time was for our future. I know over last five years I have had to prioritise studying, over things more important to you, but now it is finished and you have got me to yourselves!

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Abstract

This dissertation is an in depth investigation into the innovative approach of reusing vacuum tower bottom residue and overflash from an oil refining process in a more cost effective way, in order to increase profits and secure the refinery's long term future in a highly competitive global market.

A description of the various plant processes involved in this project is included, along with a current overview of how the refinery currently operates and this is compared with the proposed changes. Project timescales are also featured and any problems encountered during the project are investigated accordingly, along with recommendations for future improvement.

Part of this project specifically includes a relatively new technology of a spiral heat exchanger, which could potentially be used to optimise the output and efficiency of Valero's Pembroke refinery. This investigation considers the advantages and disadvantages of spiral heat exchangers in comparison to more traditional shell and tube heat exchangers, as well as detailed information of both of their designs and functionality; including sizing calculations. The initial outlay costs for both methods are considered, along with their ongoing associated maintenance costs. Consideration for the viability of wider use of spiral heat exchangers throughout further refining processes in the longer term is also discussed.

As well as economic benefits, also highlighted are environmental advantages to modernising Pembroke refinery's processes, this is significant as currently governing bodies are pushing for lower CO₂ emissions and targets for reductions are constantly being reviewed globally.

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Nomenclature

FCCU	Fluid Catalyst Cracking Unit
VDU	Vacuum Distillation Unit
CDU	Crude Distillation
VBU	Visbreaker Unit
HCGO	Heavy Cycle Gas Oil
LCGO	Light Cycle Gas Oil
HVGO	Heavy Vacuum Gas Oil
LVGO	Light Vacuum Gas Oil
VTB	Vac Tower Bottoms (vac tower residue)
STE	Shell and Tube Heat Exchanger
SHE	Spiral Heat Exchanger
GHG	Green House Gases
EU	European Union
PPM	Parts Per Million
Mt	Million tonnes
MtCO ₂	Million tonnes of carbon dioxide (1,000,000,000 kg of carbon dioxide)
LR	Long Range
P&ID	Piping and Instrumentation Diagram
TC	Temperature Cold
TH	Temperature Hot
ΔT	Change in Temperature
GNP	Gross National Product
CBM	Condition Based Monitoring
CMMS	Computerise Maintenance Management System
Opex	Operational Expenditure
Capex	Capital Expenditure
CFD	Computational Fluid Dynamics
LPS	Loss Prevention System
LI	Loss Investigation
AFE	Authorisation for Expenditure
MM	Million

1. Introduction

Valero's Pembroke oil refinery is situated on the south bank of the Milford Haven Waterway on the Pembrokeshire coast. There once were many oil refineries in this area which was a vibrant hub for oil refining in Europe. Nearly all have gone out of business, Valero owns the last remaining of these oil refineries. In order to stay in business, profitable and competitive in this fluctuating market Valero Pembroke needs constant updating with new innovative improvement projects.

One of the major goals in oil refining on the Pembroke site is to optimise the mix of petroleum products output from the refinery so that profit is maximised whilst reducing the environmental footprint. About 44 percent of Pembroke's products are petrols, including ultra-low sulphur petrol, and about 40 percent of products are distillates all of these refined from crude oil that is found in the ground.

The feedstock for all petroleum refineries is crude oil. Crude oil is a natural substance created by the decomposition of living organisms over millions of years. This decomposition has left vast underground deposits throughout the world. Crude oil is extracted from the earth it contains a wide array of hydrocarbon components.

Oil Refineries are essentially industrial process plants designed to transform crude oil into beneficial finished products such as, petrol, diesel, kerosene, liquefied petroleum gas and heating oil. Process fluids (gases and liquids) to harvest these products flow through the refinery via numerous pieces of process plant equipment which are used to influence temperature, velocity and fluid flow these can include Heat Exchangers, Pressure Vessels, Pumps and Valves.

Crude oils from different regions of the world have different viscosities, the lower the viscosity the lighter hydrocarbons are present; thus, a greater fraction of fuels like petrol can be refined. The drawback of relying solely on the type of crude oil is that low viscosity crude costs more than high viscosity crude; thus, higher input costs which cuts into refinery profits. An additional approach of optimising the mix of petroleum products in a refinery is to convert lower value heavier products into higher value products.

One new innovative project that intends to do just that is the multimillion-pound FCCU Feed Optimisation project. The overall business objective of the project is to provide the refinery with a flexible feed system for the Fluid Catalyst Cracking Unit (FCCU) that allows the plant to process heavier feeds when it is economical to do so. At present expensive residue imports are being bought in to spike the FCCU feed line, so this project will potentially save and make Valero millions of pounds.

The project will basically take heavy Vacuum Tower Bottoms (VTB) residue and overflash from the vacuum tower on the Vacuum Distillation Unit (VDU) over to the FCCU, which will crack the heavy hydrocarbon chains into shorter more valuable chains that can be used for more expensive fuels; such as high-octane petrol and ultra-low sulphur petrol. Currently VTB residue serves as feed to the less profitable Visbreaker Unit (VBU), the VBU turns these process fluids into less valuable bitumen/asphalt, waxes and heavy gas oils. The VBU feed will be replaced with an FCCU by-product slurry, otherwise known as Heavy Cycle Gas Oil (HCGO).

The VTB residue will serve as a suitable FCCU feed as it is, however, the same cannot be said for the overflash which at 400°C is excessively hot. The overflash needs to be cooled to around 200°C to be suitable. This poses a big problem. In order to get the overflash to a suitable temperature it will need to go through a heat exchanger, which is a large and expensive piece of equipment, this also needs to be installed in a part of the refinery where space is limited.

Typically, Valero use shell and tube heat exchangers, they are used in various processes all over the refinery. However, this time it is proposed to potentially use an innovative new design, a spiral heat exchanger. It is the first of its kind on the refinery, it has a revolutionary spiral design which is very different to a shell and tube exchanger.

As well as the full FCCU Feed Optimisation project as a whole being comprehensively investigated and analysed in this dissertation, focus and investigation will also be carried out on different types of potential overflash cooler heat exchangers; with regards to their suitability when compared to other methods, including: performance; economics; safety; design; maintenance; reliability; sizing calculations; and environmental impact followed by Multi-Criteria Weighted Decision Analysis (MCDM).

When successfully completed the FCCU project should: increase refinery profits; lower the environmental footprint; increase reliability and efficiency; recycle by-products whilst lowering maintenance costs and at the same time potentially use pioneering new technology, which will keep the refinery moving towards the future and remain competitive.

2. Timing Plan

Please find the dissertation timing plan in Appendix 10.

3. Valero Energy Corporation

Valero Energy Corporation was established on Jan. 1, 1980 and is the result of a \$1.6 billion settlement agreed in 1978 by the Texas Railroad Commission, the state's natural gas regulatory agency. Valero's primary core business is crude oil refining; currently Valero has a workforce of approximately 10,000 employees and a refining throughput capability of approximately 3.1 million barrels per day, making it the world's biggest independent refiner.

The operation began with only a crude unit and vacuum unit on a modest plot of land near the Corpus Christi Ship Channel. During the following years, Valero built up its "Refinery of the Future," and through its holdings added more refineries beginning in 1997, Valero has 15 plants today. Valero also possesses a 50 percent joint venture which functions a 10,000-barrel-per-day renewable diesel plant in Norco, Louisiana; that processes recycled cooking oil, animal fat and corn oil into renewable diesel fuels. In addition to this Valero co-owns Sunray Wind, a 50-megawatt wind farm that harvests electricity for the McKee refinery in Sunray, Texas.

Valero is additionally a leading ethanol manufacturer with 11 ethanol plants in the Mid-Continent region of the U.S. and a collective production capacity of 1.4 billion gallons per year. Valero also branched into wholesale markets as well as retail and now supplies independently held wholesale outlets carrying its products in Canada, the United Kingdom, Ireland and the United States.

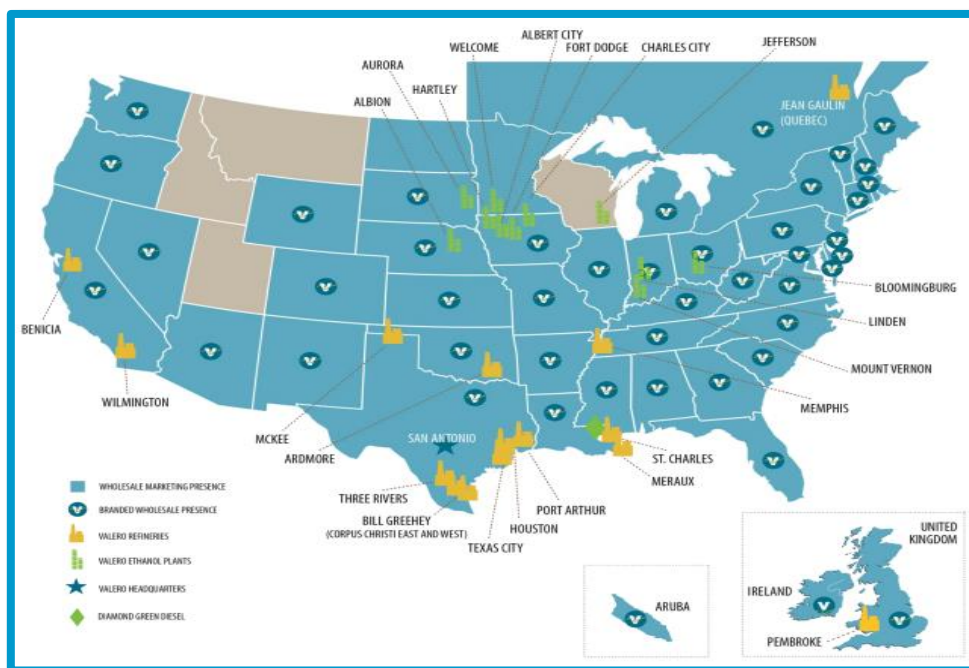


Figure 1: Valero's global operation (Valero Energy Ltd 2018).

In 2011, Valero purchased the Pembroke oil refinery in Wales; along with associated marketing and logistics operations throughout Ireland and the United Kingdom. This marked Valero's entry into the European refining market with personnel including 400 contractors and 600 employees. Pembroke Refinery initially opened its gates in 1964 as a hydroskimmer and today is one of the most complex, largest refineries in Western Europe with a Nelson complexity rating of 11.6. It produces products including liquefied petroleum gas (LPG), petrol, diesel fuel, kerosene, and petrochemical feedstocks.

Valero Pembroke occupies approximately 450 acres of a 1,275-acre site on the southern shore of the Milford Haven Waterway in Pembrokeshire, Wales. The Deep-water port and docks ensure very large tanker ships can be handled without reliance on pipelines or third-party terminals.

Upgrades and installation of special equipment over the years have boosted the plant's complexity and its ability to process difficult crudes, such as acidic, heavy crude. The refinery has several large process units including the Vacuum Distillation Unit (VDU), the Crude Distillation Unit (CDU), The Visbreaker Unit (VBU) and the Fluid Catalyst Cracking Unit (FCCU) all working together to produce the final product. The Fluid Cat-Cracking (FCC) capacity was added in 1982, providing the refinery with large FCC and alkylation units and creating significant volumetric production gains.

The total throughput capacity of Pembroke as an individual refinery is 270,000 barrels per day, including 220,000 barrels per day of crude oil, plus 50,000 barrels per day of other feedstocks, with approximately 10.5 million barrels of storage with half used for feedstocks.



Figure 2: Pembroke Refinery (Valero Energy Ltd 2018).

4. The FCCU Feed Optimisation Project

4.1. The Process Units Involved in the Project

Refineries are comprised of a number of processing units. The types, sizes, numbers, and flow sequences of the units will vary depending on the crude oil quality, desired product type and quality, and the Environmental, Health, & Safety (EHS) constraints. Typically, the units are named for the refining step they are accomplishing. As shown in appendix 1 plot plan there are four main units involved in the Feed Optimisation Project;

- Crude Distillation Unit (CDU)
- Vacuum Distillation Unit (VDU)
- Fluid Catalyst Cracking Unit (FCCU)
- Visbreaker Unit (VBU)

4.1.1. Crude Distillation Unit (CDU) Explained



Figure 3: CDU with main distillation column (Valero Energy Ltd)

The CDU is literally the heart of the refinery, distillation is the base process for refining crude oil and promotes the separation of the many hydrocarbon molecules in crude oil into raw products. These raw products are then further refined into saleable products. Distillation is a process in which a mixture of two or more hydrocarbons are separated by their boiling point temperatures. This is achieved by the application and removal of heat. It is based on the fact that different hydrocarbon components change state from a liquid to a vapor at different temperatures. Lighter components have lower (cooler) boiling points and will vaporise at lower temperatures. Heavier chemical compounds have higher (hotter) boiling points and will require higher temperatures to vaporise. Distillation equipment is designed to take advantage of these differences by heating lighter hydrocarbons to their vapor phase while keeping heavier hydrocarbons in their liquid phase.

The CDU is capable of processing 1500 m³/hr of crude oil which is approximately 226,433 US barrels each day. Imported crude oil delivered via oil tanker vessels is sent to the Crude Distillation Unit (CDU) and then fed into the crude distillation column, it is then split into distillate fractions, or commonly known as “cuts”. This is the initial step in the Pembroke refining process. These main cuts are harvested by heating the column to precise boiling - point ranges, the crude then is separated in terms of its decreasing volatility into residue, gas oils, middle distillates, light distillates, and gases.

Using recovered process heat from other product streams, the crude feed is preheated and directed to fired heaters; it then enters the main crude distillation column (figure 3) close to the bottom at a temperature of approximately 342.8 °C and at a pressure just above atmospheric. Horizontal steel trays for separating and collecting the liquids are housed in the column, this maximises liquid/vapour contact and improves separation. Vapour from below enters valves and perforations, which permits the vapours to bubble through the liquid on the above tray, this causes condensation at the temperature of that tray. As they rise through the column the lighter fractions' temperatures are reduced, resulting in their condensation. The condensate is drawn off by overflow pipe drains which forms uncondensed gases, kerosene, naphtha and heating oils from the top portion of the column. The residue from the process settles at the bottom of the column, then it is removed and used as VDU feed. Figure 4 represents the main fractions of the crude distillation column.

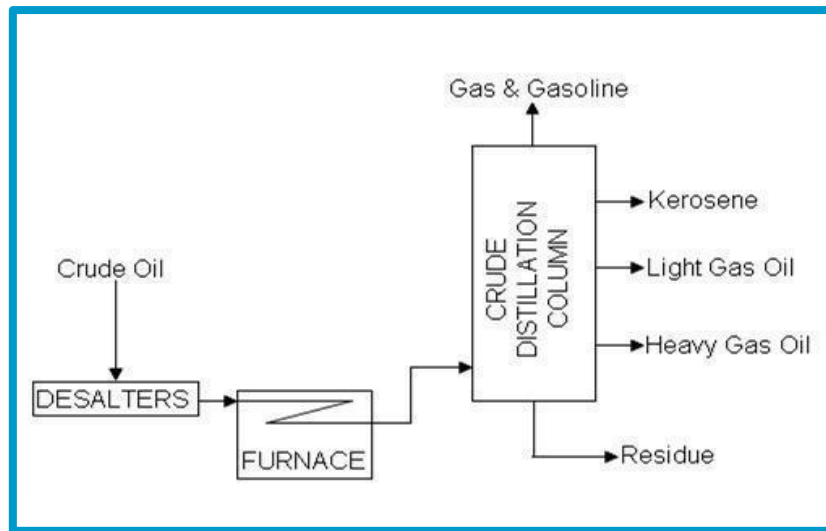


Figure 4: CDU products (Valero Energy Ltd 2018).

4.1.2. Vacuum Distillation Unit (VDU) Explained



Figure 5: Vacuum Distillation Unit including main vacuum column (Valero Energy Ltd 2018).

The VDU can achieve a process rate of 640m³/hr; it is designed to re-distil the residue sent from the CDU, to provide a low carbon and low metal content feedstock to the FCCU. These carbon compounds, or asphaltenes and metals, are undesirable to the FCCU feed because they lay down coke on the catalyst. The hot atmospheric residue from the CDU and some cold residue from storage, feeds the VDU. The variations in feed is evened out to ensure a steady feed through two parallel heaters. The then partially vaporised feed enters the flash zone of the vacuum column (Figure 5) where it is then separated into products. Vacuum towers operate at very low pressure (vacuum pressure) maintained by a vacuum pump and /or vacuum jets. By lowering the pressure in the tower, the boiling point temperature for the residue is also lowered. The lower boiling point temperatures cause the lighter hydrocarbons from the residue to vaporise at much lower temperatures than in crude unit distillation. Any remaining vacuum tower bottom residue material (VTB) that will not vaporise, is sent to the VBU to be made into products such as asphalt/bitumen and heavy gas oils.

The products from the vacuum column are represented in Figure 6. These are diesel, light vacuum gasoil (LVGO), heavy vacuum gasoil (HVGO) (which combined, make the primary feedstock for the FCCU) and heavy bottoms product vacuum residue (which as mentioned above makes up the feedstock for the VBU).

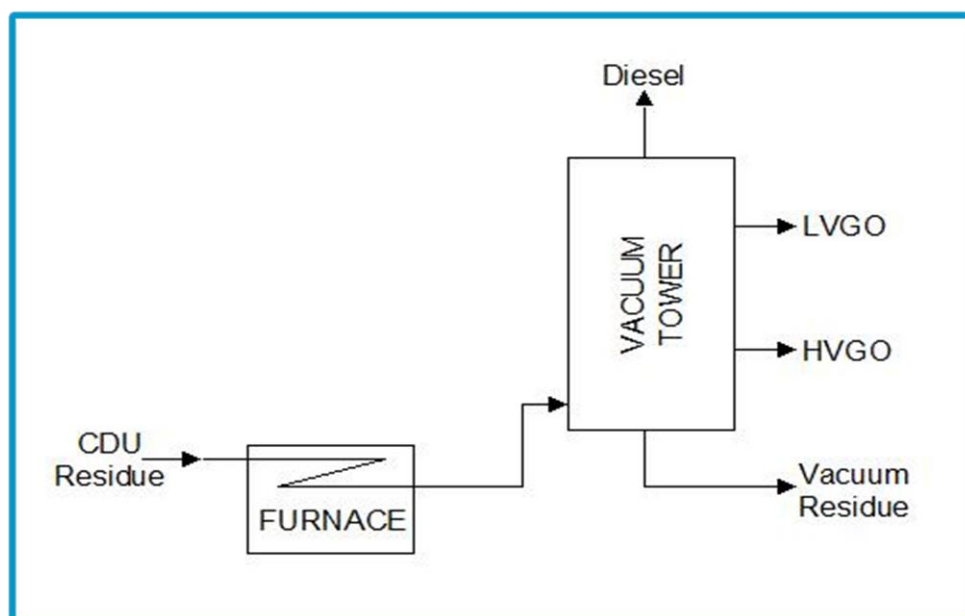


Figure 6: VDU process and products (Valero Energy Ltd 2018).

4.1.3. Fluid Catalyst Cracking Unit (FCCU) Explained

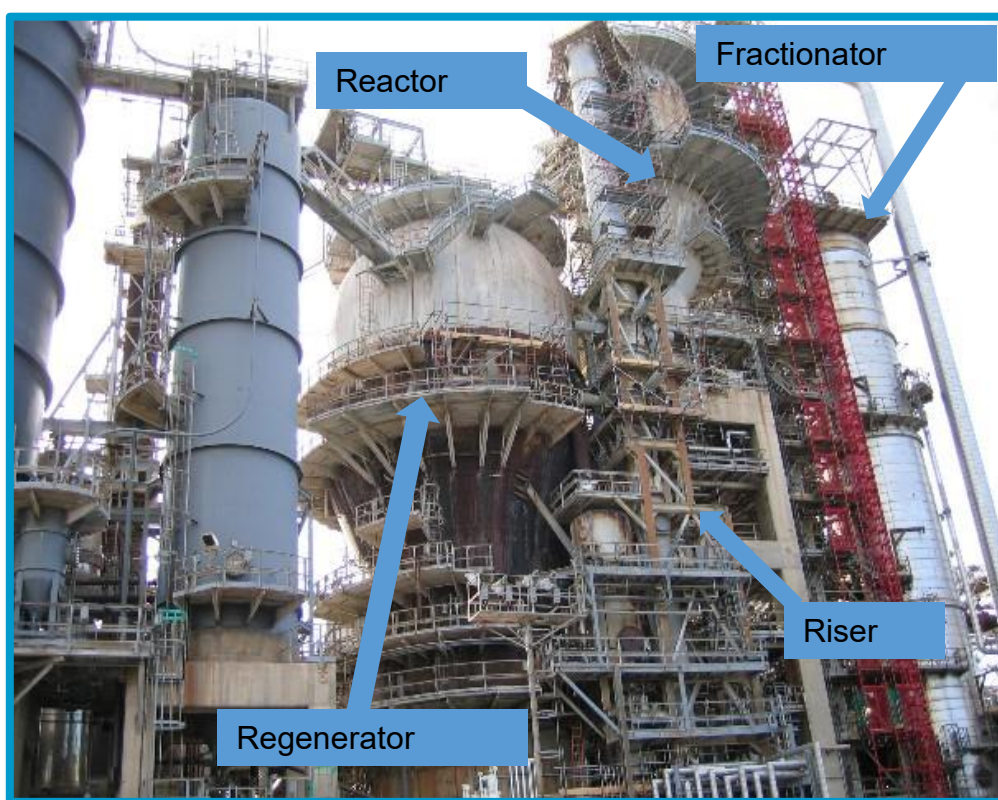


Figure 7: Fluid Catalyst Cracking Unit (Valero Energy Ltd 2018).

In order to refine heavier products one of the processes Pembroke use is 'fluid catalytic cracking' which cracks long complicated chains of hydrocarbon molecules into shorter more valuable molecule chains, this can then be used to produce fuels such as expensive high-octane petrol or used as a feed stream for other more profitable processes.



The FCC Vacuum gasoil (LVGO/HVGO) feed stream from the VDU is heated along with expensive imported residue to a high temperature, it is mixed with a very fine zeolitic alumina catalyst powder in the riser, then vaporises and continues up to the reactor. The reactor separates the cracked Hydrocarbons from the catalyst using cyclones. The catalyst is a solid substance that initiates or accelerates the chemical reaction needed to crack the heavy gas oils into light gases, petrol, and distillates. The catalyst is heated to 541°C and is fluidised using steam and air to allow the catalyst to flow like a liquid. Over time, the catalyst becomes covered in carbon ("coke") and is considered "spent." Spent catalyst is sent to a regenerator section where air burns the carbon off of the catalyst.

The catalyst is then sent back to the reactor (Figure 7). Hot gases produced during regeneration are recovered in a waste heat boiler that converts water into steam. This steam is used by different areas of the refinery.

The hydrocarbon vapor from the reactor is fed into the fractionator. The FCC fractionator operates in the similar manner as the crude oil distillation tower. In the FCC fractionator, the lighter hydrocarbons vaporise and rise, while the heavier hydrocarbons fall. The overhead vapours are sent to a gas plant to recover hydrogen and olefins. An olefin is a high-quality hydrocarbon compound that does not occur naturally in crude oil.

As shown in Figure 8 products of the FCC process include: off gas to fuel gas system, propane, butane, olefins to the Alkylation unit, FCC petrol (cat gas), FCC Naphtha (cat naphtha), light hydrocarbon vapours, LCGO, slurry or HCGO, steam from heat recovery to various users.

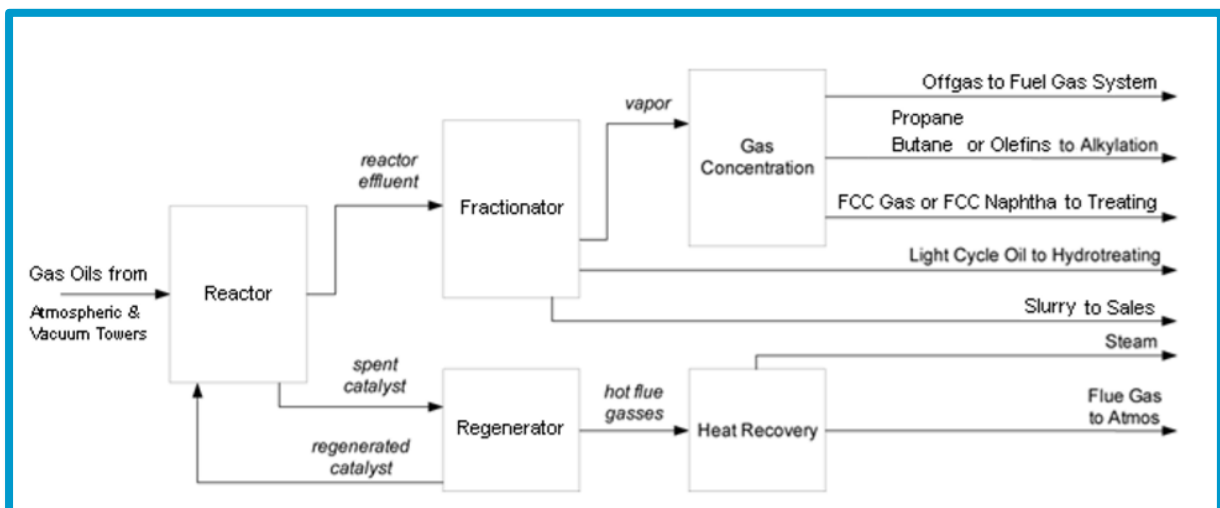


Figure 8: Typical FCCU process and products (Valero Energy Ltd, 2017).

