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Individual Project

BEng Mechanical Engineering

Sulphuric acid pump upgrade



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Declaration of authenticity

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Abstract

This report details the process and research carried out to determine that the most cost-effective and suitable replacement pump for the spent sulphuric acid duty, is an MKPL 25-25-160 model with a 140mm trim closed impellor, manufactured by CP Pump Systems.

From research carried out for suitable materials, it was found that metallic materials suitable are alloy 20, Hastelloy C-276, alloys 625 and alloy 254SMO, and that any pump of a fluorinated plastic lining would be suitable so long as its relatively low temperature limitations aren't exceeded.

From a thorough performance analysis, using calculations for viscosity corrections and impellor corrections, it was determined that either a PFA lined magnetic drive pump with a 140mm trim closed impellor manufactured by CP Pump systems, or an alloy 20 constructed canned motor pump with a 152mm trim closed impellor manufactured by Nikkiso Pumps would be suitable, however the option from CP Pump systems was calculated as the most cost effective option, totalling a cost after 5 years of **£110,699.95** compared to the cost of the Nikkiso option of **£214,456.92**.

It has been determined that by installing the specified pump from CP Pump systems, that the pump will likely be more reliable, cheaper to run, whilst exceeding the current pump performance and having adequate instruments to ensure process safety.

It has also been preliminarily estimated that a total time of 4 months is required to take this project from theoretical, to installing and operating the specified replacement pump on plant.

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Introduction

The purpose of this project/report is to find a suitable replacement for a spent sulphuric acid pump duty, currently in operation at the Dow Chemical Barry site, as the pump is no longer deemed as fit for service.

The replacement pump is required to meet multiple criteria due to the hazards associated with the duty and is required to meet or exceed the performance capabilities of the current pump.

With increased industrial focusing on costs, this project aims to find a cost-effective solution with respect to both the purchasing costs and operating costs.

The last section of this report will also outline any remaining work to follow to successfully implement the findings of this project with regards to the work required to install the specified replacement pump.

Aims and objectives.

The following list outlines the aims and objectives of this project:

- Investigate a variety of different materials for compatibility with sulphuric acid, considering both metallic and plastic materials.
- Determine specific performance data for the currently installed pumps, to be used as the base line for comparison for the replacement options.
- Research and compare suitable replacement pumps, particular focus on theoretical performance from both a fluid flow perspective, and power requirements/efficiency.
- Assess the installation requirements to install shortlisted pumps.
- Carry out a thorough cost analysis of shortlisted pumps, considering purchase costs, installation costs, operating costs, and maintenance costs.
- Determine the most suitable replacement pump based on performance research and cost analysis.
- Create a preliminary plan for work to be done following the conclusion of this project.

Company and process information

This project concerns the selection of a replacement pump to be installed at Dow Silicones Barry site. Dow Silicones is a world leading producer of silicones and silicone-based products and is a part of the larger chemical manufacturing company, Dow Chemical. The Barry site has been in operation since 1952, and has seen considerable growth and investment to make it the largest Dow Silicones site in Europe, where silicon metal is used as a raw material before being reacted with various chemicals to create silicone fluids, rubbers, gums and speciality polymers, to be supplied to customers around the world for the production of finished products, ranging from shampoos and make up, to automotive components. (Dow Chemical Company, 2023)

The pump in question is a part of the sulphuric acid recovery system on the Methyl Chloride production plant, the pump is based at the bottom of a sulphuric acid column, where clean concentrated sulphuric acid is used to remove an unwanted impurity, dimethyl ether, from the produced methyl chloride as part of the reaction process, this pump is used to transfer the contaminated sulphuric acid, referred to as “spent sulphuric acid” throughout this report, from the bottom of the column back to a storage vessel where the spent acid is then transferred into a road tanker to be taken to another facility to have the contaminants removed from the sulphuric acid, where it is then transported back to the Barry site as clean concentrated acid, to be used again. (Ridgeway, 2022)

Timing Plan

Below, figure 1 details the updated timing plan following the Interim viva stage of this project, key points are outlined along with estimated time durations, The graph has been created using an Excel template (Vertex42, 2003).

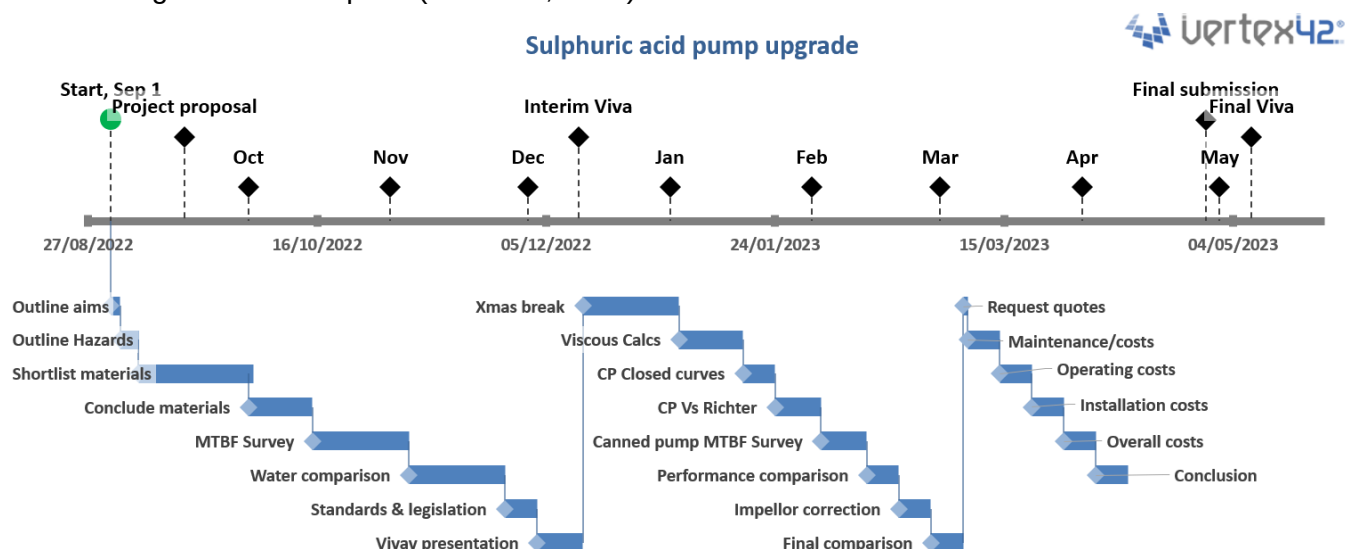


Figure 1 - Timing plan

Actual project timings

Whilst many of the timings and dates were accurate to the initial plan, some stages deviated from this plan:

- The time taken to correct the performance curves for different viscosity fluids was considerably longer than initially planned, this was due to limitations in resources available as the required documentation isn't readily available, this was overcome once the document was eventually obtained using contacts through Dow Chemical. Overall, viscous corrections took over a month, as opposed to the 14-day preliminary estimation. This process can be reduced significantly in future by obtaining specific software available for performing such calculations.
- The required quotation from Nikkiso for the canned motor pump option took over a month to receive due to issues using a third-party representative, a learning from this is to avoid the use of third-party suppliers and communicate directly with OEM's where possible.
- Overall cost analysis had to be performed more quickly than initially planned due to the previously mentioned delays, this however didn't impact the accuracy of the final calculated costs.

The currently installed pumps

What are they?

The currently installed pumps were installed in May 1996 during the building of the 'Genesis' expansion project. The pumps are:

- Magnetic drive PFA (Perfluoroalkoxy) lined pumps, manufactured by Richter Pumps.
- Horizontally mounted on a baseplate
- Long coupled (Have a flexible coupling connecting to a separately mounted electric motor)
- Fitted with a 130mm closed impellor (Upgraded from the original 105mm)
- Connected via 1" 150# ANSI B16.5 flanges on both the suction and discharge.
- Single stage

Magnetic drive pump principles

A standard centrifugal pump is driven by a separate motor which requires the shaft to protrude beyond the pump housing for a coupling to connect the 2 machines, this means that The shaft must be sealed to the pump casing in order to prevent leakage of the pumped fluid to the outside atmosphere, this is conventionally achieved using either a packed gland or a mechanical seal, the downside to both of these methods is that both seals require small amounts of leakage in order to cool and lubricate them, creating a hazard when the pumped fluid is hazardous and leakage to atmosphere cannot be tolerated.

According to (Michael-Smith-Engineers, 2022), in a magnetic drive centrifugal pump, a hermetically sealed housing contains the impellor and the pumped fluid. An assembly of magnets is attached to the shaft driven by the motor outside of the housing, and on the inside of the housing are the opposing magnets mounted to the shaft the impellor is on. The torque is transferred through the housing because of the coupled magnets, all conventionally designed magnetic drive pumps use a containment shell (commonly referred to as a can) to separate the wetted and non-wetted areas of the pump. The can must be as thin as possible to allow the inner and outer magnets to run close together to run efficiently. This presents challenges as contact between the rotating elements of the pump and the stationary isolation shell can easily lead to rupture thus breaking the containment boundary of the pump.

This leak free design makes magnetic drive pumps particularly desirable for hazardous duties such as the duty detailed in this report.

Figure 2 below shows a cross sectional view of a basic magnetic drive pump arrangement.

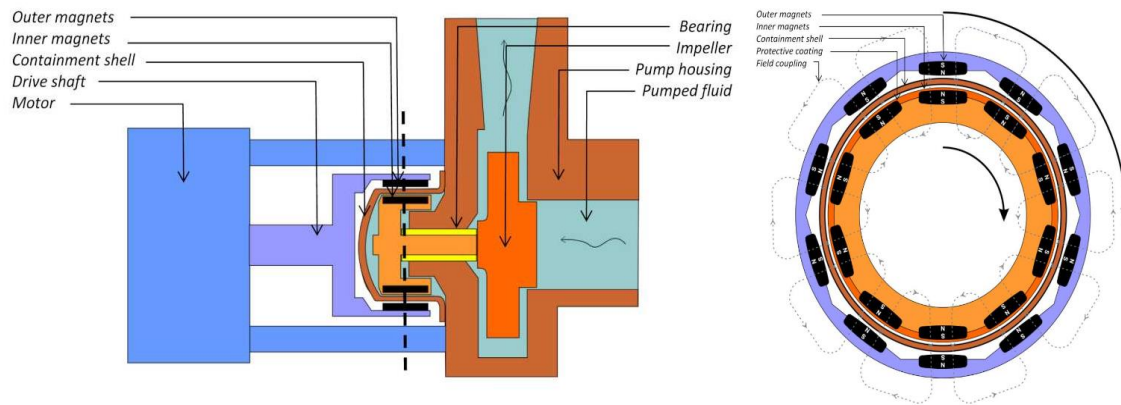


Figure 2 - Cross sectional view of magnetic drive pump arrangement (Michael-Smith-Engineers, 2022)

Why do they need replacing?

When the pumps were originally installed, they were fitted with an instrument known as “can protection”, this device monitors the space between the PTFE (Polytetrafluoroethylene) and carbon fibre layers of the containment shell for signs of a rupture to either layer. If a rupture is detected, an alarm will be triggered in the control room so that the plant operator can shut the pump down and isolate the lines to prevent a PSCE (Process safety containment event). Without this feature, there is no way to detect a potential leak before it happens.

This can protection device is no longer an option on the replacement containment shells or new pumps, so these pumps are no longer deemed fit for this duty.

Containment shell monitoring (Can protection) principles

As mentioned previously, the can protection features on mag drive pumps used in hazardous duties is a critical safety device which prevents leaks. There are multiple methods of incorporating a variant of this feature, each differs depending on the manufacturer. Some of which are:

- The currently installed pump manufactured by Richter uses an electronic circuit, according to (Ridgeway, 2022), it operates by continuously monitoring the electrical continuity of the wired circuit. If either layer is breached, then the electrical continuity will decrease or become open circuit. This condition is detected by a relay in the MCC (Motor control centre), which in turn trips the electrical supply to the motor and raises an alarm on the DCS (Distributed control system) to alert the plant operator to the fault.

- There are also pumps manufactured by (Klaus-Union, 2022) which are in operation at the Barry site with similar technology, these pumps however have double skin metallic containment shells with a void between the 2 layers, this void is then connected via an ANSI B16.5 piping flange connection to a pipe assembly with a pressure switch monitoring the pressure between the 2 layers, once a pump is installed with this feature the pressure in the void is reduced down to a vacuum with a vacuum pump, if either layer is ruptured during operation then the pressure switch will detect the pressure increase and trip the pump to prevent the 2nd layer failing whilst triggering an alarm in the DCS to alert the plant operator to the fault.

Figures 3 and 4 below, show photographs taken of the containment shells used in the currently installed pumps.

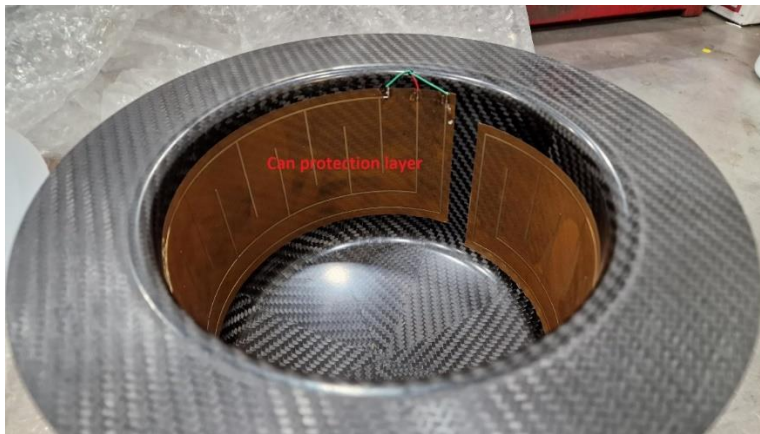


Figure 3 - The can protection circuit on the Carbon fibre layer



Figure 4 - Fully assembled containment shell with can protection feature

Replacement pump criteria

For a replacement pump to be suitable for this duty, there are several conditions that it would have to meet:

- Be resistant to the corrosive nature of this duty.
- Have adequate safety measures/devices to prevent/detect any process leaks.
- Meet the required flow rate and head for this duty.
 - Minimum of 24m of head at 4.4m³/hr flow rate, based on water data (ITT Richter Chemie-Technik GmbH, 1995)
- Meet all regulation requirements for this duty e.g., ATEX regulations.
- Be cost-effective considering the following:
 - Initial purchase cost
 - Predicted maintenance costs (Spare parts, mean time between repairs)
 - Energy requirements/running costs.
 - Installation costs (pipework, electrical supplies, and baseplate modifications)
- Be current/supported. There are a growing number of pumps & compressors used on site that are now considered obsolete as the manufacturers no longer make them or spare parts, this makes them difficult and expensive to maintain/repair as if it isn't viable to replace them with a modern alternative, the only solution is using reverse engineering which is costly and takes considerable time.

ATEX Directive requirements

As the pump in question is to operate on a top tier COMAH plant, within a classified hazardous area, there are legal requirements that the replacement pump must be certified too (HSE, 2002). This will be achieved by selecting a pump which is certified in accordance with the ATEX directive 2014/34/EU. Selecting a pump certified in accordance with this directive is also a legal requirement under the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR).

The specification of the area classification has been obtained from the original datasheet (Appendix A) supplied with the currently installed pumps and is detailed in figure 5 below.

45	AREA CLASSIFICATION	ZONE 2, GROUPS IIA, IIB, T3
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Figure 5 - ATEX classification

Zone 2, this is the classification given to determine how frequently an explosive atmosphere may be present where the equipment is located, for gasses and liquids there are 3 zone classifications, zone 0, 1 & 2, zone 0 being the most severe where flammable atmospheres are continually present, such as inside a vessel. Zone 2 means that whilst explosive atmospheres are possible, during normal operation it is unlikely.

IIA & IIB, these are the designations of the gas groups which may be present in the area, the classifications are A, B & C, where C is allocated to the most explosive gases such as hydrogen and acetylene.

T3, this is the temperature classification of the equipment which relates to the maximum temperature the equipment can reach during operation and is related to the gas groups, this is important as it is essential the equipment can't reach a temperature high enough to ignite a flammable substance that may be in the vicinity, the temperature classifications range from T1 to T6, T1 being the most severe where the temperature can reach 450°C, and T6 being the best where the temperature won't exceed 85°C.

Note: The ATEX classification is to be guaranteed by the OEM (Original equipment manufacturer) supplying equipment and must meet or exceed the requirements detailed above to be suitable for this duty.

Material selection

Pumped fluid composition and properties

A critical step during the selection process for any piece of equipment used in a chemical plant is the materials used for its construction, improper selection can lead to catastrophic consequences. For the pump to be used, the pumped fluid must be considered, according to the datasheet for the currently installed pump (John Brown, 1996), the pumped fluid is of the following composition:

- 71% H₂SO₄ (Sulphuric acid)
 - According to (NIOSH, 2019), Sulphuric acid is considered an extremely corrosive substance and it can have a severe impact on an individual's health, it is harmful to skin, eyes, teeth and lungs, and in serious cases can result in death.
- 24% Dimethyl Ether
 - According to (ACS, 2022), The main hazards associated with dimethyl ether is that it is extremely flammable and explosive, with minor toxic effects.
- 3% H₂O (Water)
 - Water is a non-hazardous substance although it can cause corrosion on certain steels and irons.
- 0.9% Methyl Chloride
 - According to (Carey, 2017), Methyl Chloride is "*a colourless, flammable, toxic gas*".
- 0.1% MEOH (Methanol)
 - According to (NIOSH, 2011), Methanol is classified as flammable and toxic.

From the information above, the assumption can be made that the greatest hazard regarding materials of construction is the high concentration of sulphuric acid, due to the dangers of corrosion and its harmful health effects, when the original specification for the Richter pumps was being determined, they were specified to be suitable for 75% H₂SO₄, this will be the case for the replacement.

Corrosion from sulphuric acid

As mentioned, the primary concern of this duty is the corrosive properties of sulphuric acid, so the construction of the selected pump must be carefully selected. According to (Tantaline, No date), the corrosion rates for sulphuric acid is highly dependent on the temperature and concentration of the solution, as is common with acids. This is demonstrated in figure 6 below.

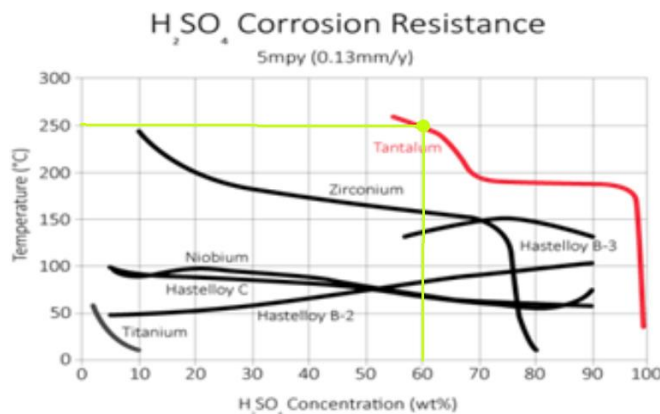


Figure 6 - Sulphuric acid ISO corrosion curve (Tantaline, No date)

Figure 6 demonstrates where specific materials will be useful, based on the properties of the sulphuric acid, the lines represent the conditions where no more than 0.13mm of corrosion will occur in a year.

For an example of how to use this graph, if a material is required to handle 60% sulphuric acid at 250 degrees Celsius, a line can be drawn at both points as shown in figure 6, any material below this point can expect more than 0.13mm of corrosion in a year, so the only material suitable at this condition is Tantalum.

Corrosion from 75% sulphuric acid at 0 degrees C

For this duty, the material must be suitable at 75% sulphuric acid at 0 degrees C. A conclusion can be drawn from figure 6, that whilst the temperature doesn't add any specific dangers, this concentration of sulphuric acid is severely corrosive.

Whilst there are many materials suitable to handle sulphuric acid at the specified composition and temperature, there are limited materials used for pump construction. To limit the possible materials to be assessed for compatibility, the materials of construction commonly used by pump manufacturers were surveyed and a shortlist was created.

The shortlist was created from information obtained from the following pump manufacturers:

- Hermetic-Pumpen (Hermetic-Pumpen, 2022)
- HMD Kontro (HMD KONTRO, 2022)
- CP Pumpen (CP Pump Systems, No year)
- Nikkiso Pumps (Nikkiso Pumps, 2022)
- Klaus-Union Gmbh (Klaus Union Gmbh, 2022)
- Flowserve (Flowserve , 2022)

From the survey of available materials of construction for pumps, the following shortlist specifies the common materials offered by OEM's:

- Metallic materials:
 - Carbon steels & cast irons
 - Stainless steels (Multiple grades)
 - Alloy 20
 - Titanium
 - Hastelloy C-276
- Non-metallic materials/lined pumps:
 - PTFE
 - PFA
 - PVDF

With the above materials available, it's important that careful consideration is made to determine what materials are suitable. There are many sources available which detail research and results based on materials corrosion resistance to sulphuric acid, however according to (Ashby, 1999) if a material is suitable for storing sulphuric acid at a given composition and temperature, it isn't necessarily suitable for pumps as the velocity of the fluid can have a severe impact on a materials corrosion resistance. There are multiple standards specific to pumps that are useful sources of information which includes general guidance for material selection, one of which being the API standards.

The following information is detailed in the API 685 standard (American Petroleum Institute (API), 2022).

Materials of construction are separated into classes, these classes are recommended by the standard for some specific applications, Sulphuric acid being one of these.

