Cost effective materials selection for pumps

This paper discusses the importance of materials selection for satisfactory pump operation using examples from the offshore oil and gas industry. The importance of adequate information and the experience to use this is discussed. The identification of the key requirements for a specific application is essential and requires a close relationship with the customer to ensure adequate information exchange. Some case studies are presented to demonstrate the benefits of application of these principles and the consequences of selecting materials with inadequate information.

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In most industries pumps provide the means for transporting fluids from one place to another. There is an increasing demand for pumps to be more reliable, with less maintenance and at lower cost. A determination of cost effectiveness requires consideration of numerous factors such as material cost, material resistance to the pumped fluid and expected life. Weighting based upon customer preference, fiscal and operational demands must be attached to each of the factors and a materials choice made accordingly. Because of the wide range of pumping conditions and media compositions across industry it has been necessary to narrow the scope of this discussion somewhat. This paper examines the materials options for the pumps most commonly used by the oil and gas Industry as a typical example. Although the comments will be directed to the pumping requirements and fluids of this industry, the general guidelines are applicable across the whole of industry, and show that cost effective materials selection is a complex operation.

Pump types

Five pump duties are being considered:

* **Firewater pumps:** These are usually multi-stage submersible pumps suspended from the deck level, and are driven via a gearbox from a diesel engine on the deck. These pumps handle seawater and are usually idle although they are tested for about 1 hour/week. Reliability is an essential feature of these pumps.

* **Seawater lift pumps:** These provide seawater for various requirements and are similar to firewater pumps in design, although they are usually driven by an electric motor below the pump or sometimes via a line shaft from the deck. However, the duty cycle is very different and seawater pumps are used continuously, although they can be idle for extended periods if they are on standby.

* **Injection pumps:** These are used to pump water into the oil/gas bearing strata to maintain well pressure and hence production rate. The pumps are usually multistage barrel pumps handling either deaerated seawater or produced water. The pumps must be capable of delivering at high pressures, typically 200 – 300 bar, and because they operate at higher speeds compared with firewater and seawater lift pumps, erosion corrosion resistance becomes an important factor.

* **Main oil line pumps:** These are similar to injection pumps in design, and operate at similar high discharge heads. They are used to pump separated oil from the platform ashore, or to a storage facility.

* **Downhole pumps:** These are inserted down the well and are usually relatively small diameter multi-stage pumps that handle formation water or process fluids. These pumps operate in deep wells and have to lift the fluids to the surface and so have high, generated heads.

Information requirements

In order to select materials for a pump there is a level of information that is required to make the most cost-effective choice. The individual parameters are listed below, not necessarily in any order of priority. In addition, these factors cannot be taken strictly in isolation, and several are interdependent. Some of these inter-relationships are described below. The main problem when selecting materials is obtaining sufficient accurate information. A deficiency of information, or "cover all" estimates, makes selection more difficult and leads to a conflict between engineers, who tend to opt for conservatism and will often over specify in this case, and project managers, who want functionality at the most competitive price along with ready availability. Because of problems such as these, experienced staff or external advice is essential to make the most cost-effective materials selection.

* **Pumping conditions:** This covers not only the flow and head but also the operation, e.g., standby, intermittent or continuous. These conditions often dictate the type of pump to be employed and this can then influence the choice of materials from which it can be made.

Natural waters (excluding seawater)	
pH value	Chloride
Conductivity	Temperature
Total alkalinity	Suspended solids
Calcium hardness	Chlorine
Total hardness	Dissolved oxygen
Seawater (plus high chloride brines)	
pH value	Chloride
Total alkalinity	Temperature
Calcium hardness	Suspended solids
Magnesium hardness	Chlorine
Sodium	Dissolved oxygen
Potassium	Sulphides
Sulphate	Sulphate reducing bacteria
Produced water	
Chloride	Hydrogen sulphide
Bicarbonate	Carbon dioxide

Table 1. Water analysis requirements

* **Fluid composition:** The main factor that causes corrosion is water and so knowledge of the composition of the water phase in the fluid is essential. This must cover not only chemical composition but also other factors such as dissolved oxygen and temperature. Typical composition requirements for natural seawater and produced waters are shown in Table 1. Whatever fluid is being handled, its operating temperature is also important. The pump operating conditions can also affect the fluid composition. For example: firewater pumps handling seawater are largely idle and during extended stagnant periods the organic material in seawater can decompose and sulphate reducing bacteria can become active, both of which produce sulphides and sulphur compounds which can cause rapid corrosion of some alloys.