4.1.4. Visbreaker Unit (VBU) Explained



Figure 9: Visbreaker unit (VBU) (Valero Energy Ltd 2018)

The complex composites of vacuum residue from the VDU are broken down to recover lighter products using thermal cracking. The back end of this unit has a distillation column that separates out the new products, which, as shown in Figure 10 are LPG, naphtha, gasoil and vistar (Bitumen/Asphalt). The vistar is blended with light cycle gas oil and heavy cycle gas oil (LCGO and HCGO) from the FCCU to give a fuel oil suitable for use in industry and also used in the refinery fired heaters.

Thermal cracking decreases the molecular size of the hydrocarbons by application of heat without the addition of catalyst or hydrogen. Larger hydrocarbon molecules become unstable at a temperature of 722-773 °C and break into smaller molecules, therefore by varying temperature, along with residue time and pressure, the desired degree of cracking can be controlled.

The hot vacuum residue is fed to the VBU's surge drum at about 285 °C, where it is then routed to a series of exchangers and then to the feed heater. This heater raises the temperature to about 450 °C and here the thermal cracking begins. The feed is then routed to the soaker, where the main cracking reaction takes place during a 10-15-minute residue time.

The cracked feed then leaves the soaker via a pressure control valve, which maintains a back pressure on the soaker and heater. This feed is then “quenched” to reduce its temperature by 50 °C before entering the fractionator. The fractionator (a sophisticated distillation column) separates the cracked feed into its products.

The initial use of high viscosity units was to produce petrol. Today, at the Pembroke Refinery, thermal cracking is used primarily to visbreak short residue (vacuum tower residue) to produce bitumen/asphalt, naphtha to ethylene gas (and chemicals) and wax to olefins for the manufacture of chemicals.

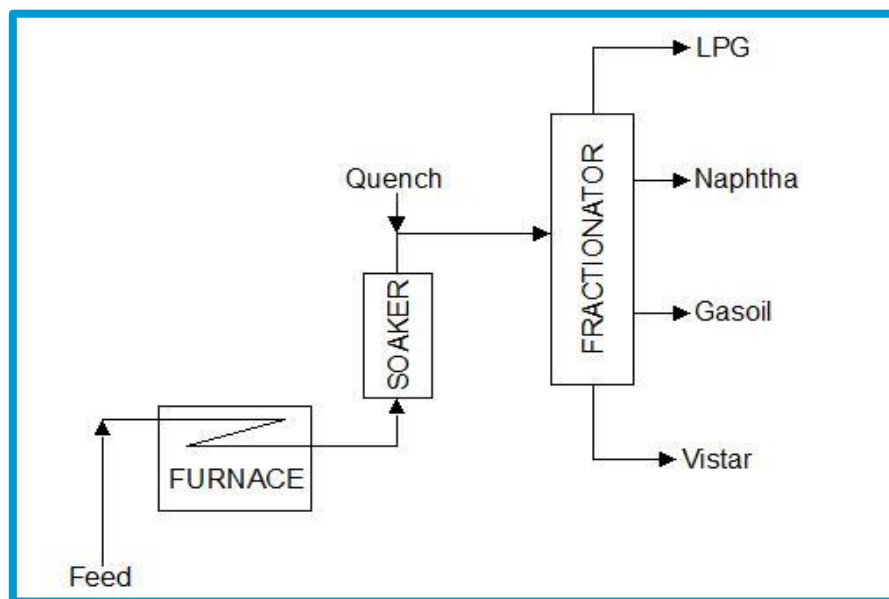


Figure 10: VBU process and products (Valero Energy Ltd 2018).

4.2. FCCU Feed Optimisation Basis of Design

The objective of the project is to provide the refinery with a flexible feed system for the FCCU that allows the plant to process heavier feeds when it is economical to do so. Pembroke Refinery has limited flexibility to route internally generated residue and overflash to the FCCU. All Pembroke's vacuum tower bottoms residue is routed to the Visbreaker and the overflash is looped back into the VDU tower (Figure 11), there is no system to route either to the FCCU. In order to guarantee the quality of the gas oil fractions in an oil refining distillation column, more crude must be flashed than is possible to recover (more vaporisation to take place than is actually necessary).

Overflash is the liquid flowing from the lowest tray above the flash zone in the column and according to Jones (2006), its purpose in the process is to provide extra heat in order to generate sufficient reflux down flow over the trays to satisfy the prescribed degree of separation between the products, basically to provide liquid wash to the vapours going up the column from the flash zone to improve distillation on the trays above the flash zone. Overflash is usually fixed at between 3 and 5 percent volume on crude. The VTB residue is simply the left-over bottom product of the distillation (Figure 11).

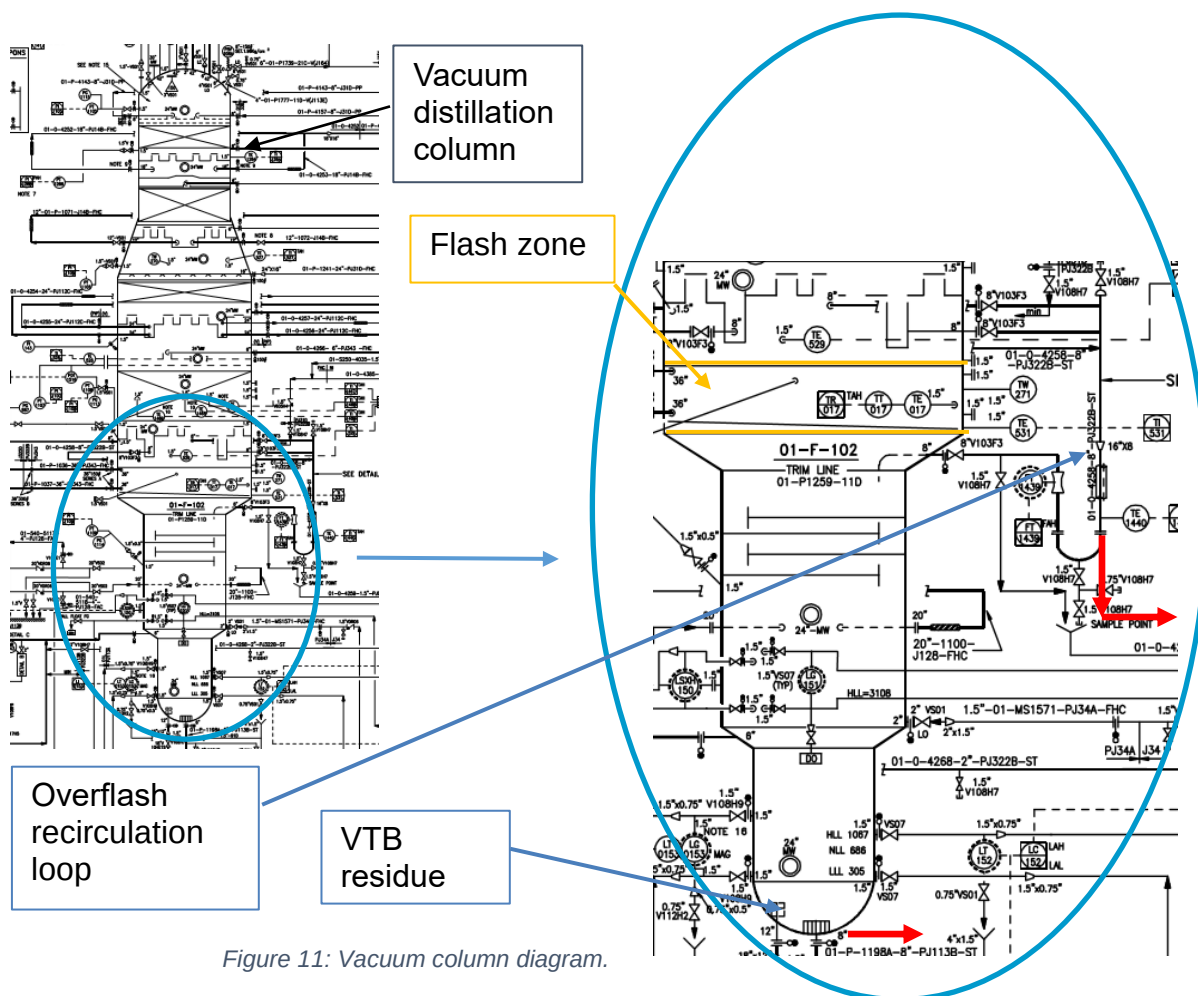


Figure 11: Vacuum column diagram.

Figure 11, displays a section of Pembroke Refinery's vacuum column (Appendix 2 displays the full P&ID). The blue arrows point out the existing overflash loop and bottoms residue section. The red arrows show the new proposed take offs to the FCCU and the yellow section points out the flash zone of the column.

The FCC Feeds Optimisation project will provide means to transfer heavy VTB residue and overflash material from the VDU to the FCCU together with the existing LVGO, HVGO and partial CDU residue feed, so as to increase the refinery output of higher value materials at the same time as reducing production of low margin fuel oil. The project will also provide means to route HCGO slurry from the FCCU to the VBU so as to maintain VBU feeds at minimum permissible feed-rates.

By rerouting VTB residue to the FCCU this in turn takes away VBU feed. However, FCCU slurry (HCGO) has been identified as a very good source of feed for the VBU and can replace the VDU residue that will be sent to the FCCU.

At present expensive residue imports are being bought in to spike the FCCU line while downgrading internally generated VTB residue to low value fuel oil blend stock (VBU feed). At other Valero sites in America VDU overflash is used to spike the FCCU feed with heavier components and some sites also use VDU residue. Overflash benefits does outweigh VTB residue by approximately 3:1 due to reduced metals and carbon, which means less catalyst is required and less residue needs to be processed overall.

The first part of the project is relatively straight forward and mainly pipework, the second part however is more complex and comprises of new pumps and a new heat exchanger (overflash cooler) as well as more substantial piping and instrument modifications.

One of the major problems of the project is that the overflash removed from the VDU column must be cooled to the right temperature to serve as FCCU feed. This heat removed from the VDU column will in turn be lost from the VDU residue stream which is already exchanged with flashed crude feeding the CDU. Therefore, in order to maintain the same CDU feed temperature, flashed crude will be used to cool the overflash stream.

VDU overflash, at around 400°C will be withdrawn from the VDU Column and fed to new pumps. From the pumps the process material will pass through the new exchanger where it will interchange with the flashed crude and be cooled to 200°C. It will then join the existing transfer line to the FCCU where the combined feed temperature will be around 190 to 200°C.

Figure 12, explains via flow diagram the Units Pre FCCU Feed Optimisation Project, Figure 13, explains post FCCU Feed Optimisation and Appendix 3 shows an overall flow scheme.

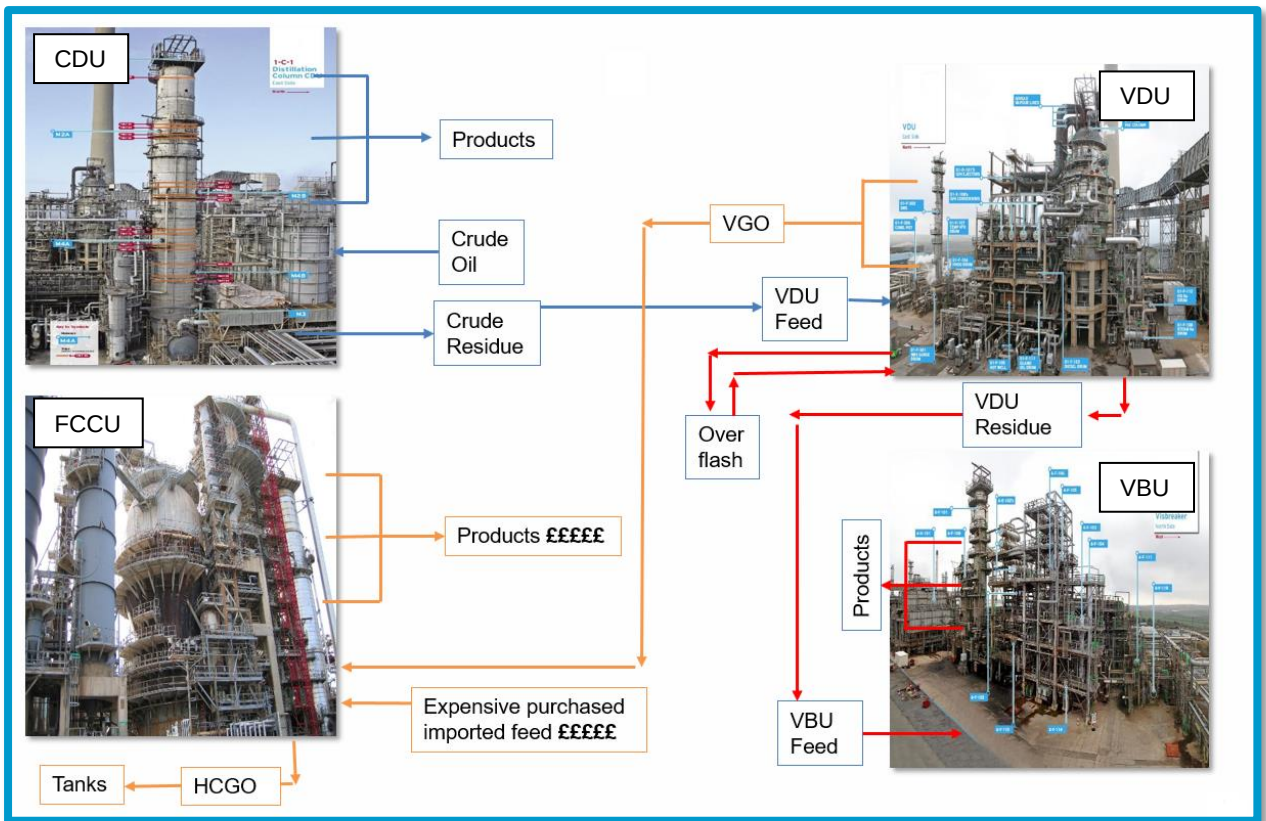


Figure 12: Units pre FCCU Feed Optimisation Project flow diagram.

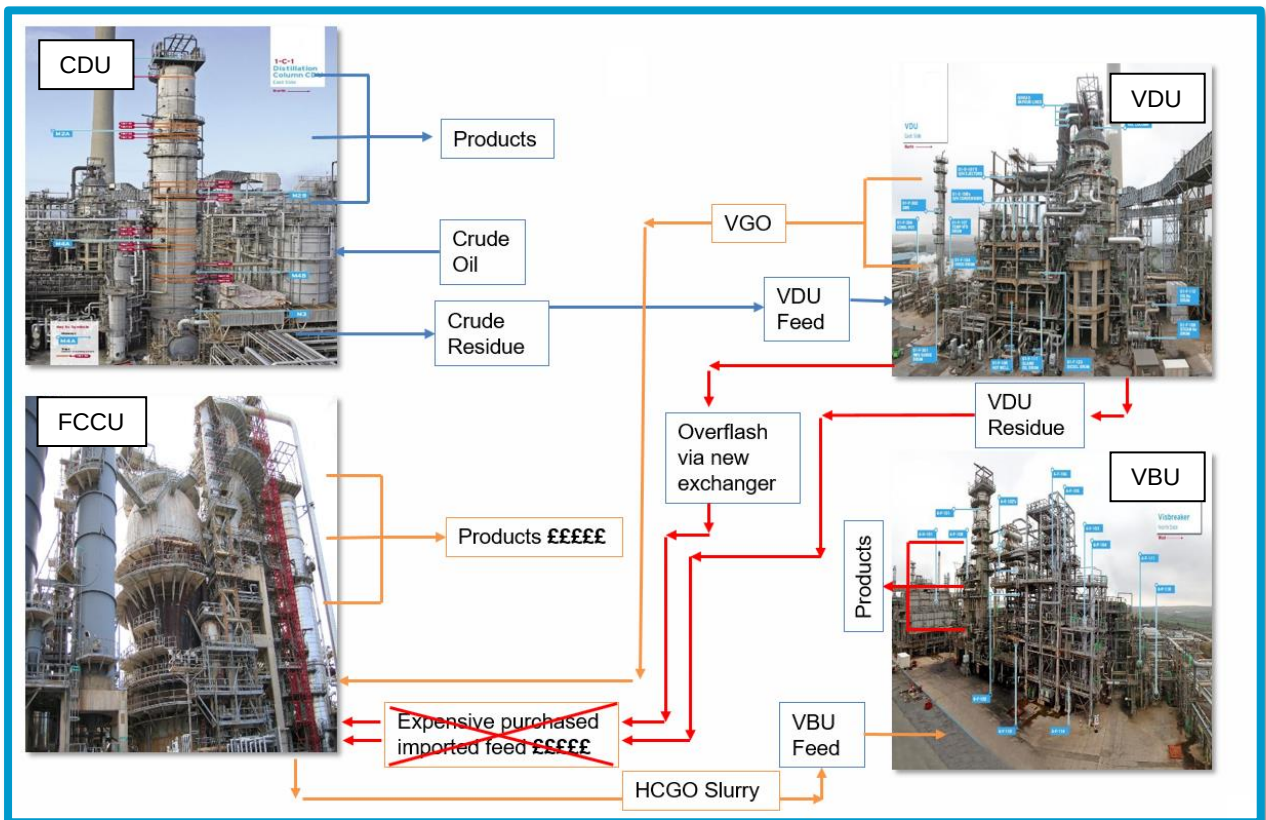


Figure 13: Units post FCCU Feed Optimisation Project flow diagram.

4.3. Overall Pembroke FCC Feed Optimisation Project Cracking Economics

Using historic data along with Monte Carlo Analysis which was gathered and generated by Valero Energy Ltd (2016) a projection of the cracking economics of using overflash and VTB together was produced.

The following line graphs (Figure 14) use EBITDA vs Time, where the EBITDA (earnings before interest, tax, depreciation and amortisation) is a measurement of a business's operating performance. It is a method to gauge a business's performance without taking into consideration financing decisions, accounting decisions or tax environments.

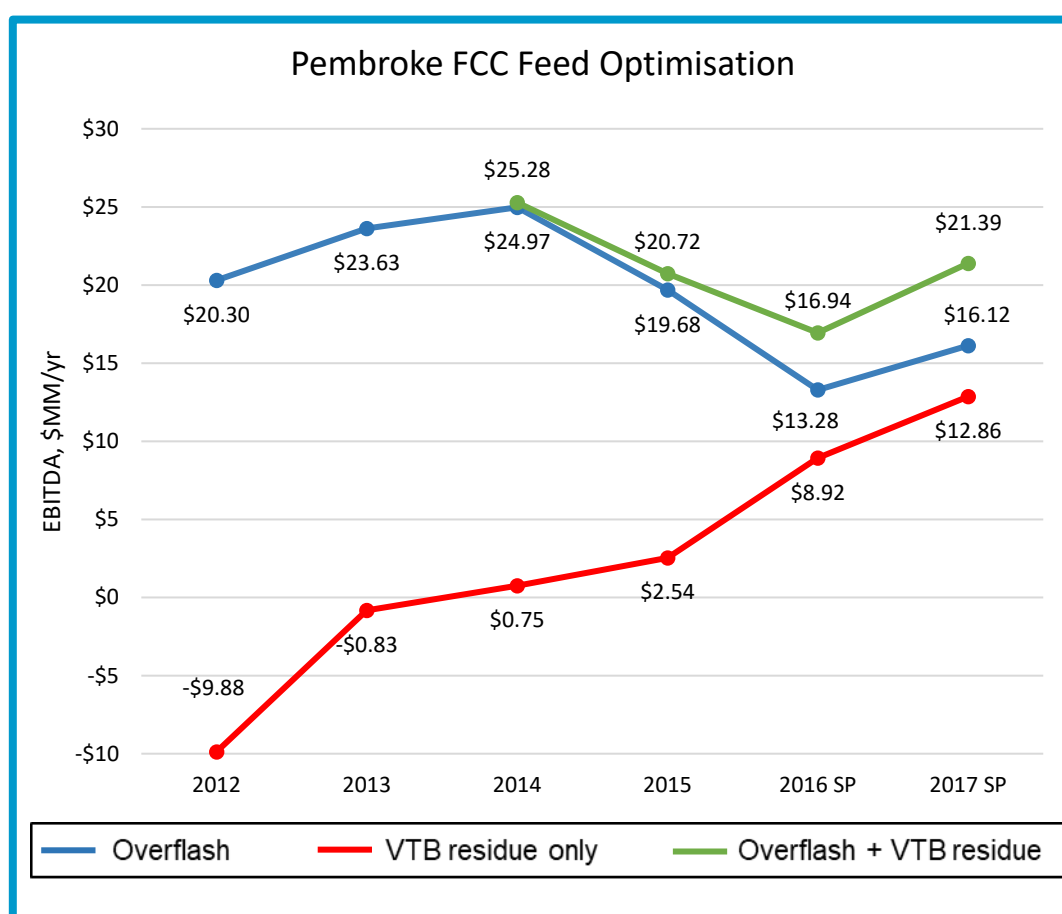


Figure 14: Overflash and VTB Economics (Valero Energy Ltd, 2016)

The data shows that although using VTB residue between 2012 and 2014 would have resulted in negative EBITDA it started to rise and from 2014 to 2017 there could have been potential average EBITDA of \$21MM/yr (£14,958,720.00) using VTB residue and Overflash together as a spike for the FCCU feed and not purchasing imported residue. That totals to £59,834,880.00 EBITDA over the four years. This is based on approximately £7,000,000 capital project expenditure.

4.4. Environmental Impact of the Project.

Carbon dioxide (CO₂) is classed as a greenhouse gas, it is the main pollutant that is warming the Earth. Although living beings release CO₂ when they breathe, CO₂ is generally considered to be a pollutant associated with planes, road vehicles, power plants, oil refineries and other large industry operations that are involved in the processing of fossil fuels such as crude oil, coal and natural gas. In the last two centuries pollution of this kind has pumped enough CO₂ into the atmosphere to increase its levels greater than they have been for hundreds of thousands of years, the last time there was this much carbon dioxide CO₂ in the Earth's atmosphere, modern humans didn't exist (Freedman, 2013). Figure 15 shows the increase in atmospheric CO₂ concentration (ppm) compared to what it has been over the last 800,000 years.

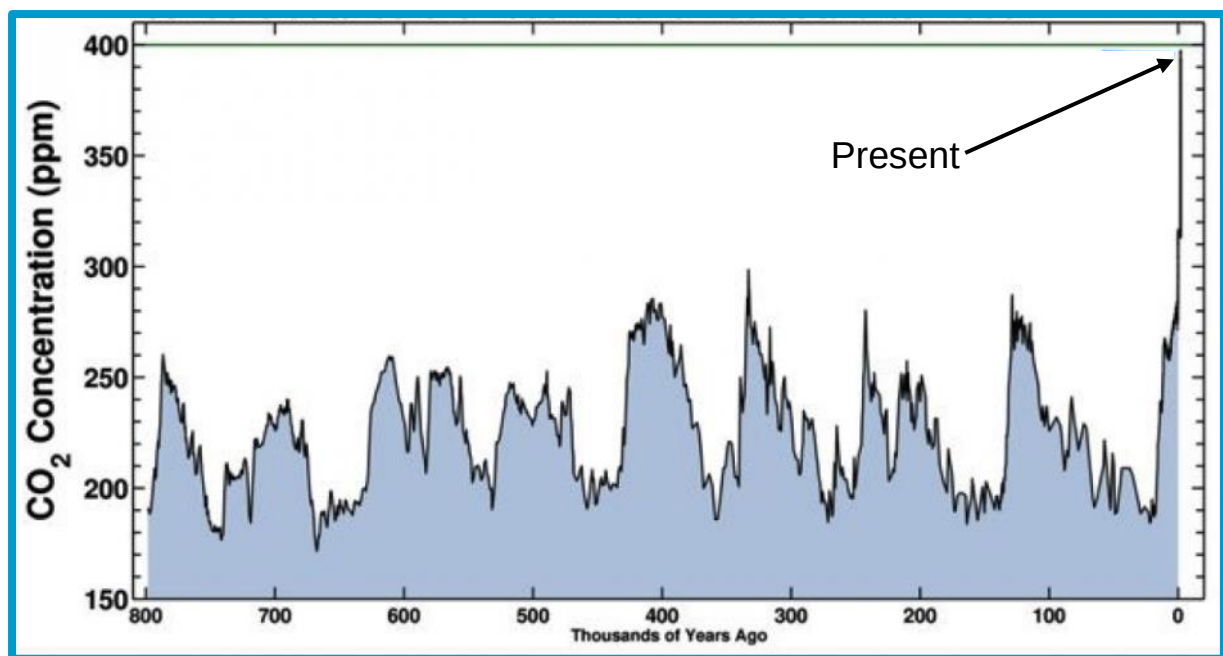


Figure 15: CO₂ levels parts per million (ppm) over the past 800,000 years compared to today (Freedman, 2013).

According to Froggatt (2015), at the turn of the century there was an increasing awareness within EU institutions and between Members States that meeting internationally agreed climate targets along with addressing increasingly globalised energy concerns required common action. This concern was subsequently addressed through two 'packages' of legislation for climate and energy. Firstly in 2007 processes begun which ultimately led to legislation in 2009 to the adoption of the first joint climate and energy package, which set key (and in some cases legally binding) targets for 2020. The first of these targets was a 20 percent reduction in greenhouse gas emissions (GHG) from 1990 levels (European Council, 2009).

