

A USER'S VIEW OF SEALLESS PUMPS— THEIR ECONOMICS, RELIABILITY AND THE ENVIRONMENT

by

Ronald G. Eierman

Senior Staff Engineer

Exxon Chemical Company

Linden, New Jersey



Ronald G. Eierman is the Lead Machinery Engineer for the Performance Products Business Group of Exxon Chemical Company. His organization is the focal point for technical support to the Exxon Chemical Worldwide Performance Products Maintenance and Equipment Engineering Network, encompassing some 35 Specialty Chemicals manufacturing locations and five research and development centers.

During an earlier assignment with Exxon Enterprises, he was a Senior Project Engineer with responsibilities for design, application and commercialization of advanced high speed, high efficiency turbomachinery systems, including rotor bearing dynamic analysis, field testing, and marketing support.

Before joining Exxon Corporation in 1979, he had worked for Union Carbide, General Motors, and the University of Virginia, in various facets of computer programming, machine design, application and troubleshooting, including chemical process machinery and heavy duty truck assembly systems.

Mr. Eierman earned his B.S.M.E., B.S.A.P.M.A., and M.S.M.E. degrees with distinction from the University of Virginia. He has coauthored several technical papers in the rotor bearing dynamics and numerical methods areas. He is a member of Tau Beta Pi, Sigma Xi, ASME, STLE, and the Board of Directors of the Virginia Engineering Foundation.

ABSTRACT

Numerous surveys have shown that the shaft seal is the dominate root cause of failure for the chemical process pump. These component failures are attributed with the lion's share of the pump maintenance cost. Moreover, even a functioning seal cannot be classified as a zero emission point within a chemical plant; the cost of these emissions will continue to rise with time.

Business competition and societal pressure demand that maintenance costs be reduced and chemical emissions to the environment be eliminated. The progress made by one chemical manufacturing company in their meeting these demands, while also satisfying the additional business objectives of safety, reliability, and profitability is reviewed.

The mechanical features and hydraulic characteristics of various types of sealless pumps are described. Centrifugal pumps utilizing canned design features and magnetic drive technology are included. Guidelines for the economic justification of sealless pumps vis-a-vis sealed pumps are outlined in a simple life cycle cost model.

Sealless pumps are not the panacea. As with most types of machinery, they are plagued by design limitations and/or faults. A cooperative program between sealless pump users, manufac-

turers, university laboratories and industrial component manufacturers aimed at delivering a reliable zero emission pump is briefly described.

INTRODUCTION

Social Responsibility

A revolution of change is beginning in the chemical process pump sector of the machinery business. The social responsibility of the pump industry (which includes pump users) requires that it go beyond its historical activities of simply producing, using and repairing pumps [1]. This social responsibility requires continuous improvement in performance as measured by system safety, releases to the environment, frequency of pump failure (reliability), and energy efficiency. Not too surprisingly, these social responsibilities are consistent with the need to operate a safe and profitable enterprise in today's marketplace. On August 11, 1989, United States Environmental Protection Agency Chief, William Reilly, met with top officials of nine major chemical companies. His purpose was to persuade them to voluntarily reduce their emissions before additional governmental regulations are put in place [2]. In 1989, the Environmental Protection Agency published its first annual Toxic Release Inventory for 1987. This annual inventory stated that the chemical industry leaked 886.5 million pounds of toxic material to the air [3, 4]. Some of this material came from leaking chemical process pumps.

Numerous surveys have shown that the shaft seal (including shaft packing) is the dominate root cause of failure for the chemical process pump. The typical distribution of primary failure causes for centrifugal pumps operated by the refining and chemical industry is shown in Figure 1 [5]. Looking at the Pareto chart, it is obvious that leaky seals and bearing failures form the significant few root causes of pump failures. The remaining failure modes comprise the trivial many. Much effort has been