* **Additions/impurities:** In addition to the bulk fluid composition, it is essential to know what additions or impurities are present, as these can have a dramatic effect on corrosion even in small quantities. Severe corrosion of nickel aluminium bronze impellers has occurred in aerated seawater containing as little as 0.03 mg/l sulphide. Impurities in cooling water particularly in coastal installations can also arise by contamination from the discharge of adjacent plant e.g., ammonia from fertiliser plant. Deliberate chemical additions are also frequently made to water and it is important to know, not only their composition and the concentration when mixed, but also where they are being added, as the pump is frequently used to mix-up chemical additions. Chlorine is usually added to seawater at 0.5 to 1.0 mg/l to control fouling. However, the concentrated solution addition could be 100 mg/l or higher and if this reaches the pump before adequate dilution it can cause severe corrosion of some materials.

* **Life and efficiency:** This is the most difficult area in which to obtain information from the customer about the requirements. This covers such items as minimum maintenance intervals and total pump life. If the customer fails to specify these and accepts the lowest bid it is possible that the pump will have only a limited life before maintenance/replacement is required. In an environment such as an offshore platform all maintenance work is costly, particularly where it involves a shutdown. This is also true for many other industries and it is important that the pumps that are purchased have an acceptable minimum life.
If the pump materials do suffer some corrosion, then the pump performance and efficiency will drop with time. If the corrosion rate is high enough, the loss of performance may be too much for the specific application and hence premature repair/replacement is required. This may not lead to catastrophic pump failure, but repair may still come at an inconvenient time if the minimum maintenance interval has not been achieved. This incurs additional cost due to both the unplanned shutdown and the cost of repair.
The final factor is criticality. The greater the consequences of failure, the greater the justification for more reliable, and usually more expensive, materials. This is discussed at more length later on.

MATERIALS

When selecting materials for the various components in a pump there are a number of material properties that need to be considered. Appropriate weight needs to be attached to each of these, depending on the duty, the fluid being pumped etc. The main factors are shown in Table 2.
Castability is very important as both the casing and impellers are usually cast. Some high corrosion resistance alloys, e.g., titanium, are much more difficult, and therefore expensive, to cast than, say, stainless steels.
Strength is also important, particularly for high-pressure applications such as injection pumps. A seawater injection pump handling deaerated seawater could be made of 316 type stainless steel. However, by designing to the superior yield strength of a super duplex stainless steel, such as Zeron 100, a smaller, lighter pump with thinner cross-sections is possible. In view of the limitation on

- Castability
- Strength
- Pressure tightness
- Corrosion resistance
- Weldability
- Machineability
- Availability
- Cost

Table 2: Some factors in materials selection

General corrosion	Generally < 0.1 mm/y, less in areas with critical tolerances
Localised corrosion	Pitting Stress corrosion cracking Crevice corrosion Erosion corrosion Cavitation
De-alloying	Total immunity in pumped fluid essential
Galvanic corrosion	Not just pump components, but also other items in the system, such as pipes, flanges, etc. must be compatible.
Corrosion fatigue	All rotating components must be resistant.

Table 3: Main types of corrosion affecting pumps

Material options	Increasing cost
Titanium	↑
Nickel alloy	
Super duplex stainless steel	
Duplex stainless steel	
316 stainless steel	
Nickel aluminium bronze	
Gunmetals	
Austenitic cast iron	
Martensitic stainless steel	
Cast iron/steel	

Table 4: Commonly used pump materials

space and weight on an offshore platform, the choice of super duplex stainless steel is very cost effective in this case.

Pressure tightness is also important for casings, but it is not readily achievable with all alloys. Phosphor bronze (BS 1400 CTI) is sometimes specified for casings because of its good corrosion resistance. However, it is difficult to obtain pressure tight castings and so its use is usually restricted to impellers and a gunmetal such as BS1400 LG4 is preferred for the casing.

