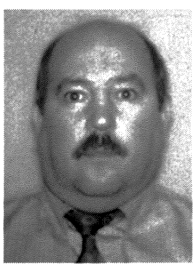
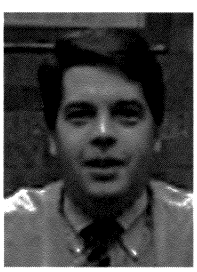
PUMP RELIABILITY AND EFFICIENCY INCREASE MAINTENANCE PROGRAM—UTILIZING HIGH PERFORMANCE THERMOPLASTICS

by
Tommy Hinkel
Machinery Reliability Coordinator
Chevron Products Company
Pascagoula, Mississippi
and
Matt Giffrow
Product Specialist and Sales Manager
Wear Products Group
EGC Corporation
Houston, Texas



Thomas E. (Tommy) Hinkel is the Machinery Reliability Specialist for Chevron Products Company, in Pascagoula, Mississippi. He has more than 26 years of refining experience in operations and reliability. Mr. Hinkel is responsible for coordinating Chevron's Machinery Reliability Program.



Matt Giffrow is Product Specialist and Sales Manager for the Wear Products Group, EGC Corporation, in Houston, Texas. He is responsible for overseeing the sales and service of thermoplastic materials, which are used to increase machinery reliability. He has spent 20 years in the technical service sector, applying and providing technical service for engineered materials, mechanical seals, flexible couplings, and the rotating and reciprocating equipment in which those products are utilized.

Mr. Giffrow attended the University of Houston and is a prior author and presenter at the International Pump Users Symposium. He has written and presented technical papers on subjects ranging from mechanical seal design to machinery reliability.

ABSTRACT

At a major oil products refinery, an aggressive effort has been ongoing to improve centrifugal pump reliability and efficiency. Working closely with a manufacturer of high-grade thermoplastics, the company has developed and implemented a program providing justification, procedures, and material information needed to modify existing centrifugal pumps and improve their reliability and efficiency. These improvements have meant lower maintenance costs, increased mean time between failures, and reduced equipment downtime. Any of these occurrences can, and too often do, result in financial incidences. The centrifugal pump improvements have also resulted in reduced energy costs and increased production.

This paper will highlight the use of thermoplastic materials as replacement wear components in place of commonly used metals. The paper will illustrate the benefits of upgrading equipment at the time of repair. It will show the general guidelines in selecting candidate pumps and how those pumps can be fitted. These materials should be used on machines that have been identified as critical equipment by virtue of the fact that there is no operating spare, or that a shutdown could cause a loss in production. The program has identified these candidates at each refinery.

The paper will illustrate a number of cases where, by upgrading to thermoplastic components, pump efficiency, reliability, and production have increased, and energy consumption has been reduced.

INTRODUCTION

In today's world of low crude oil to products price margins, to be profitable at the refinery level, all efforts must be made to reduce operating cost and increase equipment reliability. At Chevron, an aggressive effort has been ongoing since the early 1990s to improve centrifugal pump efficiency and reliability. This has been a threefold program consisting of:

- A mechanical seal standardization program
- An API 610, Seventh Edition, retrofit program
- A centrifugal pump reliability and efficiency program

This third item includes the use of high-grade thermoplastics as the wear components in centrifugal pumps. Working closely with EGC, Chevron (hereinafter referred to as "the company") has developed and implemented a program providing reasons, procedures, and material information required to modify centrifugal pumps, improve their reliability, and increase efficiency. These improvements have meant reduced maintenance costs, increased mean time between failure, and reduced equipment downtime. These improvements have also resulted in reduced energy cost and increased production.

PUMP RETROFIT PROGRAM

The principal modification consists of using polyetheretherketone (PEEK) based blends of thermoplastics rather than traditional metals for pump wear rings, sleeves, and bushings. The use of these materials has improved pump efficiency and reliability through the utilization of reduced running clearances and by taking advantage of a significantly reduced coefficient of friction. The unique properties of the material can reduce vibration and dramatically decrease repair costs when a failure does occur.