As can be seen in the figure 7 below, taken directly from the API 685 standard, for the specified composition of the fluid associated with this duty, it is recommended materials in class A-8 or A-9 be used.

Table G.1—Material Classes for Sealless Centrifugal Pump Services *(continued)*

	Temperature Range		Pressure Range	Material Class	See Reference Notes
	Degrees °C	Degrees °F			
MEA, DEA, TEA-stock solutions	< 120	< 250	All	S-4	
DEA, TEA-lean solutions	< 120	< 250	All	S-4	8
MEA-lean solution (CO ₂ only)	80–150	175–300	All	S-9	8
MEA-lean solution (CO ₂ and H ₂ S)	80–150	175–300	All	S-8	7, 8
MEA-, DEA-, TEA-rich solutions	< 80	< 175	All	S-4 or S-8	8
Sulfuric acid concentration > 85 %	< 38	< 100	All	S-4	5
85 % – < 1 %	< 230	< 450	All	A-8 or A-9	5
Hydrofluoric acid concentration of > 96 %	< 65	< 150	All	S-9 or H-2	5
Hydrofluoric acid, anhydrous (100 %)	< 65	< 150	All	A-8 or H-2	
Hydrofluoric acid, concentrations of > 90 %	< 65	< 150	All	S-9 or H-2	9

Figure 7- API 685 recommended Material classes (American Petroleum Institute (API), 2022)

The specific materials within the material classes are detailed in the figure 8 below, as can be seen there are 2 recommended materials, 316 austenitic stainless steel or alloy 20.

Table H.1—Material Classes for Pump Parts

Part	Material Classes and Abbreviations														
	Material Class	S-4	S-5	S-6	S-8I	S-9I	C-6	A-7	A-8	A-9	D-1 ^j	D-2 ^j	H-1	H-2	T-1
	Full Compliance Material ^a	STL	STL	STL	STL	STL	12 % CR	AUS	316 AUS	Alloy 20	Duplex	Super Duplex	Alloy B	Alloy C	Ti
	Trim Material	STL	STL 12 % CR	12 % CR	316 AUS	Ni-Cu Alloy	12 % CR	AUS c,d	316 AUS ^d	Alloy 20	Duplex	Super Duplex	Alloy B	Alloy C	Ti

Figure 8 - API 685 Material classes (American Petroleum Institute (API), 2022)

These recommendations, however, are for concentrations between 1 and 85%, as mentioned previously in this report the concentration has a severe impact on the corrosion resistance of a material when dealing with sulphuric acid, so the material should be suited specifically between 70 and 75% concentration, these concentrations are based on the operating concentration of 71% and the concentration used for the original pump selection of 75%.

Figure 9 on the following page, shows information from a publication by (Industrial Specialties Mfg., 2022) which gives a rating to the corrosion resistance of 316 stainless steel at various sulphuric acid concentrations, as can be seen, 316 stainless steel is only suitable

for concentrations less than 10% or cold concentrated acid, for acid between 10% and 75% it has a D rating, which represents a severe effect is likely and is not recommended for use.

This means that for the duty required, **316 stainless steel is not suitable.**

Sulfuric Acid, <10%	B
Sulfuric Acid, 10-75%	D
Sulfuric Acid, 75-100%	D
Sulfuric Acid, cold concentrated	B
Sulfuric Acid, hot concentrated	C

Key to General Chemical Resistance – All data is based on ambient or room temperature conditions, about 64°F (18°C) to 73°F (23°C)
A = Excellent *C = Fair - Moderate Effect, not recommended*
B = Good - Minor Effect, slight corrosion or discoloration *D = Severe Effect, not recommended for ANY use*

Figure 9 - Sulfuric acid 316 stainless steel compatibility (Industrial Specialties Mfg., 2022)

Alloy 20

The following information was obtained from (Sulphuric acid on the web, 2001).

Alloy 20 is a metallic material developed specifically for use in the handling and storage of sulphuric acid, it is a highly alloyed iron-base nickel-chromium-molybdenum stainless steel. Its typical chemical composition is detailed in the figure 10 below.

Nickel	Ni	32.5 - 35.0
Chromium	Cr	19.0 - 21.0
Molybdenum	Mo	2.0 - 3.0
Iron	Fe	Balance
Carbon	C	0.06 Max
Columbium + Tantalum	Cb + Ta	8 x C or 1.00 Max
Copper	Cu	3.0 - 4.0

Figure 10 - Alloy 20 chemical composition (Sulphuric acid on the web, 2001)

To determine its suitability for the specified duty, the iso corrosion curve in figure 11 on the following page shows where it is suitable for use. The minimum temperature shown on the diagram is 30 degrees, however the diagram shows that corrosion increases as the temperature increases, so the conclusion can be drawn that if it is suitable at 30 degrees then it will be suitable at the temperature associated with this duty, 0 degrees. The concentration specific to this duty has been marked on the diagram, and as can be seen alloy 20 is suitable at temperatures over 50 degrees C, making it **a suitable material for a pump operating in this duty.**

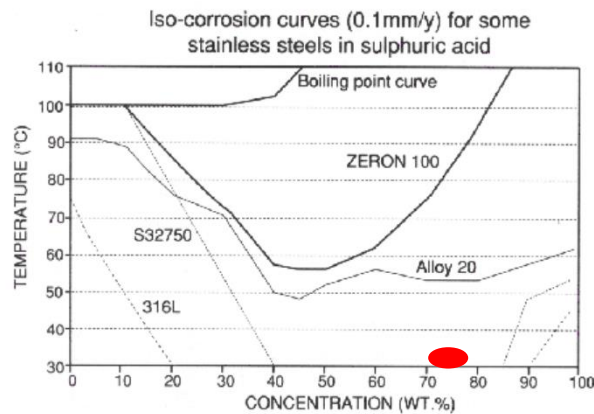


Figure 11 - Alloy 20 ISO corrosion curve (Sulphuric acid on the web, 2001)

Hastelloy C-276 and other metallic materials

Whilst the previous section of this report confirmed that alloy20 is a suitable metallic material for this duty, the survey of materials available from OEM's shown that only limited manufacturers offer it as an option for the materials of construction of their pumps, however Hastelloy C-276 is a commonly available option and is often used at the Barry site for highly corrosive applications.

According to (Haynes International, 2020), Hastelloy has proven useful for a wide range of aggressive chemicals, including sulphuric acid. Figure 12 below shows an iso corrosion diagram showing its corrosion resistance to sulphuric acid, which also includes some other common metallic materials.

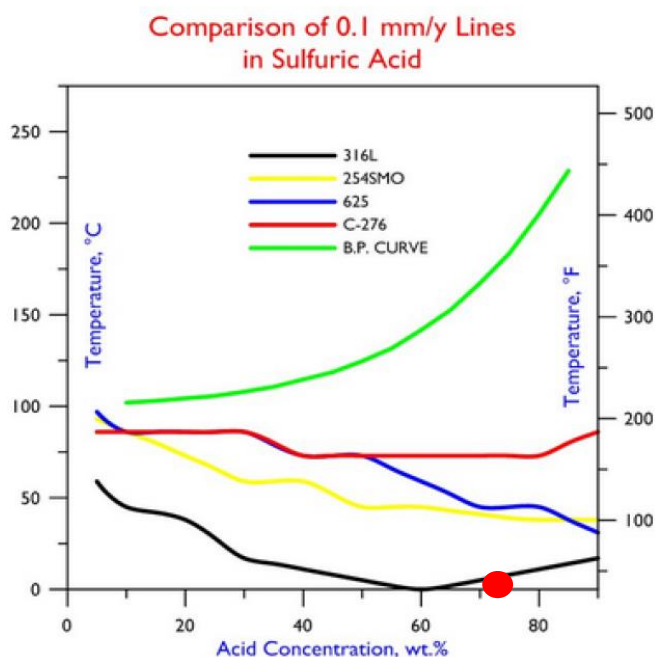


Figure 12 - Hastelloy C-276 ISO corrosion curve (Haynes International, 2020)

Figure 12 shows how Hastelloy C-276 compares against 3 other materials, Hastelloy is represented by the red line, and the operating condition for this duty is represented by the red circle. As can be seen, Hastelloy exceeds the other 3 materials, claiming a resistance up to 75 degrees C, making it a **suitable material for a pump operating in this duty**. The diagram also demonstrates and confirms the previous finding that 316L stainless steel, is not suitable as there is not much room for temperature deviation before corrosion would occur. The diagram also shows that the **materials designated 625 and 254SMO, would be suitable for use in this duty** as they both have similar resistance at the operating conditions as the previously analysed alloy 20 material.

What are alloys 625 and 254SMO?

Alloy 625, also known as Inconel 625, is a solid nickel, chromium and molybdenum alloy with added niobium. It's a high strength alloy with excellent weldability and machinability and is commonly used for its corrosion resistance in severe conditions. (Corrotherm International, No date)

Figure 13 below details its chemical composition:

Nickel Ni 58.00% min	Chromium Cr 20.00-23.00%	Molybdenum Mo 8.00-10.00%	Iron Fe 5.00% max	Niobium + Tantalum Nb+Ta 3.15-4.15%
Cobalt Co 1.00% max	Silicon Si 0.50% max	Manganese Mn 0.50% max	Titanium Ti 0.40% max	Silver Ag 0.40% max
Carbon C 0.10% max	Sulphur S 0.01% max	Phosphorus P 0.01% max		

Figure 13 - Alloy 625 chemical composition (Corrotherm International, No date)

Alloy 254SMO is a super austenitic stainless-steel grade, with a higher corrosion resistance than common grades, as well as being stronger. It has high levels of chromium, molybdenum and nitrogen, and a low carbon content. It is considered to commonly be a cheaper alternative to the high nickel alloys and titanium alloys. (Quest 4 Alloys, No date)

Figure 14 below details its chemical composition:

Alloy	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N
254SMO	0.020	0.80	1.00	0.030	0.010	20	18	6.1	0.7	0.20

Figure 14 - Alloy 254SMO chemical composition (Quest 4 Alloys, No date)

Plastic lined pump suitability

The currently installed pump is of a PFA lined construction and has never had any issues regarding corrosion during its lifetime, this was confirmed by reviewing work carried out on both pumps during the operating life of the plant using the site Computer Maintenance Management System (CMMS) – SAP. From the survey carried out for available materials of construction, there were numerous plastic lined options on offer.

According to (MTI Materials technology institute, 1997), fluorinated plastics (PFA, PTFE, PVDF, FEP, KYNAR, etc...) are only limited in the use of sulphuric acid by their temperature limitations, within their temperature limitations they are considered as completely corrosion resistance.

The temperature limitations are usually specified for the specific material by the OEM, so providing these limitations are compatible with the duty temperature, a plastic lined pump of one of the aforementioned fluorinated plastics, will be suitable for this duty, and according to (CP Pump Systems, 2022), will often be considerably cheaper than a suitable metallic pump.

Another potential limitation for plastic lined pumps, is their low abrasion resistance, however as specified in the datasheet (Appendix A), there are no solid particulates within the pumped fluid, so this is not of concern for this duty.

Pump performance

A critical aspect of pump selection is how it will perform for the specified duty. Pump performance curves are used to determine this. These performance curves are supplied by the OEM's and contain information such as:

- How much differential head the pump will produce at any flow rate within the pumps operating range.
- How much power is required in KW (Kilowatts) to produce the required flow rates/differential head.
- How efficiently the pump is at each point of its operating range.

Current pump performance

Using the pump performance curve supplied with the original pump (Appendix B), comparisons can be made against potential replacements (ITT RICHTER CHEMIE - Technik GmbH, 1996).

By using this performance curve, the following data in figure 15 was obtained:

Richter performance curve (130mm impellor)										
Flow rate Q (m ³ /Hr)	0	1	2	3	4	5	6	7	8	9
Differential head (m)	26	25.8	25.4	25.1	24.5	24	23.5	23	22.5	22
Power (KW)	0.9	1	1.05	1.15	1.2	1.25	1.3	1.35	1.4	1.5

Figure 15 - Richter water performance

As specified previously in this report, the normal duty point is 4.4m³/hr, from the information above at this flow rate the pump develops between 24.5 – 24 meters in differential head, so whatever pump is selected to replace this must match this at a minimum, otherwise there is a risk of the new pump not being capable to convey the fluid at the required flowrate.

One major consideration that must be made when analysing pump performance curves, is what fluid was used to produce the curve. The curves provided by OEMs are usually based on water performance, according to (Elvitsky, 1985), if a fluid with different properties than water is being pumped, then the actual performance can be very different than that stated in the curves. To overcome this issue, the curve must be corrected to suit the viscosity of the fluid being pumped.

Correcting performance curves for different viscosity fluids

The performance curve for the current pump states the fluid properties are for water with the following physical properties:

- Density $\rho = 1000 \text{ Kg/m}^3$
- Kinematic viscosity $\nu = 1 \text{ mm}^2/\text{s}$

Using the datasheet provided during the original purchasing of the pump (ITT Richter Chemie-Technik GmbH, 1995), the physical properties of the pumped fluid are:

- Density $\rho = 1680 \text{ Kg/m}^3$
- Kinematic viscosity $\nu = 17.86 \text{ mm}^2/\text{s}$

According to (Elvitsky, 1985) correcting performance for a different viscosity can be a complex task, however the hydraulic institute of the American national standards have standardised the process by producing a document that outlines how it can be done accurately (Hydraulic Institute, 2004).

The data for the current pumps is specified for water, so to accurately compare against replacements the curve needs to be corrected for the pumped fluid.

The process following is as per the guidelines specified in the standard mentioned.

Step 1: Calculating parameter B using the known data for water at the pumps theoretical BEP (Best efficiency point)

$$B = 16.5 \times \frac{(V_{vis})^{0.50} \times (H_{BEP-W})^{0.0625}}{(Q_{BEP-W})^{0.375} \times N^{0.25}}$$

$$B = 16.5 \times \frac{17.86^{0.5} \times 22.5^{0.0625}}{8^{0.375} \times 2900^{0.25}} = 5.29$$

$$B = 5.29$$

Where:

$B = \text{Dimensionless parameter}$

$V_{vis} = \text{Kinematic viscosity (cSt)}$

$H_{BEP-W} = \text{Head @ BEP (m)}$

$Q_{BEP-W} = \text{Flow rate @ BEP} \left(\frac{\text{M}^3}{\text{hr}} \right)$

$N = \text{Rotation speed (RPM)}$

Step 2: Calculating the correction factor for flow C_Q , this correction factor is constant for all values of the performance curve.

$$C_Q = (2.71)^{-0.165 \times (\log B)^{3.15}}$$

$$C_Q = (2.71)^{-0.165 \times (\log (5.29))^{3.15}}$$

$$C_Q = 0.942$$

Therefore, at BEP, the flowrate Q_{BEP} is corrected as follows.

$$Q_{Vis} = C_Q \times Q_{BEP-W}$$

$$Q_{Vis} = 0.942 \times 8$$

$$Q_{Vis} = 7.536 \text{ m}^3/\text{hr}$$

This correction factor has been applied to all values from the table in figure 15 and the corrected figures are shown in the table in figure 16 (Page 28).

Calculate the correction factor for head delivered at all performance points, at the BEP the correction factor for flow C_Q is used as the correction factor for head.

$$C_{BEP-H} = C_Q = 0.942$$

$$H_{BEP-Vis} = C_{BEP-H} \times H_{BEP-W}$$

$$H_{BEP-Vis} = 0.942 \times 22.5$$

$$H_{BEP-Vis} = 21.195\text{m}$$

Step 3: Calculating the rest of the correction factor values C_H for head H at the performance points of the curve. (This step has been applied to all values from figure 15 and the corrected values are shown in figure 16)

$$C_H = 1 - \left[(1 - C_{BEP-H}) \times \left(\frac{Q_W}{Q_{BEP-W}} \right)^{0.75} \right]$$

Therefore, the head correction factor at 24.5m with 4m³/hr flow is:

$$C_H = 1 - \left[(1 - 0.942) \times \left(\frac{4}{8} \right)^{0.75} \right] = 0.965$$

$$H_{Vis} = C_H \times H_W$$

$$H_{Vis} = 0.965 \times 24.5 = 23.6425\text{m}$$

Step 4: Calculating the correction factor for pump efficiency C_η

$$C_\eta = B^{-(0.0547 \times B^{0.69})}$$

$$C_\eta = 5.29^{-(0.0547 \times 5.29^{0.69})}$$

$$C_\eta = 0.75$$

From the water data displayed in figure 15, the efficiency can be corrected at the same performance point as the previous calculation where the efficiency is 21%.

$$\eta_{Vis} = C_\eta \times \eta_W$$

$$\eta_{Vis} = 0.75 \times 21$$

$$\eta_{Vis} = 15.75\%$$

This calculation was performed for all performance points from figure 15 and the corrected efficiency values are shown in Figure 16.

Step 5: Calculate the values for viscous pump shaft input power P_{Vis}

$$P_{Vis} = \frac{Q_{Vis} \times H_{Vis} \times SG}{367 \times \eta_{Vis}}$$

$$P_{Vis} = \frac{3.768 \times 23.6425 \times 1.68}{367 \times 0.1575}$$

$$P_{Vis} = 2.59KW$$

Where:

$SG = \text{Specific gravity of fluid}$

The above calculations clearly show that increasing the viscosity of the pumped fluid has a negative effect on both pump output and efficiencies.

Richter viscous performance

Using the method outlined by (Hydraulic Institute, 2004), the water data from the performance curve for the current pumps has been corrected to account for the viscosity of the pumped fluid. The table in figure 16 Shows the results numerically.

SI units								
Water Data			Correction factors			Viscous data		
Flow Q m3/hr	Head H m	Efficiency η	Flow	Head	Efficiency η	Flow Q m3/hr	Head H m	Efficiency
0	26.00	0	0.943	1	0.751	0.00	26.00	0
1	25.80	0.7	0.943	0.988	0.751	0.94	25.49	0.5257
2	25.40	0.15	0.943	0.98	0.751	1.89	24.89	0.11265
3	25.10	0.18	0.943	0.973	0.751	2.83	24.42	0.13518
4	24.50	0.21	0.943	0.966	0.751	3.77	23.67	0.15771
5	24.00	0.27	0.943	0.96	0.751	4.72	23.04	0.20277
6	23.50	0.3	0.943	0.954	0.751	5.66	22.42	0.2253
7	23.00	0.32	0.943	0.948	0.751	6.60	21.80	0.24032
8	22.50	0.36	0.943	0.943	0.751	7.54	21.22	0.27036
9	22.00	0.38	0.943	0.937	0.751	8.49	20.61	0.28538

Figure 16 - Richter performance corrected for viscosity.

The results from figure 16 Above have been plotted on a graph in figure 17 below, to visually show the effects of the fluid viscosity on the pump performance.

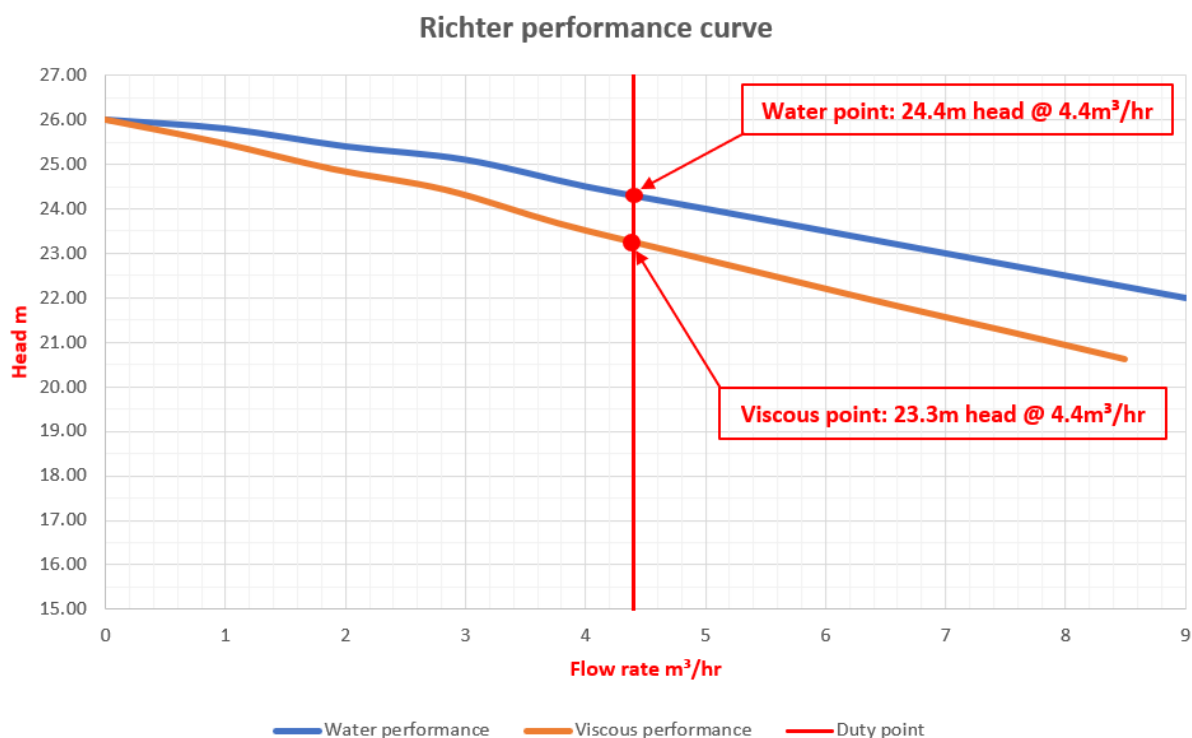


Figure 17 - Richter water performance Vs viscous performance

CP Pump systems options

The most straightforward option for the replacement would be to use a pump of similar design, of all the various pumps used at the site, those manufactured by CP Pump systems (CP Pump Systems, No year), are the most similar in comparison. Details of the pumps, obtained from official brochure (CP Pump Systems, 2022) are as follows:

- Magnetic drive centrifugal pumps
- Variety of material lining options (PFA, PTFE, PVDF, etc...)
- Variety of containment shell options, including a can protection feature
- Compliant with necessary directives (ATEX, machinery)
- Variety of sizing options to suit specific duties

Reliability comparison

To determine whether a pump from CP Pump systems is a suitable option, a reliability survey was carried out. Whilst there are currently no CP pumps operating in a like for like duty as the Richter, a sample of 5 pumps in operation at the Barry site of each manufacturer was selected, each operating in a clean duty with no solids present, and data was obtained from Dow's Computerised maintenance management system (SAP) for each to determine the MTBF (Mean time between failure) of each pump.