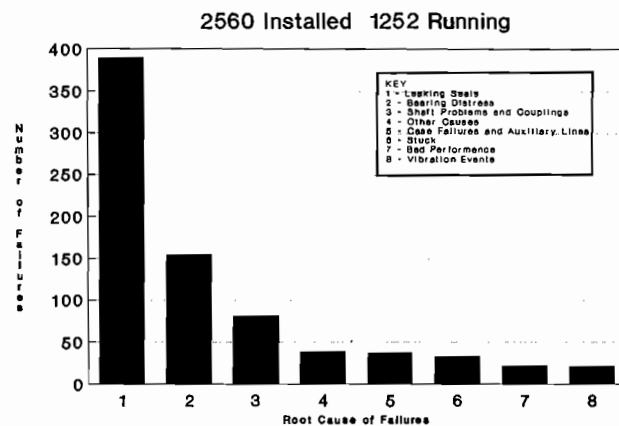


Figure 1. Primary Failure Causes for the Chemical Process Pump.

spent trying to reduce the number and frequency of chemical pump shaft seal failures, yet they continue to overshadow all other failure modes. One major chemical company has even begun to see their strong inhouse pump failure reduction program plateau, consuming more effort and failing to return the expected benefits [6].

The industry must work to reduce these seal failures to very low levels. Zero failures is the goal of any continuous improvement program [7].

Tax Treatment Affects Choice

Peter Drucker has stated many times that major business decisions are often driven by their tax consequence [8]. He goes further to point out that accounting rules and methods also play a part in distorting the clear path to overall sound business objects and success. Even the system by which the chemical process pump is selected has been influenced by tax and accounting system oddities. Many times the capital budget strategy stresses that the expenditure of capital funds be minimized even if long term cash flow is reduced, or operating expenses increased.

Life Cycle Cost Is Important

"Engineers have a responsibility to society to consider beforehand the impact of their projects on the public and on their employees' health and safety", said Charles O. Velzy, 1989-90 ASME President, during his inaugural speech [9]. Considering the total life cycle cost of the chemical process pump rather than simply its first capital cost will transform the pump selection criteria to one that better includes the long term impact of the pump selection. This more realistic financial analysis must include the total life cycle cost associated with the pumping system. This financial model would include the first cost of the pump system, operating cost differentials between alternate offerings, maintenance costs, estimated production losses associated with the pump system reliability, the cost of monitoring and reporting on the fugitive emissions from sealed pumps (including those seals that are not "leaking") and a cost associated with the finite and real risk of fire and/or explosion from a seal release in flammable service.

Society's Rules and Expectations

The times are changing. The results of frequent public attitude surveys taken in the United States during the last 10 years are shown in Figure 2 [10]. In eight years, the number of citizens demanding that more care be taken with regard to the environment has doubled, to almost 80 percent of the U. S. public. Our society is sending a strong message — protect the environment, regardless of cost. When a shaft seal fails, the pumped material is released to the environment. When a bearing fails, the consequential shaft motion typically destroys the seal, causing another release to the environment. Obviously, these unexpected process releases will not (can not) be tolerated.

Exxon Chemical Company announced during the summer of 1989, its new waste reduction program and its focus on international environmental safety. Gene McBrayer, president of Exxon Chemical, outlined the worldwide company program to reduce releases to the air, water, and land from its plants. The program calls for development of steps to achieve a 50 percent reduction in waste disposal and environmental releases in the next five years. This significant goal is on top of a record 70 percent reduction of air emissions from U.S. Exxon Chemical Plants over the past 10 years. Furthermore, design standards for new and modified facilities will be more stringent than local requirements, when necessary to ensure the safety of employees, the public and the environment.

Additional implementation guidelines stipulate that each Exxon Chemical operation will: identify releases to the environ-

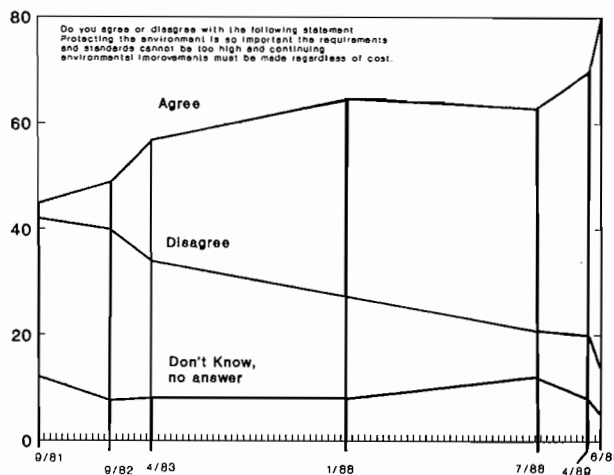


Figure 2. U.S. Attitude for the Environment: A Higher Priority.

