DESIGN OF COUPLING ENCLOSURES

by

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He co-authored the Wear Control Handbook, *the* Plant Engineering Handbook *and the* Handbook Series on Lubrication. *He has published articles in technical magazines in the USA, Canada and Europe. As a member of ASME, ASLE and ASTM, he is very active in various committees, and was Chairman of the International Power Transmission and Gearing Conference (Cambridge, Massachusetts, 1984). Before emigrating to the USA, Mr. Calistrat worked in designing drilling equipment for the Romanian oil fields, including the first hydrostatic drive for rotary tables.*

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ABSTRACT

All flexible shaft couplings must be surrounded by a guard, in order to comply with OHSA requirements. For turbomachinery applications, this guard is an oil-tight enclosure and the purpose is to trap any oil escaping the machinery seals.

When couplings rotate at high speeds in oil-tight enclosures, they shear the air, and this shearing results in a significant heat generation. The temperature of the enclosure, as well as the coupling, depends on the amount of air shearing and on the ability of the enclosure to dissipate the heat. Another problem with couplings operating in oil-tight enclosures is that negative pressures are created occasionally in the vicinity of machinery seals, causing oil to be sucked in the enclosure, which is particularly detrimental for gear reducers.

Numerous tests were conducted at Koppers' Power Transmission facilities with various types and sizes of couplings, operating at various speeds, within enclosures of many configurations. Measurements were taken of the coupling and the enclosure temperatures, pressures in the enclosures, and the cooling effect of air flow and oil spray.

Formulas useful in calculating enclosure temperatures are presented. Design guides for fabricating enclosures which operate at acceptable temperatures are also produced. Enclosures fabricated using these guidelines are successfully operating in petrochemical plants.

ARE COUPLING ENCLOSURES NECESSARY?

A coupling enclosure is defined as a cylindrical container whose main function is to capture the oil used to lubricate couplings, *and* the oil that escapes from machinery seals and to return this oil to the reservoir. A coupling enclosure is also a guard, which must be used on all couplings for compliance with Occupational Safety and Health Administration (OSHA) regulations. To satisfy its main purpose, a coupling enclosure must be oil-tight, but not necessarily air-tight. Almost all coupling enclosures are provided with a breather.

When non-lubricated couplings were initially used on high-speed machinery, attempts were made to replace the relatively cumbersome enclosure with an open guard. These attempts ended in failures, and it is now known that enclosures cannot be eliminated. Even if the quantity of oil leaking past the seals is minimal, an installation might lose all of its oil over a period of time. The resulting oil mist surrounding the machines would then become a fire hazard. Coupling enclosures are also needed because atmospheric dust tends to accumulate in any crevices of a coupling. A diaphragm coupling in the Middle East became completely rigid after it was solidly packed with sand!

With the present technology, coupling enclosures will continue to be used with all high speed machinery.

WHY ARE COUPLING ENCLOSURES A "NEW" PROBLEM?

Coupling enclosures were successfully used in connection with oil lubricated couplings for many years. Depending on their design, some worked better than others, but none were a major problem. In most cases, their design was assigned to a junior engineer.

When the first "dry" couplings were installed in oil tight enclosures, it was discovered that these enclosures can become *very* hot. It also became evident that the oil flow to the gear type couplings had not only lubricated the coupling, but also cooled it. Hence, the oil lines were reconnected and dry couplings were being cooled with an oil spray. The manufacturers of dry couplings then rushed back to the drawing board to study the heat problem and how to eliminate it.

HOW IS HEAT GENERATED IN AN ENCLOSURE?

Until dry couplings were installed in oil tight enclosures, it was believed that heat was generated by the friction between the gear coupling teeth. Recent tests [1] have shown that this friction is very small and it would account only for a few degrees of the total temperature rise.

During the last four years, numerous tests have been conducted in the Research Laboratories of Koppers' Power Transmission Division, with a variety of couplings at various conditions. Based on the results obtained, the following explanation is being offered for the heat generated in coupling enclosures.

Heat Generated by Air Shearing

The air in an enclosure is contained in an annular cylinder, with the outer diameter (OD) equal to the enclosure diameter, the inner diameter (ID) equal to the coupling's diameter, and a length equal to that of the enclosure. While the OD of this annular cylinder is stationary, the ID rotates with the coupling. A short time after startup, the air in the enclosure also starts rotating. The velocity of this rotation is variable, with maximum velocity in the vicinity of the coupling and the minimum in the vicinity of the enclosure. Hence, friction occurs between adjacent layers of air and this friction generates heat.