Corrosion resistance in the pumped fluid is very important. It is not always necessary to have total immunity to corrosion provided the pump life or maintenance interval is acceptable. It is much more important that the materials resist localised attack such as pitting, stress corrosion cracking and erosion corrosion as these tend to propagate rapidly and are more likely to lead to premature leakage and/or failure. The principal types of corrosion to be considered are shown in Table 3.

Galvanic corrosion is very important, as it is not always possible to make the whole pump of the same material. The extent of galvanic corrosion depends on the fluid being pumped, and in some fluids two alloys can be used together which would not be possible in other fluids. In addition to the pump components, the interaction of the pump with the other materials in the system such as the pipes and flanges must also be considered. For example, a submersible seawater pump in super duplex stainless steel will cause accelerated corrosion of the adjacent pipework if it is attached to a copper nickel column pipe.

MATERIALS – CORROSION

It is important to consider all the components in the pump and not just the major ones. Two examples where this was not done will show the consequences of neglecting to do this. The first concerns a submersible super duplex stainless steel seawater pump. Oil company contractors connected the motor and pump on the platform. When the column and pump were lifted for maintenance after several years the motor and pump separated. Subsequent examination revealed that 316 stainless bolts had been used instead of super duplex stainless steel. The 316 had suffered severe crevice corrosion and had fractured during the mechanical lifting operating.

A second instance concerns the use of graphite-loaded seals and bearings. These are sometimes selected without it being made clear that they contain graphite. Graphite is very noble and will cause localised corrosion of most metals in contact with it in water. Because of the critical nature of seals and bearings this has led to premature leakage/failure in a number of cases.

In addition to corrosion, four other factors in Table 2 must be considered. Weldability and machineability are self-explanatory. Availability is not always appreciated. For example, there are few foundries that can manufacture large complex castings in alloy 20 (UNS N08020), because of its propensity for hot tearing in heavy sections, and it can be more cost effective to use an alternative alloy. Finally, cost must be also be considered. However, just because the base material cost for an alternative material is substantially higher, it does not necessarily mean that the increased cost of the final pump set will be proportionately greater. As an example, consider a complex injection pump set.

An upgrade from 316 stainless steel to super duplex stainless steel increases the total cost of the wetted components by ~15%. However, the cost of the rest of the components on the skid is fixed and the upgrade represents an increase of ~2% of the total price. This is an extreme example, and an upgrade to a better material often involves a much lower increase in the cost of the wetted components. Hence, the increase in the total cost of the pump set can be 1% or

Property	Option			
	Ti	Super duplex	NAB	316SS
Castability	1	3	3	4
Strength	3	4	3	1
Pressure tightness	3	3	3	3
Corrosion resistance	4	4	2	1
Weldability	2	3	2	4
Machineability	1	3	3	4
Availability	1	3	4	4
Cost	1	2	3	4
Total	16	25	23	25

Table 5: Relative merits of four material options for an offshore seawater pump

less. This is set against the cost benefits of much reduced through-life costs. Thus an upgrade to a more expensive material can be cost effective because the initial cost increase is small and is more than offset by operational cost savings. Table 4 shows the different groups of alloys often used for pumps in order of decreasing cost. This is also roughly the order of corrosion resistance in seawater, although the corrosion ranking order can change dramatically in other fluids.

As an example of the relative merits of different materials consider a seawater pump in the following material options:

- Titanium casing and impeller
- Super duplex stainless steel case and impeller
- Nickel aluminium bronze impeller casing
- 316 stainless steel impeller and casing

Table 5 shows an assessment of the four alloys against the eight criteria in Table 2, using a grading from 1 (poor) to 4 (excellent). The ranking is a little subjective but it shows that three of the options have similar overall rankings. However, in many applications some of these factors are more important than others. Thus, when a weighting factor is attached to the factors, the overall ranking can change markedly. This can also vary from project to project depending on the requirements.

SELECTION

The previous sections have covered some of the parameters that need to be considered when selecting pump materials. The following section covers the methodology used in materials selection. Because of the number of variables and the interdependence of many of them this is not a rigorous analysis, but covers the essential elements.