The European Environment Agency (2014) stated that the EU is expected to achieve the 2020 target early. Froggatt (2015) suggests that there is an argument that the 2020 target was relatively unambitious and a greater target could have been met. This could be related to the decision made by the European council in 2014 regarding targets and objectives for energy and climate for 2030 where they increased the targets to a vast 40 percent reduction by 2030 in greenhouse gas emissions from 1990 levels (European Council, 2014). Figure 16 displays trends and projections and long-term targets for EU CO₂ (per million tonnes) emissions set by the European Council.

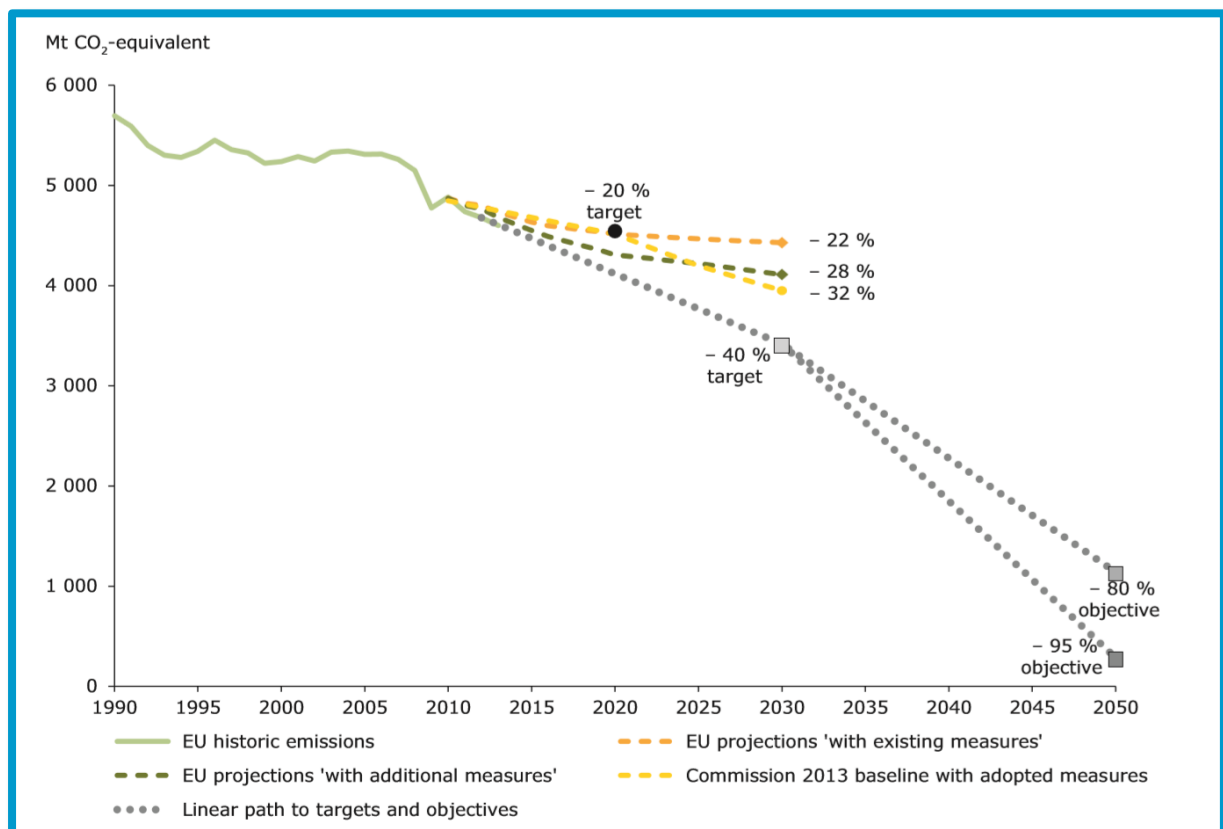


Figure 16: EU GHG per million tonnes emission trends and projections, and long-term targets (European Environment Agency, 2016)

It can be understood from the data above that in an industry which is one of the main contributors to CO₂ emissions there is a huge amount of pressure in keeping the CO₂ footprint of Pembroke Refinery to a minimum; hence, there is a lot of focus on the environmental impact when initially planning projects. Not only will the FCCU Feed Optimisation Project generate more revenue for the refinery it will also reduce the refinery's environmental CO₂ footprint, this not only is good for the environment but also has business advantages. Companies receive or buy emission allowances which they can trade with one another as needed so if emissions are low, emission allowances can be sold.

Pollution is a type of waste and any organisation that imports, produces, collects, transports, recovers or disposes of or operate of waste must take into account the waste hierarchy pyramid (Figure 17) when choosing a waste management option for their waste. This tool can be used as a measure against the FCCU Feed Optimisation Project to extract the maximum practical benefits from the product and to generate the minimum amount of waste.

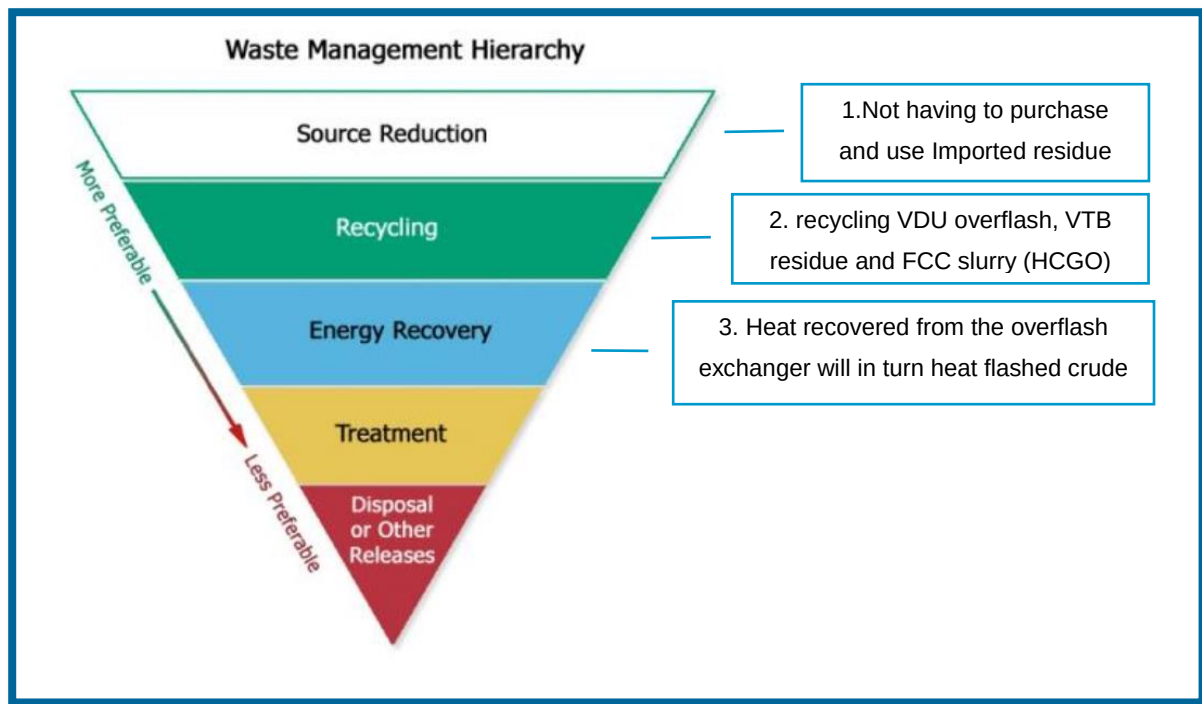


Figure 17: Waste Management Hierarchy (United States Environmental Protection Agency, 2016)

1. Source reduction - Not having to purchase imported residue, thus reducing the source, means less large pollutant oil tanker vessels travelling to and from the oil refinery. To put this into numbers there is approximately 45m³/hr of overflash available to heavy up the FCC feed and replace expensive imported residue. This can then be supplemented by the remaining 40m³/hr of VTB residue reducing further the reliance on expensive residue imports. That's 85m³/hr feed needed to spike the FCCU feed line meaning 2040m³ per day (24-hour shift) and 744,000m³ per year.

The U.S Energy Information Administration (2014) state that the most common long range (LR) class oil tanker vessels in the global fleet carries between 54,850.6m³ and 97,777.2 m³ (between 345,000 and 615,000 U.S barrels). Using an average of 76,313.9m³ and dividing the yearly residue feed needed by this (744,000m³/76,313.9m³) it can be calculated that using VTB residue and overflash to spike the FCCU instead of purchasing imported expensive residue would save ten oil tankers a year coming to the Pembroke Refinery.

These oil tanker vessels would potentially be travelling from different parts of the globe so the reduction in CO₂ emissions will be massive. A comprehensive study carried out by the International Maritime Organization (2015) revealed that international shipping emitted 796 million tonnes of CO₂ in 2012, which accounts for 2.2 percent of the total global emission volume for that year.

2. Recycling - Although VTB residue is already recycled to the VBU, it is turned into products like bitumen/asphalt and industrial fuel oil. By using it as an FCC feed it can potentially be manufactured into Ultra-Low Sulphur Petrol in a FCC post process thus potentially reducing GHG emissions in petrol driven vehicles. The same applies for overflash that would usually be recirculated to the bottom of the vacuum tower and end up as VTB residue.

The FCC HCGO slurry is a by-product from the catalyst cracking process and is generally sent to onsite tankage and sold off as heavy fuel oil, again via oil tanker vessels. Recycling this product, using it as VBU feed, cuts out additional pollutant oil tanker vessels and it can be made into supplementary recycled sellable products.

3. Energy recovery - Heat energy recovered from the overflash will in turn be exchanged with flashed crude, via the new heat exchanger raising the temperature of the flashed crude; thus reducing energy required by the CDU heaters meaning less heater fuel oil being used which results in emitting less pollution from the heater chimneys.

5. Choice of Overflash Cooler (Heat Exchanger).

As previously mentioned, one of the main problems for the FCCU Feed Optimisation project was finding a cost-effective way of cooling the VDU overflash to serve as a suitable FCCU feed. A heat exchanger needed to be selected; however, there is limited space on an already crowded refinery and next to the vacuum distillation tower is no exception. To add to this VDU overflash is a heavy fouling process, so high maintenance of the heat exchanger was expected, which involves specialist engineering companies and heavy specialist large in-situation machinery.

5.1. Pembroke Refinery Heat Exchangers in General.

Heat exchangers come in many shapes and sizes and are used in refineries to transfer heat from a hotter fluid to a cooler fluid, this transfer cools the hotter fluid as it loses heat, and it heats the cooler fluid as it gains heat.

As defined by Atkins et al. (2013) heat is a form of energy that is transferred across the boundary of a system at one temperature to another system at a different temperature by virtue of the temperature difference between them. Heat transfer is the transport of energy due to a temperature difference within a solid object or stationary fluid, between solid objects or between a solid object and a fluid.

Heat exchangers have three main functions on an oil refinery;

- Recovery of heat energy that would otherwise be lost maximising the refinery's efficiency.
- Heating or cooling a process fluid to control the temperature.
- Change the phase in a fluid by evaporation or condensation.

5.1.1. Methods of Heat Transfer

Heat exchangers are the main refinery equipment for transferring heat. The process of a heat exchanger is reliant on, according to Valero Energy Ltd (2017), two methods of heat transfer; convection and conduction.

Conduction - is the mode of heat transfer in which energy exchange happens in solids or fluids at rest due to an internal temperature rise. Direct physical contact between interacting systems is required for conduction to occur. In a heat exchanger, a hot fluid flowing on one side of a metal wall conducts heat through the wall to the other side of the wall via conduction. The heat is then transferred from the metal wall to the cooler fluid also by conduction. The transfer of thermal energy occurs at atomic levels when a fluid is heated, the molecules will gain more energy, and vibrate more.

These molecules then collide into nearby molecules and transfer some of their energy. This then continues and passes the energy from the hot side of the metal wall across to the colder side as displayed in figure 18 below.

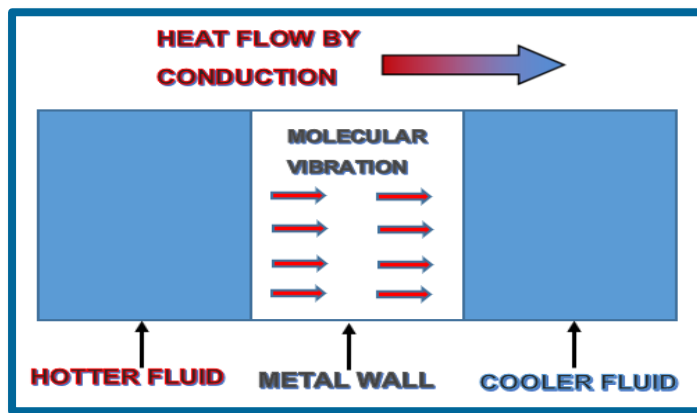


Figure 18: Heat transfer by Conduction.

Convection - is the transfer of thermal energy from hotter molecules to cooler molecules through a gas or liquid due to bulk motion (turbulent mixing action) of the fluid. Convection is the most imperative mechanism for thermal energy transfer between a moving fluid and a solid. Convection can either be free or forced, in the case of the overflash cooler and most heat exchangers on the Pembroke Refinery convection is forced due to an external source such as a pump. As fluid flows through the heat exchanger, the hotter molecules transfer heat to the cooler molecules via convection as they mix. This mixing is due to the density variances of the fluids. Hotter fluids are less dense and rise, whereas cooler fluids are denser and fall (Figure 19). The greater the turbulence in the mixing, the greater the convective heat transfer. Mixing also happens because of the friction effect of the tube surface on the flowing liquid.

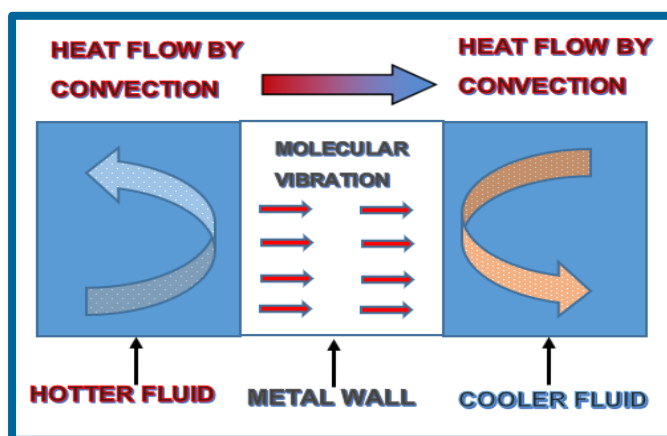


Figure 19: Heat transfer by Convection.

5.2. Shell and Tube Heat Exchangers

The most common type of heat exchanger on the Pembroke Refinery is a shell and tube exchanger (STE) (Figure 20). STE's are typically made from carbon steel but in special cases

can be made from stainless steel, they are of simple design with a cylindrical shell with inlet and outlet nozzles and a series of tubes (tube bundle) running through the shell.

Baffles are frequently used inside the shell to increase the efficiency of the heat exchanger.



Figure 20: Typical Refinery Shell and Tube Heat Exchanger (Valero Energy Ltd, 2017)

There are numerous main parts in a STE including; the Channel Head and Baffles Head, Inlet and Outlet Nozzles, Shell, Baffles, Tube Sheet and Tube Bundle. Figure 21 beneath displays how a general STE is constructed.

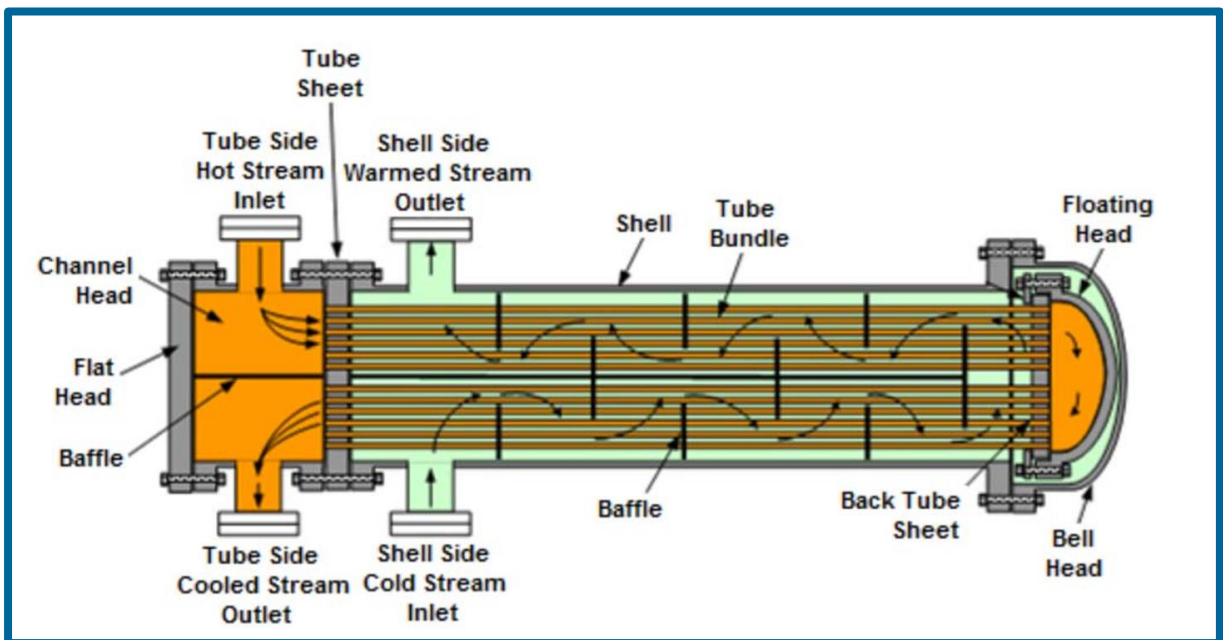


Figure 21: STE components (Valero Energy Ltd, 2017)

The shell holds the fluid that flows on the outside of the tubes (shell side flow). The shell also supports all internal mechanisms and provides for mounting of the heat exchanger to its external supporting structure. The shell side fluid flows over the tubes and around several vertical baffles; the baffles not only hold the tube bundle in place but cause constant changes in the directional flow of the fluid which results in more agitation, improved fluid flow within the tubes, as well as increased turbulence and reduction in hot spots.

The design of a heat exchanger varies with their purpose, one of the main design characteristic is the fluid flow pattern, which actually affects the rate of heat transfer. There are three basic flow patterns used in an STE; parallel flow, counter flow and cross flow.

Parallel Flow – also known as co-current in this configuration both tube side fluid and the shell side fluid flow in the same direction entering at the same end of the heat exchanger. The temperature difference between the two fluids is the greatest at the entrance to the exchanger. As the fluids transfer heat, hotter to colder, the temperature of the two fluids approach each other but the TH fluid always remains higher than the TC fluid (Figure 22).

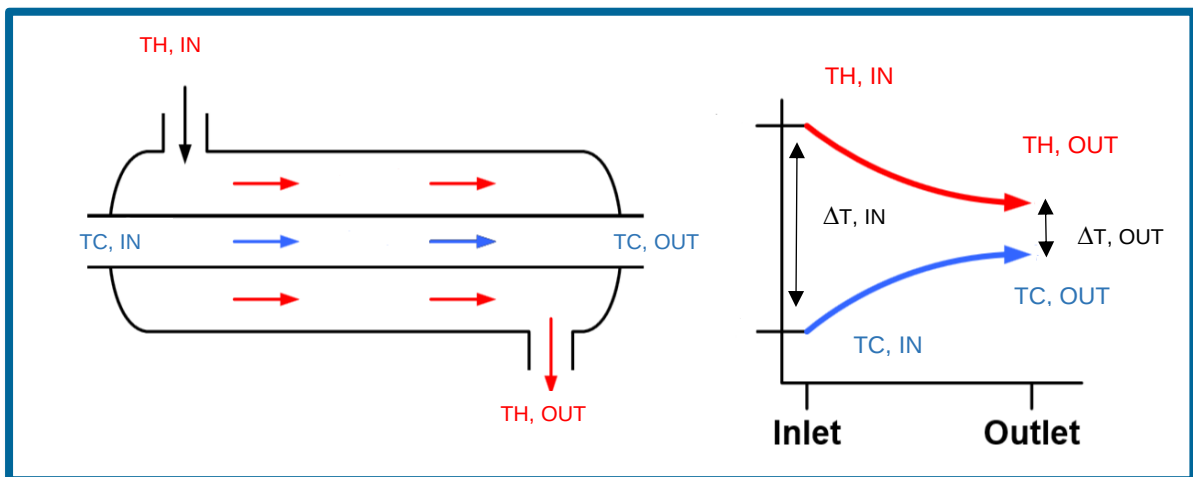


Figure 22: Parallel Flow Heat Exchanger

Counter Flow – in this configuration the two fluids enter the heat exchanger at opposite ends and flow past each other in opposite directions. Counter flow heat exchangers are the most efficient of the three types the flow pattern maximises the average temperature difference throughout the exchanger. Contrary to the parallel flow heat exchanger, counter flow heat exchanger's hottest TC fluid can accomplish a higher temperature than the coldest TH fluid (Figure 23).

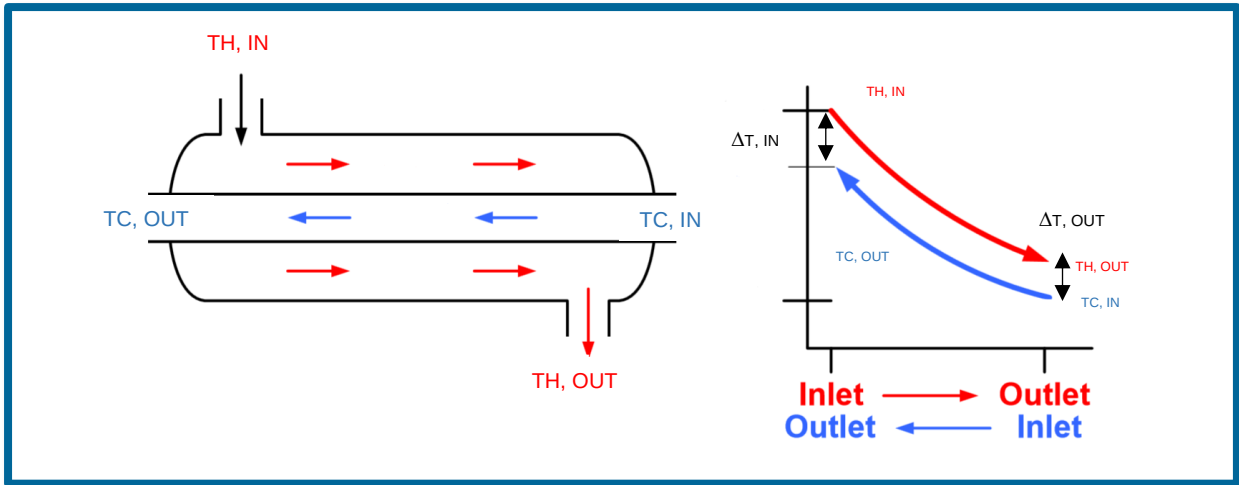


Figure 23: Counter Flow Heat Exchanger

Cross Flow – in this configuration one fluid flows perpendicular to the second fluid. As shown in Figure 24 below the first shell side fluid passes through the tubes at a 90° angle. This heat exchanger is commonly used in processes, such as condensing, where one of the fluid will change state (2-phase flow).

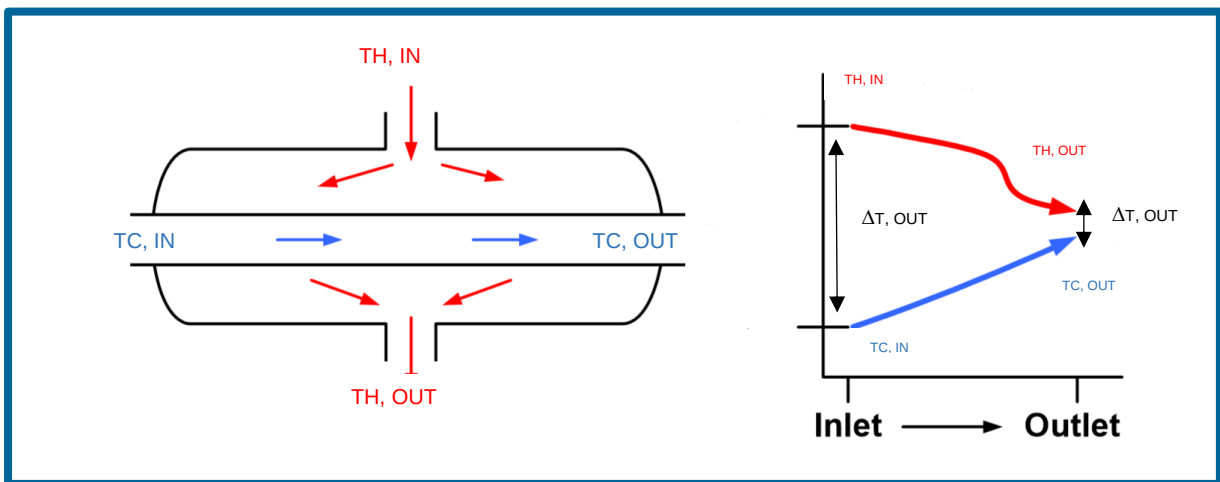


Figure 24: Cross- Flow Heat Exchanger

An additional design characteristic of an STE is the amount of passes the process fluid makes when flowing through the exchanger. 'Passes' refers to the number of times the fluid in the tubes pass through the fluid in the shell or the fluid in the shell passes the fluid in the tubes.

There are generally two pass arrangements; single pass and multi-pass. Multi-pass can be double pass and four pass configurations, although custom multi-pass heat exchangers with yet more numbers of passes are also attainable. A single pass is the simplest STE, both process fluids travel in one direction, not necessarily the same direction from the point of entrance to exit.