Heat Generated by Air Turbulence

With few exceptions, the three elements of a coupling (two flexing elements and one spacer) have dissimilar diameters. The spacer is smaller in diameter than the rest of the coupling, being particularly evident with diaphragm type couplings (Figure 1). Due to the friction between the air and the face of the disks, a circular motion is generated, and this motion generates additional heat.

Turbulence is also generated by the heads of bolts and nuts connecting the various components of the coupling. A well designed coupling incorporates shrouds over bolt heads and nuts, particularly those which are placed at large diameters.

PREDICTING COUPLING TEMPERATURE, WITHOUT COOLING

When a high speed drive is retrofitted from an oil lubricated coupling to a dry coupling, the temperature of the new

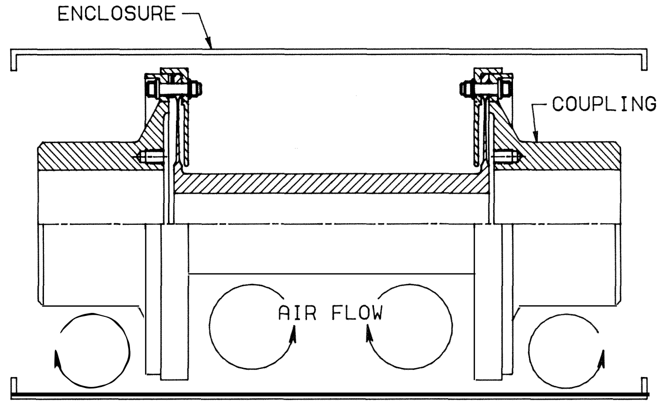

Figure 1. Air Flow in Enclosures.

coupling can be estimated. The following equations, based on experimental results, are being suggested: (*Note:* All dimensions are in inches, all temperatures are in F°.)

$$T_c = K_2 (K_3)(K_4)\left(\frac{\text{cpm}}{1000}\right)^{1.8/K_1} + (T_a + T_s)/2 \qquad (1)$$

where:

T_c = Coupling temperature

T_a = Ambient temperature

T_s = Shaft temperature

$$K_1 = \left(\frac{\text{Enclosure Diameter}}{\text{Maximum Cooling Diameter}}\right)^{0.27} \qquad (2)$$

$$K_2 = \frac{[(D_1^{2.8})(L_1)] + [(D_2^{2.8})(L_2)] + [(D_3^{2.8})(L_3)] + \text{etc.}}{\text{Enclosure Surface Area}} \qquad (3)$$

$$K_3 = \left(\frac{\text{Maximum Coupling Diameter}}{\text{Minimum Coupling Diameter}}\right)^{0.2} \qquad (4)$$

$$K_4 = 0.6 \qquad (5)$$

K_1 is a function of the ratio between the enclosure and coupling diameters. This coefficient does not influence the temperature directly; rather, it modifies the influence on temperature of the rotational speed. It was shown previously that the temperature generated by *air shearing* is a function of the *velocity gradient* across the gap between the coupling and enclosure. Hence, the heat depends both on the speed and on the gap size. Two extremes are possible:

- If the enclosure is very large, the exponent for the rotational speed becomes very small, i.e., the speed has little influence on temperature.
- If the enclosure is only slightly larger than the coupling, $K_1 = 1$ and the speed has a significant influence on the temperature.

K_2 is a coefficient which accounts for the influence of the coupling's surface area (larger the area, more friction with the air), and for the peripheral velocity. One should note that rotational speed, rather than velocity, was entered in Equation 1. The peripheral velocity is a function of the product between the rotational speed and the diameter. This fact explains the large exponent for D in Equation 3. As the components of a coupling have various diameters and length, Equation 3 enters the sum of individual influences.

K_3 is a coefficient which accounts for the influence of the air circulation generated by the coupling's geometry (Figure 1).

Coefficient K_4 accounts for the air flow in and out of the enclosure. For enclosures without provisions for air circulations, the value of K_4 is constant.

Finally, the coupling's temperature depends on the heat received (or dissipated) from the ambient air outside the enclosure (T_a), and from the shaft (T_s). As the temperature of the shaft cannot be easily measured, it is suggested that the oil temperature, as it exits the bearings, be used for T_s.