Whilst this isn't an ideal comparison, as all pumps were of various sizes and operated in different duties, it was still deemed an appropriate way to determine which pumps are more reliable in general.

The SAP data obtained was from over a 15-year span, and how often the pumps failed during those 15 years was used to determine the MTBF for each pump sample, an average was then calculated for both CP pumps and Richter pumps, the results are displayed in figure 18 below.

Table representing MTBF for a sample of Richter and CP Pumpen pumps

		MTBF in months	
		CP Pumpen	Richter
Pump sample	A	24	12
	B	34	20
	C	18	16
	D	9	28
	E	20	6
		21	16.4
		Average MTBF	

Figure 18 - Richter Vs CP Pumpen, MTBF

As can be seen from the results in figure 18, the MTBF for a CP pump is 21 months, compared to 16.4 months for a Richter, so the conclusion can be drawn that CP pumps in general are more reliable. Whilst the pump in question isn't deemed unreliable, it is important that whatever it is replaced with must be reliable, and from the data it is more likely the reliability would increase.

Failures of the sampled pumps

During the reliability survey, the root cause of the failures of the pumps were obtained and some of which were repeat offenders which are discussed in further detail below.

- Containment shell failure, many failures for both CP pumps and Richter's were due to the failure of the containment shell. Not all the sampled pumps had the can protection monitoring device installed, this option is typically used on the most hazardous of duties.
- Drive end bearing failure, all pumps across the Barry site are part of a condition based monitoring system where the vibrations of the pumps are measured at strategic places periodically to determine the health of the bearings, there were a considerable number of failures where the pumps were replaced and then overhauled due to the condition monitoring reports, the reason why the bearings had failed could be down to a number of reasons, such as:
 - Improper lubrication
 - Improper mounting of bearings
 - Wear and tear, end of life bearing failure.
 - Containment shell failure resulting in contamination of the oil.
- Process end bearing failure, both Richter and CP pumps use a similar bearing design for the process end, and both pumps are sensitive to these bearings failing, the most common cause of these bearings failing was down to operational error, such as:
 - Running the pumps dry, these pumps rely on the pumped fluid to lubricate these bearings so if the pumps are run without any fluid in them, these bearings will run dry and fail due to large amounts of heat generated. This can result in shattering of the silicon carbide bearings.
 - "Dead heading the pump", dead heading a pump is when it is operated with a closed discharge valve, this is an issue as the pump generate heat during operation and without a flow of fluid the heat can't be dissipated away from the pumps causing the bearings to overheat.

Fluid flow Performance assessment

As mentioned previously during this report, it is important that the replacement pump can perform as required to meet the demands of the plant. To determine this, the pump performance curves require comparison.

Preliminary assessment

Before an in-depth assessment was completed, a preliminary analysis of basic information that is readily available was carried out to determine if CP pump systems offers a pump that would be suitable for the duty.

The first stage was obtaining the capacities range from the brochure (CP Pump Systems, 2022), the information obtained is shown in figure 19 below.

Technical data		Directives	
Capacities (min./max.)	0.5 to 400 m ³ /h 2.2 to 1761.2 gpm	EC Machinery Directive	
Heads (min./max.)	3 to 90m 9.8 to 295.2 ft	EC ATEX Directive	
Temperatures (min./max.)	-20 to +200°C -4 to +392°F	FDA 21 CFR §177	
Kinematic viscosities	0.5 to 350 mm ² /s cSt		
Solids handling	up to 10% solids concentration, depending on the pumped fluid*		
		Standards	
		DIN EN ISO 2858	
		DIN EN ISO 5199	
		DIN EN ISO 15783	

Figure 19 - CP Pump systems brochure information (CP Pump Systems, 2022)

From the information shown in figure 19, it was determined CP pump systems can supply a suitable replacement pump from a performance point of view because:

- The required duty has a head requirement of 24.5m, options from 3m to 90m are available.
- The required duty requires 4.4m³/hr, options from 0.5m³/hr to 400m³/hr are available.
- The required duty requires the pump to run at 0°C, the available pumps have a range from -20°C - 200°C.
- The required duty has a kinematic viscosity of 17.86mm²/s, the available pumps can handle from 0.5mm²/s to 350mm²/s.
- No solids are present in the required duty, but the available pumps can handle up to 10% solids.

The information from the brochure displayed in figure 19 above, also states that the pumps manufactured by CP Pump systems are also compliant with the required directives and legislation, specifically the machinery directive and ATEX directive.

Next, the readily available performance curves were required to determine an approximate size and specification for the replacement pump, the following performance curve in figure 20 was obtained from the CP pump systems brochure (CP Pump Systems, 2022):

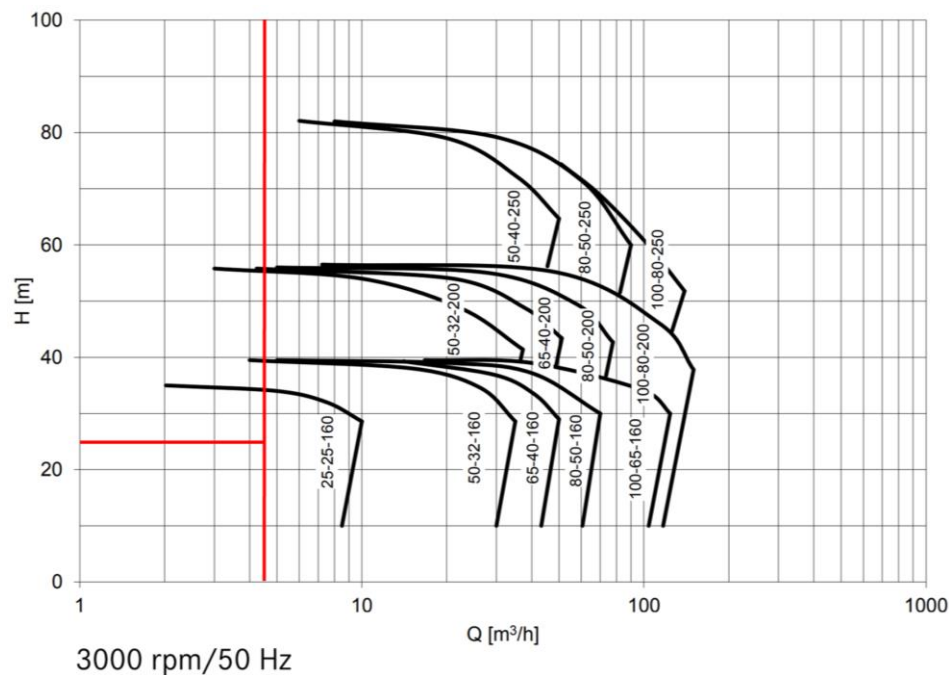


Figure 20 - CP Pump systems basic performance curves (CP Pump Systems, 2022)

The red lines represent the duty point required, being 24.5m of head @ 4.4m³/hr, this is an approximate annotation to determine what size pump will be required, from this information it can be confirmed that a pump size of 25-25-160 would satisfy the required performance. The sizing information is formatted as Suction size(mm) – Discharge size(mm) – maximum impellor size(mm). The curve shown for this size represents the overall range of all impellor variations for this size of pump.

To determine an exact specification for the replacement pump, more accurate and specific performance curves are required from the OEM.

In-depth performance assessment

From the preliminary assessment It was determined that a pump variation from the size 25-25-160 is likely to be suitable, following this CP pump systems were contacted to obtain specific and accurate performance curves for pump options in this size. The information initially provided was of their standard options utilising an **open impellor**, The document containing the provided performance curves can be seen in appendix C.

Using the performance curves provided, 2 possible variants were selected for comparison against the current Richter pump, one with a 140mm impellor, the other with a 150mm impellor, the performance points are detailed in the figure 21 below.

Richter Vs CP pump performance options											
Pump variant		Q Flow rate m ³ /hr									
		0	1	2	3	4	5	6	7	8	9
Richter 130mm	Head (m)	26	25.8	25.4	25.1	24.5	24	23.5	23	22.5	22
CP 140mm		26	25.3	24.7	24	23.5	22.7	22	21	20.3	19.5
CP 150mm		28.5	28	27.2	26.8	26	25.2	24.45	23.5	22.8	22

Figure 21 - Richter Vs CP Pump initial comparison

Using the values from the above table which contains information from the performance curve of the current pump, and the performance curve provided by CP pump systems, all 3 curves were plotted on a graph, shown in figure 22 below.

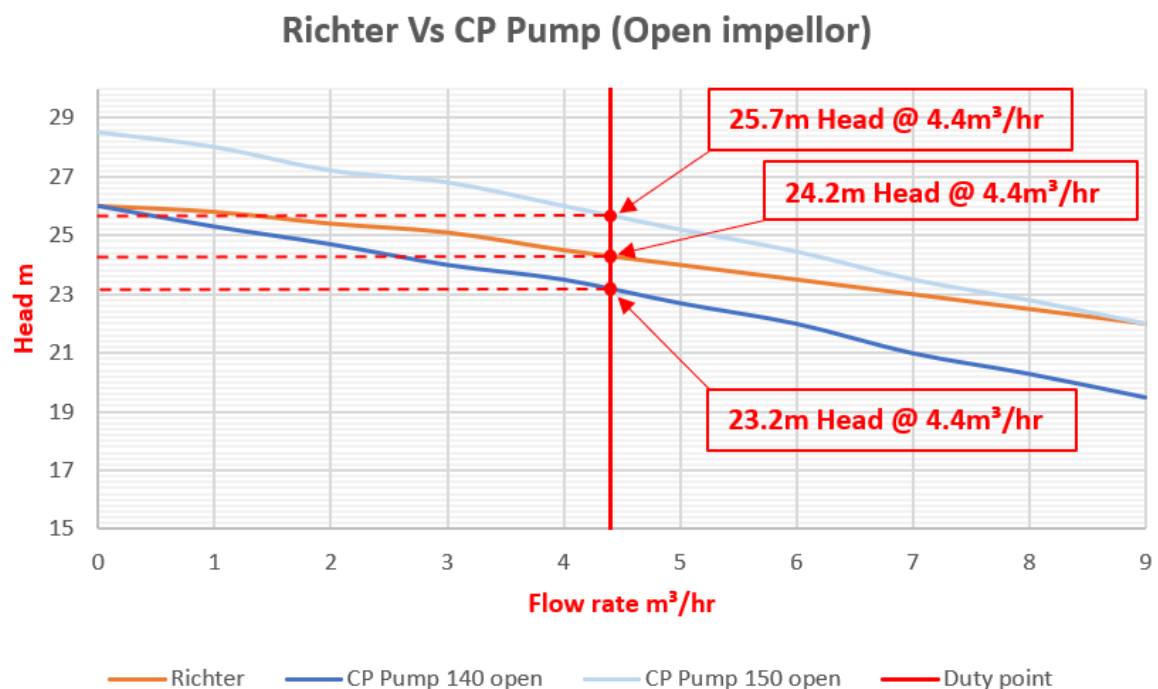


Figure 22 - Richter Vs CP Pump, open impellor, water performance curve

The graph in figure 22 illustrates how both options of CP pump would perform in comparison to the current Richter, an interesting point is how the Richter curve is flatter than both CP pumps, of the 2 CP pump options presented here, the 150mm impellor option would be preferable as it will either exceed or match the Richter performance throughout its entire operating range. However, from an efficiency point of view, a flatter curve is more desirable, the reason the CP pump options seem to lose head capacity more as the flow increases in comparison to the Richter is likely because the Richter uses a closed impellor, whereas the curves shown for the CP pump options are using an open impellor.

Open impellor vs closed impellor.

Centrifugal pumps are generally available with 2 main types of impellers, open and closed. Each impeller variant has its specific advantages and disadvantages.

An open impellor has no wall either side of the pumping vanes and are typically used when there is a low workload and the requirement to pump abrasive particles. (Engineer Know, 2021)

The advantages of open impellers are:

- Easy to clean.
- Easy to repair.
- Cheaper than closed.
- Can handle a solid content.

The disadvantages are:

- Have a lower efficiency.
- Require a higher NPSH (Net positive suction head)



Figure 23 - Open impellor example (Engineer Know, 2021)

Figure 23 demonstrates what a typical open impellor looks like.

A closed impellor has a wall either side of the impellor vanes, which increases its strength and is generally used when pumping a clean fluid with no solid particles, and a typical example of one can be seen in figure 24. (Engineer Know, 2021)

The advantages of closed impellors are:

- Higher efficiency compared to open/semi open impellors.
- Require a lower NPSH (Net positive suction head)
- Give constant efficiency.

The disadvantages are:

- A more complex design
- Expensive
- More prone to clogging/blockages.
- Can't handle any solid contents.



Figure 24 - Closed impellor example (Engineer Know, 2021)

There are also semi-open impellors available which has a wall on the rear of the impellor making it stronger than an open impellor, and generally lands in the middle between open and closed impellors with regards to performance and efficiency.

With the results from the previous comparison, it was determined that a closed impellor could be the better option for the replacement pump. A performance curve was obtained from CP pump systems showing the performance of the closed impellor variants for this size pump, the curve supplied can be seen in appendix D.

Using the performance curve for the closed impellor options from CP pumps, an impellor diameter of 140mm was selected for comparison against the current Richter pump, and the previously selected 150mm open impellor option from CP pumps, the new 140mm closed option is highlighted in red. The performance points are displayed in the figure 25 below.

Richter Vs CP pump performance options											
Pump variant		Q Flow rate m ³ /hr									
		0	1	2	3	4	5	6	7	8	9
Richter 130mm	Head (m)	26	25.8	25.4	25.1	24.5	24	23.5	23	22.5	22
CP 140mm (Closed)		27.7	27.5	27.2	27	26.7	26.2	25.5	24.8	23.9	23
CP 150mm		28.5	28	27.2	26.8	26	25.2	24.45	23.5	22.8	22

Figure 25 - Richter Vs CP Pump w/140mm closed impellor.

Using the values from the table in figure 25, all 3 sets of performance points were plotted on a graph for comparison which can be seen in figure 26 below.

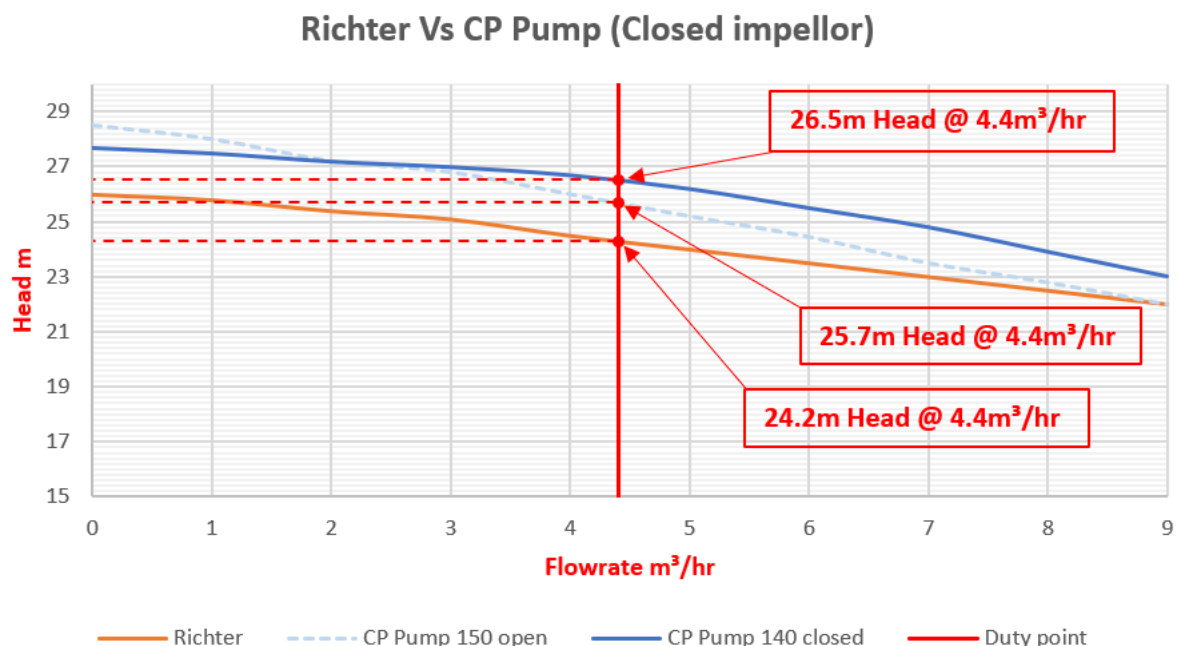


Figure 26 - Richter Vs CP Pump, performance curve, w/140mm closed impellor.

The 150mm open impellor option discussed from the previous graph, has been displayed as a dashed line for easier comparison between the Richter and the closed impellor option from CP pump, as can be seen that by using a closed impellor as opposed to an open impellor, the curve is a lot flatter and a better match to the current Richter pump, it outperforms it with

regards to head, so the discharge pressure will be slightly higher, however this would only become an issue if the pressure were to exceed the pump and piping design pressure.

CP Pump viscous performance

Up to this point, the pump selection has been carried out using the water data available with regards to performance, however as previously mentioned this isn't an accurate method for predicting/assessing performance where the pumped fluid is of different viscosity to water, so the performance curve for the 140mm closed impellor option requires correction to account for this using the method outlined by the (Hydraulic Institute, 2004). The results are displayed numerically in figure 27 below.

SI units								
Water Data			Correction factors			Viscous data		
Flow Q m ³ /hr	Head H m	Efficiency η	Flow	Head	Efficiency η	Flow Q m ³ /hr	Head H m	Efficiency
0	27.71	0	0.942	1	0.75	0.00	27.71	0
1	27.49	0.7	0.942	0.988	0.75	0.94	27.16	0.525
2	27.19	0.15	0.942	0.98	0.75	1.88	26.64	0.1125
3	27.01	0.18	0.942	0.972	0.75	2.83	26.25	0.135
4	26.70	0.21	0.942	0.966	0.75	3.77	25.79	0.1575
5	26.21	0.27	0.942	0.959	0.75	4.71	25.14	0.2025
6	25.51	0.3	0.942	0.954	0.75	5.65	24.34	0.225
7	24.81	0.32	0.942	0.948	0.75	6.59	23.52	0.24
8	23.90	0.36	0.942	0.942	0.75	7.54	22.51	0.27
9	23.01	0.38	0.942	0.937	0.75	8.48	21.56	0.285

Figure 27 - CP Pump, 140mm closed impellor, Viscosity corrected.

The results from figure 27 have been plotted on a graph in figure 28 below, to better display how the viscosity of the pumped fluid will affect the performance of the 140mm closed impellor option from CP pumps.

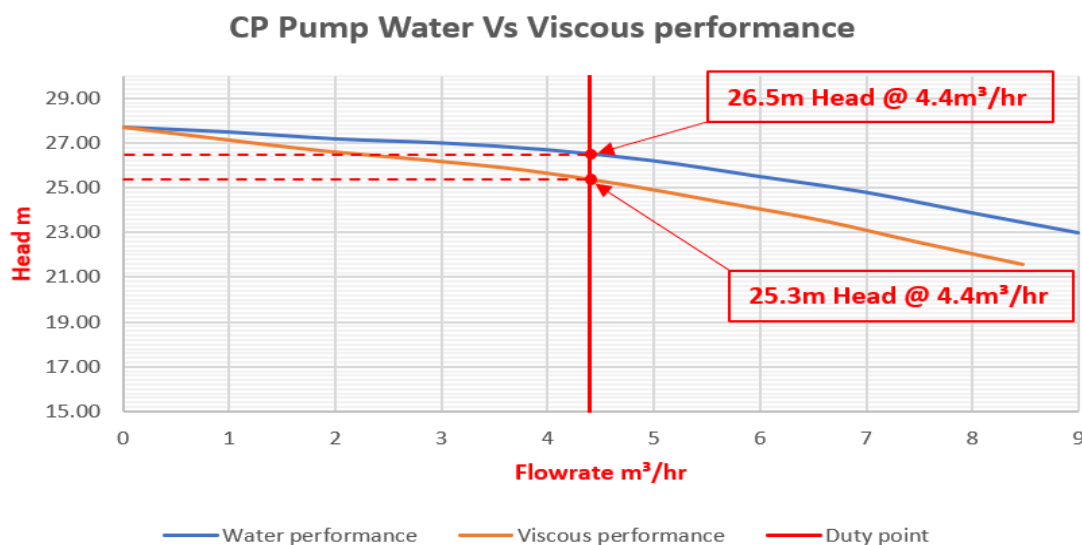


Figure 28 - CP Pump, water Vs Viscous performance, 140mm closed impellor.