The first, and probably most important item, is to establish a good link with the customer to obtain the details necessary to optimise materials selection. As explained above, decisions made with inadequate data are not necessarily cost effective. As information is not always easy to obtain it is necessary to rely on experience to assess probabilities where data is lacking.

The next item is to establish the key requirements for the specific applications, as these are the ones that will attract the greatest weighting in materials selection. These requirements could be, for example, resistance to high velocities, resistance to sand erosion, high efficiency and a minimum 2 years maintenance interval. Prior experience in a particular application can result in more weight being given to some requirements than the customer realises is necessary.

Another factor that requires assessment is criticality. Determination of criticality is not easy for the supplier and requires input from the customer. Pumps fall into three main categories. The higher the risk, the greater the justification for moving to higher alloy, more resistant materials:

- High risk: this is where failure will result in a loss of safety, or failure of the pump will result in lost production at high cost. (e.g. firewater pumps).
- Medium risk: this is where failure is not so critical, but repair is difficult/expensive, e.g., offshore platforms. Some reduction in production efficiency may also result.
- Low risk: this is where failure involves no safety issues and shut down for repair causes no major inconvenience. These are usually auxiliary pumps rather than the major items covered previously in pump types.

In order to explain the selection of materials philosophy in more detail it will be helpful to cover the materials commonly used for the five types of pumps described previously in pump types, and the reasons for these selections.

* **Firewater pumps:** A low cost option would be a 316 impeller in an austenitic cast iron body. While these pumps can work well in operation, there have been failures of the cases by stress corrosion cracking, particularly in warmer waters (Figure 1). Another option is a nickel aluminium bronze (NAB) impeller in an NAB or gunmetal body. While NAB has good resistance to corrosion in clean seawater it is very prone to attack due to sulphides produced under stagnant conditions. This has meant that for this high reliability/high safety application, super duplex stainless steel is commonly used and it has given high reliability in service, as shown in Figure 2.

* **Seawater lift pumps:** The same comments that were made for materials options for firewater pumps, generally apply for seawater lift pumps. Additionally corrosion problems have been seen with NAB due to excessive chlorine levels at the pump inlet. As for firewater pumps, super duplex stainless steel has proved to give the high reliability required.

* **Injection pumps:** In the early days in the North Sea these pumps were usually pumping deaerated seawater and 316 stainless steel was commonly used with alloy 625 weld overlay in critical crevice areas, e.g. "O" seals. With the need for high discharge pressure the use of duplex or super duplex stainless steel offered reductions in wall thickness due to its higher strength. In addi-


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Fig. 1: Stress corrosion cracking of an austenitic cast iron column pipe

Fig. 2: Firewater pump in Zeron 100 for the South Arne project

tion, it is common to re-inject produced water later in a field's life, and this often contains chloride concentrations greater than that of seawater plus substantial H_2S concentrations. Super duplex stainless steel has excellent resistance to both chlorides and H_2S and injection pumps handling both produced water and seawater have given excellent service. A typical unit is shown in Figure 3.

* **Main oil line pumps:** In addition to the oil, the fluid usually contains some water that has not been separated and this can contain high levels of chloride. The pumps are usually made with carbon steel casing and shaft and with 13/4 martensitic stainless steel impellers and diffusers because of their erosion resistance. The carbon steel is often weld overlaid with 309 or 316 stainless in critical areas to minimise the effects of corrosion. These alloys work because the corrosion is not great at low water contents. Where higher water contents are expected it may be necessary to upgrade the materials. 316 stainless steel is not usually used because the oil is pumped hot (e.g., 60°-70°C) and chloride stress corrosion cracking (SCC) may occur and the alloy also has lower strength than martensitic alloys. In this case a duplex stainless steel gives increased resistance to corrosion and pitting as well as chloride SCC.

* **Downhole pumps:** These pumps are installed downhole and must resist aggressive fluids both inside and outside. Frequently sand, drilling mud or other abrasive media are mixed with the process fluid. Because of the need to resist both wear and corrosion in hot brines which often contain high chloride concentrations it is essential to use materials resistant to both corrosion and erosion. Typically the pipes and casing would be super duplex stainless steel with cobalt-chrome alloy (Stellite-type) impellers. Bearings and seals would be weld overlaid or solid cobalt-chrome as a minimum. In very erosive media it is common to use tungsten carbide or other ceramics.