ment, assess opportunities for reduction, formulate reduction plans that encompass health effects, operating efficiency and long range waste management methods, track performance, and communicate plans and progress with employees and the public. Adoption of this worldwide plan has forever effected the chemical process pump selection and application strategy at Exxon Chemical Company. Elimination of the chemical process pump shaft seal is a major contribution to this important effort.

Uncontrolled Fugitive Emissions

The process pump seal does not have to fail to be the source of unacceptable environmental release. Emissions from "non-leaking" process pump seals are a significant portion of the total uncontrolled fugitive emissions lost to the environment. Estimates for the total annual uncontrolled emissions from properly functioning sealed process pumps range from seven tons in a model chemical plant to 161 tons for a 100,000 barrel/day refinery [11].

The sealless pump market is a dynamic one, recently growing faster than the gross national product of the United States. A 1989 Frost and Sullivan market survey showed that sealless pump sales grew at 10 percent in 1988 [12]. Believing that society is serious about the earth's environment, the industry must embrace sealless pumps as the main process pump workhorse.

Eliminate the Root Cause of Failure

Recognizing the magnitude of the business and societal pressures being brought to bear on this problem, it is time for a step change in the way the industry engineers chemical process pumping systems. That change is dramatic; make sealless pumps the first pump of choice in every new application possible. Sealed pumps should only be considered when the required hydraulic performance and/or physical properties of the pumped fluid are outside the operating envelope of sealless pumps. On a rational basis, either driven by attrition of the existing pumps or tightening of environmental laws, retrofit with sealless pumps. This approach eliminates the most significant root cause of process pump failures, and will exempt the facility from the monitoring and maintenance regulations issued by the EPA in 1983 and 1984 [11]. The object of the information that follows is fourfold. First, to briefly overview the generic designs for sealless pumps and their current operating range. Second, to uncover the hidden life cycle costs associated with process pumps. Third, to highlight some of the design limitations now plaguing sealless pumps. Fourth, and most importantly, to encourage the fraternity of engineers in the pump industry, includ-

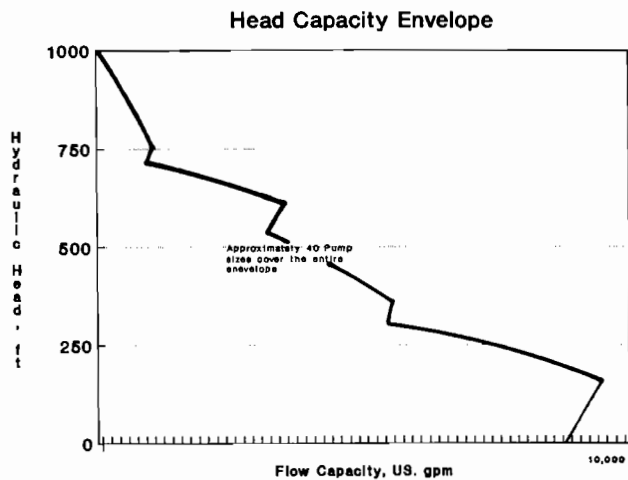


Figure 5. Current Hydraulic Range for Canned Motor Pumps.

The efficiency has been reduced by approximately five percent, because of the constant recirculation of pumped fluid through the motor and bearings. The motor electromagnetic field must penetrate the non-magnetic containment can to reach the motor rotor. The increased "air gap" distance and increased effective resistance because of the intervening can and pumped fluid reduces the overall efficiency another five to 15 percent.