For a final comparison of the proposed 140mm closed impellor option from CP pumps, the viscous performance has been plotted against the previously calculated viscous performance of the currently installed Richter pump, this can be seen in figure 29.

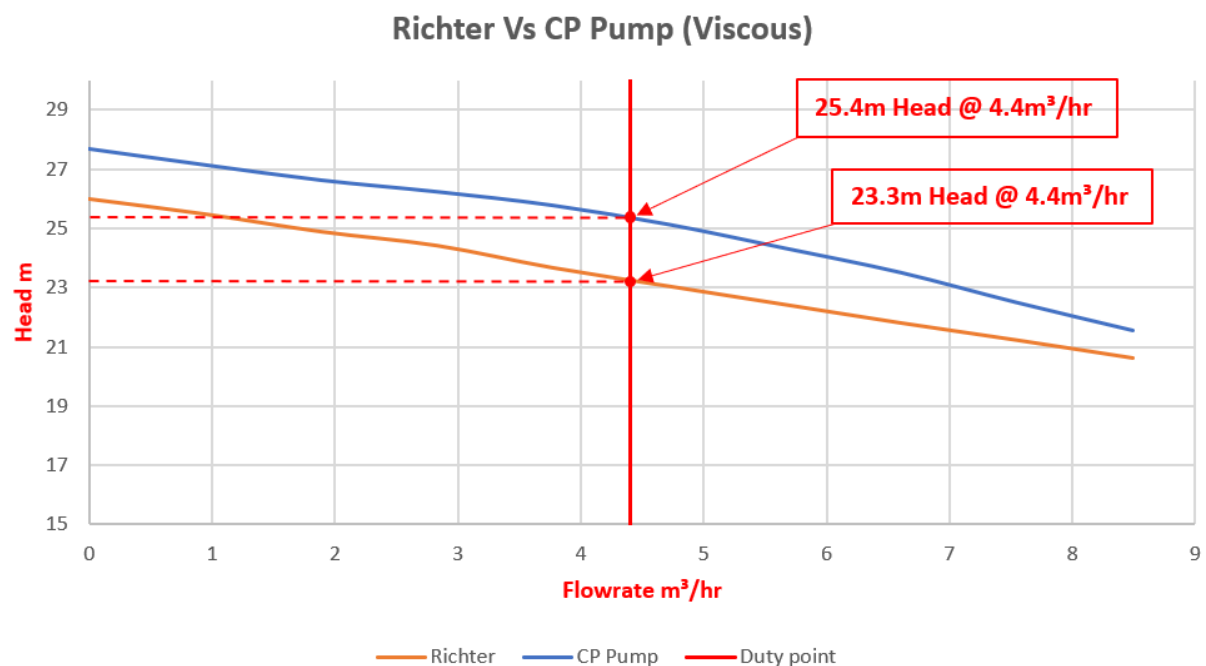


Figure 29 - Richter Vs CP Pump, final viscous comparison, performance curve.

As can be seen in figure 29 above, the proposed 140mm closed impellor variant from CP pump will exceed the Richter performance in its actual viscous duty throughout its entire operating range, as mentioned previously, the only concern regarding the extra head that a CP pump will develop is whether the resulting increase in pressure will exceed the design pressure of the piping system. To determine if this is possible, the discharge pressure requires calculating.

Pressure calculations

According to (Engineering toolbox, 2004), the head developed by a pump can be converted to pressure using the following formula:

$$p = 0.0981 \cdot h \cdot SG$$

Where:

p = Pressure (Bar)

h = Head (m)

SG = Specific gravity (Value of 1.68 obtained from (ITT Richter Chemie-Technik GmbH, 1995))

Using this method, the pressure values for multiple points for each pump were calculated. As the performance curves show, the highest pressure a pump can develop is when it is dead headed with zero flow rate, so the discharge pressures were calculated for both pumps in this scenario:

Currently installed pump

With the currently installed **Richter pump**, whilst dead headed it will develop 26m of head, using this value and the formula above, the differential pressure between the suction and discharge was calculated at **4.29Barg**, and using the suction pressure stated on the datasheet (ITT Richter Chemie-Technik GmbH, 1995) at **1.96Barg**, the actual highest discharge pressure possible from the Richter pump is **6.25Barg**.

However, the pump is mainly operated at its duty point of 4.4m³/hr where it develops 23.3m of head, at this point it develops **3.84Barg** differential pressure, resulting in a total discharge pressure of **5.8Barg**.

Proposed CP Pump

Using the same method for the Richter pump, the pressures at TDH (Total dead head) and the duty point have been calculated for the proposed 140mm closed impellor variant from CP pump.

At TDH, the pump develops 27.71m of head, this results in a differential pressure of **4.57Barg** and using the suction pressure from the datasheet (ITT Richter Chemie-Technik GmbH, 1995) of **1.96Barg**, the highest discharge pressure possible with this pump variant is **6.52Barg**. At the duty point of 4.4m³/hr the pump will develop 25.4m of head, this results in a differential pressure of **4.19Barg**, resulting in a total discharge pressure of **6.15Barg**.

Max pressure rating of piping system

As previously stated in this report, the piping system for this pump is of ANSI B31.3 150# class, it is critical that the pressure rating of this piping system isn't exceeded, according to information from (Project Materials, 2017), the maximum rated pressure for this piping system is **19.6Barg**. This means that even at the maximum possible pressure the proposed 140mm closed impellor variant from CP Pumps, **6.15Barg**, the pressure within the piping system is considerably less than the maximum rated pressure.

This means that the proposed pump will not exceed the design ratings of the current piping system and no piping upgrades are necessary, this is important as this project is focusing purely on the pump, and a piping upgrade would significantly change the scope and cost of this project.

Power and efficiency assessment

Up to this point, the focus has purely been on pump performance relating to the flow of fluid, however the power requirements and pump efficiencies haven't been considered. The power required to operate the pump is of considerable importance as if it is not considered, a motor of incorrect specification could be selected which the required power to operate the pump could exceed the output power of the motor. The operating cost of the pump is also directly related to the power requirements and efficiency of the pump.

As was the case for fluid performance, the viscosity also significantly impacts the power requirements and efficiencies of the pumps. During the performance corrections for the different viscosity fluid, steps 4 and 5 from the method outlined by (Hydraulic Institute, 2004) considered this and the power requirements have been calculated as well as the efficiencies using data obtained from the original water performance curves.

Power comparison curves

Using the data from the OEM water performance curves and the calculation method outlined by (Hydraulic Institute, 2004), the viscous power curves for both the Richter and proposed CP pump have been plotted on a graph shown in figure 30 below.

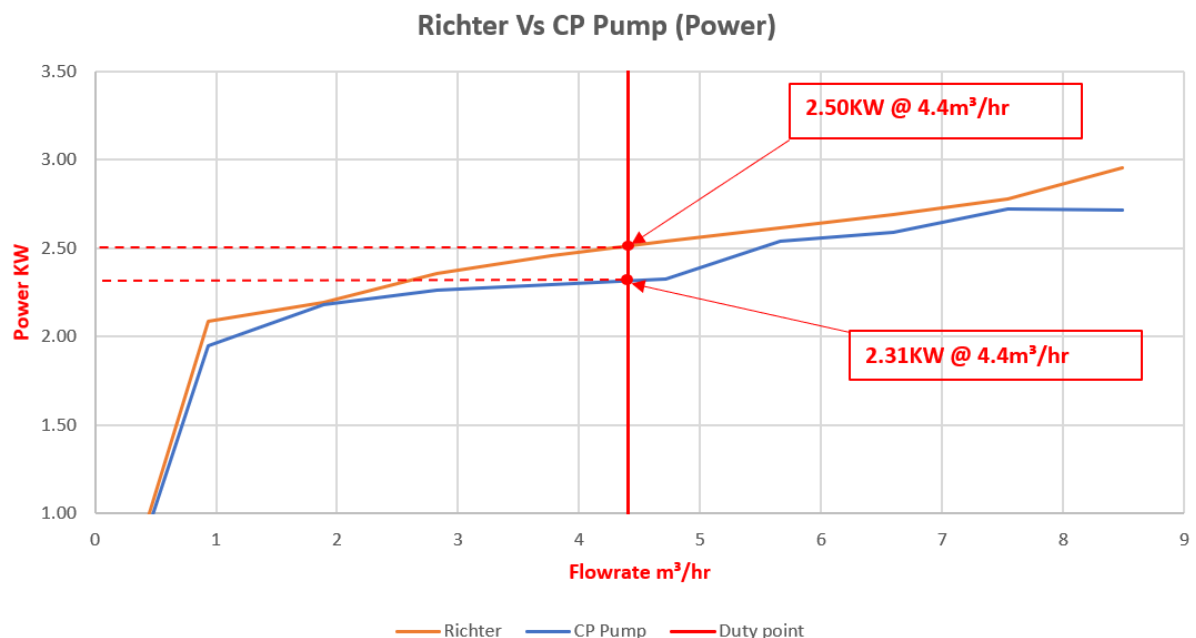


Figure 30 - Richter Vs CP Pump, Power curve

As can be seen in the graph above, at the duty point of 4.4 m³/hr, the CP Pump requires slightly less power of 2.31KW, compared to the 2.50KW required by the Richter pump. This means the CP Pump would be cheaper to run, and is likely more efficient, this is discussed further on the following page.

From the above figures, in a 24-hour period the proposed CP pump will consume 55.44Kwh of energy, whilst the Richter currently consumes 60Kwh.

Efficiency comparison curves

Using the data from the OEM water performance curves and the calculation method outlined by (Hydraulic Institute, 2004), the viscous efficiency curves for both the Richter and proposed CP pump have been plotted on a graph shown in figure 31 below.

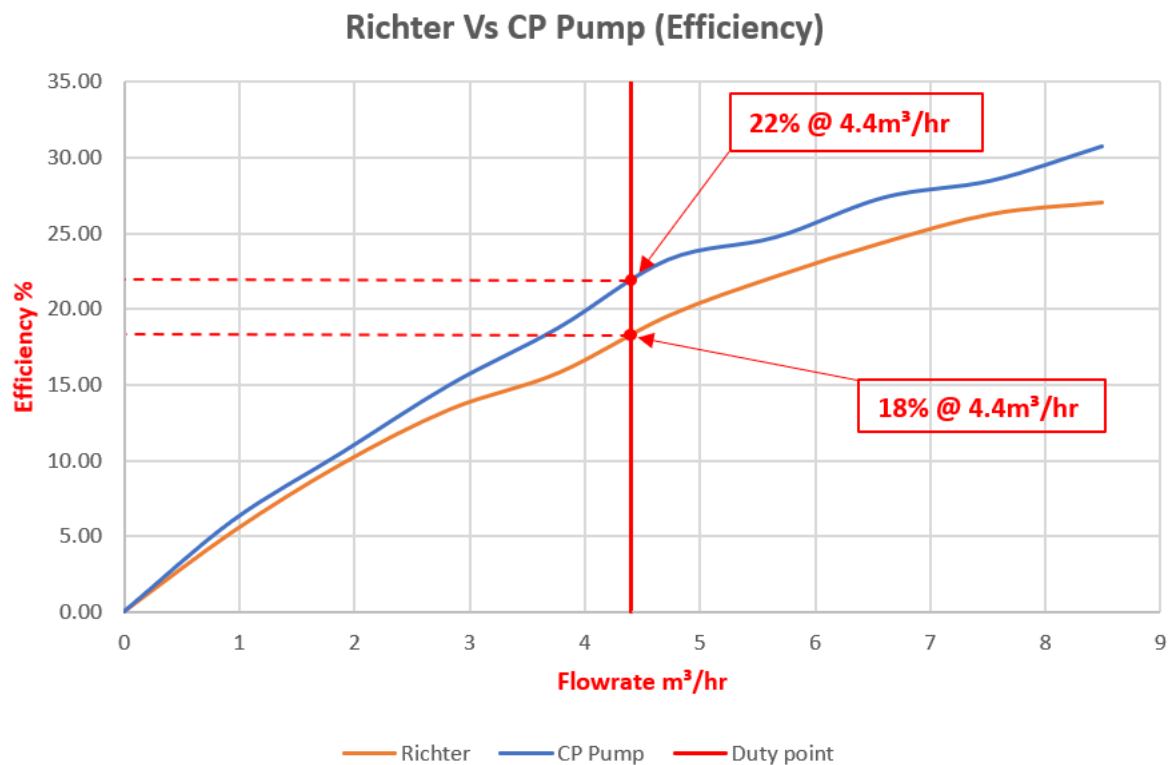


Figure 31 - Richter Vs CP Pump, efficiency curve

As suspected from the previous graph showing power requirements, this graph showing efficiency proves that the proposed CP Pump will be running more efficiently at 22%, compared to the current 18% efficiency of the Richter pump.

Canned motor pump option

Due to the hazardous conditions associated with this duty, a leakproof pump is essential which is why the current pump is of magnetic drive design. However according to (Karassik, 1985) another option for the replacement pump could be a canned motor pump, this would be a more complex option as the motor and pump are contained within one unit, so would have an entirely different footprint to the current pump, however canned motor pumps are considered the safest option when handling hazardous fluids.

Figure 32 below, shows a sectional view of a typical canned motor pump (Walker, 2018).

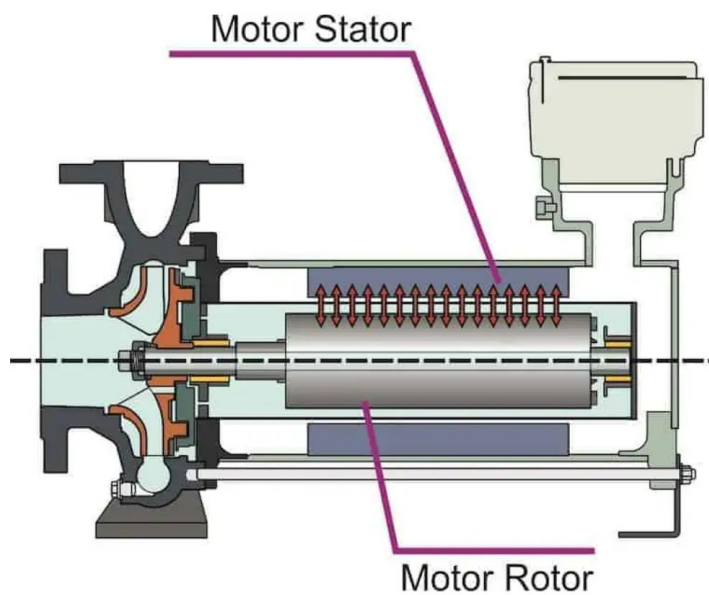


Figure 32 - Typical canned motor pump, cross sectional view (Walker, 2018)

The pump and motor are one item with the pump impellor mounted directly onto the motor shaft/rotor, The pumped liquid is contained within the pumping chamber and is also used to lubricate the rotor bearings and cool the rotor and stator, in the event of a breach to the layer between the pumped chamber and motor stator, the pumped fluid is still contained within the housing of the motor stator, preventing a leak to atmosphere. (Karassik, 1985)

Reliability comparison

To determine which canned motor pump is the best option, a reliability survey was carried out. Whilst there are currently no canned motor pumps operating in a like for like duty as the Richter, a sample of 5 pumps of each manufacturer in operation at the Barry site was selected, each operating in a clean duty with no solids present, and data was obtained from Dow's computerised maintenance management system (SAP) for each to determine the MTBF (Mean time between failure) of each pump.

Whilst this isn't an ideal comparison, as all pumps were of various sizes and operated in different duties, it was still deemed an appropriate way to determine which pumps are more reliable in general.

The SAP data obtained was from over a 15-year span, and how often the pumps failed during those 15 years was used to determine the MTBF for each pump sample, an average was then calculated for all 3 manufacturers, the results are displayed in figure 33 below.

Table representing MTBF for a sample of canned motor pumps				
		MTBF in months		
		Hermetic	APV	Nikkiso
Pump sample	A	26	30	60
	B	46	12	36
	C	31	18	24
	D	9	15	41
	E	18	24	20
		26	19.8	36.2
		Average MTBF		

Figure 33 - Canned motor pumps, MTBF survey

As can be seen from the results in the table above, the most reliable pumps from the survey are from Nikkiso (Nikkiso Pumps, 2022), so the conclusion can be drawn that a pump from Nikkiso would likely be the most reliable of the canned motor pump options, with an average MTBF of 36.2 months. As mentioned previously, whilst the pump in question isn't deemed unreliable, it is important that whatever it is replaced with must be reliable, and from the data it is more likely the reliability would increase, as from the previous survey the average MTBF for Richter pumps on the Barry site is 16.4 months.

Nikkiso pump options

To select an appropriate Nikkiso pump, firstly the readily available brochure was obtained and analysed for performance requirements and suitable materials of construction.

The information displayed in figure 34 below is from the information contained within the brochure (Nikkiso Pumps and systems, 2020).

Flow rate max.		1,000 m ³ /h (4,400 gpm)
Head max.		600m (1,970 ft)
Pumped liquid	Fluid temperature range	-130°C to +450°C (-201 to 842°F)
	Viscosity max.	500 mPa·s
Design pressure		20 MPa (2,900 psig)
Casing Material		Austenitic Stainless steel (304SS, 316SS, etc.) Alloy20 Hastelloy [®] C/B Equivalent Alloy Titanium Zirconium Monel [®] , others Equivalent Alloy
Motor power range		0.75 to 250kW
Ex-Protection		Various international explosion-protection (ATEX, IEC, CSA, TRCU, etc.) CE marking

Figure 34 - Nikkiso pumps, brochure information (Nikkiso Pumps, 2022)

From the information above, it was determined Nikkiso pumps and systems can supply a suitable replacement pump from a performance point of view because:

- The required duty has a head requirement of 24.5m, options up to 600m are available.
- The required duty requires 4.4m³/hr, options up to 1000m³/hr are available.
- The required duty requires the pump to run at 0°C, the available pumps have a range from -130°C - 450°C.
- The required duty has a viscosity of 30mPa.s, the available pumps can handle up to 500mPa.s
- Casing materials are available in Alloy20 and Hastelloy equivalents.

The information above also states that Nikkiso pumps are compliant with ATEX regulations and requirements for CE certification.

Next, the readily available performance curves were assessed for an approximate size for a suitable pump. The performance curves in figure 35 were obtained from the brochure (Nikkiso Pumps and systems, 2020).

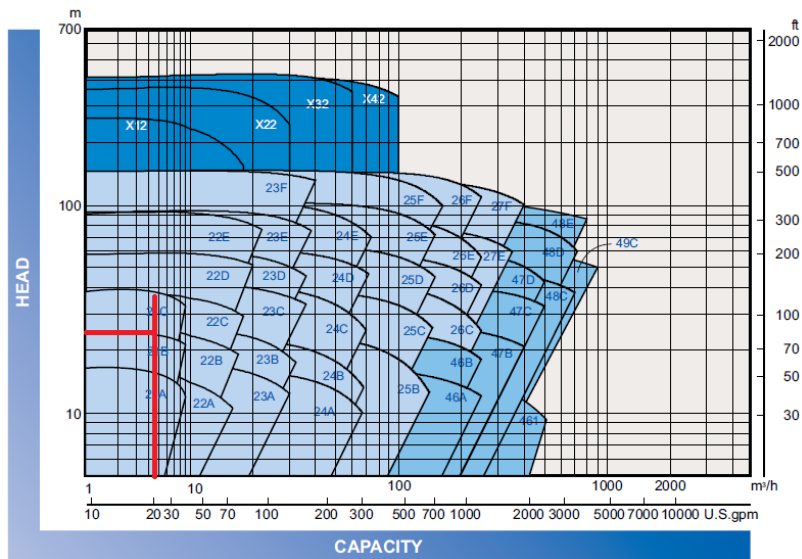


Figure 35 - Nikkiso pumps, basic performance curves (Nikkiso Pumps, 2022)

The red lines represent the duty point required, being 24.5m of head @ 4.4m³/hr, this is an approximate annotation to determine what size pump will be required, from this information there are 3 models that could be suitable for the required duty, 21C, 22B and 22C. The curves shown for these sizes represents the overall range of all impellor variations for these sizes of pumps.

To determine an exact specification for the replacement pump, more accurate and specific performance curves are required from the OEM, However Dow do not currently deal directly with Nikkiso because they are a Japan based company, so they use a third party company to supply the UK, Kinder Janes (Kinder Janes, 2023), the use of a third party company can often come with its own specific challenges which is discussed further in this report, specifically the third party has a limited amount of resources and information in comparison to the OEMs.

In-depth performance assessment

From the preliminary assessment It was determined that a pump variation of either 21C, 22B and 22C would be suitable, following this Kinder Janes were contacted to obtain specific and accurate performance curves for pump options of these sizes. One downside of using third party companies was noticed here as with the previous assessment of CP Pumps, the requested curves had complete customizability with regards to the pump size, impellor size and impellor type, however according to their representative, (Piyush Pithwa, 2023), Kinder Janes could only provide curves that were automatically selected by their pump selection software, so they didn't have the capabilities to change the specifics of the pump.

Using the performance curves provided, 1 possible variant with a **124mm open impellor** was selected for comparison against the current pump. The performance points are detailed in figure 36 below. **Note: Curves are viscous performance, no correction required.**

Richter vs Nikkiso performance											
Pump Variant	Head (m)	Flow rate m ³ /hr									
		0	1	2	3	4	5	6	7	8	9
Richter (Current)		26	25.5	24.8	24.2	23.5	22.8	22.1	21.5	20.9	20.5
Nikkiso 124mm		24.5	25	25.3	25	24.4	23.5	22	20	18	16

Figure 36 - Richter Vs Nikkiso, 124mm open impellor

Using the values from the table in figure 36 above, the performance of the current pump and the proposed Nikkiso have been plotted on the graph shown in figure 37 below.