DISSIPATING THE HEAT

Radiation

The heat generated within the enclosure is normally dissipated by its outside surface into the surrounding air. To increase this dissipation common engineering sense should be used:

- Increase the surface area, either by making the enclosure large, or by adding radiating fins.
- Allow air circulation over the enclosure.
- Shade the enclosure from exposure to the sun or from other hot components, such as turbine exhausts and steam lines.

Oil Cooling

If the enclosure cannot be modified, and its temperature is unacceptably high, spraying the coupling or the inside surface of the enclosure with oil will dissipate additional heat.

To determine the temperature drop that can be obtained with oil cooling, the following equations are suggested:

$$T_c = 1.18\ (T_e - 10) \tag{6}$$

$$T_d = K_5\ (\sqrt{T_c - T_o}), \text{ in percent} \tag{7}$$

where

K_5 is an experimental coefficient, found in Figure 2
T_e is the enclosure's temperature
T_o is the cooling oil temperature
T_d is the drop in temperature (percent)

Example: The measured enclosure temperature is 220°F, and 0.3 gpm oil at 110°F is sprayed on each end of the coupling.

The coupling temperature, before oil spraying, is:

$$T_c = 1.18\ (220 - 10) = 248°F \tag{8}$$

From Figure 2, $K_5 = 3.5$. The temperature drop with oil spraying would be:

$$T_d = 3.5\ (\sqrt{248 - 110}) = 41 \text{ percent} \tag{9}$$

The enclosure temperature, with oil cooling, would be:

$$T_e = 220\ (1 - 0.41) = 130°F \tag{10}$$

Air Cooling

If the air heated by friction is allowed to escape from the enclosure, and if outside air is allowed to replace the heated air, the enclosure's temperature can be significantly reduced. However, venting the air out of the enclosure could create the problem of oil mist escaping into the atmosphere. Through proper enclosure design, this problem can be eliminated.

The following items must be considered when designing an enclosure with air cooling:

- sizing the air ports
- separating the oil from the air
- avoiding negative pressures

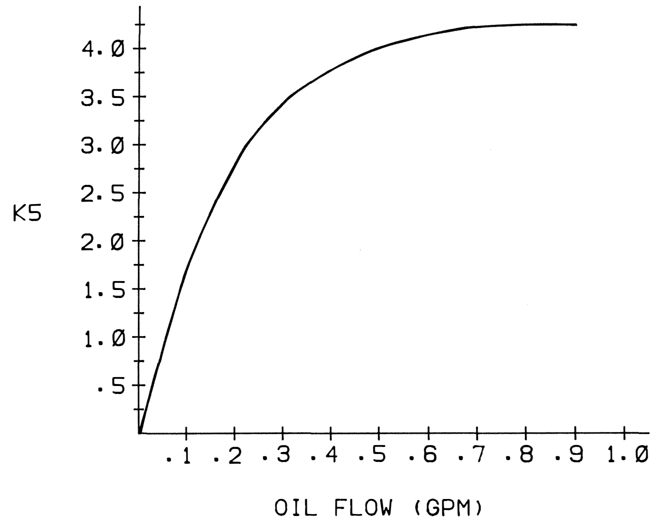

Figure 2. Oil Spray Cooling.

Sizing the Air Ports

The exhaust port should be tangential to the enclosure's outside diameter and directed with the coupling rotation, as shown in Figure 3. This port (or ports) can have any profile; however, a tubular port is the most convenient to use. The larger the port, in comparison with the enclosure, the lower the enclosure's temperature. A large exhaust port, on the other hand, can create problems in separating the oil from the air.

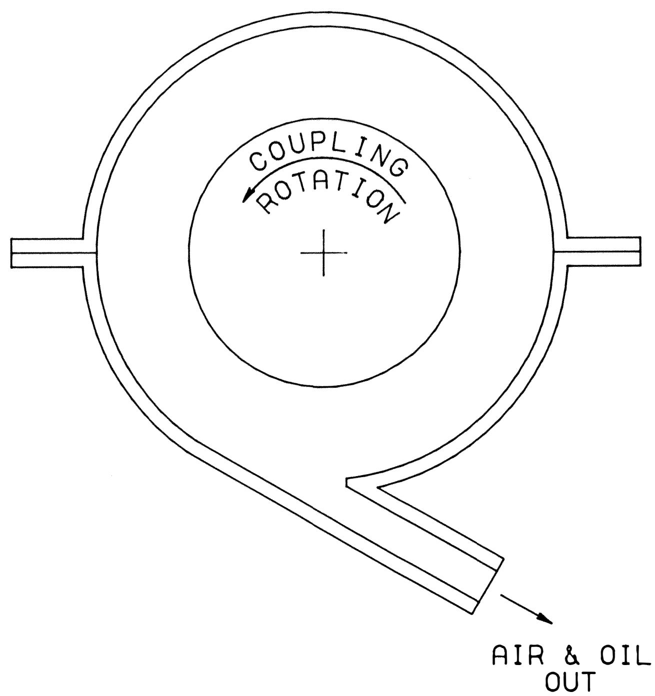

Figure 3. Exhaust Port.