MATERIAL CHARACTERISTICS

The company has successfully implemented the use of two basic thermoplastic blends. Both blends contain PEEK as the bonding agent. Added inert materials (carbon fiber) provide extra strength, which allows the material to be used as high duty mechanical components. One material is a melt compression or injection molded material. The other is a blended continuous wind of carbon fiber and PEEK. It was developed for, and currently is heavily used in, the aerospace industry due to its lightweight and extremely high strength and temperature capabilities. In many cases, the nonmetallic rings can exceed the strength of the metal components being replaced. The materials have already been proven to be a premier offering for reciprocating and centrifugal compressor components such as valves, rider bands, rod packing, piston rings, and labyrinth seals. PEEK is a nongalling material. This reduces the potential of the equipment to seize during upset conditions. Between the two materials, equipment with operating temperatures of up to 600°F can be retrofitted. The extremely wide range of chemical compatibility helps complete the ability to retrofit a majority of the pump applications in service today.

PEEK differs from other nonmetallic materials in a number of ways:

- The material has a lower coefficient of friction than other nonmetals currently used for high duty pump components. This translates into less energy required to turn a shaft.
- The material is not brittle; therefore it is not sensitive to mishaps such as dropping on the shop floor.
- The material is strong under expansion as well as contraction. It can therefore be utilized as either stationary or rotating components.
- It does not emit dust while machining. No venting is required.
- The material is resistant to swelling in the presence of water. Reduced running clearance at temperature in all applications is therefore possible without the fear of component hangup.

PROGRAM OUTLINE

This program is intended to be used by the company's reliability analysts, shop and field mechanics, machinists, and plant engineers. The program consists of detailed technical information for all aspects of the modifications for existing and new equipment. Some sections, such as the section on benefits of implementing the program, will also be of interest to nonmaintenance personnel such as operations and management.

This paper will address five specific areas of the program. It will describe guidelines for using the material and illustrate how the program has benefitted from upgrading pumps with thermoplastic. The areas are as follows:

- Applications
- Benefits of implementing the program
- Wear ring design and installation
- Machining
- Standard worksheet and case histories

APPLICATIONS

The company has utilized these PEEK based nonmetallic materials for a number of years. The materials are commonly used in many applications such as:

- Wear rings (both case rings and impeller rings).
- Interstage bushings in multistage pumps.
- Line shaft bearings and bowl rings in vertical turbine and sump pumps.
- Throat bushings and throttle bushings.
- Mixer and reactor steady bearings.

Thus far, there has been little success utilizing these thermoplastics for the product-lubricated bearings in sealless pumps. This is primarily due to the fact that PEEK is an insulating material and does not conduct heat well.

When to Upgrade Materials

The company has found that approximately 60 percent of their pumps are candidates for material upgrades. Many are pieces of equipment that could create a lost profit opportunity (LPO) if taken out of service for any length of time. Of these pumps, approximately 75 percent fit within the capabilities of both the wound composite and molded materials.

When a pump is removed from service, it is determined whether or not it is a candidate pump. This determination includes the critical nature of the service, whether the equipment is spared, and if the operating conditions fall within the material guidelines.

Wear Ring Considerations

The program recommends first consideration for the use of PEEK materials to be on the impeller rings. The primary reason is that, in many cases, the pump case can actually be left in the field and only the impeller will need modification.

When retrofitting impeller rings, the linear wound composite is typically the recommended material. This is due to a number of considerations:

- The expansion rate is less than that of metal, therefore it will not have a tendency to grow off the impeller or grow into the corresponding case ring. The blended and molded grade of material has a coefficient of expansion greater than that of metal. The press fit onto the impeller and the clearance between the corresponding case ring would therefore differ from that of the wound composite material.
- The wound composite is less susceptible to being pushed off the impeller by differential pressure, since the impeller is always trying to grow at a greater rate. This would have the effect of increasing the shrink fit on the impeller eye. For example, a 6.00 inch OD composite ring will expand about 0.0005 inch from ambient to 600°F.
- When using the wound composite as the impeller ring, its cross section must be less than that of the cross section of the impeller eye, if the temperature differential is greater than 100°F. This is done because the tensile strength of the composite is three times that of metal. Excessive stress can cause the impeller eye to crack, especially if the impeller is an iron-based material.
- To account for the low expansion of the wound composite ring, a light cold interference fit is used. The general guideline for interference fits is 0.001 in/in diameter. Experience may show that a looser cold fit is satisfactory. However, 0.0005 in/in of diameter should be considered the minimum. The fit will vary, depending on the temperature of the pumped liquid and of the metallurgy of the corresponding component.