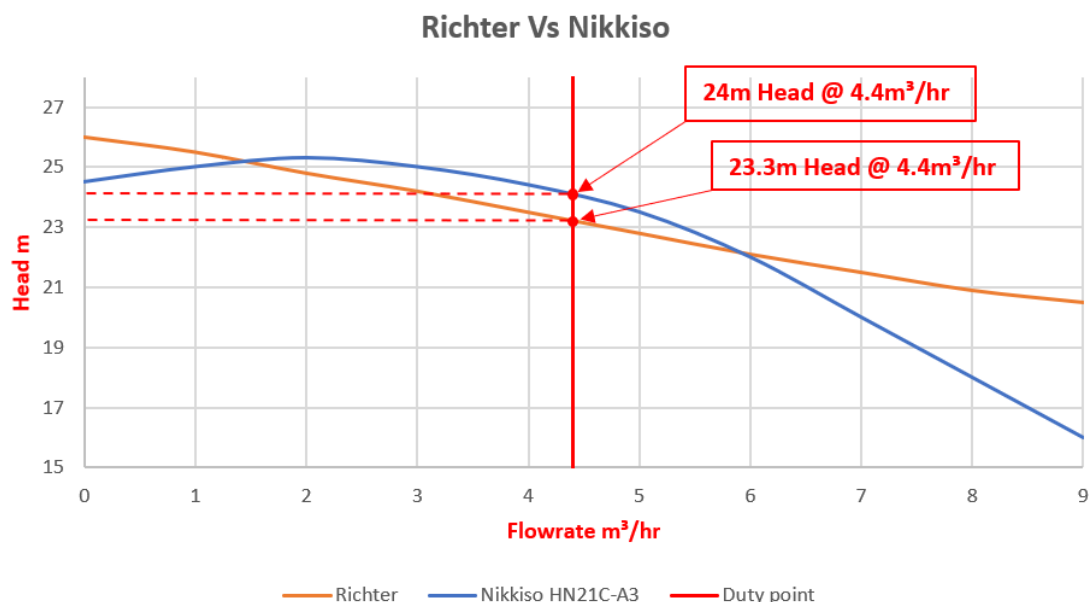


Figure 37 - Richter Vs Nikkiso 124mm open impellor, performance curve

The graph in figure 37 illustrates how the proposed Nikkiso pump would perform in comparison to the current Richter pump, at the duty point of 4.4m³/hr (Indicated by the red

line) the proposed Nikkiso would exceed the Richter with 24m of head, compared to 23.3m of head, however as can be seen by the graph once the flow rate reaches 6m³/hr the developed head of the Nikkiso declines considerably in comparison to the Richter, this presents a potential problem as whilst at duty the Nikkiso would have no issues, but if the flow rate required is higher than 6m³/hr, it will not be able to develop as much head as the current pump, which limits the overall operating range.

This is likely due to the same reason mentioned during the comparison with options from CP Pumps, because the Richter uses a closed impellor whereas the proposed Nikkiso utilises an open impellor. Kinder Janes was contacted following this to attempt to obtain a curve for the same size pump that utilises a closed impellor, with the assumption that the curve would be flatter with a less significant decline in head at higher flow rates, however as mentioned previously their selection software limits the customization of pumps, so at this size pump that wasn't an option.

Curve adjustment for larger/smaller impellers (Affinity laws)

Whilst a closed impellor is likely going to produce a flatter curve, an open impellor could still be viable if its performance exceeds the Richter throughout its operating range, up to 9m³/hr.

From the datasheet provided with the curve for the proposed pump (Nikkiso, 2023), a maximum impellor size of 148mm can be used for the selected pump. According to (Kittredge, 1985), a pump performance curve can be adapted for different impellor sizes using mathematical methods known as the "Affinity laws for pumps".

These pump affinity laws are a set of formulas used to predict head, flow and power absorbed at different shaft speeds, if a performance curve is known at a certain speed or certain impellor diameter, these laws can be used to predict the performance of the same pump with a different shaft speed or impellor diameter (Crest Pumps, 2021).

Law 1: Flow is proportional to shaft speed or impellor diameter.

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \text{ or } \frac{D_1}{D_2}$$

Where:

Q = Volumetric flow rate

N = Shaft speed

D = Impellor diameter

Law 2: Head is proportional to the square of the shaft speed or impellor diameter.

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 \text{ or } \left(\frac{D_1}{D_2}\right)^2$$

Where:

H = Developed head

N = Shaft speed

D = Impellor diameter

Law 3: Power is proportional to the cube of the shaft speed or impeller diameter.

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3 \text{ or } \left(\frac{D_1}{D_2}\right)^3$$

Where:

P = Power

N = Shaft speed

D = Impellor diameter

These formulas required re-arranging to allow impellor diameter changes, resulting in the following:

Law 1: Flow rate $Q_2 = \frac{Q_1 \times D_2}{D_1}$

Law 2: Head $H_2 = \frac{H_1}{\left(\frac{D_1}{D_2}\right)^2}$

Law 3: Power $P_2 = \frac{P_1}{\left(\frac{D_1}{D_2}\right)^3}$

Using the affinity laws formulas, multiple impellor variations were calculated and plotted against the current Richter pump using a specifically made excel spreadsheet, with a final impellor diameter of 135mm being selected, the table in figure 38 below, shows the performance points for the current pump (Richter), the proposed 124mm Nikkiso option, and the calculated 135mm Nikkiso option.

Change red value for new calculation									
Original Values				New Values				Richter	
Diameter	flow	head	power	diameter	flow	head	power	Flow	Head
124	0	24.5	1.35	135	0.00	29.04	1.74	0	26
124	1	25	1.5	135	1.09	29.63	1.94	1	25.5
124	2	25.3	1.65	135	2.18	29.99	2.13	2	24.8
124	3	25	1.8	135	3.27	29.63	2.32	3	24.2
124	4	24.4	1.95	135	4.35	28.92	2.52	4	23.5
124	5	23.5	2.1	135	5.44	27.85	2.71	5	22.8
124	6	22	2.25	135	6.53	26.08	2.90	6	22.1
124	7	20	2.4	135	7.62	23.71	3.10	7	21.5
124	8	18	2.55	135	8.71	21.34	3.29	8	20.9
124	9	16	2.7	135	9.80	18.96	3.48	9	20.5

Figure 38 - Nikkiso, Affinity law corrections, 124mm - 135mm

Using the values from the table above, all 3 performance curves have been plotted on the graph displayed in figure 39 below.

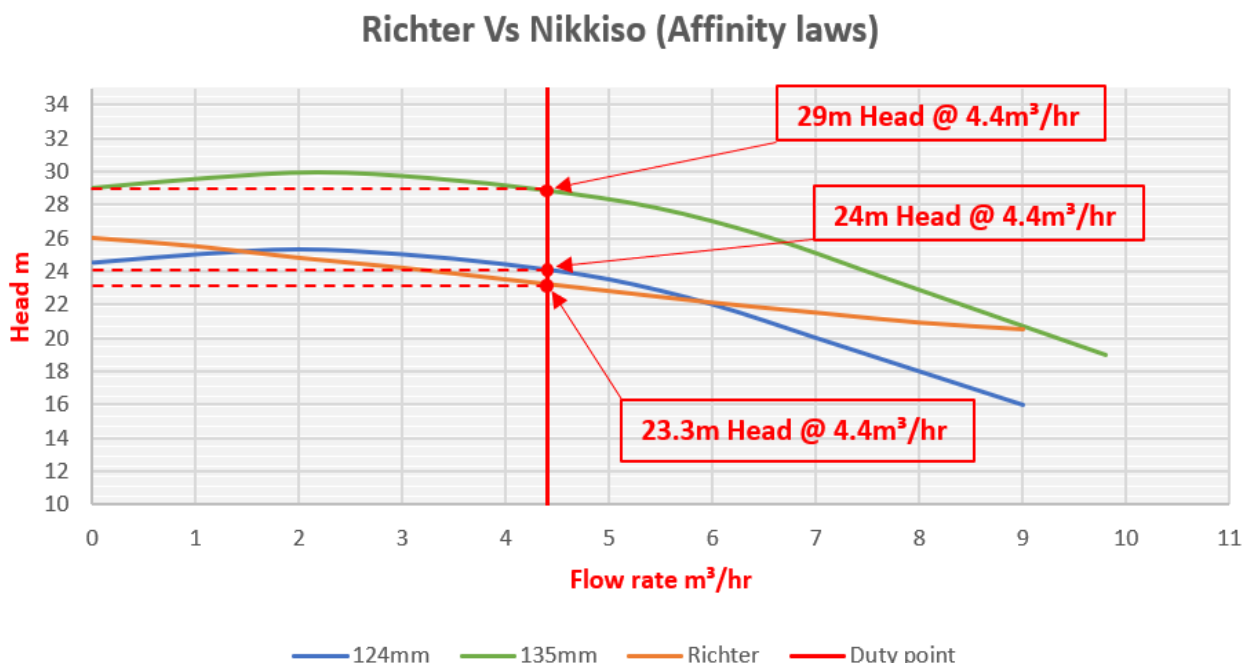


Figure 39 - Richter Vs Nikkiso (Affinity laws) 124mm - 135mm

From the performance curves on the plotted graph, it can be determined that a 135mm impellor will match or exceed the current Richter pump throughout its entire operating range,

however the specified pump has a maximum rated power of 3Kw, the graph in figure 40 below shows the increase in power required from the larger impellor diameter in comparison to the original 124mm impellor.

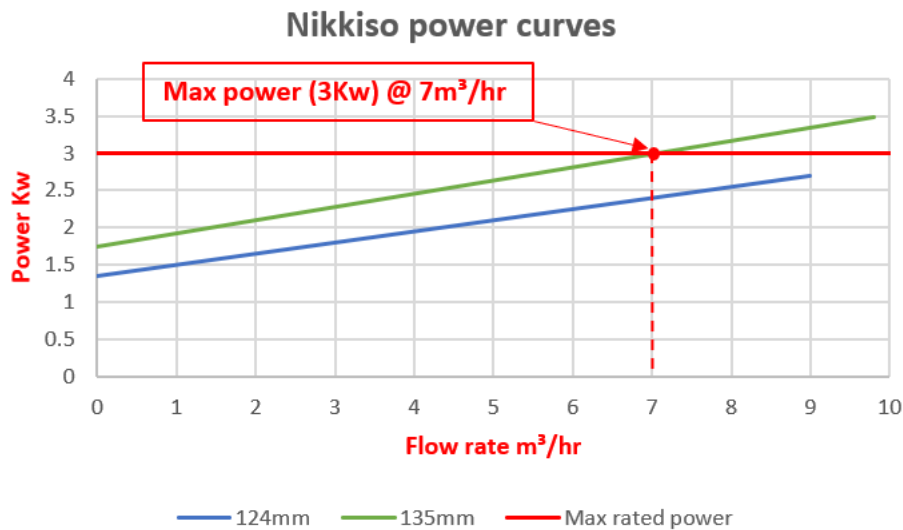


Figure 40 - Nikkiso power curve (Affinity laws)

The graph above shows that the maximum flowrate the pump can be operated at with a 135mm impellor is 7m³/hr, whilst the duty point is only 4.4m³/hr, the current pump can operate up to 9m³/hr if required so if this pump was selected, the operating range will be reduced which could be a problem.

Ideally, performance curves for closed impellor options of this pump size would be useful to determine if a closed impellor option can meet the required operating range without exceeding the maximum power rating of the pump, however limitations of the resources available to Kinder Janes prevent these from being obtained, but once contacted, another performance curve for a larger size of pump was supplied, the curve supplied was for a HN22C model with a **186mm closed impellor**, rated at 4Kw.

The preliminary analysis of the performance curve shown that the pump has a much larger operating range available (Up to 18m³/hr), however at the duty point the developed head was significantly higher than required at 36m, this would result in a significant increase in pressure, whilst this isn't a major issue providing it doesn't exceed the maximum rated pressure of the piping system, it is still desirable to keep pressure increases to a minimum to avoid any unforeseen issues with the rest of the process. The datasheet shows that the pump can have a minimum impellor size of 148mm, so a smaller impellor could possibly meet the operating conditions without too large of a pressure increase or exceeding the 4Kw power rating of the pump.

Using the same method previously (Affinity laws), the performance curve for smaller impellor variations were calculated and plotted on a graph, with a final impellor size of 152mm being selected. The fluid performance and power requirements are shown in figure 41 below.

Change red value for new calculation							
Original Values				New Values			
Diameter	flow	head	power	diameter	flow	head	power
186	0	34	2.4	152	0.00	22.71	1.31
186	1	34.5	2.6	152	0.82	23.04	1.42
186	2	35	2.8	152	1.63	23.37	1.53
186	3	35.5	3	152	2.45	23.71	1.64
186	4	35.8	3.2	152	3.27	23.91	1.75
186	5	35.9	3.4	152	4.09	23.97	1.86
186	6	35.8	3.6	152	4.90	23.91	1.96
186	7	35.5	3.8	152	5.72	23.71	2.07
186	8	35	4	152	6.54	23.37	2.18
186	9	34.6	4.2	152	7.35	23.11	2.29
186	10	34.2	4.4	152	8.17	22.84	2.40
186	11	33.8	4.6	152	8.99	22.57	2.51
186	12	33.2	4.8	152	9.81	22.17	2.62
186	13	32.2	5	152	10.62	21.50	2.73
186	14	31.5	5.2	152	11.44	21.04	2.84
186	15	31	5.4	152	12.26	20.70	2.95
186	16	29.8	5.6	152	13.08	19.90	3.06
186	17	29	5.8	152	13.89	19.37	3.17
186	18	27.5	6	152	14.71	18.37	3.27

Figure 41 - Nikkiso HN22C, Affinity laws, 186mm - 152mm

The performance points above were then plotted on the following graph in figure 42.

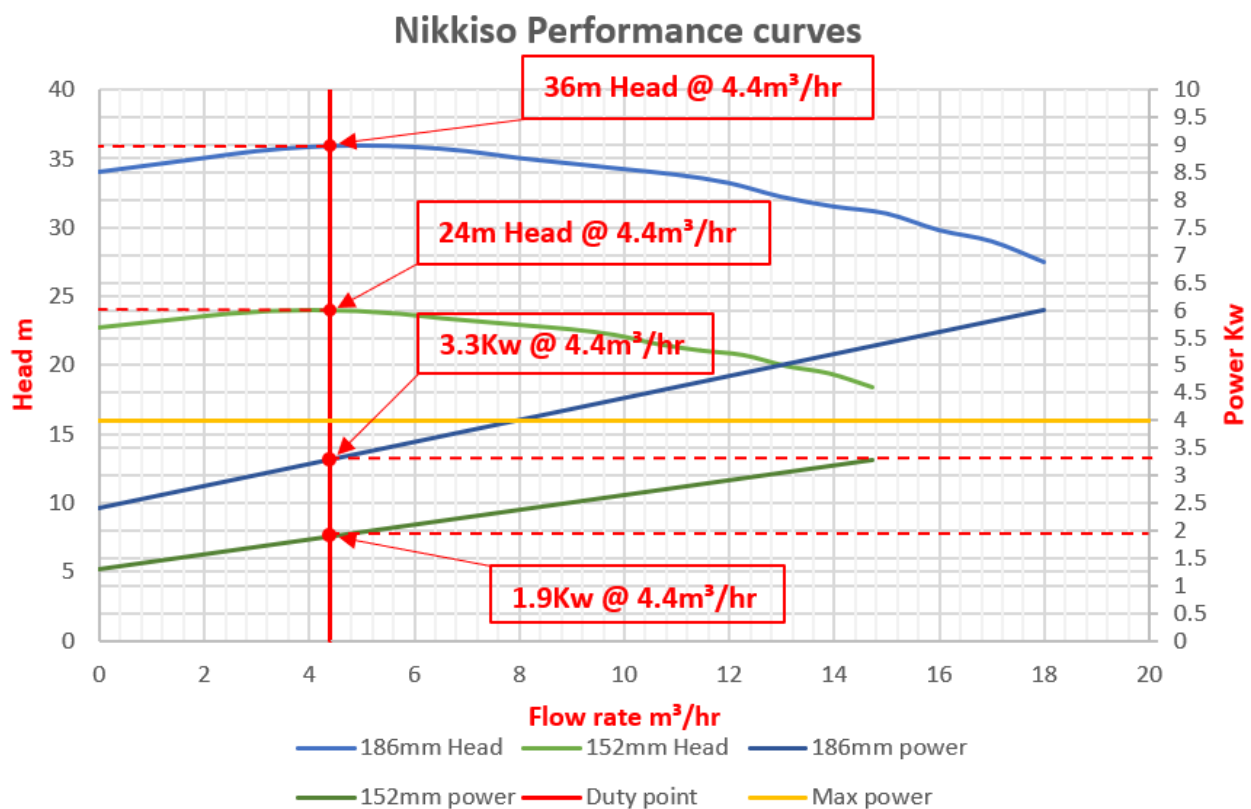


Figure 42 - Nikkiso HN22C performance curves, Affinity laws, Flow & power

The graph in figure 24 shows that the 152mm impellor variant of the higher power Nikkiso, is significantly closer to the required head at the 4.4m³/hr duty point, with 24m, and it will not exceed the maximum rated power of 4Kw throughout its entire operating range.

With an appropriate size impellor that won't exceed the power rating of the pump, next was to compare the 152mm impellor variant to the current Richter pump, the performance points are detailed in the following table and graph, displayed in figure 43 below.

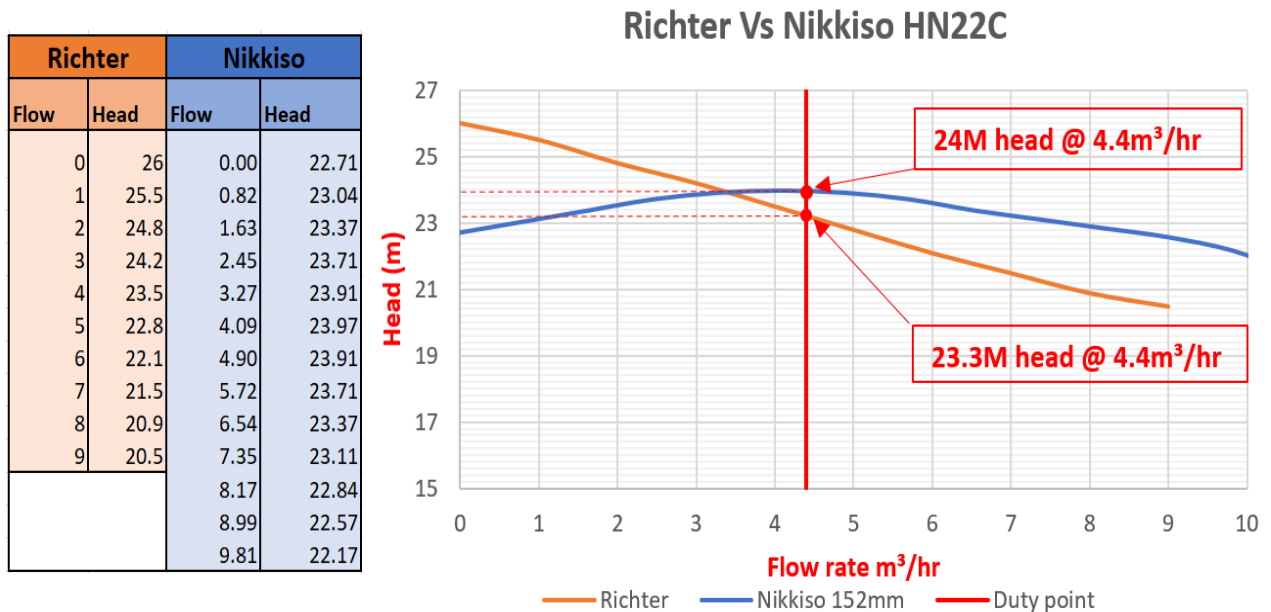


Figure 43 - Richter Vs Nikkiso, Final performance curve comparison

The table and graph above show how the proposed 152mm impellor variant of the 4Kw Nikkiso will perform in comparison to the current Richter pump, it would develop slightly less head up until approximately 3.5m³/hr and from then it will exceed the head of the Richter, this is unlikely to cause any issues as the process has a minimum required flowrate of 2m³/hr (ITT Richter Chemie-Technik GmbH, 1995), and the developed head between this point and 3.5m³/hr is still higher than that of the higher flow rates above 6m³/hr for the current pump.

Note: The overall operating range of the 152mm impellor Nikkiso variant is much larger than the current pump and can go as high as 14.7m³/hr, this isn't shown on the above curve for easier reading, and flowrates that high are not required from the process.

Pressure calculation

As done previously for the option from CP Pumps, the maximum pressure for the proposed 152mm impellor variant from Nikkiso requires calculating to predict how it would change the discharge pressure in the required duty to ensure no maximum pressure ratings are exceeded.

According to (Engineering toolbox, 2004), the head developed by a pump can be converted to pressure using the following formula:

$$p = 0.0981 \cdot h \cdot SG$$

Where:

$p = \text{Pressure (Bar)}$

$h = \text{Head (m)}$

$SG = \text{Specific gravity (Value of 1.68 obtained from (ITT Richter Chemie-Technik GmbH, 1995))}$

Using the above formula, the highest possible discharge pressure was calculated for the proposed pump, which also happened to be the duty point, at this point the differential pressure was calculated as **3.95Barg**, giving a total discharge pressure of **5.92Barg**.