The tube bundle comprises of straight tubes joined to fixed tube sheets on each end. A multi-pass heat exchanger is a little more complicated and designed so that the tube side fluid flow is channelled through the tube bundle additional times. This flow configuration is made possible by the channel head on the end of the exchanger, which holds baffles to direct the fluid flow in two or more directions.

The shell side flow can likewise be multi-pass by utilising longitudinal baffles, which splits the shell side into two. Figure 25 displays the workings of a single and multi-pass STE.

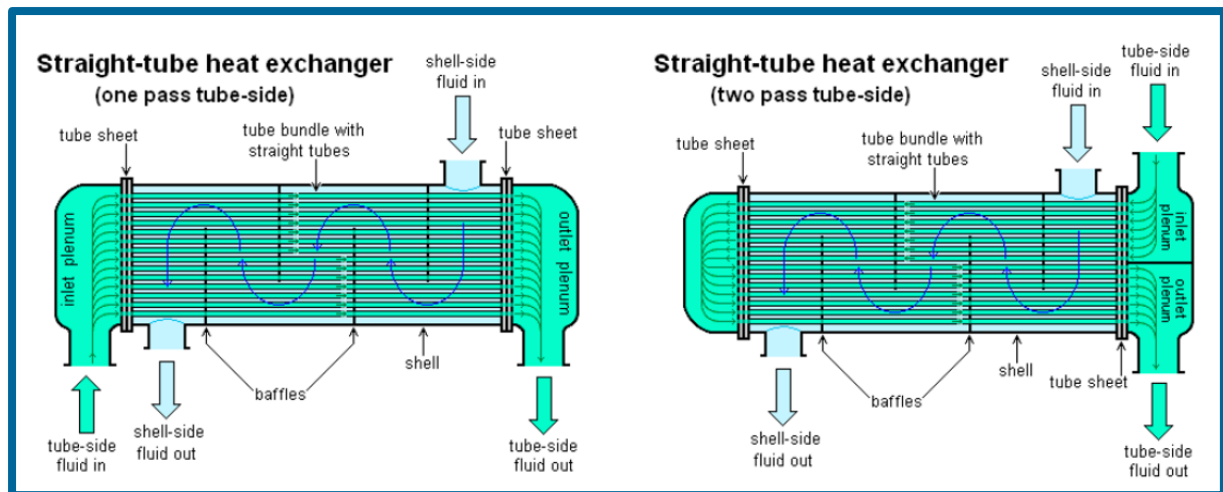


Figure 25: Single and Multi-Pass Heat Exchanger (Bright Hub Engineering, 2016).

5.2.1. Fouling in Refinery Heat Exchangers and Maintenance

There are several major failure mechanisms related to a heat exchanger on an oil refinery these include;

- **Exceeding unit design** - operating outside of the exchanger's design specific range of temperatures and pressures.
- **Air or vapor binding** - a consequence of non-condensable matter caused by improper venting.
- **Tubes and/or internal gasket leaks** – higher pressure fluid leaking into the lower pressure fluid.
- **Fouling** – build-up of deposits in tubes and other areas where fluid flow is most easily restricted.

Out of these mechanisms a heavy process STE such as an overflash cooler is likely to be more commonly susceptible to fouling, due to the heavy fouling nature of the crude/overflash refining process it would be in.

Fouling as described by Ibrahim (2012) is the deposition and accumulation of unwanted materials such as scale, algae, suspended solids and insoluble salts on the internal or external surfaces of processing equipment including heat exchangers in areas where flow is most easily restricted. Heavier refinery process exchangers can suffer from fouling, constant fouling ultimately leads to plugging of the tubes and baffle area between tubes. Fouling has two common build up areas or “dead zones” as they are also known, inside the tubes and in the corners of the baffle plates which is agreed with by Ibrahim (2012) who states that in a shell and tube heat exchanger, the conventional segment baffle geometry is largely responsible for higher fouling rates, shown in red on Figure 26 below.

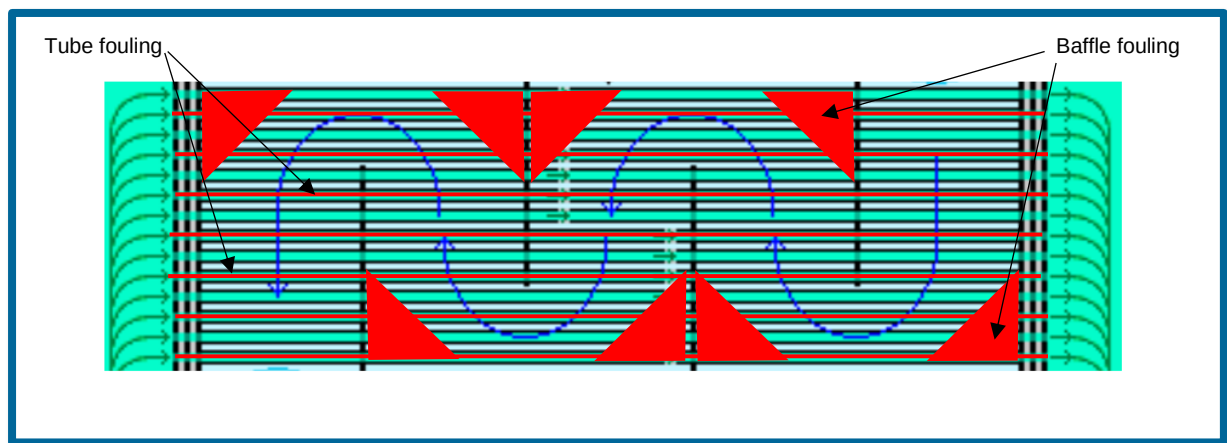


Figure 26: Heavy fouling areas

In most industries today, a major economic drain is caused by fouling. Fouling in heat exchangers can have a substantial, negative influence on the operational efficiency of the process unit they are operating in. The broad industrial use of shell and tube exchangers as known today, started in around 1900 to accommodate the demands of the emerging oil industry (Taborek, 2018); yet the actual basic design of the STE has change very little in nearly one hundred and twenty years. Despite the enormous costs associated with heat exchanger fouling, it seems that limited research has been carried out to accurately determine the economic consequences of this design.

In a 1995 study (Muller-Steinhagen,1995) the total fouling related costs for major industrialised nations was estimated at \$45 Billion annually (approximately £31 Billion annually). Over thirty years ago Thackery (1980) and Pritchard (1988) stated that about 15 percent of the maintenance costs of a process plant can be attributed to heat exchangers and boilers, and of this, 50 percent is probably caused by fouling. Muller-Steinhagen (2000) reported that total annual fouling costs for highly industrialised countries such as the United States and the United Kingdom are approximately 0.25 percent of the country's gross national product (GNP).

Costs linked to heat exchanger fouling include production losses due to efficiency decline; loss of production during planned or unplanned shutdowns; maintenance and material costs resulting from the cleaning of fouling deposits; and the replacement of damaged equipment due to corrosion and damage from plugging. Continuous fouling or plugging may be detected by a decrease in temperature change in the fluid passing through the exchanger, conversely it may be detected by an increase in the pressure drop and flow will ultimately be reduced through the exchanger.

According to Ibrahim (2012), this is a result of the low thermal conductivity of the fouling layer, or layers, which is lower than the thermal conductivity of the fluids or conduction wall. By consequence of this lower thermal conductivity, the overall thermal resistance to heat transfer is increased thus the thermal efficiency and effectiveness of the heat exchanger is reduced. Due to the onset of fouling and the resultant build-up of fouling layer or layers, the cross-sectional area of tubes or flow channels through the shell side is reduced.

Furthermore, greater surface roughness due to fouling will increase frictional resistance to flow. Such effects unavoidably lead to an increase in the pressure drop across the heat exchanger, which is required to maintain the flow rate. As the flow rate decreases it can lend time for particles to settle out of the fluid, leading to fouling or plugging, which reduces the heat transfer rate in the exchanger. In order to get the process feed back up to the required temperature and rate, the heat duty of the furnace/heater potentially will have to be increased with extra fuel required, pumps may have to work harder and consequently resulting in increased fuel use and cost thus additional CO₂ emissions.

Pugh (2002) cites that it was estimated that fouling was responsible for more than 180,000 tonnes of additional CO₂ into the atmosphere every year from UK refineries alone. Figure 27 and 28 display shell side and tube side fouling.



Figure 28: Shell side baffle fouling (INTECH, 2018)



Figure 27: Tube side fouling (Parry, 2010)

The maintenance strategy for an STE on the Pembroke Refinery is typically conditioned based preventative maintenance (CBM). The example below (Figure 29) shows operational instrument readings for the HCGO Slurry STE on the FCCU, a similar heavy fouling process to the required overflash heat exchanger, for a period of approximately 8 months.

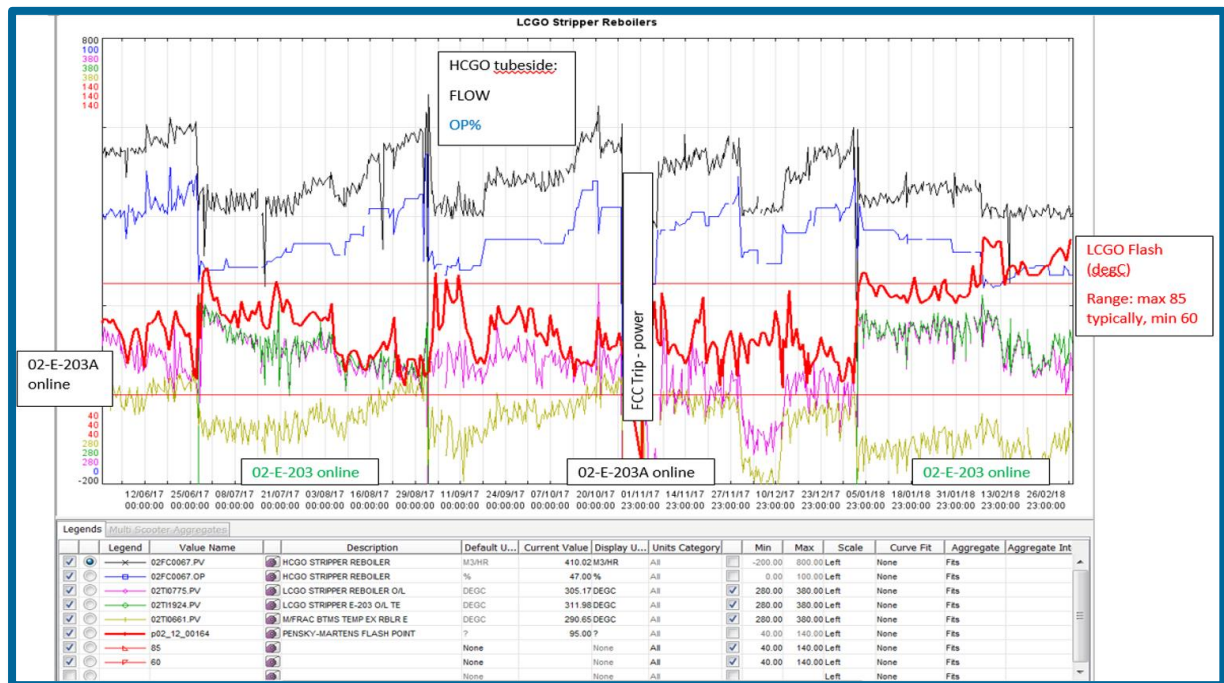


Figure 29: Operations instrument reading for STE.

The general pattern can be seen of the STE fouling up and then being taken out of service for maintenance. Control room operations staff monitor and inform the refineries maintenance department of when they feel would be the most suitable time in the close future to take the heat exchanger out of service for maintenance (usually when the cost of lost production exceeds the cost of maintenance). The overhaul is planned, scheduled and materials procured. Figure 30, below displays a flow chart of the maintenance strategy.

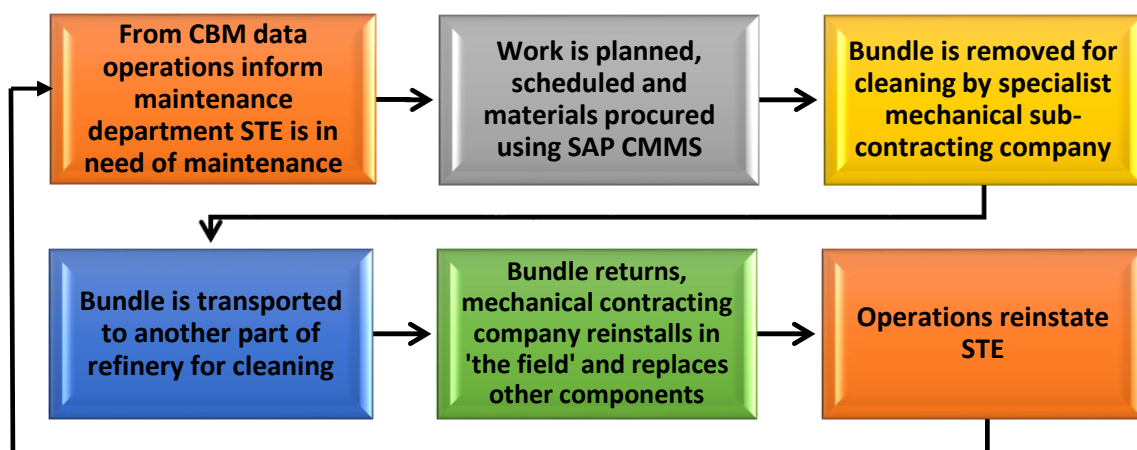


Figure 30: STE maintenance strategy.

The actual maintenance on a fouled STE is carried out by a specialist mechanical sub-contracting company and involves removing the tube bundle with specialist pulling equipment (Figure 31) and a large crane, transporting via tractor and trailer to another part of the refinery and then mechanical cleaning by hand and also via high pressured waterjets (mechanical hydro blasting).

If the tube bundle is damaged it may need replacing at this stage. The tube bundle is reinstalled using the same specialist equipment and all gaskets and bolts in the exchanger are renewed.



Figure 31: Specialist bundle puller (Jenkins & Davies Engineering, n.d.)

The cost of this type of maintenance is relatively high, Appendix 4 displays the total cost, material list and full maintenance SAP plan for the aforementioned HCGO STE. Total cost equates to £50,000 each time the tube bundle needs pulling for cleaning, not including planning costs and any downtime suffered by the process unit.

This type of heavy fouling STE is pulled for cleaning approximately between every 8-16 weeks and planned for a 1-week outage, not including scaffolding time, that's potentially £300,000 per year spent on maintaining one STE exchanger.

5.3. Spiral Heat Exchangers

The spiral heat exchanger (SHE) is a welded heat exchanger without gaskets in between the two process fluids. It is constructed by winding two long metal strips around a cylindrical central core, this forms two concentric spiral channels with rectangular cross sections, called the spiral heat-transfer body (Figure 33).

Each channel is closed off from the other by means of alternately welding on opposite edges, this forms the hot and cold side eliminating the chance of any cross-contamination in the two process fluids. The channel spacing is governed with studs, the length of the studs can be chosen to achieve channel spacing suited to the size of the fouling particles in the process.



Figure 33: Manufacture of the SHE heat-transfer body (Andersson, 2008)



Figure 32: SHE shell and covers (Alfa Laval, nd)

The spiral heat-transfer body is then housed in a cylindrical shell with inlet and outlet nozzles and covers on each end (Figure 32). On the hot cover side, the hot fluid enters the central nozzle and spirals its way out to an outlet nozzle on the shell.

The cold fluid simultaneously enters an inlet nozzle but on the shell, not cover, and flows counter currently to the hot fluid to the centre nozzle on the cold side cover (Figure 34). The cover plates house a full-face gasket that seals the open end of the channels preventing the by passing of the respective fluid from the inlet nozzle to the outlet nozzle.

What diversifies the SHE from other heat exchanger technology, like the STE, is a single channel design. Each fluid has a single flow passage, therefore will only make one large pass through the heat exchanger and as a benefit of this result no maldistribution is possible. Another large benefit to this according to Beermann and Gavelin (2014) is that potential fouling is minimised or actually doesn't happen since any build up in the channels will result in an

increase velocity at that point, which increases turbulence and the fluid shear stress this results in a scrubbing effect (Figure 34) that removes fouling that is starting to or has settled. Due to this effect SHE's are said to be self-cleaning.

Andersson (2008), cites that other features that minimise fouling in a SHE is the uniform velocity profile, the design without “dead zones” and efficient heat transfer, which minimises the wall temperature and thereby the reaction rate in the case of chemical fouling.

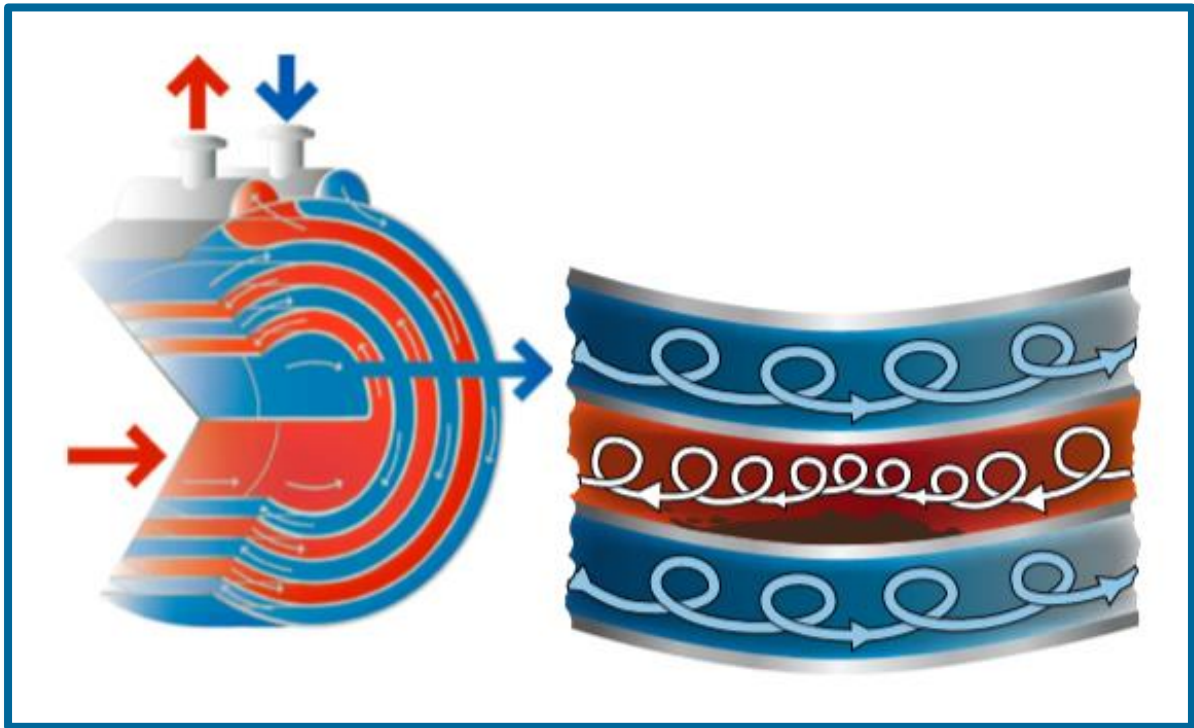


Figure 34: Single channel design and scrubbing effect of an SHE (Beermann and Gavelin, 2014)

The actual invention of the SHE was discovered in 1826 but manufacture only began in 1930 and according to Anderson (2008), the initial SHE was industrialised for use in the pulp and paper industry.

However, although manufacture started nearly ninety years ago there is currently only approximately one hundred and sixty SHEs operating in oil refineries the world over. Despite this low number there have been several successful case studies of SHE's in heavy refinery processes with data to support from different sources.

Five of these are detailed on the following pages.

1. A major US refinery was experiencing severe fouling and plugging problems in two shell and-tube heat exchangers installed to cool crude oil desalter effluent. The refinery replaced the two STE's with a self-cleaning Spiral Heat Exchanger. After fourteen months of operation, the refinery opened the SHE for the first time to check for fouling; only a thin greasy coating was found, the SHE was mechanically hydro blasted and placed back in service the next day (Alfa Laval, 2008). The table below shows the annual opex savings.

Unit	Service	Cleaning frequency, times per year	Cost per cleaning*	Total cleaning costs per year
2 Shell-and-tubes	Desalter effluent cooling	12	USD 6,000	USD 72,000
1 Spiral Heat Exchanger	Desalter effluent cooling	0.86	USD 3,250	USD 2,786

2. In a European refinery two double-pipe shell and tube heat exchangers, one in operation and one in standby, were used to cool down FCC slurry oil. The slurry oil contained catalyst fines and coke particles, creating severe fouling problems in the STE's, they plugged frequently and one needed cleaning every ten days so they were constantly swapping the two. Two SHE's were installed to replace the STE's, one in operation and one in standby. During normal operation, they required no cleaning at all and the standby SHE has therefore not been used. The installed cost for the two SHE's was around €360,000 the payback time for the project was approximately one year (Andersson, 2008).
3. A Russian oil refinery had a key concern with the high cost of maintaining their twelve STE's used in a heavy fouling VBU process. The CO₂ levels were increased and maintenance costs were significantly high at €1,650,000 per year. The twelve STE's were replaced with eight SHE's. The maintenance costs as shown in the table below dropped to €3,000 per year a saving of €1,647,000 per year compared to the previous arrangement (Alfa Laval, 2002). The table below shows the annual opex savings.

Visbreaking unit	Shell-and-tube heat exchangers	Spiral heat exchangers
No. of heat exchangers	12	8
Operating period	Before 2002	Since 2002
No. of cleaning interventions	Always ongoing cleaning	1 per year for inspection
Duration per intervention	4 days	1 day
Cost per intervention (EUR)	4,500	3,000
Yearly cost maintenance (EUR)	1,650,000	3,000
SHE payback period based on cleaning costs		12 months

4. According to Andersson (2008), another European refinery had severe fouling problems in their VBU feed (VDU bottoms similar to proposed FCCU feed optimisation exchanger) shell and tube heat exchangers. In total, twelve four-pass STE's were used suffering very high fouling rates and the tube side of the exchangers had to be cleaned every two to three months, taking up to thirty days and losing the refinery revenue. Eight SHE's were installed replacing the STE's at a significant cost of €2,200,000 but the annual savings in terms of improved heat recovery, no capacity loss and reduced maintenance costs amounted to around €1,100,000 per year which means the payback time for the project was approximately two years.
5. According to Beermann and Gavelin (2014) a major US refinery decided to revamp its CDU after suffering from severe fouling in its existing STE's. The original heat transfer arrangement was replaced with SHE's saving \$66,000 per year on maintenance, \$52,000 per year savings on fuel consumption and \$250,000 per year savings on loss of production. Although the upfront cost was high the investment paid back within one to two years.

With a SHE, intervals between maintenance are also hugely extended, if maintenance is needed at all. If maintenance is required SHEs are relatively easy to clean, the spiral heat transfer body does not need removing. Both end covers are simply dismantled and the channels hydro blasted, limiting potential health and safety risks with heavy pulling equipment and additional resource, this takes approximately four days on average. However, the unit will need transporting to a jetting bay.

A SHE also offers significant benefits in exceedingly high heat transfer, this is due to the spiral design. The large quantity of turbulence formed in the spiralling channels results in heat-transfer efficiency that can be three times higher than in a STE's. Another key feature to the SHE heat transfer efficiency is true counter-current flow, that permits a heat transfer situation where the cold process fluid can be heated to temperatures extremely close to the temperature of the hot fluid. Hence, the closer the temperature difference between the two process fluids, the greater value of heat is recovered.

The failure mechanism known as "dead spots" are also eliminated in an SHE due to the single-channel geometry and stud arrangement; the process fluid is fully turbulent at a low velocity and each process fluid travels at constant velocity throughout the whole unit. The Computational Fluid Dynamics (CFD) analysis model shown in figure 35, displays this attribute of the SHE with no "dead spots" and a uniform velocity profile.

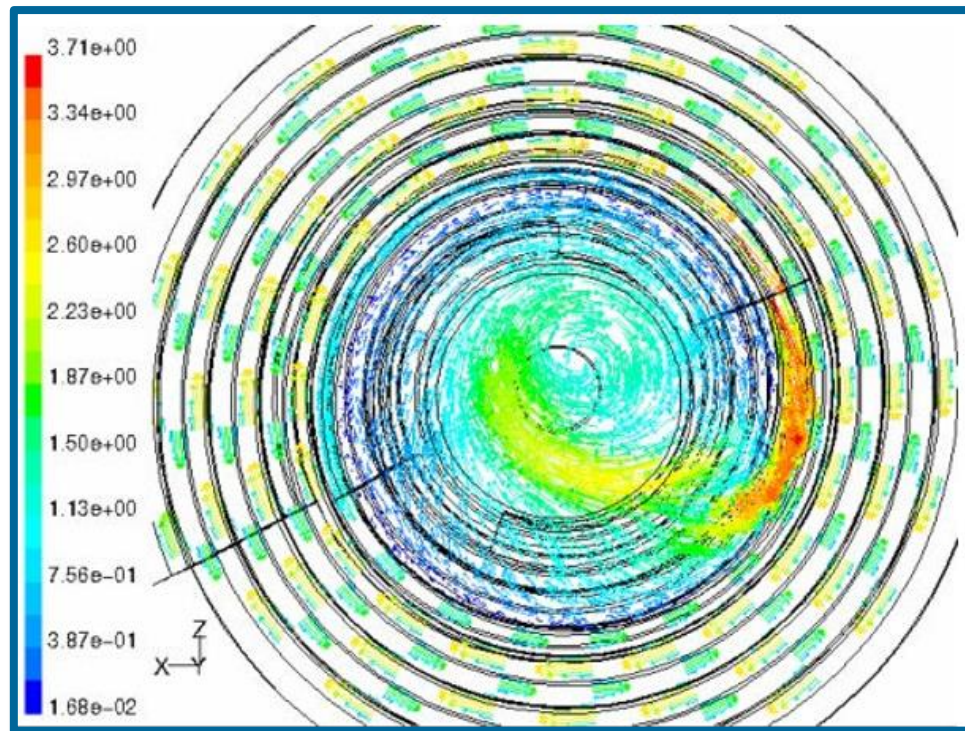


Figure 35: CFD of a SHE in operation (Alfa Laval, nd)

SHE's also have significant advantages with regard to floor space. A SHE typically needs only a fraction of the floor space required by a STE for installation and maintenance. Andersson (2008) cites that an SHE with a heat-transfer surface of 500 m² has a footprint of only 5.2 m².