For enclosures with air cooling, Equation 1 can be rewritten as:

$$T_c = K_2\ (K_3)\ (K_4)\ \left(\frac{\text{cpm}}{1000}\right)^{2.2/K_1} + (T_a + T_s)/2 \tag{11}$$

K_1, K_2, and K_3 are the same as before; however,

$$K_4 = \frac{1}{1000} \left(\frac{\text{enclosure skin area}}{\text{exhaust port cross-section}} \right) \tag{12}$$

While K_4 cannot have a value larger than 0.6 (in case of no air flow), a properly designed enclosure will have $K_4 = 0.1$ to 0.2.

The enclosure skin area is:

$$A_e = \pi\ (D_e)\ (L_e) \tag{13}$$

where

D_e = enclosure diameter

L_e = enclosure length

Note that the rotational speed has a larger influence on temperature when the enclosure is air cooled than when no air circulation is permitted. The larger exponent for speed can be explained by the fact that a vented enclosure acts to some extent as an inefficient blower. However, considering the significant reduction in the value of K_4, the increase in the influence of rotational speed is not very important.

The intake and exhaust ports should be placed so that no "dead zone" is left in the enclosure. Hence, if one exhaust port is placed in the middle of the enclosure's length, one intake port should be used at each end of the enclosure. Conversely, if two exhaust ports are used (this is desirable for enclosures longer than 36 in), then one intake port should be placed halfway between the exhaust ports.

The total intake port area should be half the total exhaust area. For example, if one exhaust port of 3 in diameter is used, each of the two intake ports should be 1.5 in in diameter.

Separating the Oil from the Air

The amount of oil that escapes past a seal is usually very small. Some compressor manufacturers, however, decided to eliminate the seals completely and to recapture the bearing oil from the coupling enclosure rather than from the compressor housing. It is therefore possible that flowrates of up to 3 gpm are still flowing into the enclosure, even when the couplings are non-lubricated. This is hot oil and does not provide cooling.

To prevent this oil from becoming a mist, many enclosures rely on the centrifugal effect created by the rotation of the air, similar to the working of a cyclone separator. One way to help the air rotation is to install the intake ports tangentially to the enclosure, as shown in Figure 4. Another way to prevent the formation of oil mist is to shorten the residency in the enclosure of any oil particle. A baffle should be installed, oil tight, along the enclosure, over the exit port, as shown in Figure 5. This baffle will force the oil out of the enclosure and prevent it from rotating more than one revolution before exiting.

The actual separation between air and oil is done outside the enclosure, as shown in Figure 6. All ports should have breather caps, provided with a coarse wire mesh filter.

Avoiding Negative Pressures

When large diameter disks are mounted on shafts in the vicinity of the seals, their rotation generates a negative pressure, which causes oil to be sucked out from the machine housing into the coupling enclosure. This phenomenon is particularly detrimental to gear boxes, which have an independent oil supply. As couplings are mounted closer and closer to the bearings (in order to reduce the overhung moment), the problem of oil being lost into the enclosure is encountered more often.

To avoid this problem, an air tube can be installed close to the coupling, as shown in Figure 7. This tube allows atmospheric pressure near the seal and cancels the negative pressures. Preferably, this air tube should be in addition to the normal air inlet port, rather than instead of it. If this tube does not eliminate the oil loss, then this tube should be connected to a positive pressure area of the enclosure, usually over the largest rotating part, as indicated in Figure 8.