Power and efficiency assessment

With a suitable pump specified from a fluid performance perspective, the power requirements and efficiencies now require comparison.

Power assessment

Using the calculated power requirements of the Richter using the method outlined by the hydraulic institute (Hydraulic Institute, 2004) for the higher viscosity fluid, and the calculated power requirements for the proposed 152mm closed impellor variant of Nikkiso pump using the affinity laws, the power requirements for both pumps have been plotted on the graph displayed in figure 44 below.

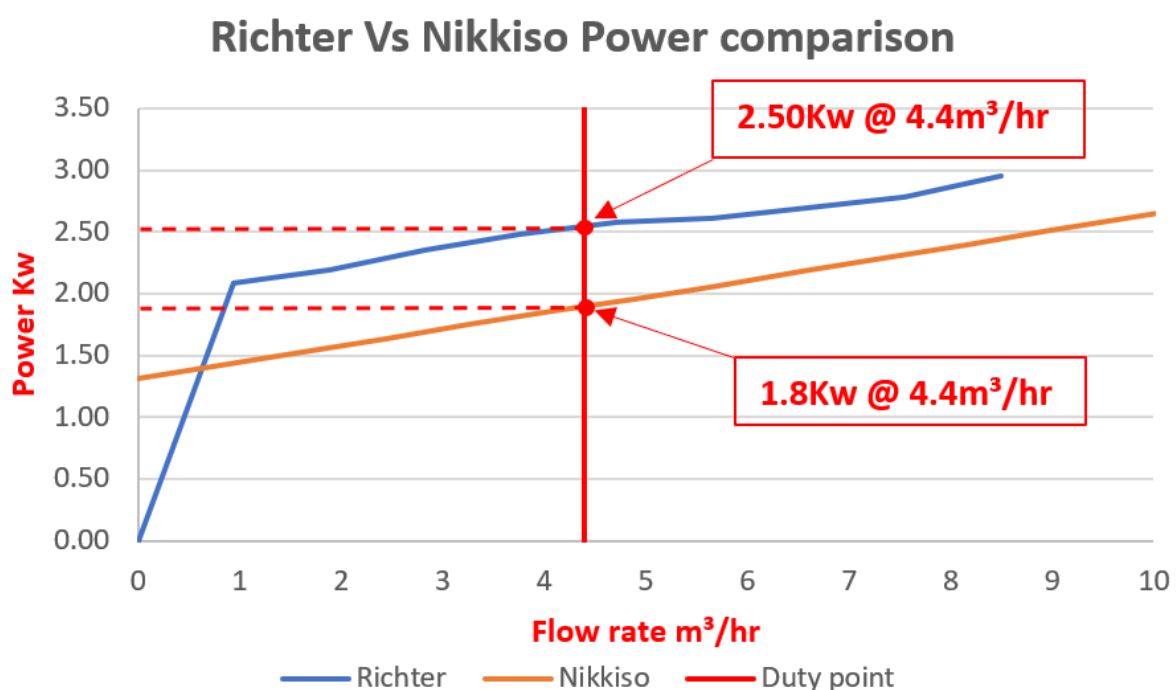


Figure 44 - Richter Vs Nikkiso, power comparison

As can be seen in the graph above, at the duty point of $4.4\text{m}^3/\text{hr}$, the Nikkiso pump requires significantly less power of 1.8KW, compared to the 2.58KW required by the Richter pump. This means the Nikkiso pump would be significantly cheaper to run, and is likely more efficient, discussed further on the following page.

From the figures above, in a 24-period the proposed Nikkiso will consume 43.2Kwh of energy, whilst the Richter currently consumes 61.92Kwh.

Efficiency comparison curves

Using the previously corrected efficiency curve for the Richter pump, and the efficiency curve supplied from Kinder James for the Nikkiso pump, both have been plotted on the graph displayed in figure 45 below for comparison.

Note: The efficiency curve for the Nikkiso, was originally against the pump with a larger impellor (Before the affinity law calculations), according to (Evans, 2006), when using the affinity laws to modify performance curves, the efficiency is assumed to remain constant, however if efficiency is vital the OEM must be contacted to confirm the new efficiency value.

With the impellor diameter being reduced, it is most likely they efficiency will also be lower than that shown on the curve.

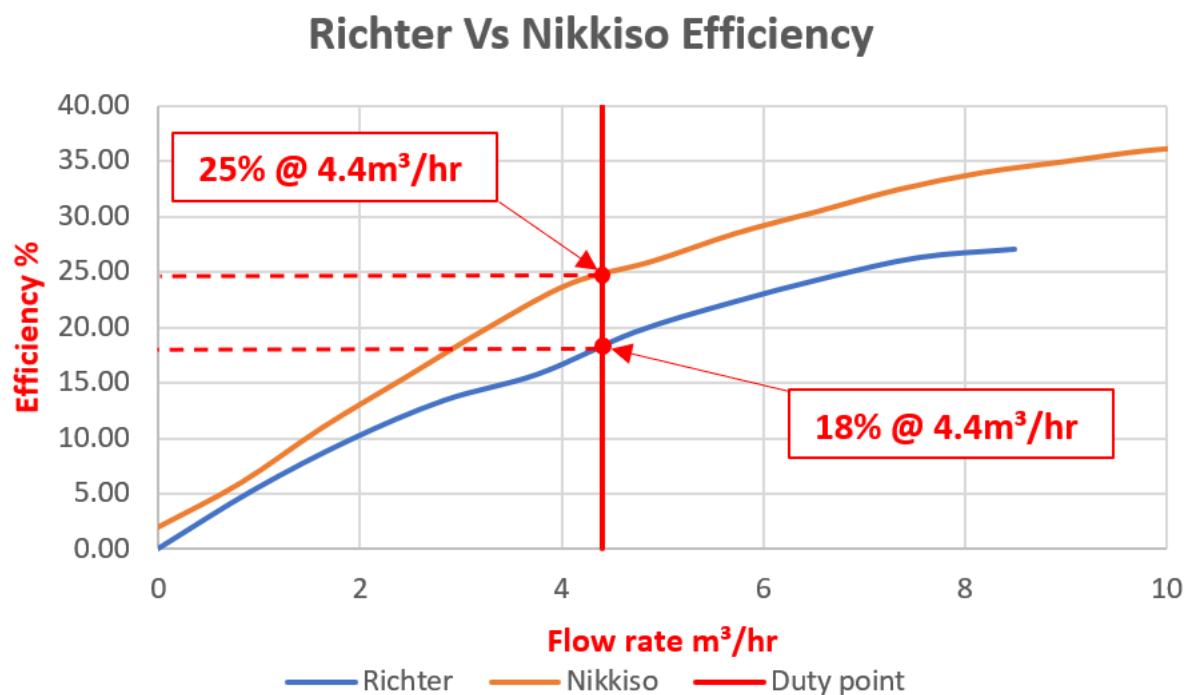


Figure 45 - Richter Vs Nikkiso, efficiency comparison

The graph above shows that the Nikkiso is 7% more efficient than the Richter at the duty point, however as mentioned this is likely higher than reality, so would have to be confirmed by Nikkiso if this pump variant is selected.

Cost analysis

With the 2 suitable pump variants determined, quotes could be obtained from the vendors.

As the current process has 2 installed pumps, an online pump and a standby, as well as a fully built spare pump in storage, a total of 3 pumps are required.

Magnetic drive option (CP Pump) purchase cost

The magnetic drive option from CP Pump systems, requires a separate motor to drive the pumps installed on the plant, so this option requires 2 complete pump units (supplied with a motor, bedplate & coupling assembly), as well as a separate spare pump.

The quotes were obtained directly from CP Pump systems (CP Pump Systems, No year) and are detailed as follows:

- Pump unit X2 £11,638 each
 - Pump (MKPL 25-25-160, 140mm closed impellor)
 - Bedplate
 - 4KW motor
 - Coupling
 - Shroud monitoring system (Can protection)
 - PT100 temperature sensor
- Bare shaft pump (Spare pump) £9728
- Total purchase cost = £33,004

Canned motor pump option (Nikkiso) purchase cost

The canned motor pump option from Nikkiso has an integrated electric motor, so the pumps come supplied on a bedplate with no other ancillaries.

The quotes were obtained through the third-party representative, Kinder James (Kinder Janes, 2023), and are detailed as follows:

- Pump unit X3 £36,457 each
 - Pump of alloy20 construction (HN22C, 152mm closed impellor)
 - Bedplate
- Total purchase cost = £109,371

Purchase cost summary

As can be seen above, the magnetic drive pump option by CP Pump systems is considerably cheaper with regards to initial purchase cost at £33,004, whereas the canned motor pump option from Nikkiso is over 3 times the cost at £109,371, this is likely due to the Nikkiso option requiring an alloy 20 construction, as according to (The Hendrix group inc, 2023), alloy 20 is approximately 2.6 times more expensive than 316 stainless steel.

Predicted maintenance assessment.

As part of this project, the maintenance of the proposed pumps also requires assessing to ensure they will operate efficiently and can also be repaired/maintained throughout their lifetime. Dow's strategy for pump repairs/overhauls utilises an on-site rotating equipment workshop, so for an efficient system any required spares are available as required. Dow also utilises a **condition based monitoring program** as opposed to a planned maintenance schedule to determine when repairs are required, according to (Ridgeway, 2022), this program uses vibration and oil analysis to determine the health of all pumps on site, this saves expensive overhauls which may not be required if using a planned maintenance schedule.

Spares to be stocked.

For efficient maintenance, it is important that pumps can be repaired efficiently to a high standard, so it is necessary to keep genuine replacement parts in storage, so repairs can be completed with minimal time implications, as plant downtime caused by equipment failures can result in hundreds of thousands of pounds per day in lost production.

There are 2 different pumps proposed as suitable replacements, each of which will require their own BOM (Bill of materials) which will specify the spare parts available for that pump. Both pump manufacturers are utilised on the Dow site with various sizes for each, so maintenance manuals have been used along with information in SAP (Previous rebuild reports, costing information, etc...), to determine what spares are required and how much they cost.

Magnetic drive pump (CP Pump)

There are currently 53 pumps manufactured by CP Pump systems in operation at the Barry site, many of which also have fully assembled spares in storage. 4 of these pumps in operation are of the same size as the proposed model for the duty outlined in this report, an MKPL 25-25-160, with slight differences such as impellor diameter and containment shell options (I.e. can protection feature) (DOW SAP system, 2023) , this means that most of the required spare parts are already stocked on site and costing data is available.

Using Costing data from SAP (DOW SAP system, 2023) and the operating manual for CP pumps (CP Pump Systems, 2016), the following spare parts are recommended to be stocked:

- Power end:
 - Bearings (£20.62)
 - Labyrinth seals (£143.82)
 - Gaskets & O-rings (£19.59)
 - Outer magnet (£1757.53)
 - Drive shaft (£352.76)
- Process end:
 - Impellor radial bearing (£857.50)
 - Impellor thrust bearings (£1355.86)
 - Impellor bearing bracket (£3446.84)
 - Impellor (£1316.51)
 - Impellor shaft c/w nut & washer (£378.35)
 - Inner magnet (£1271.39)
 - Inner magnet cap (£800.90)
 - Containment shell (£1937.09)
 - Gaskets & O-rings (£430.04)

****Note: whilst these parts are recommended to be stocked, many of which are not considered as consumables, so are only replaced in the event of damage/defects as determined by the technician carrying out the maintenance work****

According to the maintenance manual (CP Pump Systems, 2014), “All seals / gaskets and round section joint rings should be replaced during servicing”. This outlines the parts that must be replaced every time the pump is disassembled and can be considered as the consumable parts. From the data on the previous page, the total cost for these parts is £449.99.

However as mentioned previously, pumps on site are only typically repaired when deemed necessary by the condition monitoring reports, or in the event of a failure, so the assumption can be made that parts will be required outside of the consumables. To determine what the likely cost of pump repairs will be for the proposed pump, a survey was carried out using SAP to determine the average repair cost for similar pumps currently in operation on site.

From this survey, it was determined the average repair for a CP pump MKPL 25-25-160 model consisted of the following:

- Labour costs, total = £1568
 - 16 hours at a rate of £98 per hour = £1568
- Parts cost, total = £4621.06
 - Consumables (Gaskets & O-rings) = £449.99
 - Power end bearings = £20.62
 - Impellor radial bearing = £857.50
 - Impellor thrust bearings = £1355.86
 - Containment shell = £1937.09

This results in a total average cost of repair at £6189.06.

Canned motor pump (Nikkiso)

There are currently 50 pumps manufactured by Nikkiso in operation at the Barry site, many of which also have fully assembled spares in storage. 4 of these pumps in operation are of the same size as the proposed model for the duty outlined in this report, HN22C, with slight differences such as impellor diameter and materials of construction, so many of the required spare parts will already be stocked on site.

****Note: Currently there are no pumps of alloy 20 construction on site, most are of 316L stainless steel, however according to (Piyush Pithwa, 2023) the parts below are common between 316L pumps and alloy 20 pumps****

Using Costing data from SAP (DOW SAP system, 2023) and the operating manual for Nikkiso pumps (Nikkiso Pumps Europe, 2003), the following spare parts are recommended to be stocked:

- Bearing bush set (£997.51)
- Bearing sleeve set (£1232.32)
- Bearing thrust washer set (£1270.13)
- Gaskets & O-rings (£51.61)
- Bearing monitor (£521.50)
- Impellor tab-washer (£83.95)
- Rear bearing tab-washer (£57.88)

****Note: whilst these parts are recommended to be stocked, many of which are not considered as consumables, so are only replaced in the event of damage/defects as determined by the technician carrying out the maintenance work****

According to the operating manual, *“Nikkiso’s recommendation is to replace all seals after disassembly (seals are wearing parts!)”*. This outlines the parts which must be replaced every time the pump is disassembled and can be considered the consumable parts, from the data above, the total cost of these parts is £51.61.

However, as mentioned previously pumps are only repaired based on condition monitoring reports or in the event of a failure, so it is likely parts beyond the consumables are required. As was done for the CP pump systems option, a survey was carried out using SAP to determine the average repair cost for similar pumps in operation at the Barry site.

From this survey, it was determined the average repair for a Nikkiso HN22C model consisted of the following:

- Labour costs, total = £1568
 - 16 hours at a rate of £98 per hour = £1568
- Parts cost, total = £4214.90
 - Consumables (Gaskets & O-rings) = £51.61
 - Bearing bush set = £997.51
 - Bearing sleeve set = £1232.32
 - Bearing thrust washer set = £1270.13
 - Bearing monitor = £521.50
 - Impellor tab-washer = £83.95
 - Rear bearing tab-washer = £57.88

This results in a total average cost of repair at £5782.90.

Magnetic drive pump vs Canned motor pump

With an estimated overhaul cost for both pump options, a comparison can be made between them. From the calculations, it is predicted that a canned motor pump (Nikkiso) would be the cheaper in comparison to a magnetic drive pump (CP Pump), with regards to maintenance costs, as it has been calculated that a typical repair would cost £5782.90 for a Nikkiso, and £6189.06 for a CP pump.

The reliability surveys also indicate that the Nikkiso would require less frequent maintenance, as the average MTBF (Mean time between failure) for a Nikkiso pump on site is 36.2 months, whereas the average MTBF for a CP pump is 21 months.

To put this into perspective, the maintenance costs for each can be calculated over a 5-year time span:

Nikkiso, over 60 months it is calculated that a Nikkiso will require maintenance 1.66 times ($60/36.2\text{MTBF}$). With an estimated service cost of £5782.90, **over 5 years it is estimated to cost £9584.92** ($£5782.90 \times 1.66$).

CP Pump, over 60 months it is calculated a CP pump will require maintenance 2.86 times ($60/21\text{MTBF}$). With an estimated service cost of £6189.06, **over 5 years it is estimated to cost £17,683.03** ($£6189.06 \times 2.86$).

The conclusion can be made that a Nikkiso pump would be considerably cheaper to maintain following installation, however if any parts outside of the standard stocked requirements require replacing, the assumption can be made that the costs could rise considerably based on the initial purchase cost of a Nikkiso being over 3 times the cost of a CP Pump option.

Installation considerations

Whilst the overall purchase cost is a major factor to be considered, the modifications required to the current installation must also be considered as piping modifications can be expensive and time consuming.

Figure 46 Below, shows a basic piping and instrument diagram that shows the current process set up local to the installed pumps, all pipework is of PTFE lined ANSI B16.5 flanged piping connections.

Note: the actual installation includes considerably more instrument T's, valves, pressure gauges & instruments.

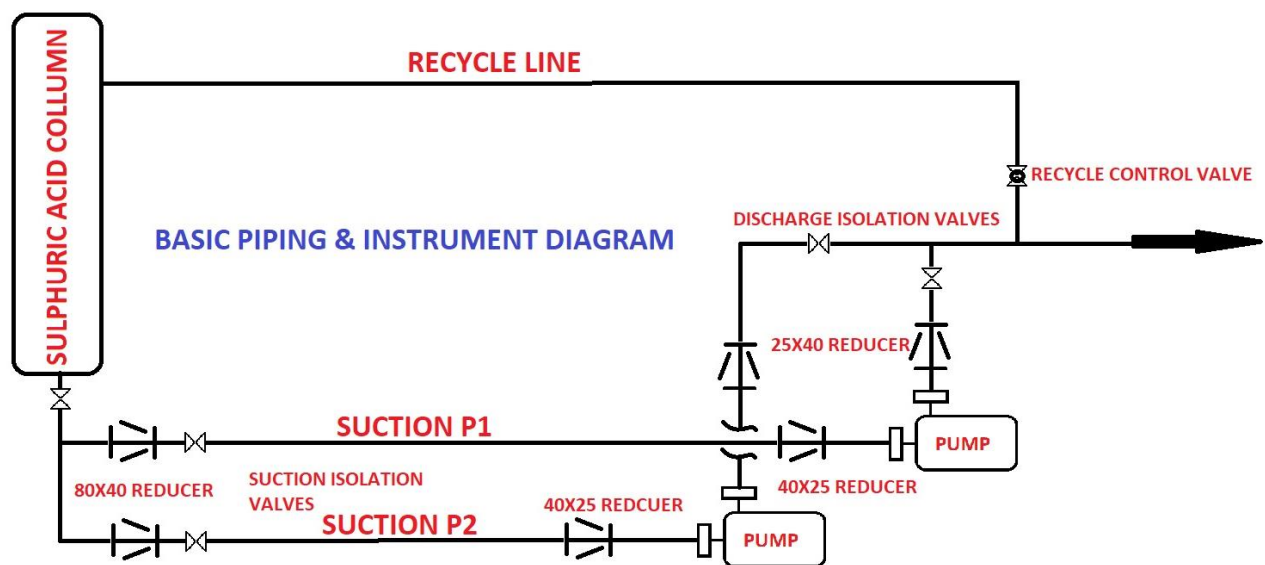


Figure 46 - Basic P&ID of current process

The diagram above represents the following:

- The suction pipework
 - 80mm direct to the bottom of the sulphuric acid column
 - 80mm isolation valve
 - Pipework decreases from 80mm to 40mm on both pump suction lines.
 - 40mm isolation valve for each pump suction line
 - Pipework decreases from 40mm to 25mm at pump suction.
- The discharge pipework
 - Pipework increases from 25mm to 40mm at pump discharge.
 - 40mm isolation valve
 - T-piece with a recycle control valve to control minimum flow requirements, feeding back into sulphuric acid column.

For any pipework modifications, DOW uses the following costing data for the fabrication of new PTFE piping (Ridgeway, 2022):

- £800 per meter length of 25mm bore pipework.
- £1200 per meter length of 40mm bore pipework.
- £1600 per meter length of 50mm bore pipework.
- £2400 per meter length of 80mm bore pipework.

Richter Pump dimensions (Current pump)

By using general arrangement drawings of the current Richter pump and the proposed CP pump and Nikkiso options, any modifications required to the mounting plinth and pipework can be determined.

Figure 47 below, is the general arrangement drawing for the currently installed pumps (ITT Richter Chemie-Technik GmbH, 1995) with **dimensions of interest circled in red**:

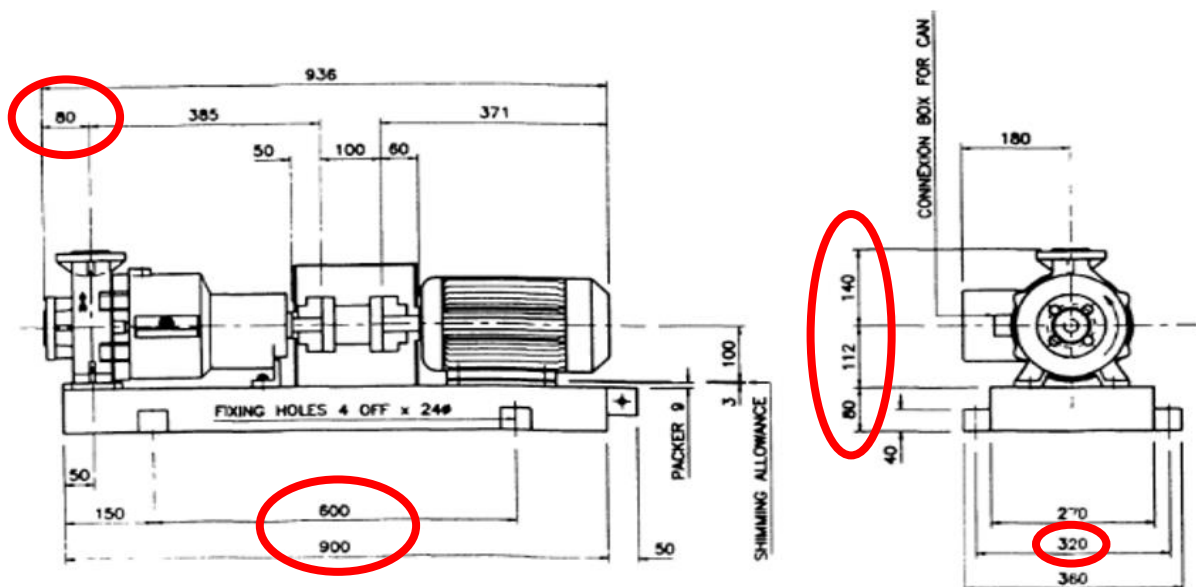


Figure 47 - Richter general arrangement diagram (ITT Richter Chemie-Technik GmbH, 1995)

They dimensions circled above shows the following:

- The overall length of the baseplate is 900mm.
- The distance between the fixing holes along the length of the baseplate is 600mm.
- The distance between the fixing holes along the width of the baseplate is 320mm.
- The total distance from the bottom of the baseplate to the top of the pump discharge flange is 332mm.
- The distance from the bottom of the baseplate to the centre of the suction flange is 192mm.