Potential Operating Problems

Very few nonproprietary documents have been published that specifically address operating difficulties with canned motor pumps. However, the U. S. Environmental Protection Agency has published its comments on the needed improvements for canned motor pump designs [13]. Many engineers in the industry have had similar problems with their earlier canned motor pump installations. As more manufacturers move quickly to participate in this market, additional temporary operating problems will naturally occur. These entry level difficulties should not become the justification for reverting back to sealed pumps.

Loss of Flow

Typical problems have included frequent bearing, motor, and containment can failures. Make no doubt about it, when a canned motor pump is run dry or backwards (and it is difficult to determine the direction of rotation sometimes), the bearings lose their lubrication, the motor loses its cooling, the pump containment can is likely to fail. The severity of these failures can be significantly reduced if any of a number of simple low cost protective systems are applied. Thermocouples installed to measure the pump containment can temperature will easily provide the necessary warning that motor cooling has been lost. Numerous low motor current trip devices have been applied for the purpose of alarming a low or no flow condition for the pump. Owing to the rapid heat build up in these pumps during upset operation, it is advisable to use these protective devices to trip the pump off the line, rather than suffer the typical consequential damage.

Entrained Solids

Process fluid is required for cooling and lubrication of the canned motor pump. Entrained solids can cause severe upsets to the lubricating performance of the process fluid. Many times, the lubricating characteristics of the process fluid are marginal under the best of operating conditions. Process sediment, unreacted catalyst, and pipe scale can all cause premature failure

of a canned motor pump. Self cleaning recirculation filters and magnetic filtration devices are typically employed to protect the pump. Be careful not to overly penalize the canned motor pump in these types of services, since very few sealed centrifugal pumps work well when given solids to pump.

Reverse Operation

Since no part of the rotating assembly is visible from outside the pump casing, it is difficult to ensure that the motor has been properly connected to the site power supply. Improper wiring can result in reverse rotation of the pump. Continuing to operate a canned motor pump in this wrong direction typically overheats the motor, starves the bearing of lubrication and increases the risk of a containment can failure. The consequential damage can include most of the pump. Owing to the canned motor pump's inherently low noise and vibration characteristics, distressful operation is not always apparent from a quick visual check. Reverse rotation can be eliminated by careful commissioning and documentation.

Pumpage Heat Removal Capacity

The application of canned motor pumps in chemical processing typically requires a greater degree of understanding for the overall pumping system and its fluid than for a sealed pump. The motor driving a sealed pump is cooled by the ambient air. A canned motor pump depends on the pumpage for cooling. If the pumpage has poor heat transfer characteristics or is operating near its flash temperature, it is possible to starve the motor of its cooling fluid. Damaging vaporization of the liquid can also take place inside the bearings, if the heat transfer properties of the pumpage are inadequate.

External heat exchangers can be installed in the recirculation line to improve the pumpage heat removal capacity, if necessary. However, the maximum pumping temperature for a canned motor is always limited by the maximum operating temperature of the motor. Some of the design techniques shown in Figure 6 are used by canned motor pump manufacturers to isolate the motor area from the full effect of the hot pumpage.

Light Hydrocarbon Service

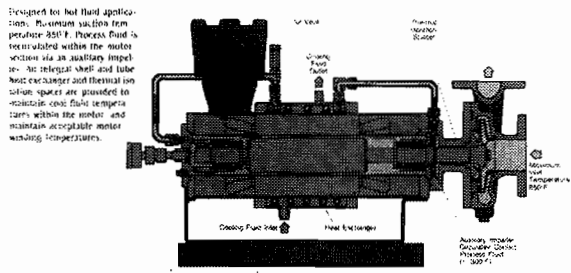
Canned motor pumps have been avoided by some users in light hydrocarbon services for two main reasons. Light hydrocarbons tend to flash very easily (one of the characteristics that makes them so difficult to contain within a sealed pump), filling the pump with vapor prior to startup or during transient operation. Careful review of the various styles of canned motor pumps available on the market reveals that some are designed to vent the vapor while most are not. Of course, the pump system designer should apply the same installation guidelines for sealless pumps in light hydrocarbon service as are applied for sealed pumps [14, 15, 16].