When utilizing the molded material as the impeller ring, careful consideration of expansion rates must be considered. This material expands at a greater rate than metal. To account for the greater expansion of the blended material, a heavy cold interference fit is used. The typical cold press fits vary from 0.002in/in to 0.004 in/in of diameter. The temperature limit of this material for impeller ring use also varies from 200°F to 250°F, depending on the metallurgy of the impeller ring.

The considerations for both the composite and molded materials for impeller rings are the same as other shrink-on applications.

When retrofitting shrink-in applications such as case rings, you can see that the opposite considerations apply. The composite material must have a greater cold fit than the molded material because of their respective expansion characteristics. A guideline to consider is that if there is sufficient cross section of the existing case ring, that ring can be bored out and have the PEEK ring pressed in. This reduces the initial cost of material, plus reduces replacement costs if the equipment experiences a failure. At that time, all that would be required is to replace the PEEK insert rather than manufacture a complete new case ring.

Compatibility with Pumped Liquids

In general, these materials have excellent resistance. They are currently in use in numerous hydrocarbons, from crude oil to propane. They are in use in condensate, boiler feedwater, sour water, and a wide variety of other dirty water applications. Other services include ammonia, caustic, DEA, and carbonate. These materials should not be used in sulfuric, nitric, or HF acid services. They should also not be used in concentrated chlorine services.

Temperature Limits

The limit of the molded material is 350°F, except as previously noted on shrunk-on applications. The wound composite material can be utilized in applications up to 600°F whether shrunk-on or shrunk-in.

Corresponding Metal Components

The two materials should not be run against each other in the same pump. Every effort should be given to run these materials against the hardest corresponding component possible. The company has chosen 416 SS as the material of choice, due to its low wear and heat generation characteristics in dry run applications. Other materials will work, however. Cast iron and other porous materials are not recommended as they serve as a lapping tool in touch-off situations.

BENEFITS OF IMPLEMENTING THE PROGRAM

The basis for savings and increased profits from the pump modifications in this program can be divided into three categories:

- Improved hydraulic performance
- Greater reliability
- Increased efficiency

These benefits will be highlighted along with detailed operating scenarios. This will show the advantage of implementing thermoplastics into any pump improvement program.

Improved Hydraulic Performance

Improvements in efficiency have demonstrated significant amounts of savings in energy costs. This can be accomplished in various ways in addition to reduced horsepower consumption. Improved hydraulic performance can be provided in other ways as well. Reduced internal recirculation effectively creates a head-capacity curve that is higher than the original curve. The company has documented cases in which the greater throughput from modified pumps translated directly to very profitable production increases.

Greater Reliability

Greater reliability translates into smoother running equipment, reduced shaft deflection, increased MTBR, lower maintenance costs, and less equipment downtime. This also adds to the life of the bearings and of the mechanical seal.

Operational mishaps, such as loss of suction, frequently result in heavy rubbing between rotating and stationary components due to the loss of product lubrication and hydraulic stability. With the conventional metal to metal interface, extremely high temperatures are generated very quickly.

This usually results in the seizing of the rotating and stationary components, which leads to long and more expensive overhauls. In many cases, the direction taken was to open up the clearances to avoid the rubbing potential. This of course leads to reduced efficiency and a less hydraulically stable machine.

This can be particularly true in high-pressure multistage pumps. Wear rings can gall and break, resulting in major damage to the impellers, shaft, and even pump casings. Casings can suffer distortions and loss of metal that require very expensive and time consuming weld buildup, milling, and line boring.

When thermoplastics have been used in applications that have experienced operational upsets, the equipment has been repaired in a fraction of time and at a fraction of the cost. This is due to the thermoplastic components becoming the sacrificial parts. Twisted shafts and distorted cases are being rendered nearly obsolete. In many cases, the cost of a pump repaired after originally installing thermoplastics is as little as 1/10th of the cost of a pump that has to be repaired after experiencing a failure with all metal components. The time saved can be weeks on a given pump. The company originally was most interested because of this particular benefit. Faster and less expensive repairs directly result in increased profitability.