To summarise some positive attributes of a SHE;

- reliable operation.
- practically no fouling.
- low maintenance costs, easy to open and clean.
- less pipework and steel structures, low installation costs.
- greenhouse gas emissions reduced.
- potential short payback times.
- economic savings due to high heat recovery.
- lower consumption of fossil fuel.

There are, however, some negative features of an SHE. They can be limited by maximum temperature, pressure and velocity figures compared to a STE. Also, if a failure between channels of the spiral heat-transfer body does occur such as hole or crack it results in drastic surgery and the whole unit returning to the manufacture for what is called “window opening” repair (Figure 36). It is not as simple as pulling the bundle of a STE exchanger and replacing a tube.

A “hydro-test” will take place to identify where the defect is, then the repair will begin. The material of the spiral channels need to be cut out piece by piece on each spiral turn as displayed in Figure 36. After replacing the failure piece, the other layers need to be welded back with extensive dye penetrant weld testing of each layer.

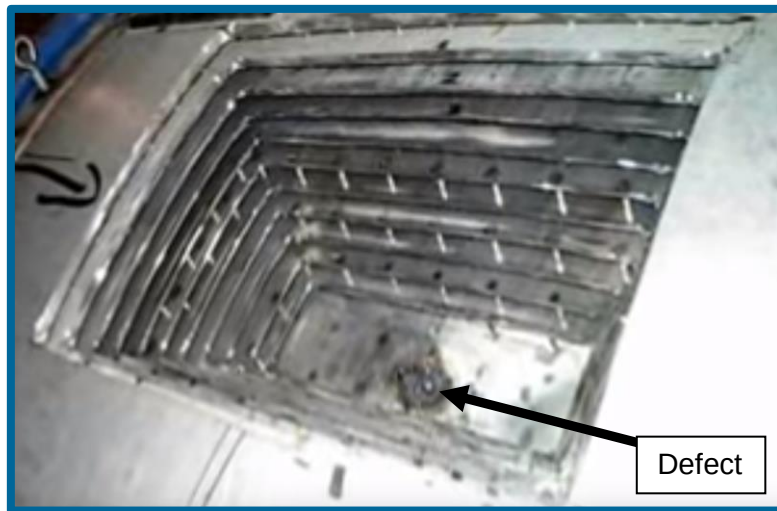


Figure 36: spiral heat-transfer body “window opening” repair (Alfa Laval, 2014)

Another weakness of the SHE is when removing the covers for maintenance. If one side is not completely de-pressurised and the other side is opened, it will result in the spiral heat-transfer body expanding outwards, as shown in figure 37, causing extensive damage and again resulting in the whole unit needing to be sent back to the manufacture for repair and testing.



Figure 37: SHE de-pressure failure (Alfa Lava, ndl)

5.4. The Overflash Cooler Heat Exchanger Sizing Comparison Calculations.

The area of the refinery where the overflash cooler heat exchanger is to be situated is heavily congested with existing refining equipment. This makes sizing of proposed heat exchangers extremely important. In order to determine the size of the proposed heat exchanger several calculations need to be made. These calculations will be carried out using the 'log mean temperature difference formula' (Branan, 2002) and associated correction factors. The following calculations are made for a shell and tube heat exchanger in counter current flow with the following assumptions made;

- a constant overall heat-transfer coefficient in each pass.
- equal heat transfer areas in each pass.
- there is no leakage of fluid between shell passes.
- the temperature of the shell-side fluid in any pass is constant across any cross section.

Although these conditions will not be stringently satisfied in practice for a shell and tube heat exchanger, the F values attained by the correction curves will produce an estimate of the "true mean temperature difference" that is satisfactorily accurate for most designs.

Log mean temperature difference formula;

$$Q = UAF \cdot \Delta T_{LM}$$

Where;

Q = Heat energy (Kw)

U = Overall heat transfer coefficient (W/m²°C)

A = the surface area of the tubes (m²)

F = Correction factor (value obtained from correction curves)

ΔT_{LM} = log mean temperature difference (°C)

Rearrange for 'A'

$$A = \frac{Q}{UF\Delta T_{LM}}$$

First find 'Q' using specific heat formula (Allen, 2001);

$$Q = \dot{M}C(\Delta T)$$

Where;

$\dot{M}$ = Overflash flow (kg/s)

C = Specific heat (J/kg°C)

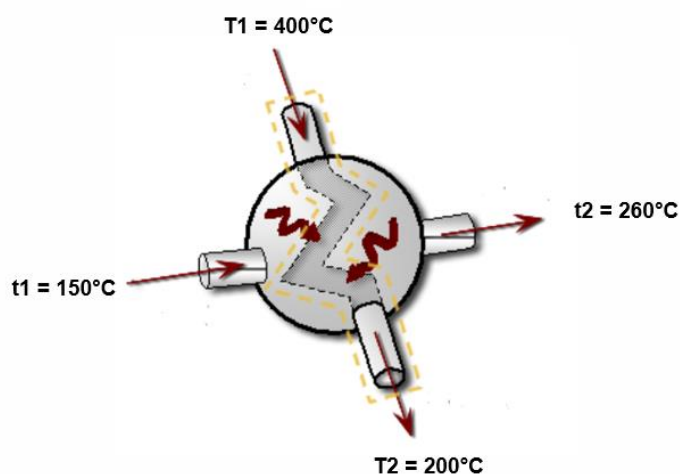
ΔT = Change in temperature (°C)

$\dot{M}$ = 36317 Kg/h (Valero Energy, 2018) convert to kg/s

$$\frac{36317}{3600} = 10 \text{ kg/s}$$

C = 2800 J/kg°C (Valero Energy, 2018)

$$\Delta T = T_1 - T_2 \quad \therefore \quad \Delta T = 200^\circ\text{C}$$



$$\left. \begin{array}{l} T_1 = 400^\circ\text{C} \\ T_2 = 200^\circ\text{C} \end{array} \right\} \text{Tube side}$$

$$\left. \begin{array}{l} t_1 = 150^\circ\text{C} \\ t_2 = 260^\circ\text{C} \end{array} \right\} \text{Shell side}$$

$$\therefore Q = 10 \times 2800 \times (400 - 200)$$

$$\therefore Q = 5600000 \text{ w}$$

$$\therefore Q = \underline{5600} \text{ Kw}$$

U = 50 BTU/hr/ft²/°F (Valero Energy, 2018) covert to W/m²°C 50 x 5.678 = 283.9 W/m²°C

Find ΔT_{LM} ;

$$\Delta T_{LM} = \frac{\Delta T_{out} - \Delta T_{in}}{\ln \left(\frac{\Delta T_{out}}{\Delta T_{in}} \right)}$$

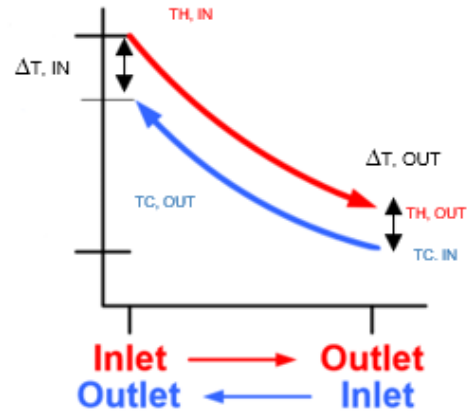
Where;

$$\Delta T_{out} = (T_2 - t_1) \text{ and } \Delta T_{in} = (T_1 - t_2)$$

$$\Delta T_{out} = (200 - 150) = 50^\circ\text{C}$$

$$\Delta T_{in} = (400 - 260) = 140^\circ\text{C}$$

$$\therefore \Delta T_{LM} = \frac{50 - 140}{\ln\left(\frac{50}{140}\right)} = 87.41^\circ\text{C}$$



Using the log mean temperature difference correction factor curves as originally cited by Bowman et al. (1940) the correction factor F and number of heat exchanger shells can be determined;

Where, as stated in (Figure 38, 39);

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$

And;

$$P = \frac{t_2 - t_1}{T_1 - t_1}$$

Therefore;

$$R = \frac{400 - 200}{260 - 150} = 1.81$$

And;

$$P = \frac{260 - 150}{400 - 150} = 0.44$$

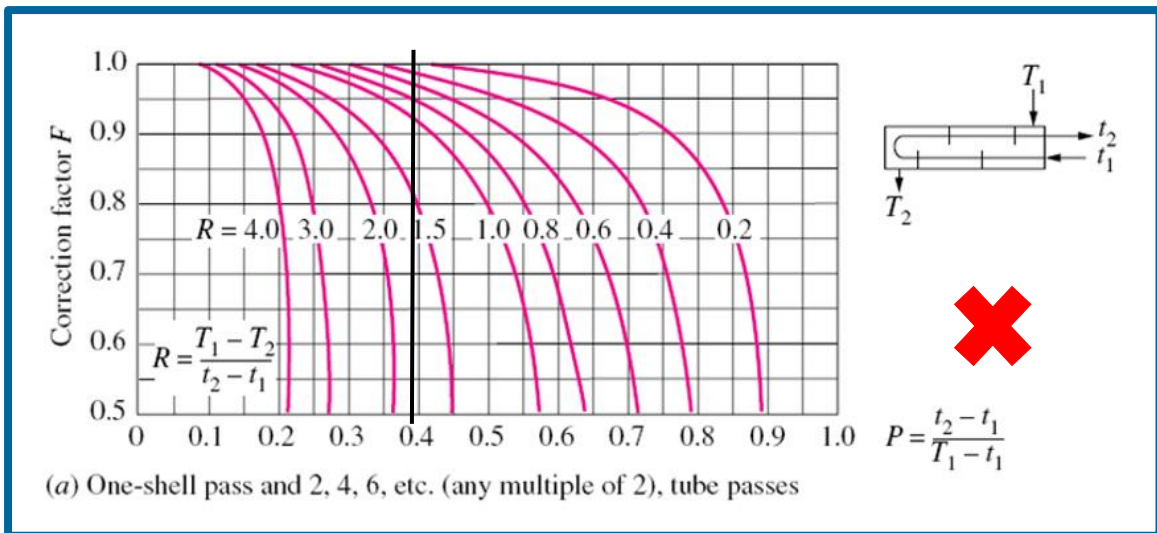


Figure 38: Single-shell pass and 2 tube passes correction factor table.

Not possible using one shell due to curve none intersection, F value is indeterminable.

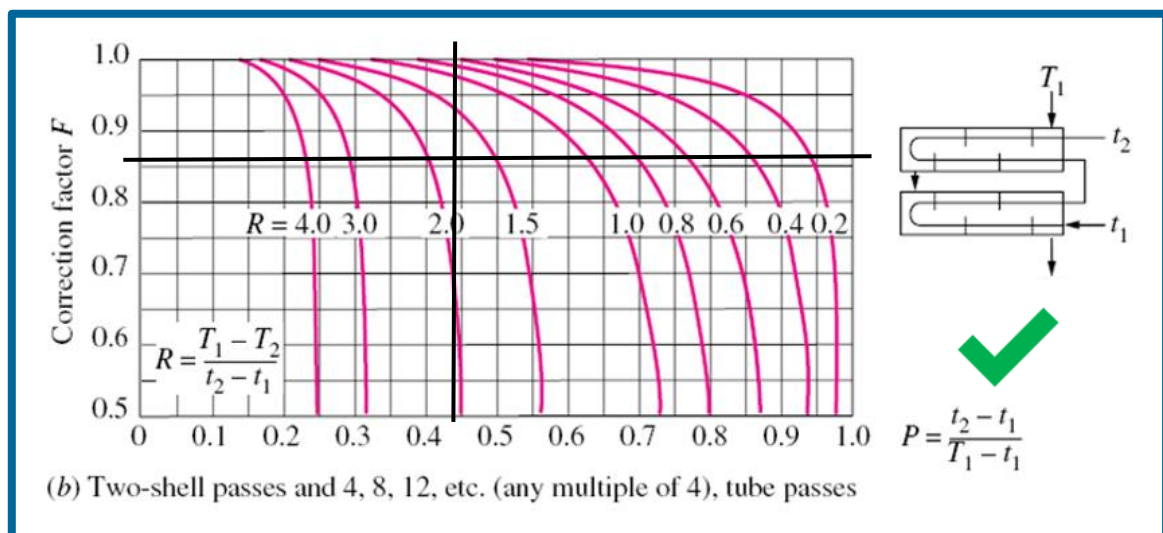


Figure 39: Two-shell passes and 4 tube passes correction factor table.

Two shells are possible using a correction factor $F=0.86$. This is a satisfactory value of F as according to Perry (1997), values of F less than 0.8 (0.75 at the very lowest) are generally unacceptable because the exchanger configuration chosen is inefficient and could lead to a thermodynamically inoperable exchanger.

Now all the unknown values have been obtained the exchanger size can be determined using the previously rearranged log mean temperature difference formula;

$$A = \frac{Q}{UF\Delta T_{LM}} \therefore A = \frac{5600 \times 10^3}{283.9 \times 0.86 \times 87.41}$$

∴ $A = 262.4 \text{ m}^2$ (total surface area of tubes)

Using 25.4mm O/D tube 6096mm in length (Appendix 5) for the heat exchanger;

$$0.0254\text{m} \times \pi = 0.0798 \text{ m}$$

$$0.0798 \times 6.096 = 0.486 \text{ m}^2(\text{per tube})$$

$$\frac{262.4}{0.486} = 539 \text{ tubes}$$

539 tubes, 25.4mm O/D, 6096mm long divided between two shells with 2 passes per shell
Using the square pitch tube-sheet layout table in appendix 6 the shell size is determined as 27" I/D.

$$27" \times 25.4\text{mm} = 686\text{mm shell I/D.}$$

Assuming 20mm thick shell wall and 300mm head each end, the footprint of each shell will be 0.726m x 6.696m.

Total footprint of both shells **1.452m x 6.696m (9.7 m²)**

The same process data for the proposed overflash cooler heat exchanger was also sent to a specialist spiral heat exchanger manufacturer for sizing and quotation. The manufacturer returned with a quotation for the cost of manufacture, this along with sizing drawing can be found in appendix 8.

Total footprint of spiral heat exchanger **2.150m x 2.374m (5.1 m²)**

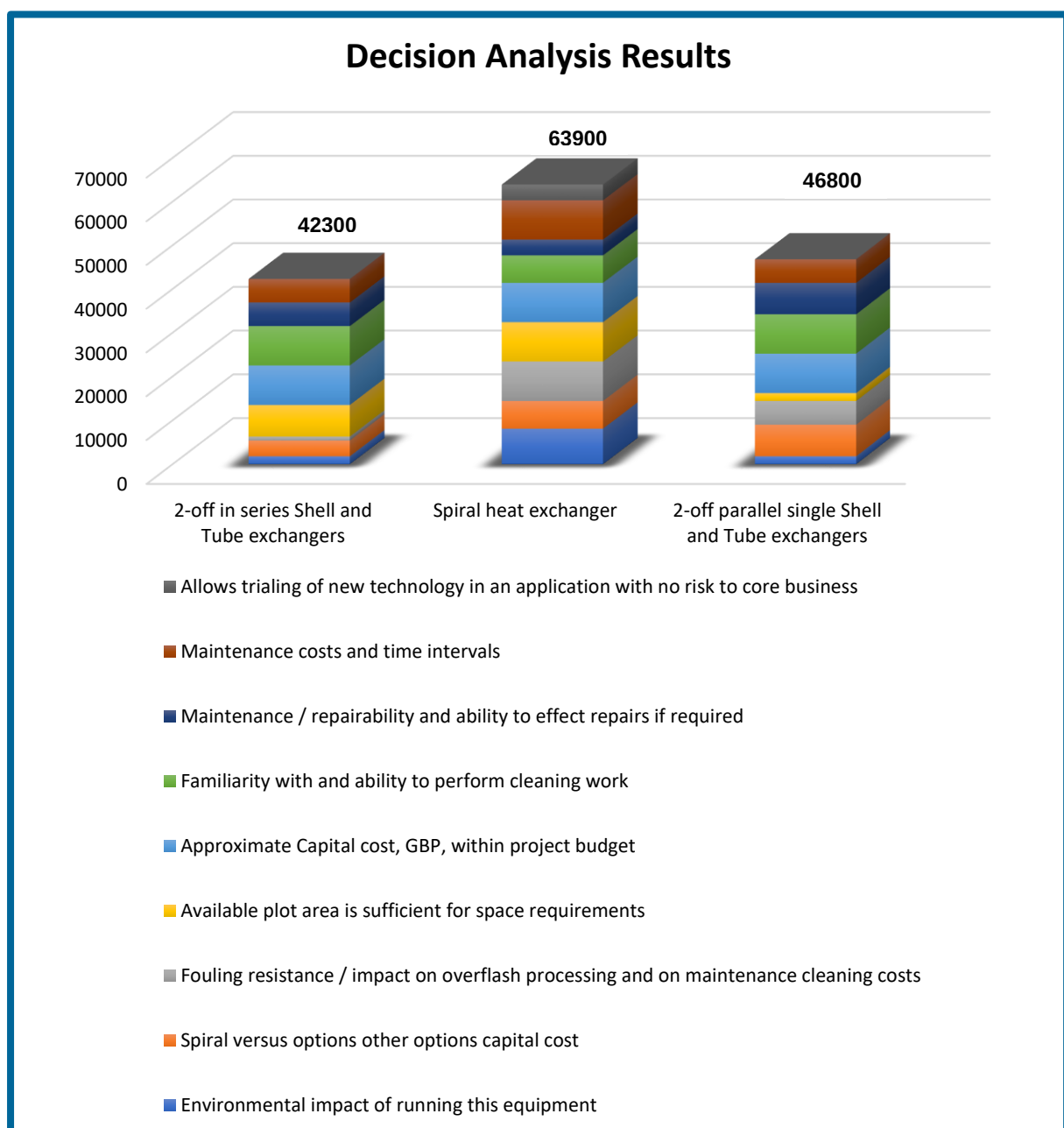
Appendix 7 displays a manufacturing quotation for a shell and tube arrangement using the same process data.

5.5. Multi-Criteria Weighted Decision Analysis

Using data obtained through Valero and through the aforementioned research, appendix 9 displays a multi-criteria weighted decision analysis matrix (Pugh, 1991) with the available options of different types of overflash cooler heat exchangers. There are three options in the matrix;

- 2-off in series shell and tube exchangers
- spiral heat exchanger
- 2-off parallel single shell and tube exchangers

The results from the decision analysis are displayed in the graph below;



The findings from the multi-criteria weighted decision analysis (appendix 9) shows that the spiral heat exchanger option came out on top for use as an overflash cooler. However, although it scored considerably higher overall than the other options, there were some areas that it lacked strength in; such as having the highest initial capex cost, familiarity with cleaning procedure and required repairs if needed. Some other criteria's, such as environmental impact; fouling resistance; learning from new technology and maintenance costs, the SHE considerably outweighed the other options. Interestingly with regard to cost; the spiral option, although more expensive than the other two options, is still competitive and evidentially seems to have more advantages attributed to it.

6. Project Loss Investigation and 'Five Whys'

No project is without problems and the FCCU Feed Optimisation is no exception. The first phase of the project (installation of the transfer line from the FCCU to the VBU) started in March 2017, this ran close to the scheduled baseline and finished as projected in August 2018; a progress report 'S-Curve' and productivity report can be found in Appendix 11 displaying this. The project was approaching the monetary budget towards the end of the first phase and two months into the second phase of the project (overflash cooler installation and associated equipment and transfer line to the FCCU) it ran out of money; consequently, production slowed and the project came to a stop. Appendix 12 displays phase two progress report 'S-Curve' and productivity report. A high-level construction project plan for both phases can be found in Appendix 13.

If a Capital Project goes over budget on the refinery and is not completed, a supplemental authorisation for expenditure (AFE) is applied for to gain additional funds. Before additional funding is released, a loss investigation is carried out through the refinery's loss prevention system (LPS). Valero Pembroke uses the 'Five Whys' technique (Toyota Motor Corporation, 2006) to find the root cause of the problem and to prevent the loss from recurring.

The 'Five Whys' technique was used twice in the loss investigation for the FCCU Feed Optimisation project, the following displays this process;

1.
 - What? Original cost submitted was for £7 MM and now the estimated cost to complete project is £10 MM
 - Why? Material, construction and engineering costs considerably differ from the original AFE cost.
 - Why? Documents submitted by the operations review board did not replicate the approved estimate.
 - Why? Limited supervision through the process, to certify information included in operations documentation.
 - Why? Operations documents and estimate certification was completed by different personnel.
 - Why? Lack of communication with regards to procedures and standards

The solution and action to prevent this loss from happening again was to advise project engineers, through a team meeting, that all operations review documents are to be populated by them following the confirmation of the estimate and this is then to be reviewed by the Capital Projects Manager.

2.

- What? Engineering costs increased significantly, which resulting in increased costs for materials and construction labour to try to sustain schedules. Additional to this, scaffold costs increased significantly from initial estimate.
- Why? Engineering contractor changed mid project and the new estimate was based on previous feed study information, which didn't match the full value of project scope and related schedule.
- Why? Prior to the new engineering estimate being submitted, no 'field' review or information check completed.
- Why? Doing the job according to processes and procedures takes longer.

The solution and action to prevent this loss from happening again was to gain assurance from the engineering contractor that all estimates are validated to the correct standard, by discussing and agreeing that all future estimates will be validated through their existing quality control process, regardless if feed study was completed by a third party.

After this investigation took place the supplemental AFE was approved to finish the project and it is currently being rescheduled for completion.

7. Conclusion

Oil refining is a highly competitive business, the Pembroke Refinery is not situated close to crude oil like a lot of its competitors which means it has to be efficient and discover new ways to re-refine process fluids to obtain as many usable and sellable products as possible.

The FCCU Feed Optimisation Project proves that even in an already profitable process plant there can be potential for large improvement. In this case not only was profit maximised further, through reduction in maintenance costs and optimising the mix of petroleum products output from the refinery, but also a significant reduction was made in the refinery's environmental footprint.

The four process units involved are not expected to work any harder or experience any additional load by the modifications, whilst still meeting all required feed rates. The construction of the project has not interfered with the operation of the units either. The overflash VDU vacuum tower outlet tie-in was carried out during an already planned VDU outage that took place in March 2018, ensuring no additional loss of time to running plant.

Using vacuum tower bottoms residue as a fluid catalyst cracking feed in terms of earnings is more lucrative when combined with vacuum tower overflash as its benefits outweigh vacuum tower bottoms residue by approximately 3:1. Used together, as suggested by the aforementioned data there is a large potential for additional revenue. Furthermore, this results in high priced imported residue no longer being bought. Rerouting HCGO slurry to the VBU to be made into more sellable products reduces onsite tankage storage which results in vast health and safety benefits.

Given that expensive residue will no longer need to be purchased not only has revenue benefits it also has huge pollution benefits. Any way of reducing the refinery's environmental footprint is greatly beneficial, not only for the refinery and the planet but also with regards to corporate social responsibility and the local community. The environmental research and the waste hierarchy pyramid show that this source reduction could result in ten less oil tanker vessels needing to come to the oil refinery per year from potentially all around the globe. Recycling the VTB residue and recovering heat energy also had environmental impact benefits. Furthermore, with strict regulations and improvement targets imposed by governing bodies for CO₂ emissions this type of project moves the refinery forward giving it solid roots for the future.

The project did have budget problems that resulted in a large delay, these problems were traced back using the 'Five Whys' technique and resulted in two root causes;

- inadequate communication of expectations regarding procedures or standards.
- doing the job according to procedures or acceptable practices takes more time/effort.

However, after a comprehensive loss prevention investigation that resulted in the aforementioned solutions and actions, additional funding was granted and the project will restart for completion in the near future.

The choice of overflash cooler heat exchanger has been extensively analysed in this dissertation. Heat exchanger fouling in refinery processes directly affects profitability, the overflash process is considered to be high fouling and space is limited next to the VDU tower, where it is to be installed. The most common heat exchanger on the refinery is the STE and a counter flow arrangement is most efficient. However, STE's are renowned for failing in heavy processes due to fouling in the tubes and baffles which can be a significant economic drain for the refinery and increase CO₂ emissions.

A spiral heat exchanger has been analysed as a potential option. SHE's too are counter flow and have significant advantages with regards to an ingenious self-cleaning action; very low maintenance in a high fouling service; greater heat transfer efficiency and reduced greenhouse gas emissions. Although an SHE has not been used on Pembroke refinery before numerous successful case studies of SHE's in heavy refineries with data to support from different sources have been produced. SHE's allegedly use less floor space than STE's which would have advantages in this project. To prove this, calculations were carried out to size a STE using the 'log mean temperature difference formula' compared to the size of a SHE that had been quoted from a specialist manufacture. The results proved that the STE would need two shells and cover almost twice the floor space of a SHE. The analysis also pointed out that, like the STE, the SHE does have some weaknesses with regards to complex offsite repairs, delicate internal construction if not depressurised correctly as well as temperature and pressure limitations.