Secondly, light hydrocarbons tend to have very poor lubricating properties. Bearing designers are approaching this problem through improved bearing journal material combinations, innovative fluid film bearing designs and the application of magnetic bearings. Alpha grade silicon carbide has shown good success as a bearing and journal material combination. One company now has a bearing design where the inside diameter is fixed to the rotating shaft and its outside diameter runs against the pump case, thereby increasing the effective bearing area significantly [12]. Magnetic bearings are now being retrofitted to standard canned motor pumps [6].

Operational Errors

Accurate statistics are not readily available as to the frequency and/or extent of pump failure due solely to operational errors. Operating a pump with closed suction and/or discharge valves,

Type HT High Temperature with Cooling



Type HX High Temperature No Cooling Required

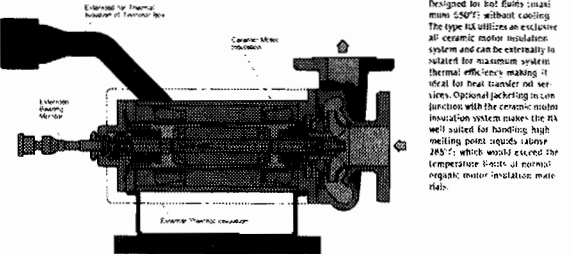


Figure 6. Canned Motor Pump Features for High Temperature Application. (Courtesy Sundstrand Fluid Handling, Sundstrand Corporation.)

with inadequate net positive suction head (NPSH), below allowed minimum flow rate, with high or varying solids content will damage most sealed as well as sealless pumps. Neither style of pump is very tolerant of this severe off design operating condition, even if it is only transitory. It has recently been pointed out that if solids were to go through an ANSI sealed pump, the most severe damage would be a failed seal [12]. Whereas, the sealless pump would suffer a major failure. This example has not been given on a level field. When the cost of the environmental release is ignored and one is only concerned with the repair cost comparison between a failed sealed ANSI pump and a sealless pump that was run until the severe distress caused major consequential damage it is clear that the sealed pump's one time repair cost will be lower.

Expanding the analysis limits from one time repair costs to life cycle costs the picture changes. Typical mean time between failures (MTBF) for sealed chemical process pumps is 18 months, whereas the sealless pumps experience about 36 months MTBF [6]. Looking closer at the services typically employing retrofitted sealless pumps and the performance of sealed pumps previously used in those same applications, shows that the reliability of the sealless pump is all that more outstanding. Published data certifying these attractive performance characteristics are difficult to find. Nonetheless, most chemical manufacturing sites that track pump population performance see this trend.

Impact of Failure

Isn't a toxic or flammable leak to the environment worse than a bearing and/or motor failure in a canned motor pump where the pumpage has been contained?

MAGNETIC DRIVE PUMPS

Design Concepts

The magnetic drive design of sealless pumps was popularized by use in very hot pumping systems, typically heat transfer

fluids being circulated at 750°F. Sealed pumps had great difficulty operating reliably at these high temperatures. Seal failures would result in objectionable odors and sometimes significant fire damage. Canned motor pumps were not well suited for these high temperatures even with special cooling and/or shielding, as shown in Figure 6. Two European companies lead the industry in the manufacture of magnetically driven sealless pumps, in the last few years the number of suppliers has increased dramatically [12].

The design concept is similar to the canned motor pump; keep the rotating assembly inside a hermetic containment can. The assembly carries the pump hydraulic end, which can be single or multistage, supported on bearings totally immersed in the pumpage. The rotating assembly carries no motor. Instead, the shaft carries permanent magnets of rare earth materials like samarium-cobalt or neodymium-iron. Outside the containment can are the driving magnets. A typical magnetically driven sealless pump is shown in Figure 7. The driving magnets are carried on a shaft supported by conventional bearings and coupled to a standard motor.