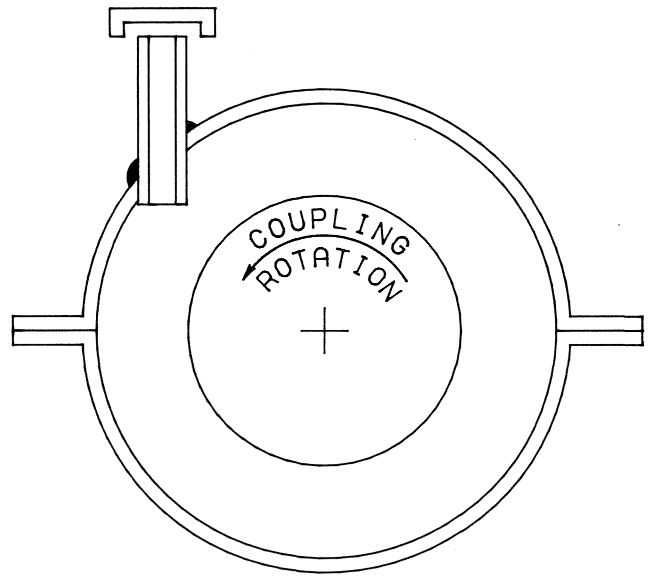

Figure 4. Tangential Intake Port.

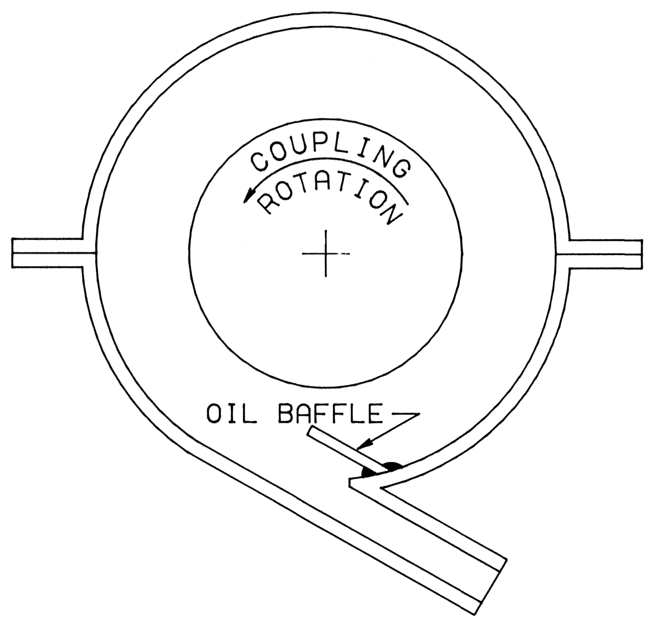

Figure 5. Oil Baffle at Exhaust Port.

BASIC ENCLOSURE DESIGN FEATURES

Usually, coupling enclosures are cylindrical and split on a diametral plane. The two half cylinders are connected by bolted flanges. A few basic design rules should be followed:

• A coupling enclosure should be free to float at both ends. The authors have seen enclosures bolted to one machine and free to move axially at the other end. Such a design allows for axial motion between machines, but the enclosure is rigid with respect to offset motions.

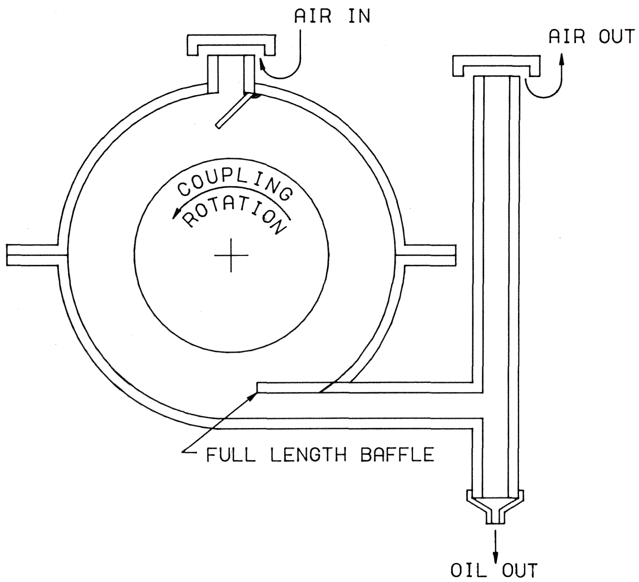

Figure 6. Separation of Oil from Air.