Naturally every effort should be made to address the root cause of the failure. The root cause may be operational, repair, installation, or application in nature. In cases where failures occur despite the best of circumstances, utilization of thermoplastic components can translate into substantial savings.

Increased Efficiency

Efficiency improvements are realized in three distinct areas:

- Wear ring clearances are reduced to 50 percent of the former "as new" clearances.
- Plugging impeller balance holes decreases the total internal recirculation to 50 percent of what it would be with two impeller wear rings.
- In services where process conditions have permanently changed, different impellers with thermoplastic rings can be installed to enable normal operation at or closer to the best efficiency point.

The actual increase in efficiency resulting from tighter wear ring clearances will vary with each situation. In general, the most significant gains are achieved with:

- Pumps with low specific speed. Pumps with specific speed under 800Ns can suffer efficiency losses of up to 15 percent from wear ring leakage.
- Pumps with large original wear ring clearances. (An API recommended clearance of 0.037 inch causes a reduction in pumping capacity 10 percent greater than the loss using the recommended thermoplastic clearance of 0.019 inch.)

Although there are several variables that affect the actual efficiency gain in any particular pump, a quick approximation of the overall magnitude of potential can be calculated using local energy costs.

Improvements in efficiency using only wear part modifications to thermoplastics generally are less than 10 percent. The company's test results showed a typical gain of about five percent above the curve. When calculating efficiency gains in this manner, the original operating clearance is assumed to be "as new" or factory clearance. In actual practice however, many pumps run for years with clearances greater than factory recommendations. One reason is that when pumps are sent for repairs, the volute is frequently left in the field. Unless a field measurement of the case ring is made, the shop personnel cannot accurately determine the actual running clearance of the suction side wear ring. Additionally, until more emphasis is placed on efficiency, shop personnel and engineers are not motivated to reduce running clearances to factory standards or even less.

The performance curve (Figure 1) and Table 1 show the results of testing on an LPG pump in a light ends rectifier unit. The modification was the installation of PEEK wear rings only. The electrical data were collected by a leading technological service company.

Conversion to thermoplastic components provides the opportunity to correct the condition of excessive wear ring clearances while reducing the concerns of running closer clearances. Great care should be taken to ensure the remainder of the pump internals are within tolerance to allow the reduced

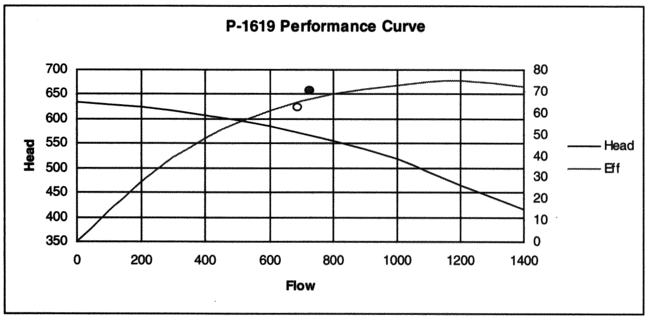


Figure 1. Light Ends Rectifier Unit Utilizing PEEK Wear Rings.

Table 1. Light Ends Rectifier Unit Electrical Data Comparison Chart.

100 HP "Nameplate" PEEK Only

Input Data	Before Modification	After Modification	Percent Change
TRP (Watts)	83,346	84,621	+1.5
TXP (VAR)	40,350	40,734	+1.0
TPF (VA)	92,593	93,919	+1.4
TPF	.900	.901	+0.1
PF	.202	.202	NA
P (Ft)	627	659	+5.1
GPM	674	718	+6.5
S.G.	.56	.54	-3.6
Calc Data			
Motor eff	90	90.1	+0.1
Motor shaft load	75,024	76,220	+1.6
Pump load (Watts)	44,491	48,035	+8.0
Pump eff	59.3	63.0	+6.2
Sys eff (%)	53.4	56.8	+6.4
Load on motor (hp)	111.7	113.4	+2.1
% load	111.7	113.4	+2.1
Calc Cost Data			
Operating costs Cost/kW pump Load/year	$574	$540	-6.0
Potential annualized Savings/year	NA	$1587	NA

clearances. Reduction in wear ring clearance will gain you nothing if the pump cannot be reassembled or will not turn.