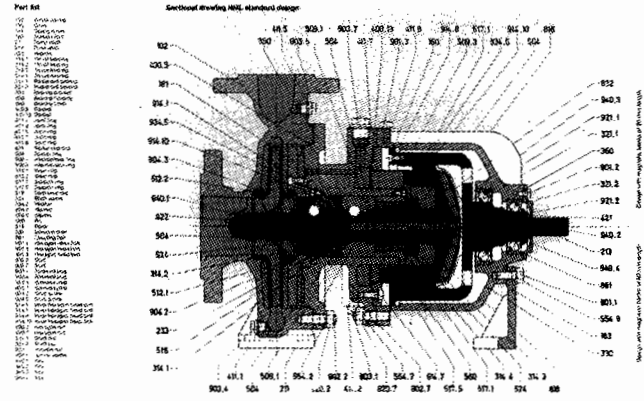


Figure 7. Typical Magnetically Driven Pump Cross Sectional View. (Courtesy Dickow Pump Company.)

Hydraulic Characteristics

As pump users specify and apply more magnetically driven centrifugal sealless pumps, the number of manufacturers will increase as will the operating window for this style of pump. The current flow and head operating range is reflected in Figure 8 for the generic magnetically driven sealless pump available today. Keep in mind that the maximum operating temperature for the magnetically driven pump is typically up to 750°F, without auxiliary cooling, compared to the 350°F limit usually applied to canned motor pumps. Not discussed herein, but nonetheless important to note, is that many styles of positive displacement pumps have recently been retrofitted with magnetic drive components previously applied to magnetically driven centrifugal pumps.

Potential Operating Problems

Historically, the magnetically driven sealless pump was plagued with all the same limitations of the canned motor pump (with the exception of the maximum operating temperature) and the additional disadvantages of higher first capital cost, lower overall efficiency owing to the magnetic losses in addition to the losses discussed for canned motor pumps, and fewer manufacturers. Over the past few years, more pump manufactures have moved in to this market by purchasing or developing their own magnetic drive technology. The drive end of their pump is then

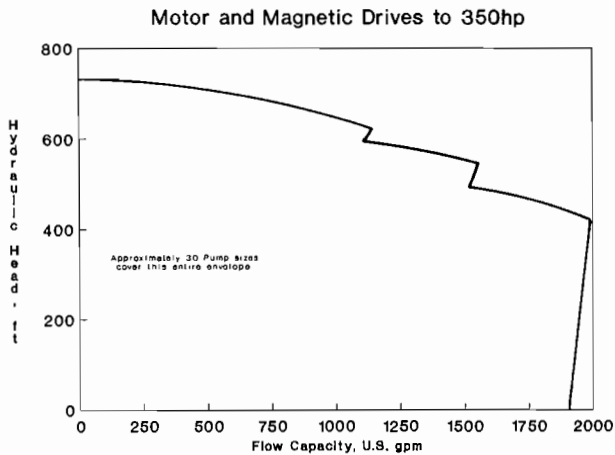


Figure 8. Current Hydraulic Range for Magnetically Driven Pumps.

modified with this drive technology and the previously sealed ANSI or API chemical process pump is transformed into a sealless magnetically driven pump.

Certainly, design deficiencies, logistical support, application assistance, and any number of other startup problems will be encountered for such a rapidly developing product.

Similar to the Canned Motor Pump

The magnetically driven centrifugal pump will behave much like a canned motor pump for any of the potential operating difficulties highlighted previously. However, since the motor is no longer a part of the rotating assembly immersed in the pumpage inside the hermetic containment can, motor cooling is no longer contributing to the heat removal requirements. Furthermore, the drive motor is now a standard motor.

The added disadvantage is now the four extra bearings—two supporting the magnetic drive assembly outside the containment can, and two supporting the motor shaft. Additionally, a coupling is now required between the motor and the magnetic drive assembly.

SEALLESS PUMP COSTS

Six different pump offerings shown in Table 1 were obtained in 1988 from various pump manufacturers for a chemical process pumping application. The table includes API, ANSI and DIN standard sealed pumps compared with canned motor and magnetically driven sealless pumps in terms of first capital cost and operating energy efficiency. In some cases, the sealless pump was offered at a lower capital cost than the sealed pump. Other examples shown illustrate that sealless pumps can have the same overall pump efficiency as the sealed pump, e.g., the sealed API 610 pump and the vertical canned motor pump (designed to meet the requirements of API 610) are both quoted as having 64 percent overall efficiency.