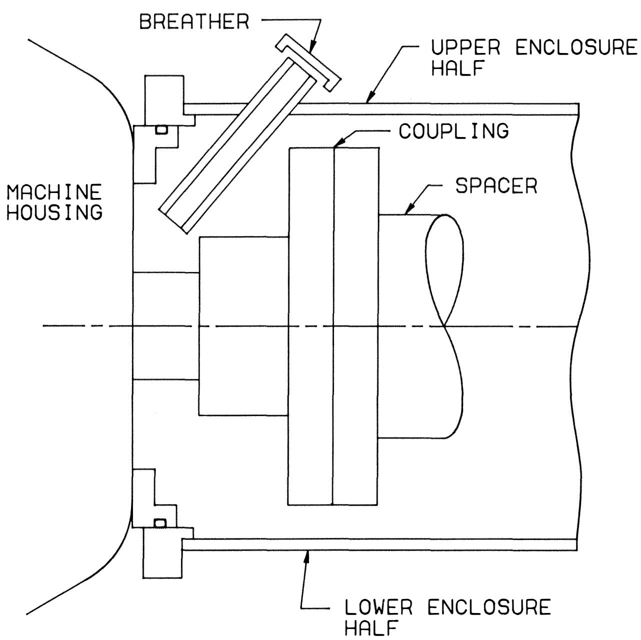

Figure 7. Compensation of Negative Pressures.

• A coupling enclosure should be oil-tight. Even though all enclosures are welded construction, oil still leaks out, usually at the flanges. Gaskets and caulking seldom can stop the leaks. A simple design, shown in Figure 9, can help eliminate these leaks.

• Breathers are required on enclosures in order to prevent the formation of an "oil plug" and to prevent the possibility of filling the enclosure with oil. Breathers should be designed so that oil cannot escape. In designing the enclosure, the direction of rotation of the coupling should be considered. A baffle should prevent the air from flowing out through the breather, as shown in Figure 10.

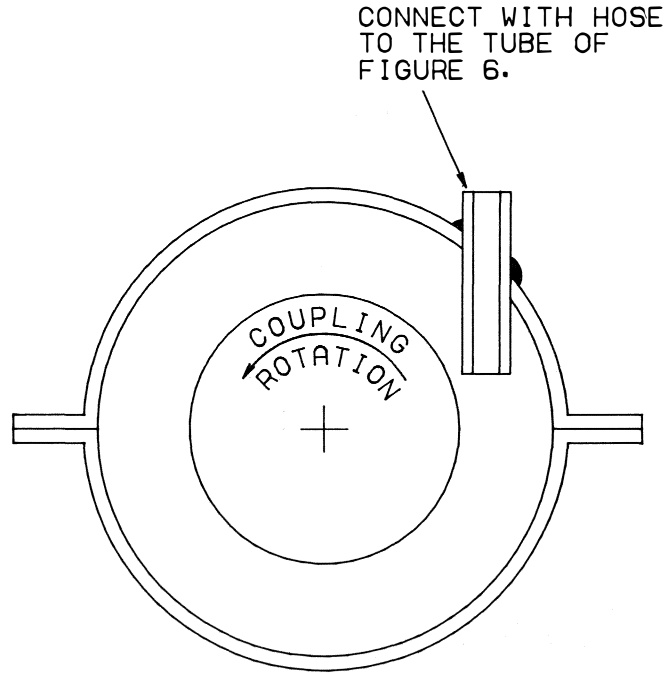

Figure 8. Means for Pressurizing the Seal Area.

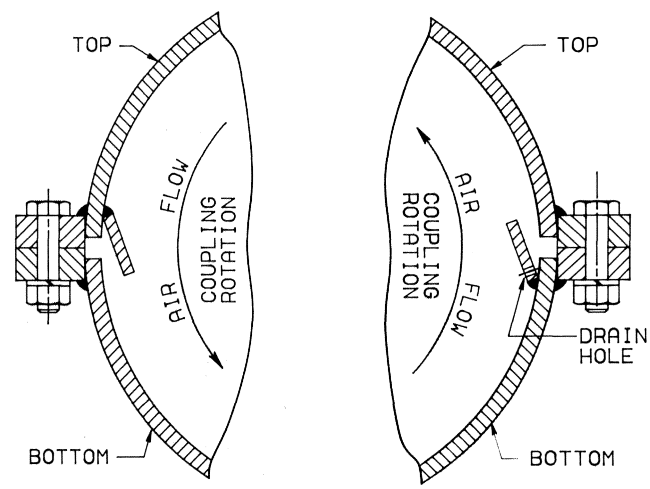

Figure 9. Seals for Enclosure Flanges.