- The distance from the centre line of the suction flange to the top of the discharge flange is 140mm.
- The distance from the face of the suction flange to the centre line of the discharge flange is 80mm.

As mentioned previously, the suction and discharge flanges of the pump are 25mm bore (1" ANSI 150#)

CP Pump option dimensions

Figure 48 below is a general arrangement drawing of the proposed CP pump option (CP Pump Systems, 2022) with the same **dimensions of interest circled in red**.

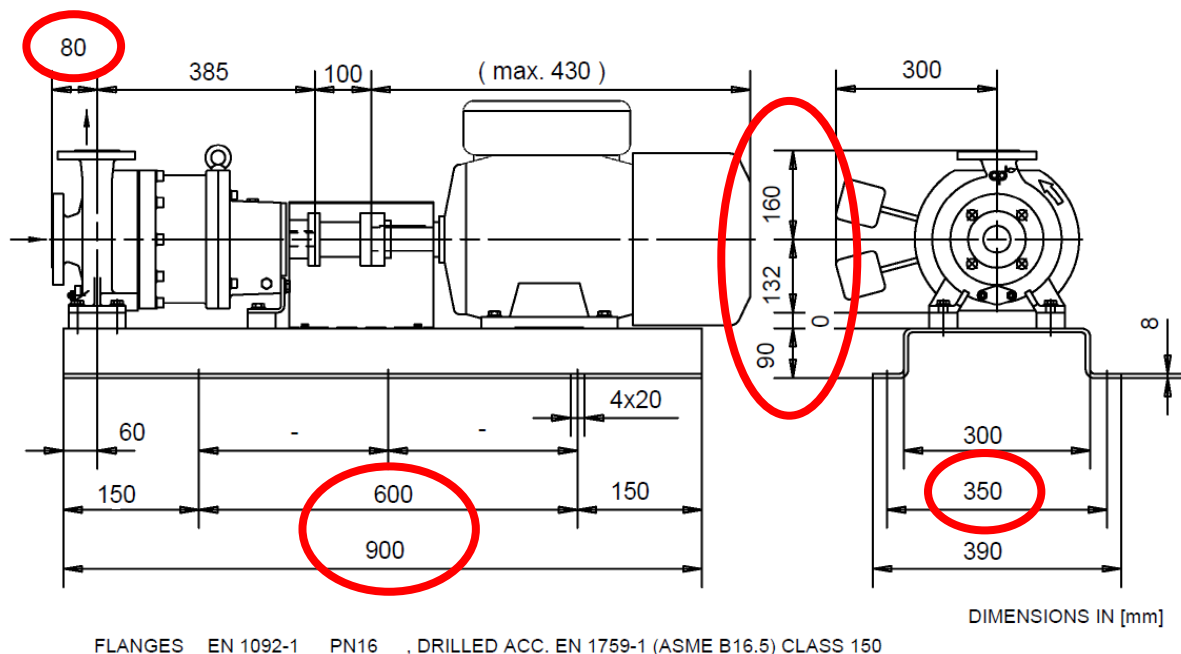


Figure 48 - CP Pump option, general arrangement diagram (CP Pump Systems, 2022)

They dimensions circled above shows the following **(The equivalent Richter dimensions are shown in red)**:

- The overall length of the baseplate is 900mm **(900mm)**.
- The distance between the fixing holes along the length of the baseplate is 600mm **(600mm)**.
- The distance between the fixing holes along the width of the baseplate is 350mm **(320mm)**.
- The total distance from the bottom of the baseplate to the top of the pump discharge flange is 382mm **(332mm)**.
- The distance from the bottom of the baseplate to the centre of the suction flange is 222mm **(192mm)**.
- The distance from the centre line of the suction flange to the top of the discharge flange is 160mm **(140mm)**.
- The distance from the face of the suction flange to the centre line of the discharge flange is 80mm **(80mm)**.

As mentioned previously, the suction and discharge flanges of the pump are 25mm bore (1" ANSI 150#), the same as the currently installed pumps.

Modifications required.

As there are some minor differences between the critical dimensions detailed above, modifications are required to the current installation if a CP Pump is selected, the modifications required are:

- The concrete plinth requires lowering by approximately 30mm to line up the centre of the suction flange with the centre line of the suction pipework.
- The anchor bolts securing the baseplate to the concrete plinth require moving by a total of 30mm across the width, an alternative to this is to slot the mounting holes of the baseplate by 15mm towards the centre.
- The piping spool directly on the pump discharge requires shortening by 20mm to accommodate the taller pump.

With the above modifications, the pump unit should fit without any further pipework or baseplate/plinth modifications.

One consideration which hasn't been detailed, is the current motor is 3KW, yet the motor proposed by CP Pump systems is a 4KW, so any modifications to the electrical supplies must be determined by an electrical engineer prior to installing, furthermore any extra electrical modifications to accommodate the can protection system and temperature sensor must also be determined prior to installing.

In summary, the modifications required to install a CP Pump are not considerable, from a piping perspective using the costing data previously detailed, the modifications to the discharge pipework will cost £800 or less (£800 per meter length of 25mm bore pipework).

As mentioned however, there are 2 installed pumps on plant so both pump systems will require modifications, giving a total estimated cost of pipework modifications at £1600.

Nikkiso pumps option dimensions

Figure 49 below is a general arrangement drawing of the proposed Nikkiso pumps option (Nikkiso Pumps and systems, 2020) with the same **dimensions of interest circled in red**.

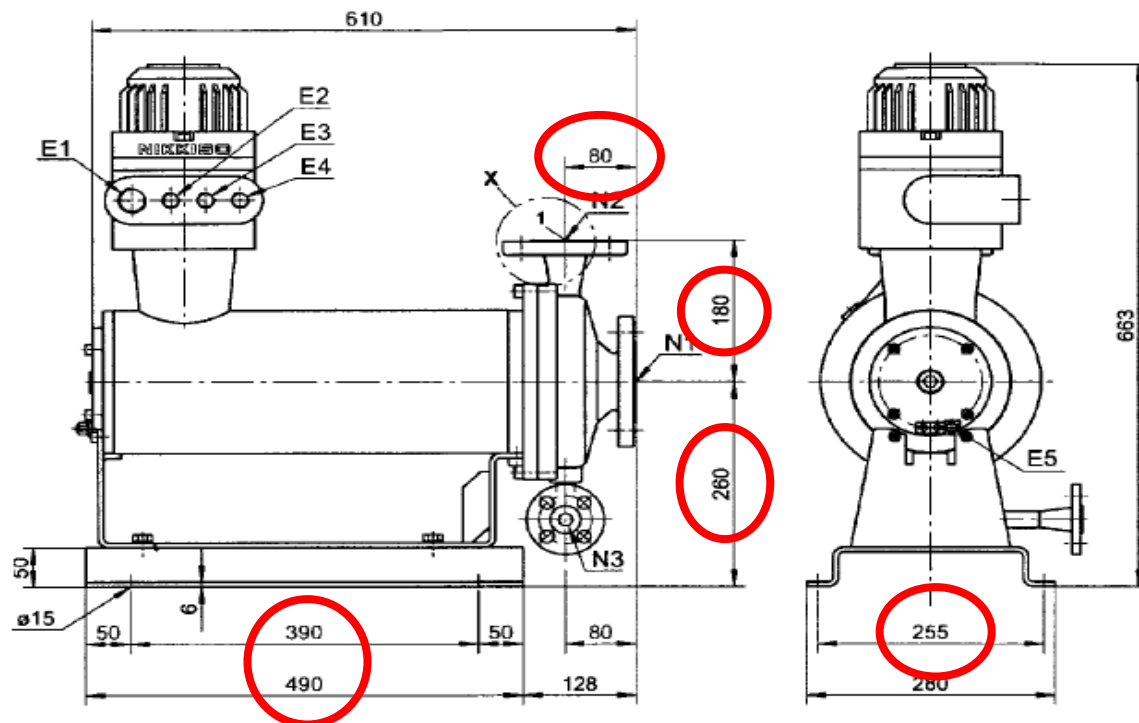


Figure 49 - Nikkiso pump option, general arrangement diagram (Nikkiso Pumps and systems, 2020)

They dimensions circled above shows the following **(The equivalent Richter dimensions are shown in red)**:

- The overall length of the baseplate is 490mm **(900mm)**.
- The distance between the fixing holes along the length of the baseplate is 390mm **(600mm)**.
- The distance between the fixing holes along the width of the baseplate is 255mm **(320mm)**.
- The total distance from the bottom of the baseplate to the top of the pump discharge flange is 440mm **(332mm)**.
- The distance from the bottom of the baseplate to the centre of the suction flange is 260mm **(192mm)**.
- The distance from the centre line of the suction flange to the top of the discharge flange is 180mm **(140mm)**.
- The distance from the face of the suction flange to the centre line of the discharge flange is 80mm **(80mm)**.

With the proposed Nikkiso pump, the suction flange is 50mm bore (2" ANSI 150#) and the discharge flange is 40mm bore (1 ½" ANSI 150#), there is also a 15mm bore (1/2" ANSI 150#) drain flange.

Modifications required.

As there are some minor differences between the critical dimensions detailed above, modifications are required to the current installation if a Nikkiso Pump is selected.

The most significant modification relates to the suction pipework as the current piping is smaller than the suction flange of the pump, and according to (Annoye, 2021), the suction pipework should be at minimum the same size of the suction flange of the pump, ideally one size larger, particularly if the viscosity of the pumped fluid is higher than water, which is the case here.

the minimum modifications required are:

- Baseplate and concrete plinth:
 - The concrete plinth requires lowering by approximately 68mm to line up the centre of the suction flange with the centre line of the suction pipework.
 - The anchor bolts securing the baseplate to the concrete plinth require moving to a smaller footprint of 390mm x 255mm, currently 600mm x 320mm.
- Suction pipework:
 - Diameter increase from the 80 to 40 reducers, replacing with an 80 to 50 reducer and remaining at 50mm to match the larger suction flange of the pump.
 - Valve replacements to suit larger piping diameter.
- Discharge pipework:
 - The reducer taking the pipe from 25 to 40 requires removal and replacement with a straight 40mm pipe to accommodate larger discharge flange of pump.
 - The replacement pipe spool to be 40mm shorter than the current length to accommodate the taller pump.

The modifications required to fit the Nikkiso pump are considerably more extensive than that of the CP Pumps option, the suction linework that requires replacing is approximately 10 meters in length, using the costing data detailed previously, the pipework modifications of the suction will cost an estimated £16,000 (£1600 per meter length of 50mm pipe), plus the

additional cost of any new valves required. The discharge pipework modifications will cost an estimated £1200 (£1200 per meter length of 40mm pipe).

As was the case with the CP Pump option, the electrical supply will also have to have any modifications determined by an electrical engineer prior to installation to accommodate the larger 4KW motor of the Nikkiso pump.

With the above modifications being required for both installed pump systems on the plant, the total estimated cost of pipework modifications is £34,400.

Note: this doesn't include any replacement valves or instruments, so in reality will be considerably higher, also this is calculated using 50mm bore suction pipework whereas ideally it would be made of one size larger being 65mm bore suction pipework, which would also increase the cost.

Operating/energy requirements cost

Using the data from the energy requirement curves detailed previously in this report, the cost to operate the replacement pump can be calculated.

Dow has its own power station on site to provide electricity to all machinery, however for the purpose of these calculations, generic industrial energy costing data has been used, according to (UK Government, 2023), the latest average cost per Kwh of electricity is **£0.775 p/Kwh**.

Using this data, the operating cost for each pump option has been calculated and is displayed below.

Note: The cost is based on continuous operation of one pump over a 5-year time span, there will be times where no pumps are operating such as during shutdown periods, however for the purpose of these calculations the absolute maximum cost has been calculated.

CP Pump systems option

From the energy comparison curve, it has been calculated that at the duty point of 4.4m³/hr, the option from CP Pumps will be using 2.31Kw of electricity. Using the cost of £0.775 p/Kwh, this gives a total cost per hour of £1.79025. Over time the costs are as follows:

- One day = £1.79025 * 24 = £42.966
- One week = £42.966 * 7 = £300.762
- One year = £42.966 * 365 = £15,682.59
- 5 years = £15,682.59 * 5 = £78,412.95

This gives an estimated 5-year operating cost of £78,412.95.

Nikkiso Pumps option

From the energy comparison curve, it has been calculated that at the duty point of 4.4m³/hr, the option from Nikkiso pumps will be using 1.8Kw of electricity. Using the same method as the CP Pumps calculations above, the total cost per hour of operation is £1.395. Over time the costs are as follows:

- One day = $£1.395 * 24 = £33.48$
- One week = $£33.48 * 7 = £234.36$
- One year = $£33.48 * 365 = £12,220.20$
- 5 years = $£12,220.20 * 5 = £61,101$

This gives an estimated 5-year operating cost of £61,101.

Cost analysis summary

With considerations being made to the initial purchase costs, installation costs, operating costs, and maintenance costs, all of these can be used to summarise and better determine the most cost-effective option. Using the values calculated for all the aforementioned costs, a total cost after 5 years has been calculated and is displayed in figure 50 below.

Cost analysis summary					
	Purchasing	Installation	Operating	Maintenance	Total cost after 5-years
CP Pumps	£13,004.00	£1,600.00	£78,412.95	£17,683.00	£110,699.95
Nikkiso Pumps	£109,371.00	£34,400.00	£61,101.00	£9,584.92	£214,456.92

Figure 50 - Cost analysis summary

From the information displayed above, the conclusion can be drawn that the option from CP Pump systems is by far the most cost-effective option. Whilst the option from Nikkiso pumps would be cheaper to operate and maintain once installed, its purchasing and installation costs being so high means it still isn't the most cost-effective option and would take considerably longer than 5 years to be deemed to be so.

Conclusion

It is the finding of this report that both proposed pump options, from CP Pump systems and Nikkiso Pumps, would be a suitable replacement as they both can meet the performance requirements of the process and are both compliant with all required directives and legislation.

However, the option from CP Pump systems is by far the most cost-effective solution due to the excessive purchasing and installation costs associated with the option from Nikkiso pumps, a total cost over 5 years equalling £110,699.95 compared to £214,456.92 for a Nikkiso, so the recommended replacement pump for the spent sulphuric acid duty is the MKPL 25-25-160 model pump from CP Pump systems, specified with a 140mm trim closed impellor.

If the specified pump is to be purchased and installed, it is the findings and predictions of this report that it will match or exceed all fluid flow performance requirements in comparison to the currently installed Richter pumps, as well as being more efficient with regards to energy consumption, requiring 2.31Kw of electricity at the duty point, compared to the current 2.5Kw consumption of the current pump.

Whilst the reliability of the currently installed pumps has never been of concern, it is also found in this report that it is likely the replacement pump will have a higher MTBF (Mean time between failure) figure of 21 months, compared to the current Richter average of 16.4 months, thus improving the asset reliability.

The replacement pump will also have sufficient safety devices to prevent process leaks to atmosphere, namely a can protection system to monitor the containment shell between the process and power end of the pump, which on the current pump is no longer available or supported, thereby triggering the requirement for a replacement and this project/report.

Further work

The results of this project have determined the specification of a suitable replacement pump for the spent sulphuric acid duty, with this complete a plan has been preliminary detailed below in figure 51, to outline the work to follow to successfully install the specified pumps onto the plant. As previously mentioned, there are 2 pumps installed for this duty, it is the recommendations of this report that initially, only one of these pumps are replaced so that there is still a single pump available to the process, avoiding any plant downtime. It is also recommended that a trial period be determined where the replacement pump can be operated and actual compatibility confirmed before the second pump is replaced, this will leave space for unforeseeable issues arising from the installation of the replacement pump, which can be rectified before the installation of the second pump.

It is also recommended that the pump not being initially replaced, be replaced with a fully rebuilt spare and the removed pump be completely rebuilt prior to the installation start, this ensures a healthy pump is installed and a spare is available in the event of a failure to minimise downtime due to the risk of only one available installed pump.

The graph in figure 51 has been created using an Excel template (Vertex42, 2003).

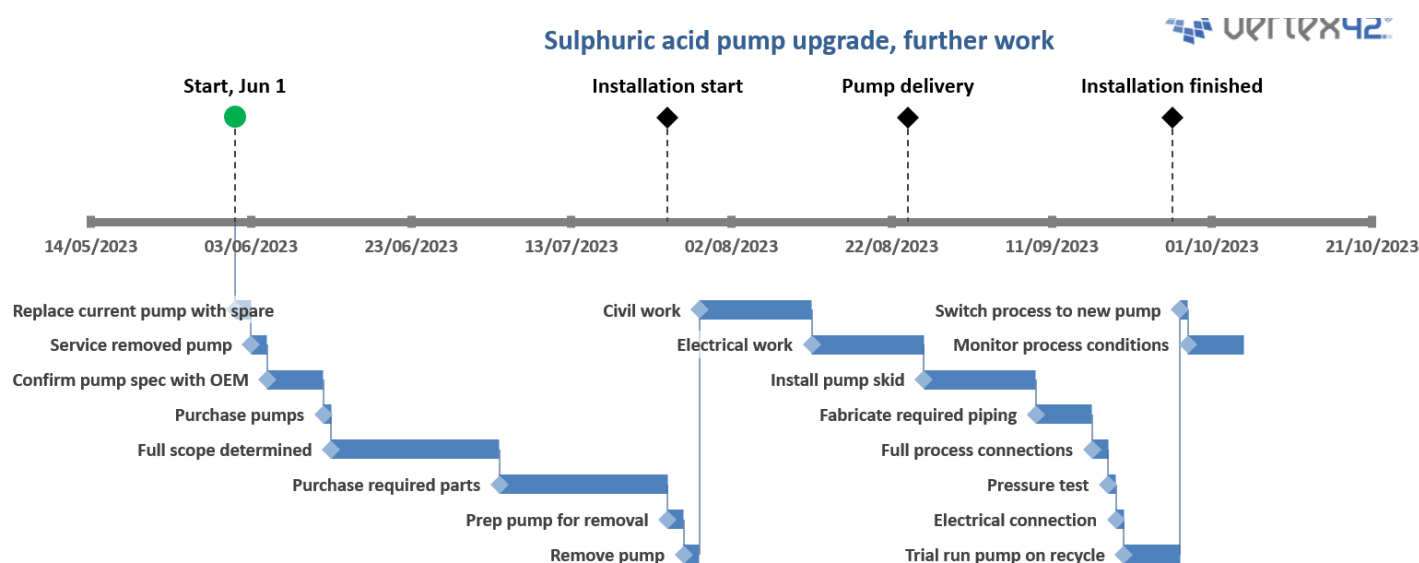


Figure 51 - Further work preliminary plan

Note: The above plan is dependent on the delivery date of the replacement pumps.