A rigorous example of overall life cycle cost comparisons is not readily available, since much of the input data is considered to be proprietary at this point in time. Some guidance can be found in the work of Lipton and Lynch [11] or through the Chemical Manufacturers Association's ongoing efforts.

COOPERATIVE CONTINUOUS IMPROVEMENT

Having made the commitment to pursue a continuous improvement program in the performance of chemical process pumps as applied by Exxon Chemical Company in a way that is consistent with the company's waste reduction and international

Table 1. Capital and Operating Cost Comparisons for Sealless and Sealed Pumps for the Same Chemical Process Pump Service.

1988 Chemical Process Pump Cost¹ Comparison
Example Service 0.6sg Hydrocarbon, 220 U.S.gpm, 175 ft Head

Pump Type	Total Net Present Value ⁵ (\$)	Overall Efficiency ² [%]	First Cost (\$)	Ten Year Life Cycle Cost		
				Power (\$)	Pump Maintenance ³ (\$)	EPA Monitoring ⁴ (\$)
API 610 Sealed	58500	64	4600	8000	20800	25100
ANSI Sealed	52900	71	2000	7200	18200	25100
DIN Canned	18100	53	4200	9700	4200	0
API 610 Vertical Canned	18800	64	5400	8000	5400	0
DIN MAG Drive	16700	47	2900	10900	2900	0
API 610 Mag Drive	17900	47	3500	10900	3500	0

Notes:

- All costs are net present values, no inflation, 10% interest.
- Efficiencies and first cost based on actual manufacturers quotations.
- Pump maintenance cost includes: 1 spare pump, driver, new seal every 18 months. No critical instrument maintenance (\$).
- EPA monitoring and maintenance cost includes: quarterly monitoring and reporting of fugitive emissions at \$1000 per report [11].
- Total estimated net present value of the 10 year life cycle cost for the chemical process pump. No production debits or environment fines included.

environmental safety program, it is natural to expect that teams and partnerships would need to be developed. Planning to work toward a zero defect goal for chemical process pumps mandated that the root cause of failure(s) be found, corrective action plans developed, and implemented. The Pareto chart (Figure 1) clearly shows that seals and bearings fail frequently enough to be included in the program.

The chemical process pump seal was quickly resolved by choosing to apply sealless pumps to the maximum extent possible. The process lubricated bearings then became the focus of attention. The Exxon Education Foundation recognized the importance of addressing this design problem during the early 1980s, and subsequently funded research at the University of Virginia to continue their study and development of low cost active magnetic bearings for use in chemical processing equipment. The University of Virginia had been working in this area since the early 1930s, clearly not a new or risky technology [6]. As the program progressed from the analysis phase and prototype bearings entered the testing phase, additional funding was contributed by others.

In Situ Plant Demonstration

Currently, active magnetic bearings are being retrofitted to a canned motor pump supplied by one of the program members. While the magnetic bearing design is based upon the work of the ROMAC Laboratory at the University of Virginia, they are actually being made by a commercial magnetic bearing manufacturer. One of the bearings is shown in Figure 9. Theoretical analyses and discussions excite many engineers, laboratory testing adds to the enthusiasm, but actual *in situ* chemical plant operation is typically required to convince all parties involved in the specification, application, operation, and maintenance of pumps that the "new" technology is ready for wider use. In early 1990, this canned motor pump supported by active magnetic bearings will be installed and operated by a domestic chemical processing plant for long term evaluation. A cross sectional view is shown in Figure 10 of the modified canned motor pump being discussed.

Cooperative programs between the pump manufacturers, components suppliers and end users are critical efforts required to progress sealless pump technology at the rate demanded by current business competition and societal pressures.