In order to fairly and extensively compare the SHE to the STE, multi-criteria weighted decision analysis was carried out between an SHE and two different STE arrangements as overflash coolers. The results, as displayed in the Decision Analysis Results graph showed that the SHE is the best option by a considerable margin.

Although the FCCU Feed optimisation project stopped half way through the overflash cooler SHE had already been purchased and will be installed once the project restarts. Figure 40 shows the new SHE overflash cooler pre-delivery at the vendors fabrication shop and has been delivered to site since.

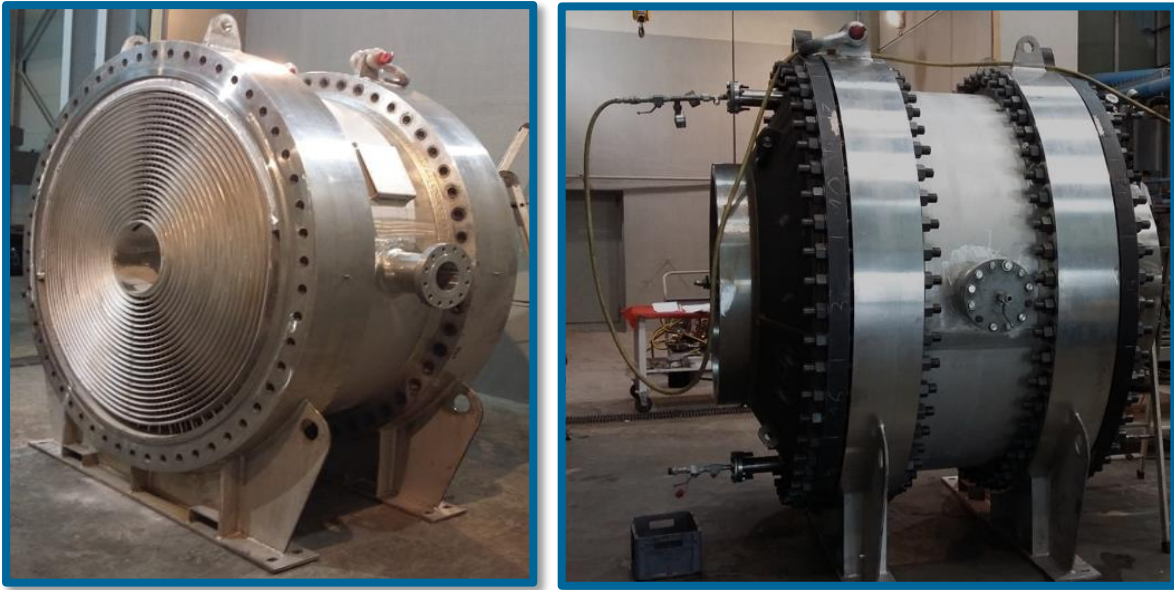


Figure 40: The overflash cooler SHE post manufacture.

The SHE is tailormade for handling fouling duties with its uniform velocity profile, no dead zones and single-channel flow. The spiralling counter current flow guarantees very high heat transfer efficiency and is an excellent choice for heat-recovery duties.

The initial investment cost for a SHE is typically higher than for a traditional STE. However, as no standby equipment is required, and the number and size of the shells are reduced, the total capex is generally in the same range. In addition, with minimised maintenance costs, no loss of heat-recovery efficiency and improved heat-recovery performance the investment will typically be returned paid within two years and after that considerable savings are made compared to a STE. From a health and safety perspective, if little or no maintenance is required, this means less heavy equipment and less workers on site which reduces the risk of potential accidents.

Having the opportunity to try out new technology and new processes on the refinery is refreshing as well as innovative; this not only benefits the Pembroke refinery but feeds data back to the whole Valero refining family to learn and benefit from. This will help oil refineries of the future operate more efficiently, by significantly increasing profit whilst using less crude oil and reducing their global environmental footprint.

8. Recommendations

8.1. The Spiral Change Over Programme

Not all heat transfer processes on the refinery could utilise a SHE. However, there is still a large number that are high fouling processes. To replace them all at once with SHE's would not only be a huge financial expenditure but also a big risk as this is essentially a new technology for the Pembroke refinery.

This could however be carried out in stages as a programme.

Phase 1 (1-6 months)

- Condition monitor the new VDU overflash heat exchanger with respect to pressure and temperature.

Phase 2 (6-12 months)

- If phase 1 was a success i.e. no fouling has occurred; both temperature and pressure monitoring is steady. Then the second SHE could be purchased; an ideal second change out would be the aforementioned FCCU HCGO heavy fouling heat exchanger. Condition monitor, as per phase 1, for research.

Phase 2 (12 months+)

- Price the next potential heavy fouling exchanger to change out. Calculate the revenue saved from reduction in maintenance that has been earned from last two installations. When sufficient funds have been saved, purchase and install the next SHE. Calculate revenue saved from last three installations to purchase forth SHE and so on, the gap should close between installations as SHE assets increase. Continue to monitor all SHE, feeding data to other Valero refineries.

8.2. General Recommendations.

Learning further from the loss investigation, if there is increasing concern of a project running over budget then the supplemental AFE can be applied for earlier so the project doesn't come to a stop and get shelved while extra funds are acquired. This could be a joint effort of the engineering and construction departments via a weekly report similar to the existing progress report sent out. Manning labour data from construction schedules could be utilised verses a monetary budget baseline and an 'S-Curve' progress report generated.

The math behind STE exchangers can be accessed relatively easily and thus educated where needed, which can be advantageous with regards to sizing. SHE calculations seem to be a more specialised unknown application and extra research into the math behind manufacturing of a SHE could prove rewarding.

SHE's claim to be self-cleaning but some extreme fouling processes may require some measure of maintenance. Instead of opening the SHE up, potentially risking pressure difference damage, chemical cleaning could be utilised. The primary objective for this scope of work is to remove gross fouling using proprietary solvent and chemical circulation processes. Typically, cleaning will be performed by flowing the solvent chemical through the exchanger (circulating or once-through) without the need for disassembly. Figure 41 displays the fouling of a SHE that has been service, it hardly warrants opening the exchanger and potentially putting the process out of operation for days when a chemical wash could suffice.



Figure 41: SHE fouling (Alfa Laval, 2015).

Finally, as mentioned earlier despite the enormous costs associated with STE fouling, it seems that limited research has been carried out to accurately determine the economic and environmental consequences of this ageing design. Further investigation in this area could potentially lead on to more innovative technology, like the SHE.

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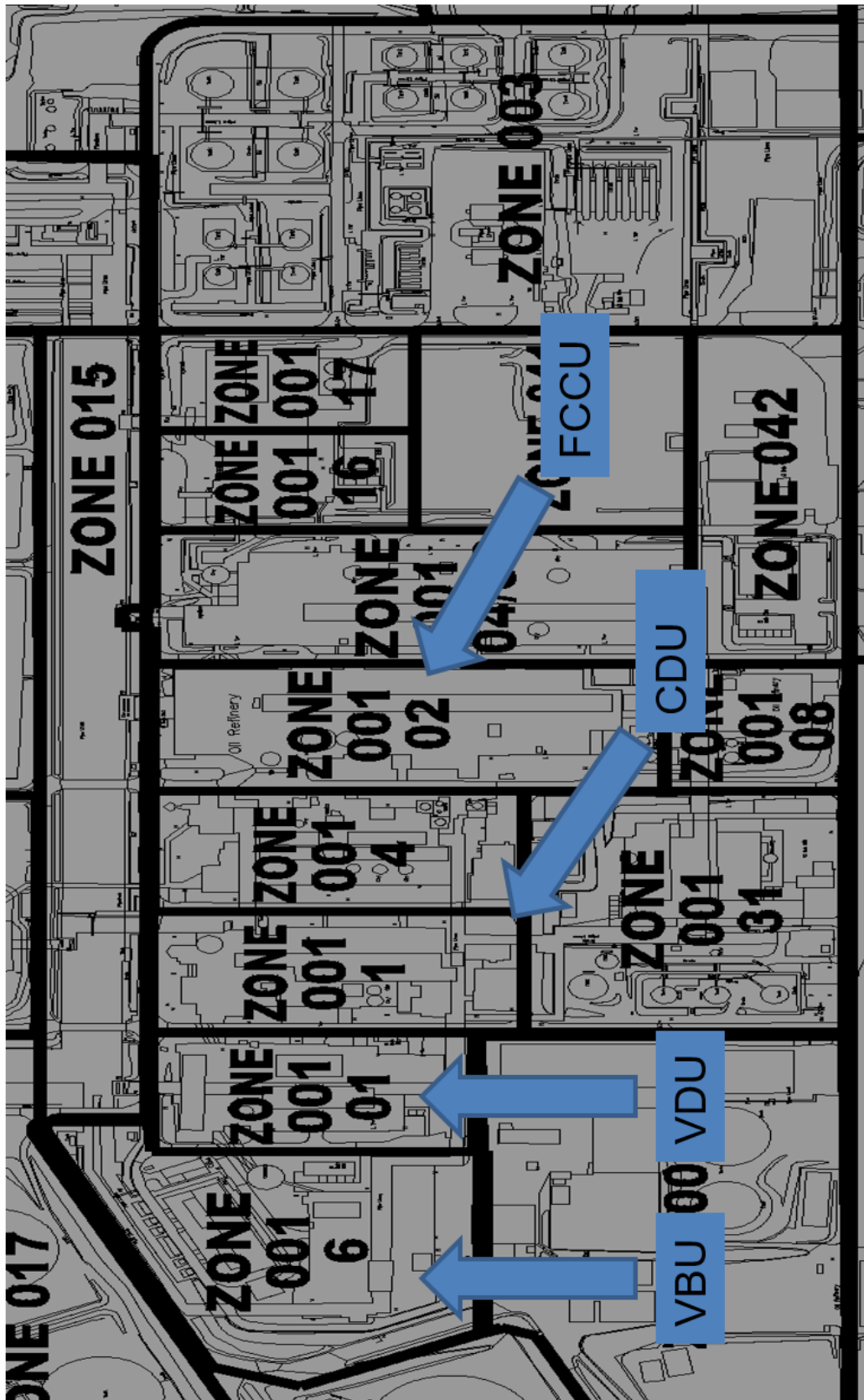
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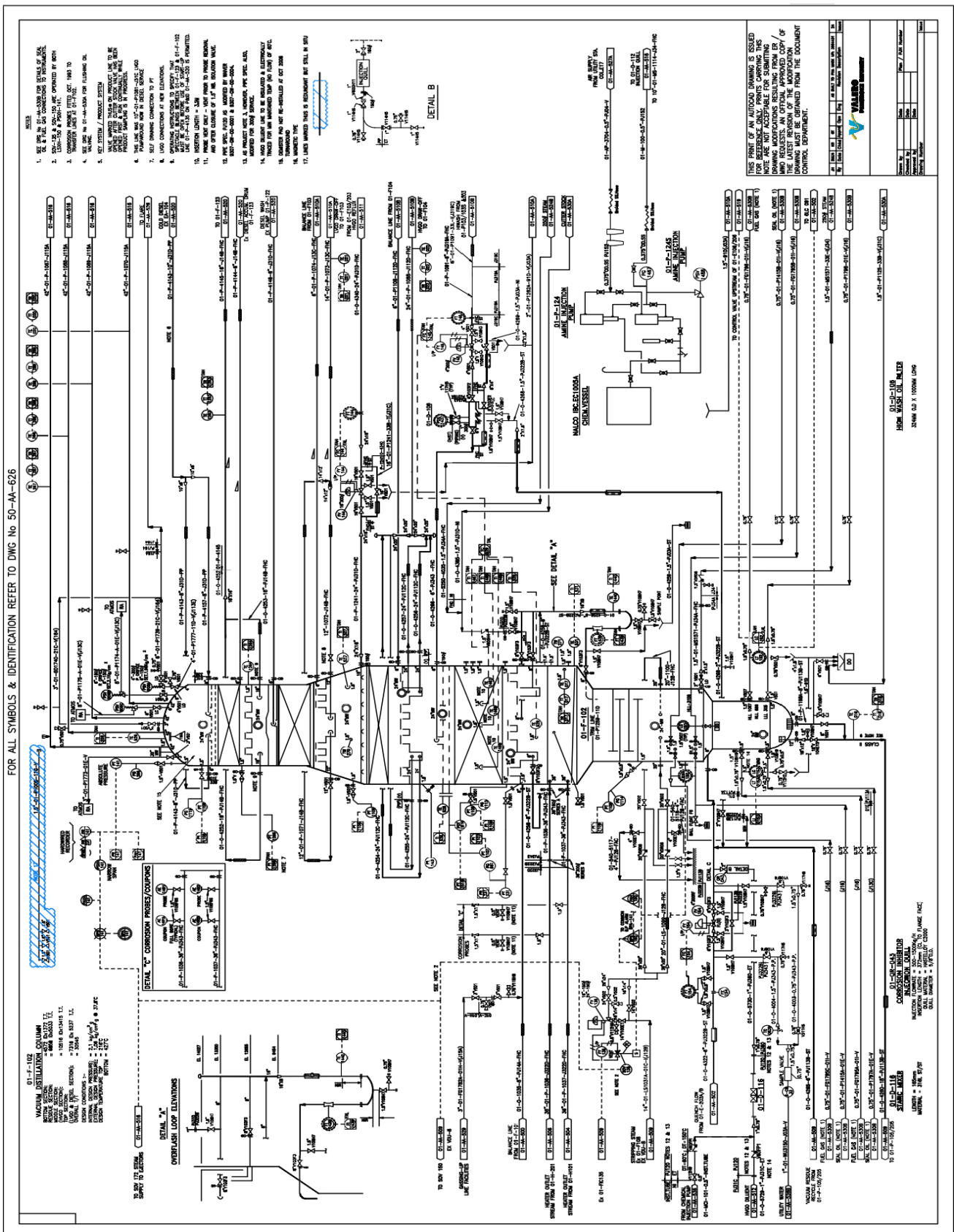
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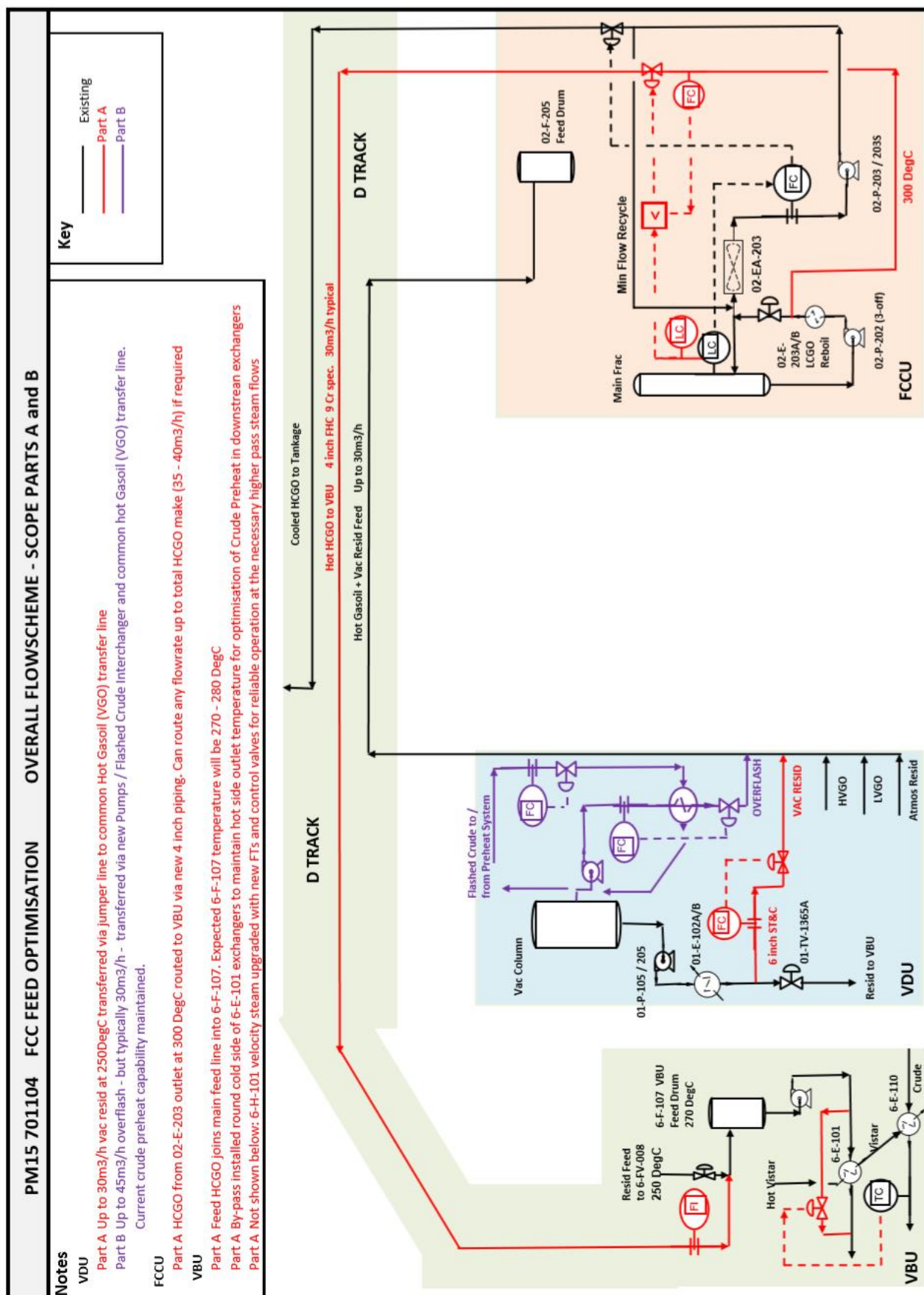
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Appendices

Appendix 1







Appendix 4

Order **PM03 5157799** **BD11535 02-E-203A bundle clean**

Sys.Status **REL ESTC GMPS MANC PRC SETC** **S**

HeaderData Operations Components **Costs** Partner Objects Additional Data Location Planning Co

Estimated costs **50,000.00** **GBP**

☒ Val.in Object Curr. **GBP**

☐ Val.in CoAreaCurr. **USD**

Rep. Plan/Act. Rep. Budget/Commit.

Overview Costs Quantities Key figures

Group/Dscrptn	Est. costs	Plan costs	Act. costs	C.
Costs	50,000.00	49,156.25		
• External Services	0.00	0.00		
• Internal Labor	42,000.00	41,220.00		
• Materials	8,000.00	7,740.45		
• Miscellaneous	0.00	0.00		
• not assigned	0.00	23.00		
• Operating Supplies	0.00	172.80		

HeaderData	Operations	Components	Costs	Partner	Objects	Additional Data	Location	Planning	Control	Enhancemt							
Item	Component	Description	LT	Reqt	Qty	Received	Recipient	Unloading Point	UM	IC	S...	SLoc	Plnt	Op...	Batch	Proc. Category	D...
0010		HYTORC REACTION WASHER, 3/4 BOLT			176.000	176.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0020		HYTORC REACTION WASHER, 1 BOLT			104.000	104.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0030		3/4 X 14-1/4 (14 First To First) Black			88.000	88.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0040		3/4 X 4 (3-3/4 First To First) Black S			16.000	16.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0050		5/8 X 3-1/2 (3-1/4 First To First) Bla			24.000	24.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0060		7/8 X 5-3/4 (5-1/2 First To First) Bla			24.000	24.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0070		1-1/8 X 7-3/4 (7-1/2 First To First) B			32.000	32.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0080		1-1/4 X 14-3/4 (14-1/2 First To First)			52.000	52.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0090		1-1/4 X 8-1/2 (8-1/4 First To First) B			40.000	40.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0100		1-1/4 X 9-3/4 (9-1/2 First To First) B			40.000	40.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0110		1-1/4 X 10 (9-3/4 First To First) Blac			40.000	40.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0120		1 X 12-1/4 (12 First To First) Black S			52.000	52.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0130		1 X 3.2/4.5 150# GT6 Spiral Wound Gask.			8.000	8.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0140		1 X 3.2/4.5 300# GT6 Spiral Wound Gask.			8.000	8.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0150		1-1/2 X 3.2/4.5 300# GT6 Spiral Wound			8.000	8.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0160		2 X 3.2/4.5 300# GT6 Spiral Wound Gask.			10.000	10.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0170		10 X 3.2/4.5 150# GT6 Spiral Wound Ga.			8.000	8.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0180		16 X 3.2/4.5 300# GT6 Spiral Wound Ga.			10.000	10.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0190		18 X 3.2/4.5 150# GT6 Spiral Wound Ga.			8.000	8.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0200	456589	ADHESIVE,3M,SPRAY TACK CONTACT			10.000	10.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0210	455229	LUBRICANT,PENETRATING OIL,TYGRIS,R			10.000	10.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0220		1-1/4# x 17-1/4# STUDBOLTS C/W NUT			52.000	52.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0230		KPN95921 EXCHANGER GASKET CHANNE			1.000	1.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0240		KPN95931 EXCHANGER GASKET CHANNE			1.000	1.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0250		KPN95941 EXCHANGER GASKET SHELL T			1.000	1.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0260		KPN95951 EXCHANGER GASKET SHELL C			1.000	1.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0270		KPN95961 EXCHANGER GASKET FLOATI			1.000	1.000	JOHNSD263	STAGES AT STORES	EA	N			PL25	0020		PReq for Order	
0280					0.000												
0290					0.000												

Change Planned & Scheduled 5157799: Operation Overview																								
Complete (business) View PRT Print PRT																								
Order PM03 5157799 BD11535 02-E-203A bundle clean Sys.Status REL ENFC GMPF MANIC EPC SETC IS																								
HeaderData	Operations	Components	Costs	Partner	Objects	Additional Data	Location	Planning	Control	Enhancemt														
OpAc	SOp	Work ctr	Plant Co...	S S...	Operation short text	LT	Work Un	N. Dur.	Un	C.Key	StartCo...	Start constr.	Start...	Earl...	Earlstart ...	EarliestEn...	Earliest finish	ActTyp	Recipient	Unloading Point				
0010	03-IMF	PL25 PM01	P	JD11535 RAP-20124022			HR		HR	Cal..	▼	▼	00:00	08:00	23.01.2018	23.01.2018	08:00:00	PMILBR						
0020	03-IMF	PL25 PM01	M		MATERIALS		HR		HR	Cal..	▼	▼	00:00	08:00	23.01.2018	23.01.2018	08:00:00	PMILBR						
0030	SC	PL25 PM01	C		ERECT SCAFFOLD 18-CTM-018		24.0HR	3	8.0HR	Cal..	▼	▼	00:00	08:00	23.01.2018	23.01.2018	16:00:00	PMILBR						
0035	SC	PL25 PM01	C		ERECT SCAFFOLD 18-CTM-018		24.0HR	3	8.0HR	Cal..	▼	▼	00:00	08:00	24.01.2018	24.01.2018	16:00:00	PMILBR						
0036	SC	PL25 PM01	C		ERECT SCAFFOLD 18-CTM-018		6.0HR	3	2.0HR	Cal..	▼	▼	00:00	08:00	25.01.2018	25.01.2018	10:00:00	PMILBR						
0040	SC	PL25 PM01	C		ERECT SCAFFOLD 18-CTM-019		24.0HR	3	8.0HR	Cal..	▼	▼	00:00	10:00	25.01.2018	29.01.2018	10:00:00	PMILBR						
0050	SC	PL25 PM01	C		ERECT SCAFFOLD 18-CTM-019		12.0HR	3	4.0HR	Cal..	▼	▼	00:00	10:00	29.01.2018	29.01.2018	14:00:00	PMILBR						
0055	SC	PL25 PM01	C		ERECT SCAFFOLD 18-CTM-020		18.0HR	3	6.0HR	Cal..	▼	▼	00:00	14:00	29.01.2018	30.01.2018	12:00:00	PMILBR						
0060	SC	PL25 PM01	C		ERECT SCAFFOLD 18-CTM-021		18.0HR	3	6.0HR	Cal..	▼	▼	00:00	12:00	30.01.2018	31.01.2018	10:00:00	PMILBR						
0070	SC	PL25 PM01	C		ERECT SCAFFOLD 18-CTM-022		12.0HR	3	4.0HR	Cal..	▼	▼	00:00	10:00	31.01.2018	31.01.2018	14:00:00	PMILBR						
0075	OP	PL25 PM01	X		LAG		HR		2.0HR	Mai..	▼	▼	00:00	14:00	31.01.2018	31.01.2018	16:00:00	PMILBR						
0081	OP	PL25 PM01	X		SET UP FIRE PURGE MONITOR		HR		2.0HR	Mai..	▼	▼	00:00	08:00	01.02.2018	01.02.2018	10:00:00	PMILBR						
0082	03-IMF	PL25 PM01	C		COLLECT MATERIALS AND SET UP EQUIPMEN.		4.0HR	2	2.0HR	Cal..	▼	▼	00:00	10:00	01.02.2018	01.02.2018	12:00:00	PMILBR						
0090	OC	PL25 PM01	C		O/C TO DELIVER AIR COMPRESSOR TO JOB F.		1.0HR	1	1.0HR	Cal..	▼	▼	00:00	12:00	01.02.2018	01.02.2018	13:00:00	PMILBR						
0100	OC	PL25 PM01	C		O/C TO DELIVER LIGHTING TOWER AND 110.		1.0HR	1	1.0HR	Cal..	▼	▼	00:00	13:00	01.02.2018	01.02.2018	14:00:00	PMILBR						
0110	EL-COR	PL25 PM01	C		EARTH PLANT		3.0HR	1	3.0HR	Cal..	▼	▼	00:00	14:00	01.02.2018	02.02.2018	09:00:00	PMILBR						
0130	03-IMF	PL25 PM01	C		INSTALL SPADES AS PER OPS INSTRUCTIONS.		32.0HR	4	8.0HR	Cal..	▼	▼	08:00	08:00	30.01.2018	30.01.2018	16:00:00	PMILBR						
0130	0010 03-IRI	PL25 PM01	C		ASSIST WITH ISOLATION		8.0HR	1	8.0HR	Cal..	▼	▼	00:00	08:00	30.01.2018	30.01.2018	16:00:00	PMILBR						
0130	0020 T50	PL25 PM01	C		LIFTING DUTIES		3.0HR	1	3.0HR	Cal..	▼	▼	00:00	08:00	30.01.2018	30.01.2018	16:00:00	PMILBR						
0130	0040 SC	PL25 PM01	C		ALTER SCAFF FOR COMPONENT REMOVAL		12.0HR	3	4.0HR	Cal..	▼	▼	00:00	08:00	30.01.2018	30.01.2018	16:00:00	PMILBR						
0131	SC	PL25 PM01	C		Alter scaff for component removal		12.0HR	3	4.0HR	Cal..	▼	▼	00:00	08:00	31.01.2018	31.01.2018	12:00:00	PMILBR						
0160	03-IRI	PL25 PM01	C		TRANSPORT PEINEMANN BUNDLE PULLER TO		4.0HR	2	2.0HR	Cal..	▼	▼	00:00	12:00	31.01.2018	31.01.2018	14:00:00	PMILBR						
0160	0010 T100	PL25 PM01	C		LIFTING DUTIES		2.0HR	1	2.0HR	Cal..	▼	▼	00:00	12:00	31.01.2018	31.01.2018	14:00:00	PMILBR						
0160	0020 CDR	PL25 PM01	C		TRANSPORT PEINEMANN TO WORK FACE		2.0HR	1	2.0HR	Cal..	▼	▼	00:00	12:00	31.01.2018	31.01.2018	14:00:00	PMILBR						
0175	BU	PL25 PM01	C		TARP TRAILOR PRIOR TO MOVING DIRTY BU.		2.0HR	2	1.0HR	Cal..	▼	▼	00:00	14:00	31.01.2018	31.01.2018	15:00:00	PMILBR						
0200	03-IMF	PL25 PM01	C		STRIP COMPONENTS AND PULL BUNDLE		12.0HR	2	6.0HR	Cal..	▼	▼	00:00	15:00	31.01.2018	01.02.2018	13:00:00	PMILBR						
0200	0010 03-IRI	PL25 PM01	C		ASSIST		12.0HR	2	6.0HR	Cal..	▼	▼	00:00	15:00	31.01.2018	01.02.2018	13:00:00	PMILBR						
0200	0020 T100	PL25 PM01	C		LIFTING DUTIES		6.0HR	1	6.0HR	Cal..	▼	▼	00:00	15:00	31.01.2018	01.02.2018	13:00:00	PMILBR						
0200	0030 03-BP	PL25 PM01	C		PULL BUNDLE		6.0HR	1	6.0HR	Cal..	▼	▼	00:00	15:00	31.01.2018	01.02.2018	13:00:00	PMILBR						