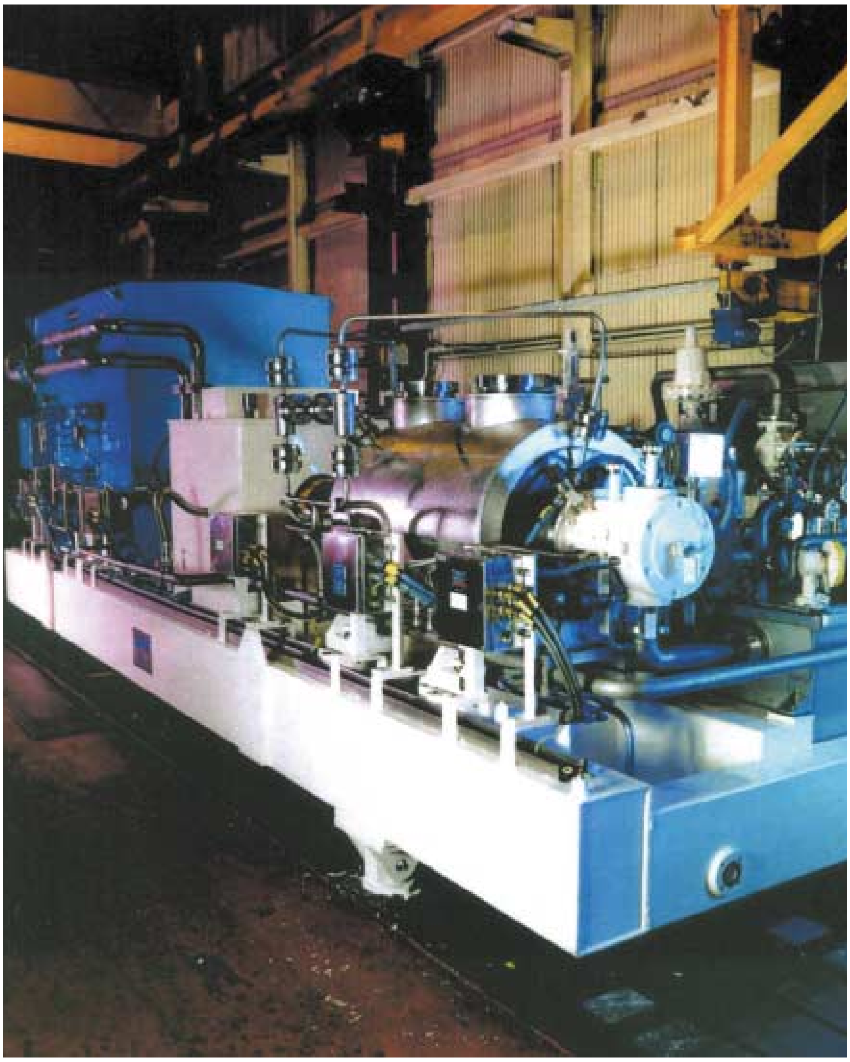

Fig. 3: Injection pump in Zeron 100 for the North Sea

Service experience

In this section there is only space to cover a few examples which demonstrate the necessity for identifying the key requirements to aid materials selection.

* **Case 1:** A pump was required to handle a quarry water which was acidic with a high chloride content. It would normally require a 316 type stainless steel as a minimum and possibly a duplex stainless steel option for greater reliability. However, it was specified that the pump had to last only 3 months and for this life a cast iron pump was the most cost-effective solution.

* **Case 2:** An injection pump handling produced water was made from duplex stainless steel with cobalt-chrome (Stellite type) weld overlay on the wear rings. In service the pump suffered severe erosion on the wear rings and balance drum due to the presence of sand, which was not mentioned in the original specification. The problem was solved by utilising Zeron 100 super duplex stainless steel and sintered tungsten carbide wear rings. This has increased pump life from seven months to ~4 years i.e., a 600% increase. Correct specification of the fluid composition would have prevented the costly failures and downtime.