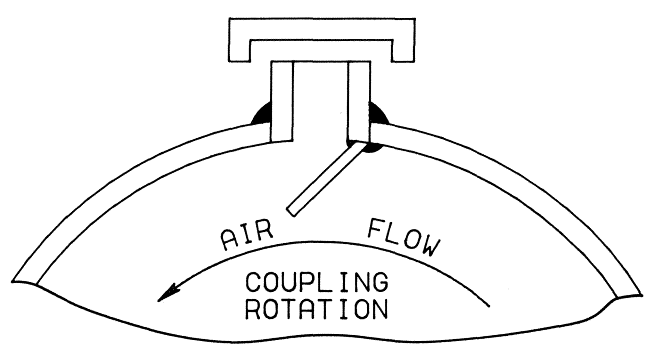

Figure 10. Baffle of Intake Port.

EXPERIMENTAL WORK

Tests were conducted over the last four years on gear, single diaphragm, and disk-pack couplings designed for 1½ in, 2 in and 4 in diameter shafts. Tests were performed, with and without cooling, at speeds varying between 3000 and 16,000 cpm. The equations presented herein are based on the test results obtained. These equations reproduce the test results with an error of ±6 percent. The results and calculated temperatures, for two of the couplings which were tested in the laboratory, are shown in Figure 11.

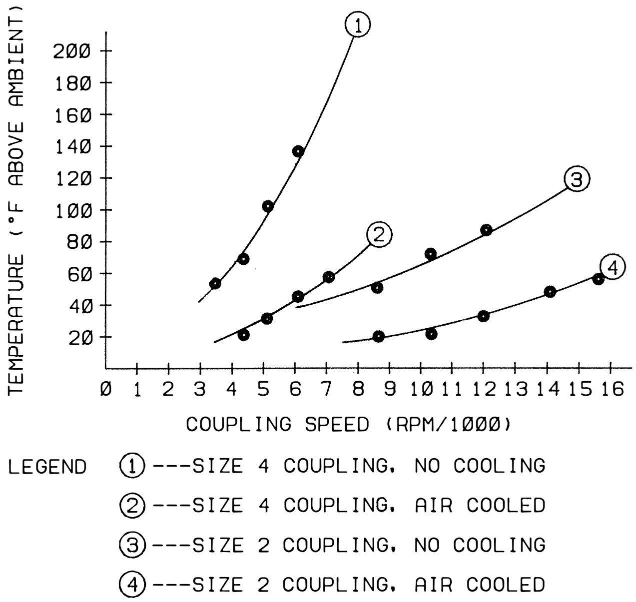

Figure 11. Test Data.

The Bendix Corporation [2] published an equation and a graph to be used for the calculation of non-cooled enclosure temperatures (Figure 12). The authors compared their results with those obtained using the Bendix formula. The equation differs from test results (Figure 13), when a single diaphragm coupling with 34 in shaft separation was used in two different enclosures, having 20 in and 23 in diameters. It can be seen that the Bendix equation is very accurate at 5000 cpm, but that the exponent for the rotating speed seems to be too large. On the other hand, the enclosure's diameter has a larger influence than the one resulting from the Bendix formula. When the Bendix formula was used for calculating the temperatures of gear type, or disk-pack coupling enclosures, the results were significantly different from measured values, as shown in Figure 14. It is evident that the Bendix equation cannot be used on coupling types other than diaphragm couplings. Enclosures with air cooling have been installed at a few chemical plants and performed as predicted.

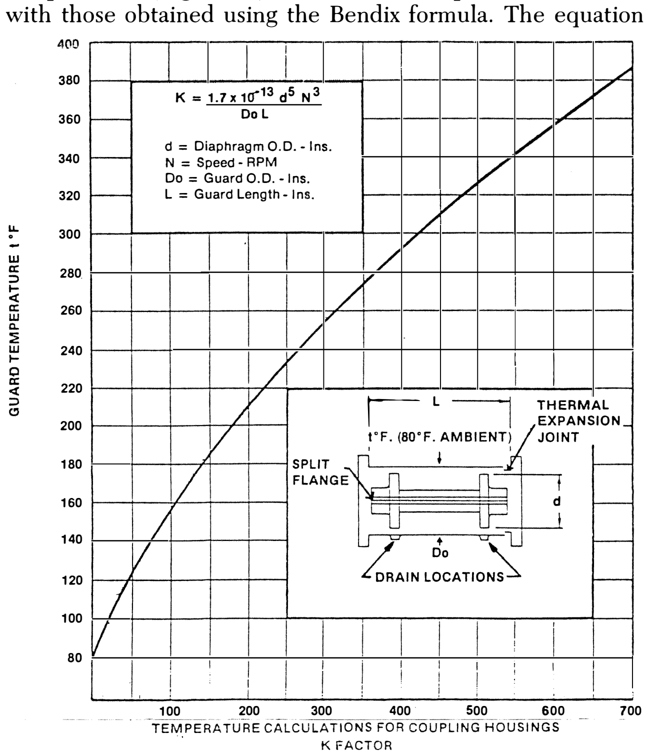

Figure 12. Bendix Method.