0200	0030 03-BP	PL25 PM01	C	PULL BUNDLE		6.0HR	1	6.0HR	Cal..	▼	▼	00:00:15:00	31.01.2018	01.02.2018	13:00:00			
0205	OC	PL25 PM01	C	B&A TO BAG UP LOSE MATERIALS		2.0HR	1	2.0HR	Cal..	▼	▼	31.01.2018	08:00:08:00	31.01.2018	31.01.2018	10:00:00	PMILBR	
0210	SC	PL25 PM01	C	SCAFF MODS AS REQUIRED		18.0HR	3	6.0HR	Cal..	▼	▼	31.01.2018	08:00:08:00	31.01.2018	31.01.2018	14:00:00	PMILBR	
0220	03-IRI	PL25 PM01	C	TRANSPORT BUNDLE AND COMPONENTS TO		4.0HR	2	2.0HR	Cal..	▼	▼	31.01.2018	08:00:08:00	31.01.2018	31.01.2018	10:00:00	PMILBR	
0220	0010 CDR	PL25 PM01	C	TRACTOR & TRAILER REQUIRED		2.0HR	1	2.0HR	Cal..	▼	▼		00:00:08:00	31.01.2018	31.01.2018	10:00:00	PMILBR	
0220	0020 T100	PL25 PM01	C	LIFTING DUTIES		2.0HR	1	2.0HR	Cal..	▼	▼		00:00:08:00	31.01.2018	31.01.2018	10:00:00	PMILBR	
0250	OC	PL25 PM01	C	JETTERS TO CARRY OUT CLEANING OF BUND.		24.0HR	1	24.0HR	Cal..	▼	▼		00:00:10:00	31.01.2018	05.02.2018	10:00:00	PMILBR	
0250	0010 ADR	PL25 PM01	C	BOWSER ASSIST		24.0HR	1	24.0HR	Cal..	▼	▼		00:00:10:00	31.01.2018	05.02.2018	10:00:00	PMILBR	
0251	03-IRI	PL25 PM01	C	TRANSPORT BUNDLE TO INSPECTION SHOP		4.0HR	2	2.0HR	Cal..	▼	▼	02.02.2018	08:00:08:00	02.02.2018	02.02.2018	10:00:00	PMILBR	
0251	0010 PL	PL25 PM01	C	TRACTOR AND TRAILER REQUIRED		2.0HR	1	2.0HR	Cal..	▼	▼		00:00:08:00	02.02.2018	02.02.2018	10:00:00	PMILBR	
0251	0020 T100	PL25 PM01	C	LIFTING DUTIES		2.0HR	1	2.0HR	Cal..	▼	▼		00:00:08:00	02.02.2018	02.02.2018	10:00:00	PMILBR	
0252	IMS	PL25 PM01	C	INSPECTION TO THICKNESS CHECK BUNDLE		3.0HR	1	3.0HR	Cal..	▼	▼	05.02.2018	08:00:08:00	05.02.2018	05.02.2018	11:00:00	PMILBR	
0255	OP	PL25 PM01	X	LAG		HR		8.0HR	Mai..	▼	▼		00:00:11:00	05.02.2018	06.02.2018	11:00:00	PMILBR	
0260	SC	PL25 PM01	C	SCAFFOLD FOR ACCESS INTO SHELL		12.0HR	3	4.0HR	Cal..	▼	▼	02.02.2018	08:00:08:00	02.02.2018	02.02.2018	12:00:00	PMILBR	
0270	03-IMF	PL25 PM01	C	J&D TO WRAP BARRELS ON PALLET READY.		2.0HR	2	1.0HR	Cal..	▼	▼		00:00:12:00	02.02.2018	02.02.2018	13:00:00	PMILBR	
0280	OC	PL25 PM01	C	B&A TO CLEAN EXCHANGER SHELL		8.0HR	1	8.0HR	Cal..	▼	▼	05.02.2018	08:00:08:00	05.02.2018	05.02.2018	16:00:00	PMILBR	
0280	0010 SB	PL25 PM01	C	STAND BY DUTIES		8.0HR	1	8.0HR	Cal..	▼	▼		00:00:08:00	05.02.2018	05.02.2018	16:00:00	PMILBR	
0350	03-IMF	PL25 PM01	C	J&D TO WRAP BARRELS ON PALLET READY.		2.0HR	2	1.0HR	Cal..	▼	▼	06.02.2018	08:00:08:00	06.02.2018	06.02.2018	09:00:00	PMILBR	
0360	SC	PL25 PM01	C	Carry out scaff mods		6.0HR	3	2.0HR	Cal..	▼	▼		00:00:09:00	06.02.2018	06.02.2018	11:00:00	PMILBR	
0370	03-IRI	PL25 PM01	C	TRANSPORT BUNDLE AND COMPONENTS BAC.		6.0HR	2	3.0HR	Cal..	▼	▼		00:00:11:00	06.02.2018	06.02.2018	14:00:00	PMILBR	
0370	0010 CDR	PL25 PM01	C	TRACTOR & TRAILER REQUIRED		3.0HR	1	3.0HR	Cal..	▼	▼		00:00:11:00	06.02.2018	06.02.2018	14:00:00	PMILBR	
0370	0020 T50	PL25 PM01	C	LIFTING DUTIES		2.0HR	1	2.0HR	Cal..	▼	▼		00:00:11:00	06.02.2018	06.02.2018	14:00:00	PMILBR	
0380	EL-COR	PL25 PM01	C	ELECTRICIAN TO DISCONNECT AND REMOVE		1.0HR	1	1.0HR	Cal..	▼	▼		00:00:14:00	06.02.2018	06.02.2018	15:00:00	PMILBR	
0400	03-IMF	PL25 PM01	C	INSTALL BUNDLE, GH & FH THEN TORQUE		14.0HR	2	7.0HR	Cal..	▼	▼	08.02.2018	08:00:08:00	08.02.2018	08.02.2018	15:00:00	PMILBR	
0400	0010 03-IRI	PL25 PM01	C	ASSIST		7.0HR	1	7.0HR	Cal..	▼	▼		00:00:08:00	08.02.2018	08.02.2018	15:00:00	PMILBR	
0400	0020 T100	PL25 PM01	C	LIFTING DUTIES		5.0HR	1	5.0HR	Cal..	▼	▼		00:00:08:00	08.02.2018	08.02.2018	15:00:00	PMILBR	
0400	0030 03-BP	PL25 PM01	C	INSTALL BUNDLE		5.0HR	1	5.0HR	Cal..	▼	▼		00:00:08:00	08.02.2018	08.02.2018	15:00:00	PMILBR	
0400	0040 SC	PL25 PM01	C	SCAFF MODS REQUIRED		12.0HR	3	4.0HR	Cal..	▼	▼		00:00:08:00	08.02.2018	08.02.2018	15:00:00	PMILBR	
0450	03-IMF	PL25 PM01	C	PRESSURE TEST TUBE SHEET (VALERO PERS.		8.0HR	2	4.0HR	Cal..	▼	▼		00:00:15:00	08.02.2018	12.02.2018	11:00:00	PMILBR	

Appendix 5

HEAT EXCHANGER DATA SHEET - PROCESS										Sheet 1 of 2	
1			Project No.		PM15 701104		Doc No.		Later		
2			Equip No.		01-E-A1/A2		P&ID No.		01-AA-NEW		
3			Process Area		VDU		By		BW		
4							Date		13/07/2015		
5							Issue		0.3 For Design		
PROCESS CONDITIONS											
			NORMAL OPERATING CONDITIONS				DESIGN CASE (15% MARGIN ON NORMAL CONDITIONS)				
			PROCESS		PROCESS		PROCESS		PROCESS		
			IN	OUT	IN	OUT	IN	OUT	IN	OUT	
6	Fluid Name		Flashed Crude		Overflash (30 Sm3/h nominal)		Flashed Crude		Overflash (34.5 Sm3/h nominal)		
7	Liquid (kg/h)		64465	64465	31580	31580	74135	74135	36317	36317	
8	Condensable Vapor (kg/h)		0	0	0	0	0	0	0	0	
9	Non condensable Vapor (kg/h)		0	0	0	0	0	0	0	0	
10	Temperature (°C)		150	260	400	200	150	260	400	200	
11	Inlet Pressure (kg/cm2a)		20.31		15.3		20.31		15.3		
12	Pressure Drop (kg/cm2) - Allowable		1		2		1		2		
13	Velocity (m/s) - Target		0.6 - 0.7		1.5 - 2.0		0.6 - 0.7		1.5 - 2.0		
14	Fouling Resistance (m²-k/W)		0.001		0.0012		0.001		0.0012		
FLUID PROPERTY CURVES											
			PROCESS - FLASHED CRUDE				PROCESS - OVERFLASH				
15		Temperature (°C)	150	186.67	223.33	260	200	270	330	400	
16		Pressure (kg/cm2a)	20.31	20.08	19.84	19.61	13.3	14	14.6	15.3	
17	L	Density (kg/m³)	724.4	713.5	680	642.4	833.1	785.9	744.6	695	
18	I	Viscosity (cP)	0.6052	0.58	0.41	0.31	8.666	3.854	1.848	0.9623	
19	Q	Specific Heat (kJ/kg*K)	2.508	2.624	2.749	2.871	2.62	2.872	3.06	3.253	
20		Thermal Cond (W/m²K)	0.1042	9.57E-02	7.78E-02	6.308-2	0.1478	0.1369	0.1271	0.115	
21		H Vaporization (J/kg)	9.20E+05	9.51E+05	9.59E+05	9.66E+05	8.2	10.83	6.694	4.42	
22	V	Density (kg/m³)	Not applicable								
23	A	Viscosity (cP)									
24	P	Specific Heat (J/kg*K)									
25	O	Thermal Cond (W/m²K)									
26	U	Vapor Pressure (kg/cm2a)									
27	R	Molecular Weight									
28	N	Viscosity (cP)	Not applicable								
29	N	Specific Heat (kJ/kg*K)									
30	C	Thermal Cond (W/m²K)									
31	D	Molecular Weight									
HEAT TRANSFER DATA											
			NORMAL OPERATING CONDITIONS				DESIGN CASE (15% MARGIN ON NORMAL CONDITIONS)				
32	Overall (Clean) Film Coeff. (W/m²K)		VTA				VTA				
33	Heat Load (kW) - Indicative		5200				6000				
34	LMTD (°C) - indicative		c. 80 DegC				c. 80 DegC				
35	Clean Area (m²)		VTA				VTA				
36	Safety Margin to be applied (%)		Note 7				Note 7				
37	Actual Area Provided (m²)		VTA				VTA				

HEAT EXCHANGER DATA SHEET - MECHANICAL										Sheet 2 of 2	
1	FUNCTION:	Overflash / Flashed Crude Exchanger									
2	SITE:	Valero Pembroke Refinery								3 BUILDING: Vacuum Distillation Unit	
DESIGN CONDITIONS						MISC INFORMATION				REQUIRED TESTS	
4	Design Pressure	Unit	SHELLSIDE	TUBESIDE	18	TEMA HX Type:	AES	Note 6	24	Hydrostatic Test:	Code
5	Design Temperature	Kg/cm2g	23	25	19	TEMA Class:	R		25	Pneumatic Test:	No
6	FV Design	°C	-7/300	-7/427	20	Orientation:	Horizontal		26	Helium Test:	No
7	Design Temp @ FV	Kg/cm2g	FV	FV	21	ASME Code	ASME VIII Div 1 Latest addenda		WEIGHT (kg)		
8	MAWP	°C	208	427	22	Stamp U	NO		27	Empty	Note 1
9	Corrosion Allowance	Kg/cm2g	VTA	VTA	23	Nat'l Bd. No./User Inspectorate No	Valero Inspectorate		28	Full of Water SG 1.5 (Min)	Note 1
10	Radiograph	mm	3	Nil	SKETCH				29	Bundle	Note 1
11	Coating/Lining		Per Code	Per Code	For each Shell. Assumed 2 identical shells in series and close coupled stacked one above the other with no intermediate valves						
12	Number of Passes		Note 1								
13	Process Fluid		Flashed Crude Oil	Overflash							
14	Fluid State (Liquid or Gas)		Liquid	Liquid							
15	Fluid Group (1 or 2)		1	1							
16	Hazard Category		VTA								
17	Conformity Assessment Module		VTA								
SHELL/BAFFLE DATA											
30	No of shells	2	31	Series/Parallel	Series						
32	Shell size:	Note 3									
33	Cross Baffle Type:										
35	Cross Baffle Spacing:										
37	Percent Cut:										
38	Long Baffle Type:										
40	Imp. Baffle:										
41	Expansion Joint:	N/A			ATTACHMENTS				COMMENTS		
TUBE DATA					48	Paint Spec.:	TSA	TSA	See Valero BEDD document		
42	Tube OD:	mm	25.4	46	Thickness:	mm	2.11	49	Insul. Thk. :	mm	Per Valero insulation spec.
43	Tube Length:	mm	6096	47	Max:	6096	mm	50	Insul. Tie Rings:	No	
44	No. of Tubes:	476 - preliminary design			51	Lifting Lugs:	Yes	Yes			
45	Tube Pitch:	Square; 31.7mm			52	Suppt Type:	Horizontal	No.	2		
NOZZLE INFORMATION											
Shellside						Tubeside					
	Service	Nozzle #	Size	Rating	Face	Type	Nozzle #	Size	Rating	Face	Type
1	Cold Inlet	A	6"	300lb	RF	WN					
2	Cold Outlet	B	6"	300lb	RF	WN					
3	Hot Inlet						E	4"	300lb	RF	WN
4	Hot Outlet						F	4"	300lb	RF	WN
5	Vent	D	1"	300lb	RF	WN					
6	Drain	C	1"	300lb	RF	WN					
7	Tubesheet drain	N/A									
MATERIAL SPECIFICATIONS Note 2											
		Material	Specification			Material	Specification				
8	Shell	Carbon Steel	VTA	20	Tubes	316 SS	VTA				
9	Shellside Head	Carbon Steel	VTA	21	Tubesheet	316 SS	VTA				
10	Cross Baffle/Tube Sup.	Carbon Steel	VTA	22	Tubeside Head	316 SS clad Carbon Steel	VTA				
11	Long Baffles	N/A	VTA	23	Tubeside Cylinder	Note 2	VTA				
12	Imp. Plate	Carbon Steel	VTA	24	Head Flanges	316 SS clad Carbon Steel	VTA				
13	Tie Rods	Carbon Steel	VTA	25	Tubeside Partitions	316 SS clad Carbon Steel	VTA				
14	Spacers	Carbon Steel	VTA	26	Tube Nozzle Necks	316 SS clad Carbon Steel	VTA				
15	Shell Nozzle Necks	Carbon Steel	VTA	27	Tube Nozzle Flgs.	316 SS clad Carbon Steel	VTA				
16	Shell Nozzle Flgs.	Carbon Steel	VTA	28	Bolts/Studs	Carbon Steel	VTA				
17	Vessel Supports	Carbon Steel	VTA	29	Nuts	Carbon Steel	VTA				
18	Lining	NA		30	Gaskets	Graphite filled spiral wound					
19	Body flanges	Note 2		31							
Notes											
1 Vendor to advise: see Note 4 re target fluid velocity											
2 All tubeside wetted parts (overflash) to be 316SS or 316 SS clad CS											
3 Vendor to advise details, but due to shellside fouling service, helical baffles to be considered and offered as an option											
4 Services are fouling both sides: Target velocity allowable pressure drop generally to be in line with Shell DEPS 31.21.01.12-Gen Tables 2 and 3											
5 Fouling allowances from Shell DEPS 31.21.01.12-Gen Tables 2 and 3											
6 U-tube design not suitable this service.											
7 No margin to be added to area provided as covered in 115% design case.											
8 Exchanger vibration to be analysed at 120% of design case flowrates.											
No	REVISION DESCRIPTION			By	Approved	Date	HEAT EXCHANGER MECHANICAL DATA SHEET				
0.1	For Review			BW		29/05/2015	Project:		FCC Feeds Optiization		
0.2	Not issues						Project No.:		PM15 701104		
0.3	For Design			BW		03/07/2015	P&ID .:		01-AA-NEW		
							Data Sheet No.:		Later		
							Equip. No.		01-E-A		

APPENDIX OF CALCULATION DATA

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TABLE 9. TUBE-SHEET LAYOUTS (TUBE COUNTS)
Square Pitch

$\frac{3}{4}$ in. OD tubes on 1-in. square pitch						1 in. OD tubes on $1\frac{1}{4}$ -in. square pitch					
Shell ID, in.	1-P	2-P	4-P	6-P	8-P	Shell ID, in.	1-P	2-P	4-P	6-P	8-P
8	32	26	20	20		8	21	16	14		
10	52	52	40	36		10	32	32	26	24	
12	81	76	68	68	60	12	48	45	40	38	36
$13\frac{1}{4}$	97	90	82	76	70	$13\frac{1}{4}$	61	56	52	48	44
$15\frac{1}{4}$	137	124	116	108	108	$15\frac{1}{4}$	81	76	68	68	64
$17\frac{1}{4}$	177	166	158	150	142	$17\frac{1}{4}$	112	112	96	90	82
$19\frac{1}{4}$	224	220	204	192	188	$19\frac{1}{4}$	138	132	128	122	116
$21\frac{1}{4}$	277	270	246	240	234	$21\frac{1}{4}$	177	166	158	152	148
$23\frac{1}{4}$	341	324	308	302	292	$23\frac{1}{4}$	213	208	192	184	184
25	413	394	376	356	346	25	260	252	238	226	222
27	481	460	432	420	408	27	300	288	278	268	260
29	553	526	480	468	456	29	341	326	300	294	286
31	657	640	600	580	560	31	406	398	380	368	358
33	749	718	688	676	648	33	465	460	432	420	414
35	845	824	780	766	748	35	522	518	488	484	472
37	934	914	886	866	838	37	596	574	562	544	532
39	1049	1024	982	968	948	39	665	644	624	612	600

COMMERCIAL TERMS AND CONDITIONS

This offer is based on the following commercial terms and conditions:

DELIVERY

Delivery is DDP Pembroke Refinery, Wales UK, as per Incoterms 2010. Packing included.

TIME OF DELIVERY

Our time of delivery is 35 working-weeks after receipt and acceptance of your written order.

Our time of delivery is based on:

- ☐ Your approval and return of drawings within 5 working-days;
- ☐ Inspection within 3 working-days after written notice.

Exceeding of these periods, caused by the principal, may have influence on the time of delivery, of which you will be informed in writing.

PRICES

As per datasheet

Item Qty Description Price/EUR

01-E-615 A 1 Overflash/Flashed Crude Exchanger A 211 000

01-E-615 B 1 Overflash/Flashed Crude Exchanger B 211 000

Commissioning spares 100% gasket 2000

20% studs/bolts 900

2 years of spares (200% gaskets) 4000

Transport 5500

Total Price EUR 434 400,-

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Spiral Heat Exchanger

Specification

Customer : Valero Energy Ltd
Model : 1H-L-1T
Project : GBCAQAD-123/PM15 701104
Item : Spiral Heat Exchanger **Date** : 07/09/2015

		<u>Hot side</u>	<u>Cold side</u>
Fluid		Overflash	Flashed Crude
Density	kg/m ³	767.1	694.9
Specific heat capacity	kJ/(kg*K)	2.96	2.69
Thermal conductivity	W/(m*K)	0.132	0.0848
Viscosity inlet	cP	0.962	0.605
Viscosity outlet	cP	9.25	0.310
Mass flow rate	kg/h	36320	74140
Inlet temperature	°C	400.0	150.0
Outlet temperature	°C	195.3	260.0
Pressure drop	kPa	189	147
Heat transfer			
Heat Exchanged	kW	6091	
Relative directions of fluids		Countercurrent	
L.M.T.D.	K	84.0	
O.H.T.C clean conditions	W/(m ² *K)	375.8	
O.H.T.C service	W/(m ² *K)	381.2	
Construction			
Cylindrical width	mm	1250	
Outer diameter	mm	1880	
Plate material		316/316L Dual certif	
Plate thickness	mm	4.0	4.0
Spacing	mm	9.0	16.0
Stud arrangement		55.0 x 40.0	70.0 x 35.0
Connection size		ND 150->ND 150	ND 150->ND 150
Channel closure		Open-Roll	Open-Roll
Design according to		ASME - PED,	
Flange standard		ASME	ASME
Design overpressure	barg	25.0	25.0
Design temperature	°C	420 (max 424)	420 (max 424)
Fluid danger		Dangerous	Dangerous

1. Design

Design according to ASME VIII Division I + U stamp

A limitation on the Design Temperature to a maximum of 424°C has been set. Please refer to deviations and enclosures for more details.