The company believes the gain in efficiency is secondary to the increase in reliability. Improved hydraulic performance, energy savings, and increased reliability are why the company continues to actively search for candidate pumps.

WEAR RING DESIGN AND INSTALLATION

The company has created a wear ring selection, sizing, and installation program. The program accounts for variables in each piece of equipment. There are two different procedures: one for case rings and one for impeller rings.

There are four pieces of information that must be known before any selection can take place:

- Case or case ring material (for expansion characteristics)
- Impeller wear ring material, or impeller material if there is no ring on the impeller (again for expansion characteristics)
- Liquid pumped (for chemical compatibility)
- Maximum operating temperature (for material type selection)

It is also important to know which component is to be replaced with the thermoplastic material. All the other parameters such as clearances, expansion rates of materials, ring thickness, interference rates, etc., have been put into the company's material upgrade program. The rules of thumb are:

- Rotating component replacement, typically use wound composite material
- Stationary component, typically use molded material
- Any abrasives, typically use wound material
- Greater than 300°F to 600°F, wound material

Now is the time to determine which component needs replacement most. If the case rings are worn beyond repair, they might be the candidates. However if the impeller rings are in need of repair, they can be replaced and sized to the case rings, which could be cleaned up and made true again.

It is also reasonable to replace a mixture of rotating and stationary components in the same piece of equipment. Just ensure that the components are not operating against each other, as mentioned in the previous section.

Again, if attempting to use the molded material as impeller rings, the maximum temperature has been reduced. These new maximums range from gray cast iron and 12 CR stainless at 200°F, to Ni-resist and bronze at 245°F. Hastelloy, carbon steel, Monel, Alloy 20, and 18-8 stainless range from 205°F to 235°F.

MACHINING

These materials are not difficult to machine, but are different from metals. With proper tools, these materials can be machined at your facility. A typical metal tool is not hard enough for rough machining. Standard carbide tools can be used for roughing the molded material, but will become dull very quickly on the wound material.

For roughing on the wound composite material, and finishing on both the molded and wound material, polycrystalline diamond tooling is required. For a better finish, as for OD surfaces such as impeller rings, wet grinding is recommended.

Both materials require higher speeds and more shallow cuts than metal. In the case of the molded material, it is because of the expansion characteristics. In the case of the wound material, it is because the material is so hard. Special care must be taken not to over cut or use a dull tool on the hard material, because it could tear rather than cut. Double tooling is also utilized in many cases to maintain uniform wall thickness. This is when both the OD and ID are cut on one pass using the same fixture.

It is recommended that extra material is left on the OD of impeller rings or on the ID of case rings, so final dimensions can be established after installation of PEEK material into place. Correct final dimensions can be assured in this way.

TYPICAL WORKSHEET AND CASE HISTORIES

Worksheet for an impeller ring of wound composite material:

A. Case material	Step A.	Carbon steel
B. Impeller material	Step B.	12 Chrome
C. Operating temperature	Step C.	550°F
D. Case material CTE	Step D.	7.1 (10-6)/f
E. Impeller material CTE	Step E.	6.4 (10-6)/f
1. Case wear ring ID @ room temp.	Step 1.	7.000 inch
2. Case wear ring ID @ op. temp.	Step 2.	7.024 inch
3. Diametral running clearance @ op. temp.	Step 3.	0.010 inch
4. PEEK ring OD @ op. temp.	Step 4.	7.014 inch
5. Impeller ring fit @ room temp.	Step 5.	6.250 inch
6. Impeller ring fit @ op. temp.	Step 6.	6.269 inch
7. PEEK ring interference @ room temp.	Step 7.	0.006 inch
8. Machine PEEK ring ID to	Step 8.	6.244 inch
9. Machine PEEK ring OD to (after install.)	Step 9.	6.995 inch
10. Diametral running clearance @ room temp.	Step 10.	0.005 inch

What this sheet shows are the many variables that go into properly selecting and installing thermoplastics as metal replacement parts. The company has created the worksheet, but the engineering criteria are the same no matter who creates the program. It is imperative that the operating and material parameters are known. It is also important to confirm that the parameters given are actual operating conditions.