CONCLUSIONS

Chemical process pumps are responsible for significant releases of toxic and flammable material to the environment through their fugitive and seal failure emissions. Constant effort

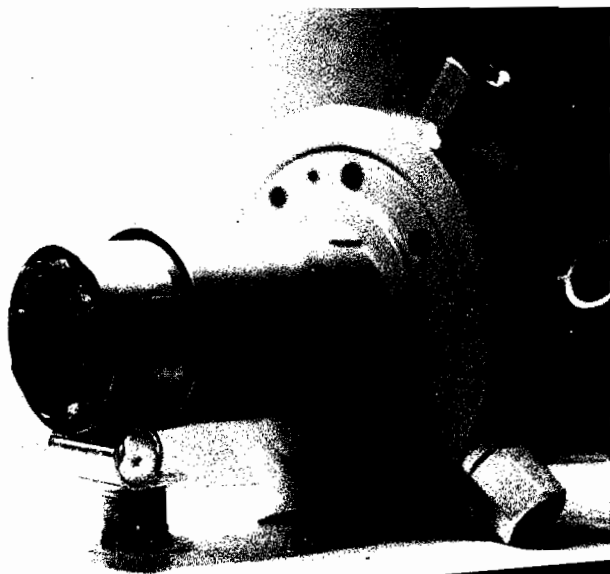


Figure 9. An Active Attractive Magnetic Bearing. (Courtesy Kingsbury, Inc.)

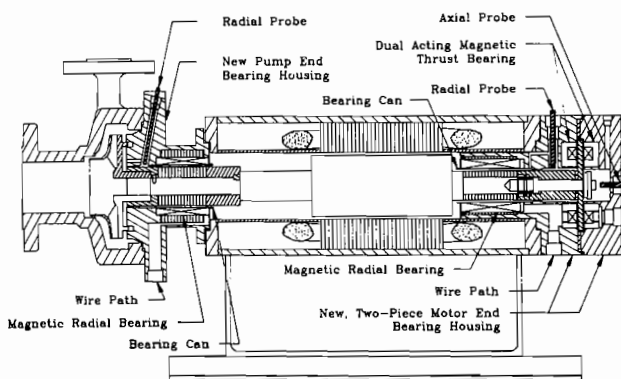


Figure 10. Cross Sectional View of a Modified Canned Motor Pump Utilizing Magnetic Bearings for Improved Reliability. (Courtesy Kingsbury, Inc.)

has been put forward by the industry to reduce the frequency and impact of seal failures through improved technology and backup systems, e.g., double or tandem seals.

Commitment to quality in everything done and continuous improvement now show that a step change is required. That change is dramatic, make sealless pumps the first pump of choice in every new application possible. Sealed pumps should only be considered when the required hydraulic performance and/or physical properties of the pumped fluid are outside the operating envelope of sealless pumps. On a rational basis, either driven by attrition of the existing pumps or tightening of environmental laws, retrofit with sealless pumps. This approach eliminates the most significant root cause of process pump failures and will exempt the facility from the monitoring and maintenance regulations issued by the EPA in 1983 and 1984.

Clearly, leaky seals will no longer be tolerated by the U. S. public. In addition, the frequency and severity of subsequent sealless pump failures must be addressed with the same systematic approach historically applied to sealed pumps. By pursuing such a program, the machinery engineering network at Exxon Chemical Company is working with all deliberate speed

to comply with the goals set out in its new waste reduction and international environmental safety program outlined in the summer of 1989.

Government tax policies negatively impact the chemical pump selection process by creating short term economic incentives that have historically hidden the true total life cycle cost of the pumping system.

Additional accounting effort must be put forward to clearly define all significant life cycle costs. A successful program for continuous improvement in the reliability and environmental impact of chemical process pumping system requires understanding and strong support from the highest management levels of the organization. Exxon Chemical Company has taken the position of protecting the environment and has presidential endorsement for the effort.

It is serendipitous that pump failure frequency and impact can be reduced, while at the same time toxic releases to the environment are also reduced solely by moving toward a broader application of sealless pumps.

Industry wide progress could be accelerated with the adoption of API or ANSI standards addressing sealless centrifugal and positive displacement pumps, specifically.

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