We propose a Spiral Wound Heat Exchanger for meeting the heating and cooling duties of the Overflash Flashed Crude Exchanger Heat Exchanger

	316 / 316L
Outer Shell	316 / 316 L
Studs	316 / 316L
Body Flange	F304
Covers	SA516 Gr 60 or 70 + 316L lining and set on nozzle connections
Bolts	ASTM/ASME SA 193 Grade B7
Nuts	ASTM/ASME SA 194 Grade 2H
Design Code:	ASME VIII Division 1 With 'U' Stamp
Gasket Material	Kamprofile dual graphite gaskets system both sides
Connection Sizes:	150 mm
Connection Standard:	ASME B16.5 WNRF 300lb

Price

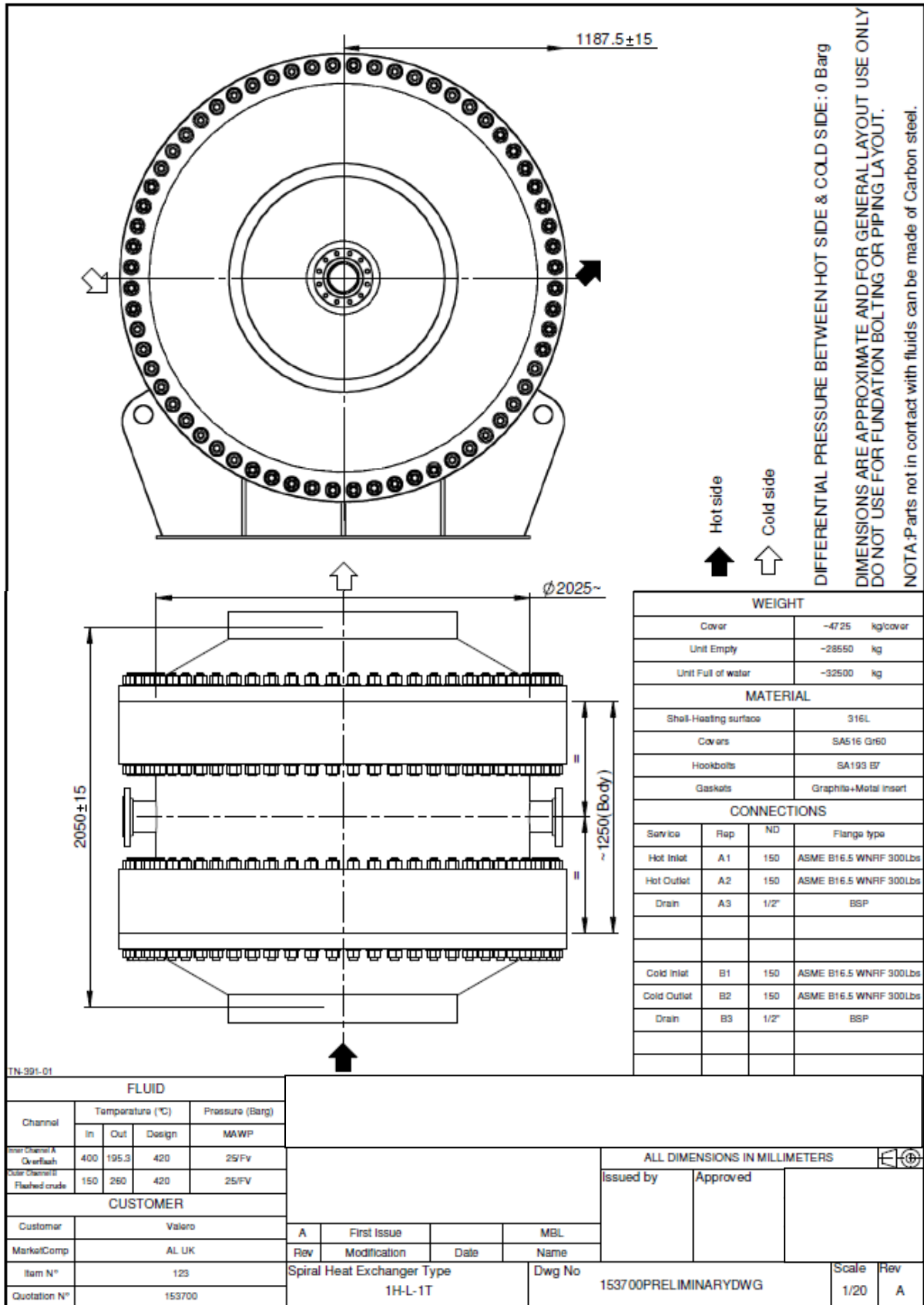
As detailed in the above scope of supply see table below:

Table 1 Pricing schedule of Spiral

NB: The delivery times below are subject to only the highlighted items within the scope of supply Item	Description/Heat at Exchanger	Quantity	Delivery Time (Working Weeks to FCA point)	Price/GBP (excluding operational spares) Price accurate within (+/- 15%)
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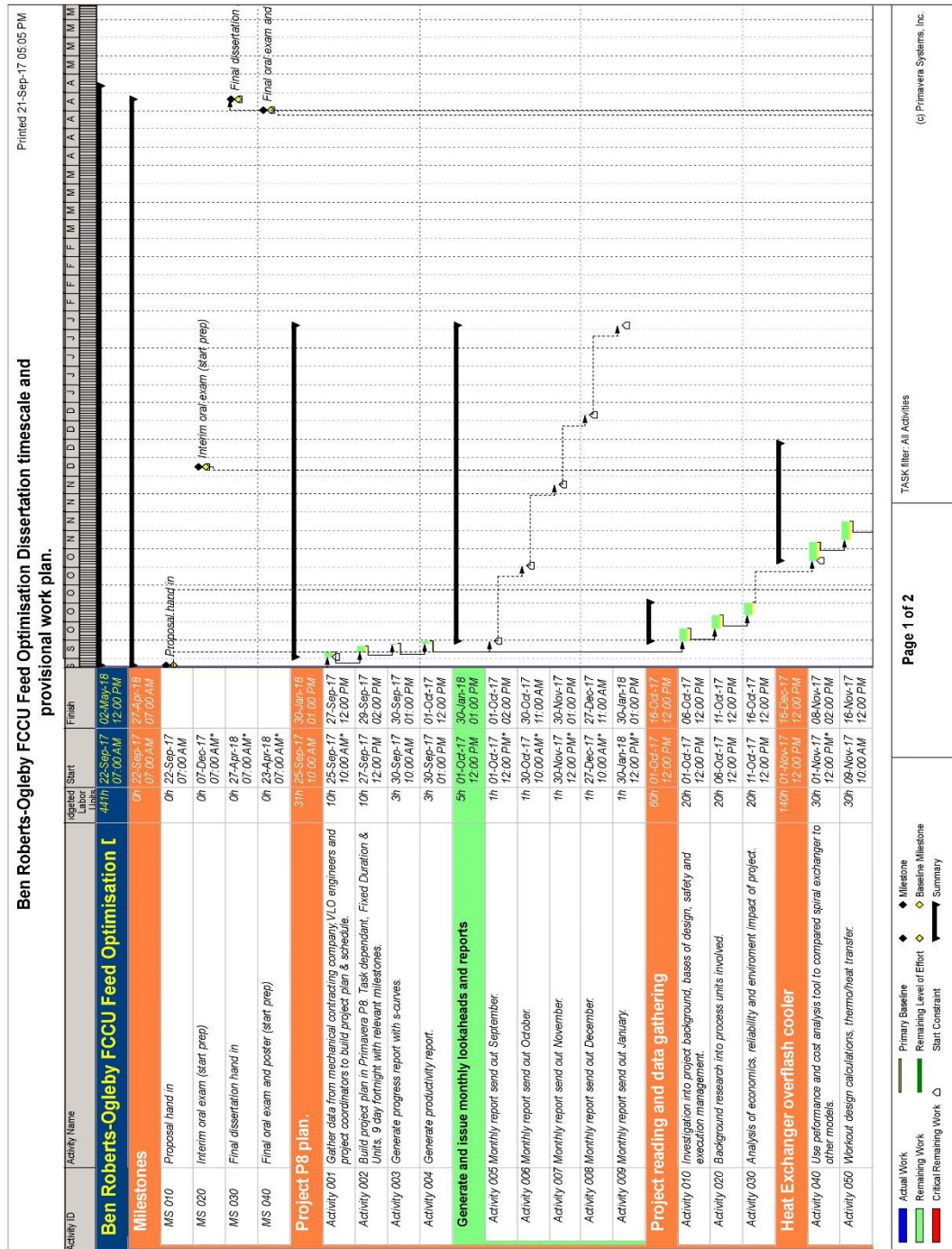
Unit Costs

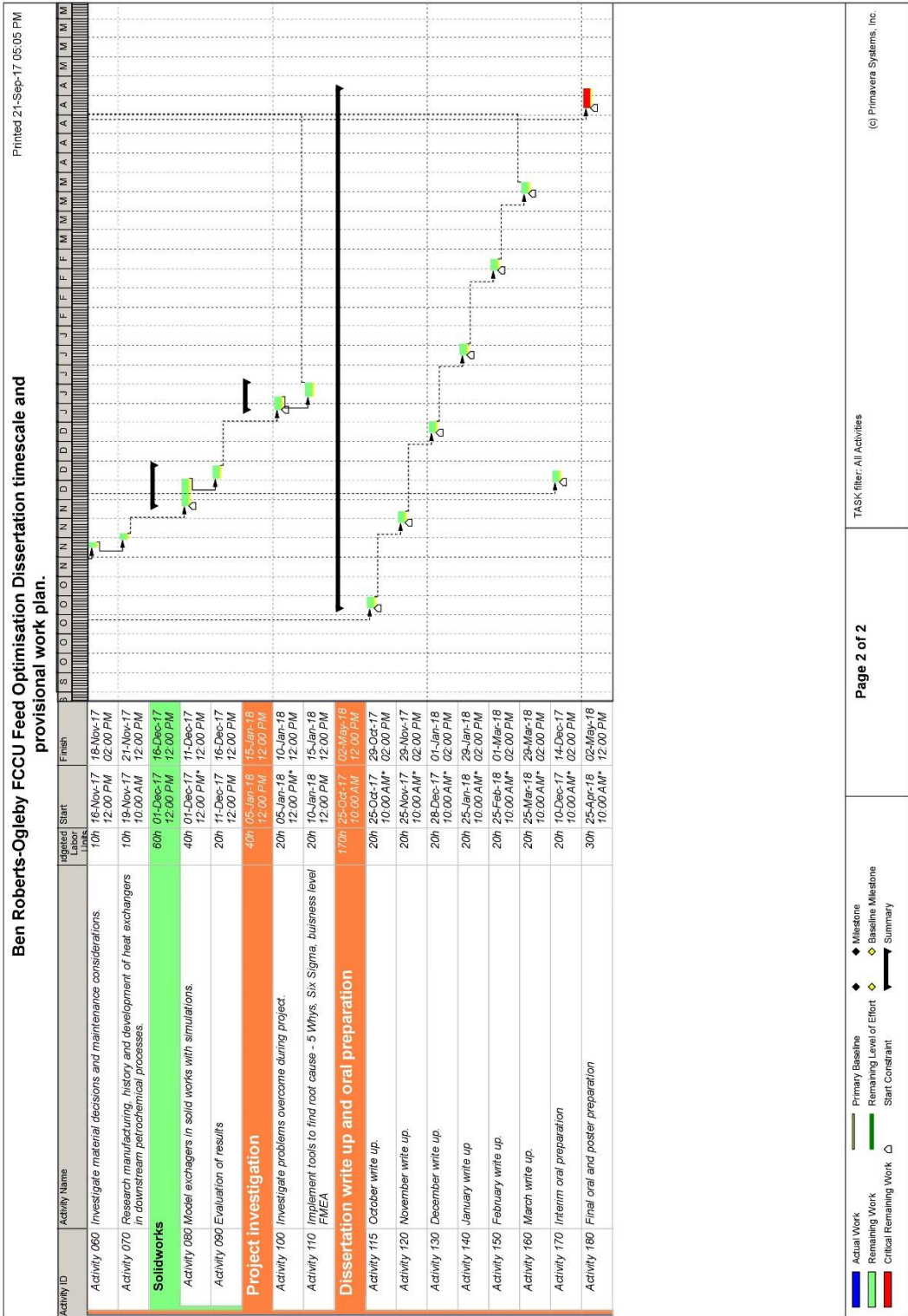
Spiral	1	TBC
Total	£400,000	
Documentation Costs	Included in scope	
Packing Costs	Included in scope	
Delivery Costs	(DAP)	All units (x1) TBC
Total (FCA)	(DAP)	TBC



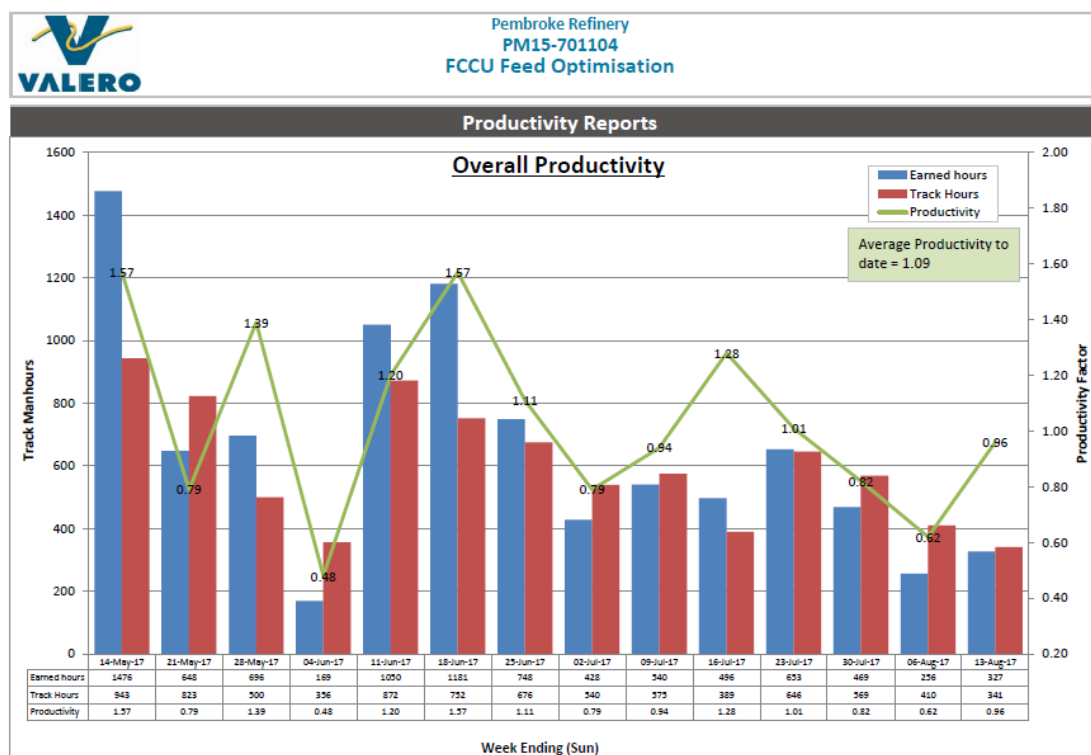
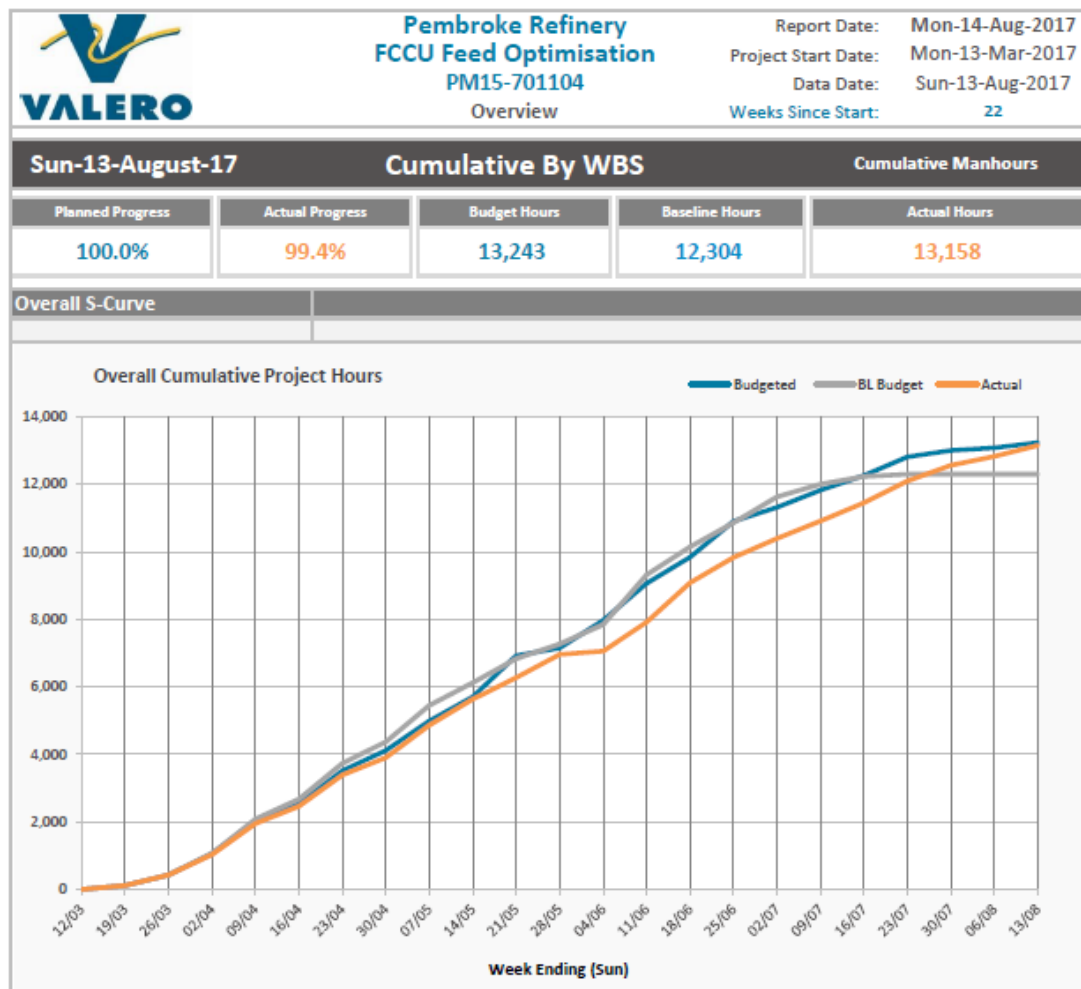
Appendix 9

		Option 1		Option 2		Option 3		
		2-off series S&T exchangers		Spiral Exchanger		2-off parallel single S&T exchangers		
Overflash Cooler Heat Exchanger summary	Weighting							
	Scorecard Measures							
	Environmental impact of running this equipment	900	Score 2	Points 1800	Info Shell and tube exchanger heavy fouling expected. Fouling leads to more CO2 emissions. A lot of experience in cleaning and waste mitigation.	Score 3	Points 8100	Info Heavy fouling - 8 months between cleans assumed (heavy maintenance required). Nothing new to learn old technology. Proven technology.
	Spiral versus options other options capital cost	900	4	3600	Lower capital cost by small margin but poor in terms of lost OPEX due to downtime for cleaning.	7	6300	Lower Capital but eaten up in time by higher OPEX compared to Option 2.
Fouling resistance / Impact on overflash processing and on maintenance cleaning costs	900	1	900	Expected to foul. No stand-by spare so production disruption after performance has deteriorated 10 days off line time assumed.	10	9000	Expected to foul, provision in place to monitor and switch to stand-by spare unit when performance deteriorated excessively, minimal off line time assumed.	
	Available plot area is sufficient for space requirements	900	8	7200	Adequate area available but largest plot area than spiral option.	10	9000	Largest footprint of the options but could fit.
Approximate Capital cost, GBP, within project budget	900		10	9000	400,000	10	9000	330000 300000 additional piping / valving costs Total 385,000
Familiarity with and ability to perform cleaning work	900		10	9000	New technology, bundle does not need pulling but unit needs taking to jetting bay. Vendor presence for duration. Cleaning may not be required. Big risk of damage to spiral if both sides are not depressurised.	7	6300	Standard technology on site. Valero and Contractors very familiar with the design. Bundle needs pulling using specialist equipment and jetting at other part of refinery.
Maintenance / repairability and ability to effect repairs if required	900		6	5400	Spare tube bundle can be held on site (75,000 GBP approx). Various UK Vendors available to repair any failure. 2-3 weeks loss of overflash processing whilst bundles pulled / replaced	4	3600	Spare tube bundle can be held on site (75,000 GBP approx). Various UK Vendors available to repair any failure. No loss of overflash processing if failed due to spare.
Maintenance costs and time intervals	900		6	5400	Approximately £50,000 per clean. 8 months estimated by operations & maintenance superintendents between cleans.	10	9000	Approximately £50,000 per clean. 8 months estimated by operations & maintenance superintendents between cleans.
Allows trialing of new technology in an application with no risk to core business	450		0	0	Nothing new.	8	3600	Nothing new.
TOTALS				42300			63900	
								46800

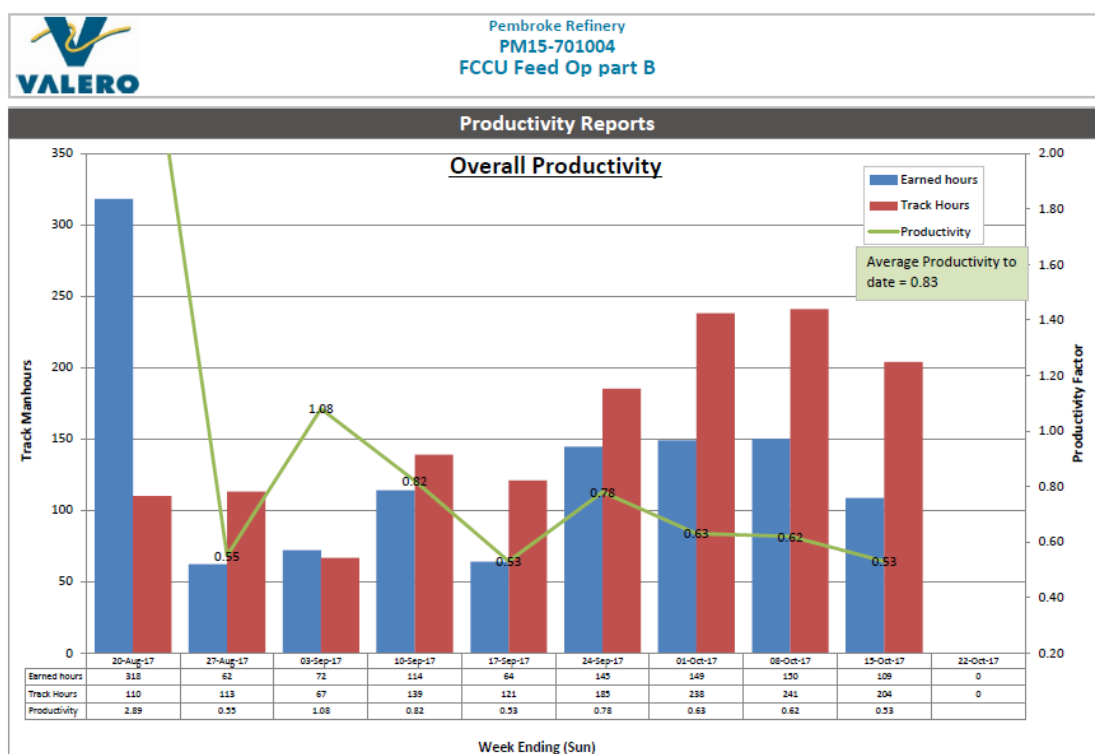
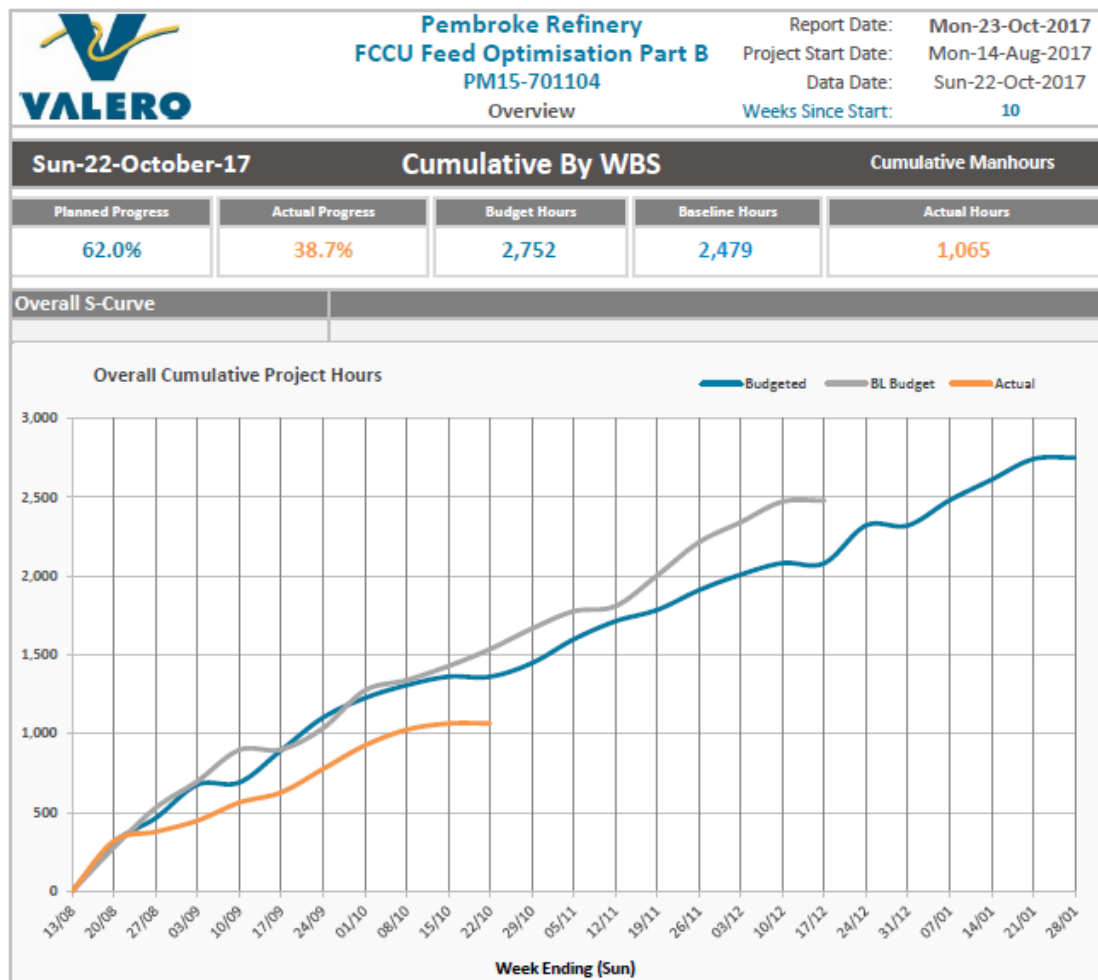




Appendix 11



Appendix 12



Appendix 13