Case 1: P-3480 Nonmetallic Wear Parts Used to Stabilize Rotor

The company's first use of these materials in a centrifugal pump was on a two stage overhung unit in LPG service, in 1989. The design of this pump consists of an overhung moment of two impellers separated by a center bushing. There is no bearing on the outer side of the second impeller. This allows for easily excited shaft deflection and vibration. The pump was pulled and overhauled using a molded material for the stationary wear rings and center bushing. Clearances were reduced to .004 inch to .006 inch, thus creating bearings from the rings and stabilizing the shaft. The material used at that time was a 60/20/20 blend of Teflon, moly, and glass. Soon after, we discovered thermoplastics and the rest is history.

The modification resulted in lower vibration and increased mean time between repair. A side benefit noticed was an increase in pump performance.

Case 2: Lean Carbonate Circulation Pumps

In 1992, after a debottlenecking project in a hydrogen manufacturing plant, adequate lean carbonate circulation could not be maintained for the new maximum feed rates. The system utilizes three four-stage, 1500 hp United MSN centrifugal pumps. They are being driven by a combination of electric motors and power recovery turbines. The pump's and power recovery turbine's wear parts were retrofitted with thermoplastic. The use of the thermoplastic material allowed for a greater than 50 percent reduction in clearances. The increase in efficiency (a net gain of more than 400 gpm) leads directly to an increase in production worth $600,000 per year. Increased performance also saved the cost of purchasing a larger pump previously thought to be required to provide the additional capacity.

These pumps also had a history of running dry due to loss of suction head that usually resulted in wear ring seizure and major overhaul dollars and time. Since the modification, there has been one occurrence. While many of the thermoplastic wear rings were melted, the metal impeller wear rings were reusable and the rotor was reinstalled without destacking.

Case 3: P-1531 Eight Stage Medium Hydrocarbon Pump

Another unit needed to run a primary feedpump and its spare to maintain maximum feed rates. These are eight stage Pacific JTC pumps. The pumps are used to supply a medium hydrocarbon to the reactor section of a hydrofiner unit. One pump could supply approximately 2000 barrels per day less than required. Usually, the weaker of the two pumps would cavitate, resulting in high vibration levels and poor mechanical seal life.

One of these pumps was retrofitted with thermoplastic along with plugging the balance line. The pump manufacturer was contacted to ensure the thrust bearing was sufficient for the greater load created by plugging the balance line. When returned to service, this modified pump could handle the maximum rates and the spare was shut down.

Test data prior to the test showed the flowrate to be 850 gpm @ 2150 ft of head before the modification and 905 gpm @ 2210 ft after modifications. The spare was modified later. The curve, shown in Figure 2, illustrates these points.

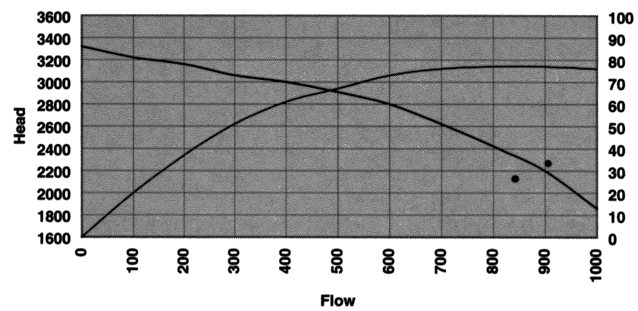


Figure 2. Hydrofiner Unit Pump, Thermoplastic/Plugged Balanced Line.

CONCLUSION

Not every pump is a candidate to be upgraded. There are applications in every industry where thermoplastics can solve difficult problems. Since the program with the company has been in place, there have been approximately 1200 pumps upgraded with thermoplastic material. Significant gains have been realized in centrifugal pump performance, reliability, and efficiency. Measurable and documented cases have been tracked to see the direct benefits of the proper use of thermoplastic materials to upgrade equipment.

Since the inception of the program, the company products' mean time between machinery repair has increased from 4.1 years to 6.4 years. In addition, assuming these pumps averaged 50 hp at a rate of $400 per hp per year, the resulting annual energy savings are: 1200 × 50 hp × $400 per hp × .06. (.06 is the average efficiency gain above curve) = $1,440,000 per year. The program has, therefore, become a beneficial way for the company to increase machinery reliability and save money.