* **Case 3:** The use of super duplex stainless steel in injection pumps was described in the previous section. The increased strength enabled the use of smaller lighter pumps, producing weight savings on platform topsides.

This is important as it has been calculated that every tonne of weight saved topside results in savings of ~GBP 100,000 of structural steel below the waterline. The high erosion corrosion resistance of super duplex stainless steel also guarantees high reliability at the high rotation speeds used in injection pumps. This is an example of the use of materials properties to provide a more cost-effective pump.

* **Case 4:** A submersible pump handling seawater had nickel aluminium bronze (NAB) impellers and casing with an alloy K-500 shaft. The pump suffered corrosion due to the presence of sulphides (Figure 4) and was replaced with super duplex stainless steel impellers and casing. However, the shaft was left in K-500, as the pump was driven by a shaft from the surface and replacement involved substantial extra cost. After a short while in service severe corrosion of the shaft occurred beneath the impeller hubs and the bushes, followed by fatigue of the shaft (see Figure 5). The shaft material (K-500) had suffered severe sulphide pitting. This did not occur previously because of the coupling to NAB, which provided galvanic protection. The solution was to fit a super duplex stainless steel shaft. Even in clean seawater corrosion has been observed on K-500 shafts in super duplex pumps and the material is no longer considered galvanically compatible with high alloy stainless steels. This demonstrates the necessity for considering the whole unit during repairs as well as in the initial design stage.

* **Case 5:** Firewater piping on offshore platforms is often installed in high alloy austenitic or super duplex stainless steel. The reason for this is that the super stainless steels can tolerate higher flow velocities than carbon steel or copper nickel, which means pipe diameters can be reduced by up to a half. This reduces the weight of water being carried on the platform and hence saves money on structural steel below the water line as described above. The pumps are usually made from super duplex stainless steel, which combines galvanic compatibility with the piping, with resistance to erosion corrosion at higher velocities enabling a reduction in the diameter of the rising main. This reduction in size means that super duplex firewater and seawater lift pumps can be cheaper than copper alloy pumps delivering to larger diameter piping. There are similar savings with the valves because of the reduced size. This shows how upgrading to a more expensive material and designing to its superior properties can result in overall cost savings.

CONCLUSIONS

The above discussion has tried to demonstrate the large number of variables which can influence materials selection for pumps and the importance of identifying the key criteria which will influence selection for a specific application. One of the most important things is to establish a good relation with the customer to obtain all the information required to optimise material selection and also to be able to offer alternatives where insufficient data is available. The experience of the pump manufacturer can then be used by the customer to find the most cost-effective solution. It is not sufficient to rely on project specifications as these rarely include all the relevant information. Pumps are expensive items and most users are happy to enter discussions to get reliable equipment at minimum cost. ●

About the authors

Dr. R. Francis has been a corrosion engineer for over 25 years. He is currently the Corrosion Services Manager for Weir Materials and Foundries, Manchester, which he joined in 1991. His duties include organisation and supervision of external R&D, in-house corrosion testing, advice on materials selection to the Weir Group worldwide and the examination of service failures. He has been employed as a consultant by several large companies, investigating major failures. He is currently a Director of NACE International and sits on more committees than he cares to remember.

Mr Leonard Phillips graduated in Metallurgy from the University of Strathclyde in 1973. He has since worked in the pump industry where he has been extensively involved in Material Selection with particular emphasis on corrosive and erosive applications and the use of high technology coatings.

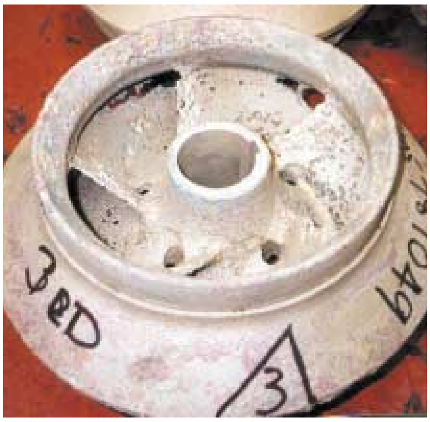

Fig. 4: Severely corroded nickel aluminium bronze impeller

Fig. 5: Corroded and fatigued alloy K-500 shaft