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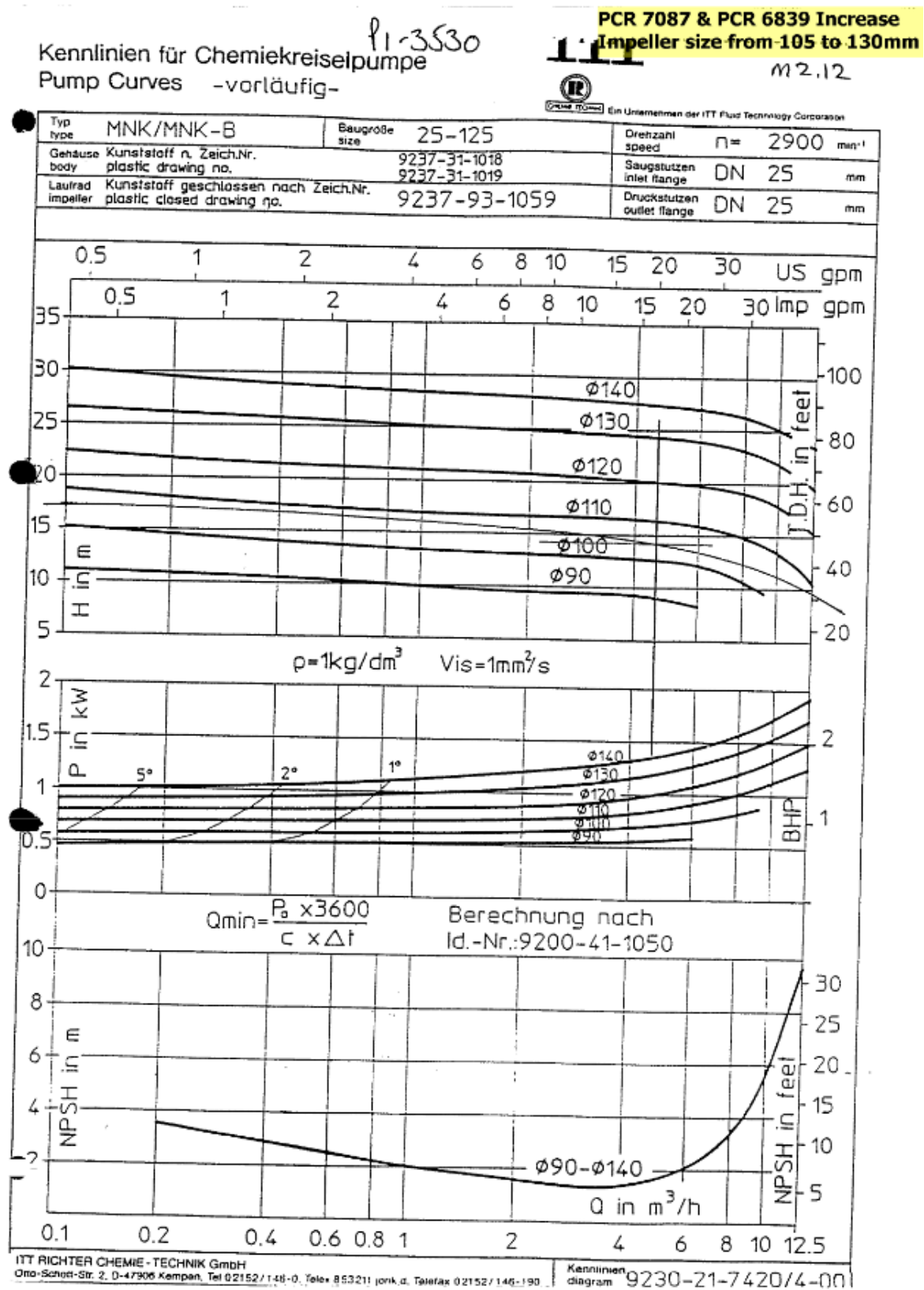
Appendix A – Richter Datasheet

PCR 7087 & 6839 Increase impeller size from 105 to 130mm

M8.3

JOHN BROWN				ISSUE	A	B	C	D	E
DATA SHEET No : 4797/35/43/104				DATE	07/06/93	18-2-94	12/07/94	15/11/94	
SHEET 1 OF 3				PREPARED BY	B LINTER	B LINTER	B LINTER	B LINTER	
MAGNETIC DRIVE CENTRIFUGAL PUMP DATA SHEET				CHECKED BY					
				APPROVED BY					
				PROC.SPEC.ISS	A	B	C	C	
JBE&C PROJECT No. : 4797				ITEM No : PI-3530				No. OFF : ONE	
CLIENT : DOW CORNING LTD				SERVICE : SPENT SULPHURIC ACID				BLDG No. W931	
LOCATION : BARRY, SOUTH WALES, UK				MANUFACTURER : RICHTER/CHEMQUIP.				PTN No. 30368	
PLANT : GENESIS - PROJECT No.				MFRS TYPE AND SIZE : MNK/F-25-125					
CONSTRUCTION					OPERATING CONDITIONS (each unit)				
1	CASING MOUNTING	HORIZONTAL/CENTRELINE/FOOT			46	OPERATION		CONTINUOUS	
2	SPLIT	ANGULAR/RADIAL			47	FLUID PUMPED		SPENT H ₂ SO ₄ (3)	
3	TYPE	Single Volute/Dual Volute/Diffuser			48	CORR/EROSION due to		H ₂ SO ₄	
4	OPENINGS SIZE/TYPE	VENT DRAIN GAUGE			49	PUMPING TEMP (P.T.) °C		0	
5	NOZZLES	SIZE	SPEC	RATING	FACING	POSITION	50	SPEC GRAVITY @ P.T.	
6	SUCTION	25	ANSI	150	RAISED	END	51	VISCOSITY @ P.T. cP	
7	DISCHARGE	25	ANSI	150	RAISED	TOP	52	VAP. PRESS @ P.T. Bar a	
8	CASE DESIGN PRESS/TEMP	15.7 bar g @ 130 °C			53	DSCH. PRESS. Bar g		4.16	
9	IMPELLER TYPE	CLOSED			54	SUCT. PRESS. Bar g		1.96	
10	ROTATION (FACING CPLG)	CLOCKWISE/COUNTERCLOCKWISE			55	MAX.CASING PRESS Bar g		15.7 @ 130 °C	
11	BEARINGS TYPE	RADIAL BALL THRUST BALL			56	DIFF. PRESSURE Bar		2.2	
12	BEARINGS LUBRICATION	OIL BATH + CONSTANT LEVEL DILER			57	DIFF. HEAD REQUIRED m		13.3	
13	BASEPLATE	YES			58	CAPACITY, NORMAL m ³ /h		2.5	
14	FOUNDATION BOLTS	BY OTHERS			59	CAPACITY, DUTY (RATED) cu.m/hr		4.4 (NOTE 4)	
15	LOCATION	OUTDOORS			59	NPSH AVAIL.(liquid) m		5.0	
MATERIALS					PERFORMANCE				
15	CASING	DUCTILE IRON			60	NPSH REQ (H ₂ O) m		2.2	
16	IMPELLER	PFA (DUT. IRON CASE)			61	EFFICIENCY @ DUTY %		21	
17	LINING	PFA			62	KW @ DUTY/MAX (Des.Imp)		2.06 / 2.55	
18	ORIFICE PLATE	15 mm DIA			63	PUMP SPEED rpm		2900	
19	CASE WEAR RINGS	GLASS FILLED PTFE			64	IMPELLER DIA. (design) mm		120	
20	SLEEVE BEARINGS	SiC (SAFEGLIDE)			65	IMPELLER MIN/MAX mm		90 / 140	
21	SHAFT	SS			66	PROPOSAL CURVE No.		9230-21-7420/4-00	
22	SHAFT SLEEVE	PFA			67	No. OF STAGES		1	
23	GASKETS/CASING SEALS	PTFE			68	MIN.CONT.FLOW cu.m/hr		0.2	
24	PRESSURE CASING	DOUBLE WALL			69	MAX.HEAD (design impeller) m		21	
25	COUPLING MEMBRANES	CARBON FIBRE/PTFE			70	CAPACITY @ BEST EFFY cu.m/hr		9	
26	COUPLING GUARD	NON-SPARK INCONEL 718 C.S. / BRASS			71	HYDR.TEST PRESS. bar g		24	
SEALING & FLUSHING / SPECIAL FEATURES					DIMENSIONS & WEIGHTS				
27	SEAL TYPE/SEALLESS	MAGNETIC DRIVE			72	CLEARANCE-WEAR RING		N/A	
28	SEAL MANUFACTURER				73	CLEARANCE-SPACER SLEEVE		N/A	
29	TYPE & MATL. CODE				74	WEIGHT PUMP & BASE kg		150	
30	CIRCULATION/FLUSH PLAN				75	WEIGHT DRIVER kg		36	
31	STUFF BOX PRESSURE bar g				76	BASEPLATE SIZE mm		900 x 380	
32	FLUSHING FLUID				77	MAX. MAINTENANCE LIFT kg		60	
33	PRESSURE bar g				78				
34	FLOWRATE cu.m/hr				79				
UTILITIES REFER TO SPEC. 4797 / 95 / 43 / 001					AUX. PIPING BY MANUFACTURER N/A				
35	COOLING WATER SYSTEM				80	COOLING HARNESS SPEC.			
36	INLET PRESS / MAX DELTA P	/ bar			81	COOLING BEARINGS/SEALS/PEDESTALS/DRIVER			
37	INLET TEMP/MAX DELTA T	/ °C			82	SEAL FLUSHING			
38	COOLING WATER FLOW	cu.m/hr			83	FLUSH HARN. TO W RINGS/THROAT BUSH			
DRIVERS REFER TO SPEC. 4797 / 95 / 59002					TRANSMISSIONS				
39	TYPE	ELECTRIC MOTOR			84	COUPLING - FLEXIBLE/SPACER/AND/OTHER NON-SPARK			
40	MANUFACTURER	BROOK HANSEN/ABB/SEC			85	MANUFACTURER - J.H. PENNER / FLEXIBOX			
41	SUPPLIED BY	PUMP VENDOR			86	TYPE - / METASTREAM TSKS 0011			
42	ELEC.SUPPLY	415V 3 ph 50 Hz			87	GEARING			
43	RATED POWER / SPEED	3 kW 2900 rpm			88	MANUFACTURER			
44	ENCLOSURE	MINIMUM IP 55			89	TYPE			
45	AREA CLASSIFICATION	ZONE 2, GROUP IIA, IIB, IIC			90	RATIO			

Appendix B – Richter performance curves



Appendix C – CP Pumps performance curves, Open impellor



MKPL 25-25-160

19 A 3 / 06

$n = 2900 \text{ 1/min}$

$\rho = 1000 \text{ kg/m}^3$

$\nu = 1 \text{ mm}^2/\text{s}$

28.05.13 Am

CP-No.:

Revision:

Date:

Item No.:

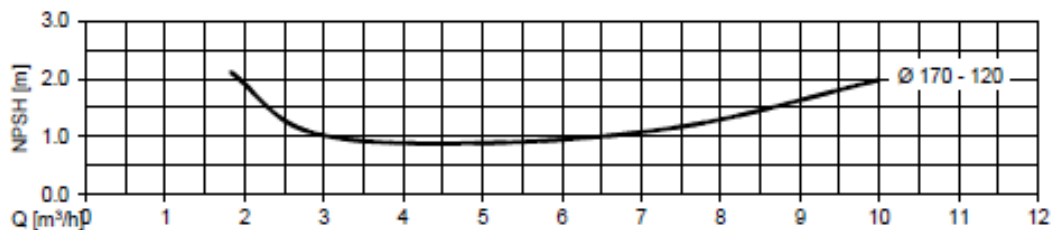
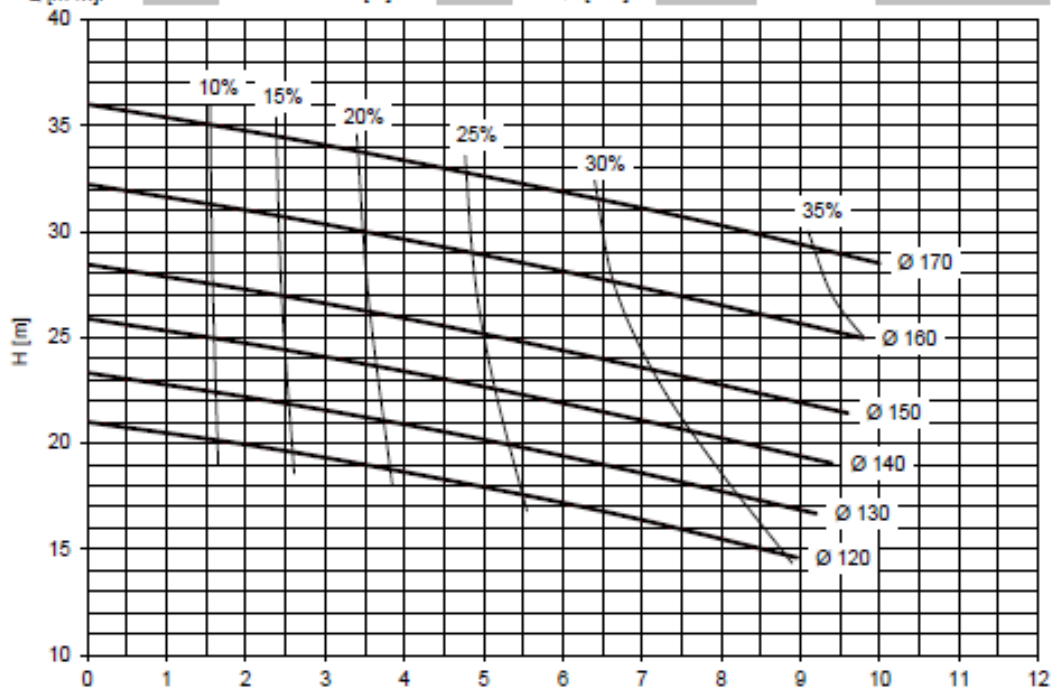
Customer:

Inq./Ord.No.:

Q [m³/h]:

H [m]:

Ø [mm]:



Appendix D – CP Pumps performance curves, closed impellor



MKPL 25-25-160

19A 3C / 03

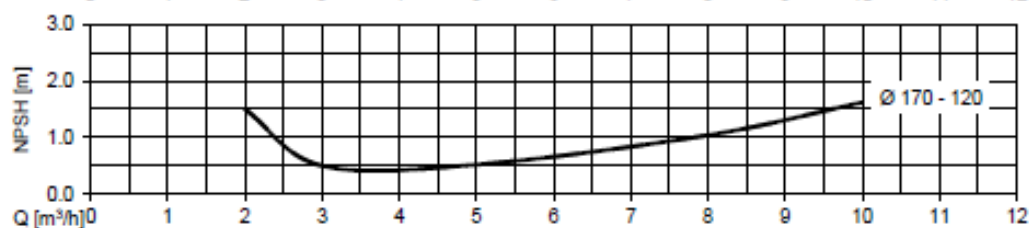
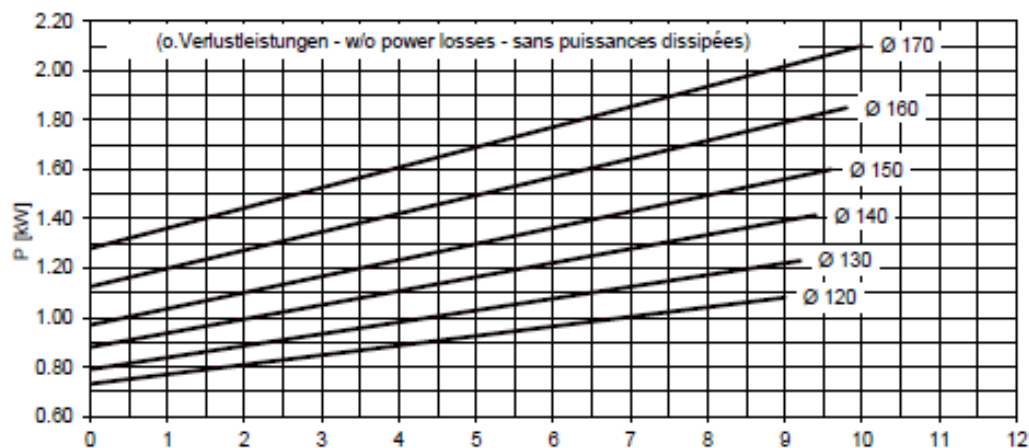
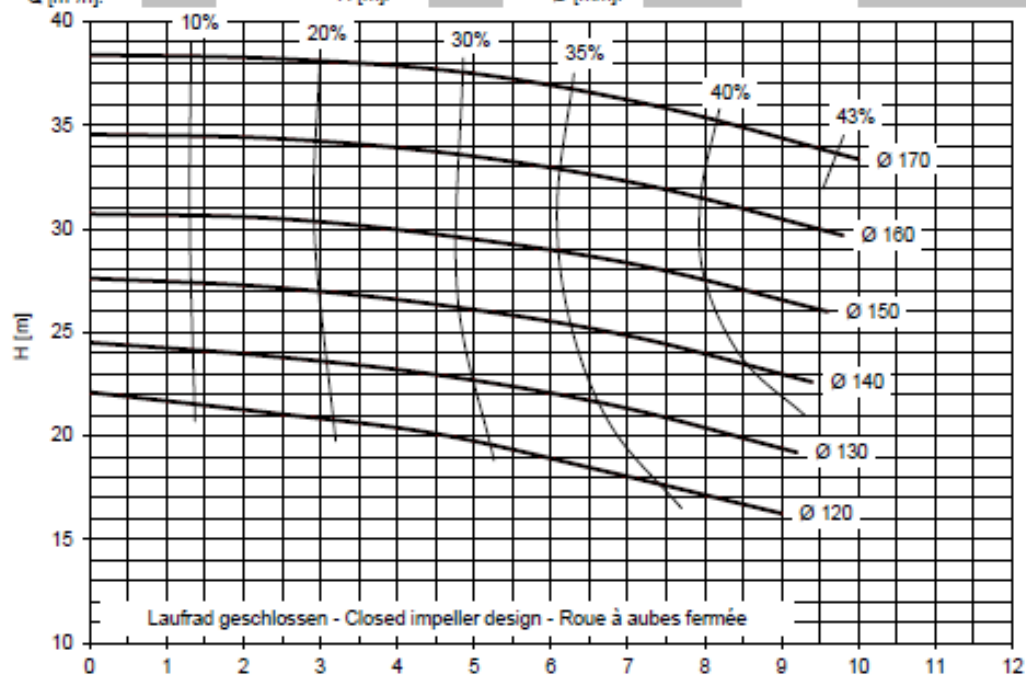
$n = 2900 \text{ 1/min}$

$\rho = 1000 \text{ kg/m}^3$

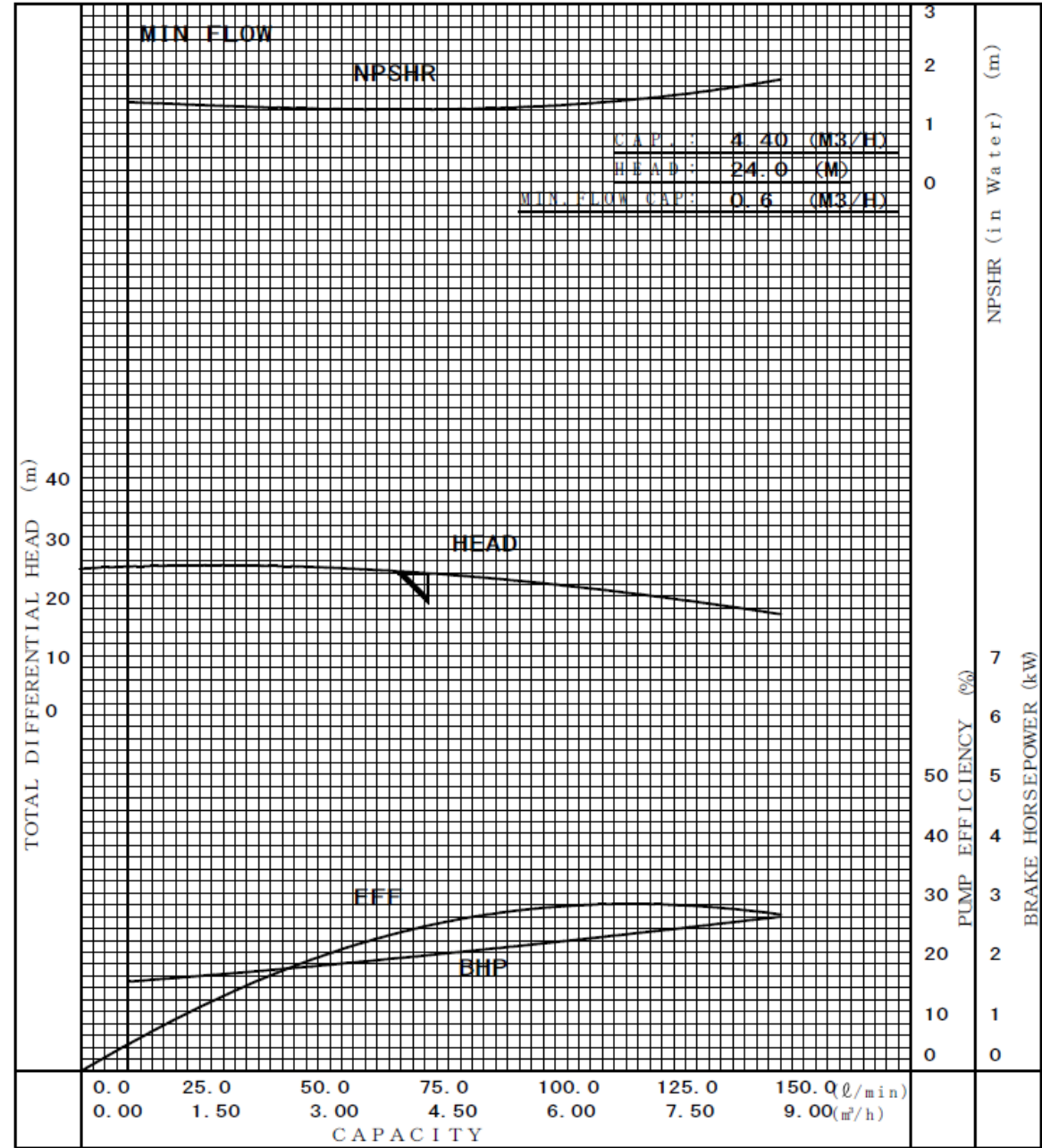
$\nu = 1 \text{ mm}^2/\text{s}$

28.05.13 Am

CP-No.: Revision: Date: Item No.:
 Customer:
 Inq./Ord.No.:
 Q [m³/h]: H [m]: Ø [mm]:



Appendix E – Nikkiso performance curve, 124mm open impellor



Appendix F – Nikkiso performance curve, 186mm closed impellor