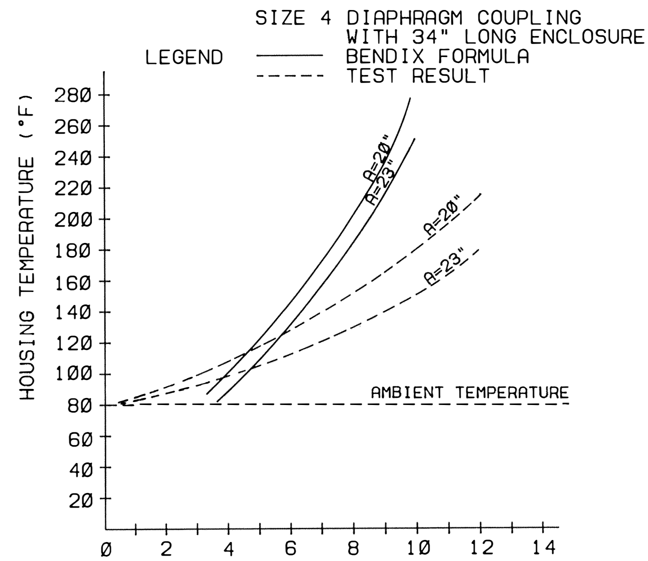

Figure 13. Bendix Formula vs. Test Results: Diaphragm Coupling.

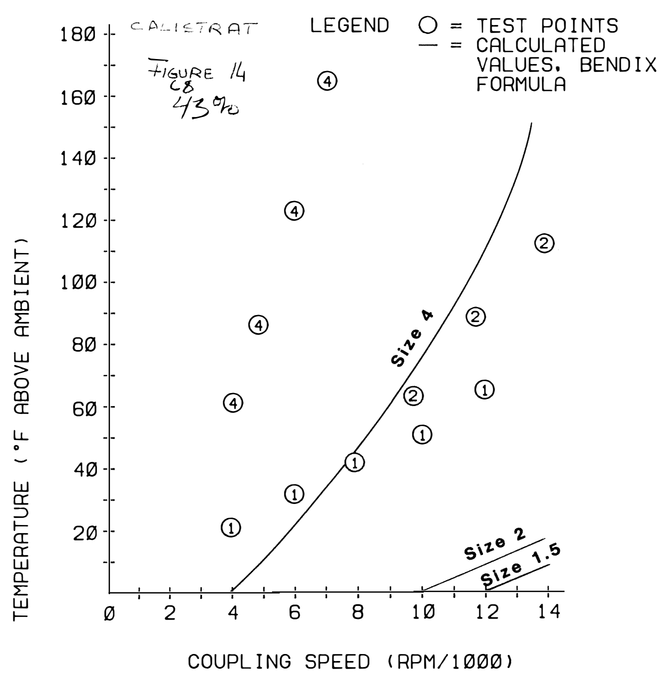

Figure 14. Bendix Formula vs. Test Results: Gear-type Coupling.

CONCLUSIONS

• Oil tight coupling enclosures are required for collecting the oil that escapes past machinery seals.

• Without proper design, or provision for cooling, the enclosure, and the coupling in particular, can become unacceptably hot. From a safety point of view, the enclosure temperature should not exceed 180°F, but even this limit might be too high for electronically instrumented couplings.

• When enclosures cannot be made large enough to prevent the build-up of excessive heat, cooling the enclosure can be successfully accomplished by oil or air cooling. Oil cooling is easier to implement on existing enclosures, while air cooling should be considered first when the enclosures are being designed.

• Methods to cool enclosures were presented; however, the first step in minimizing temperatures lies with the coupling design. A non-lubricated coupling should be designed so that it generates as little windage as possible.

REFERENCES

1. Calistrat, M. M., "Friction Between High Speed Gear Coupling Teeth," ASME Paper 80-C2/DET-5 (1980).
2. Bendix Corporation, Fluid Power Division, Catalog 67U-6-8211A (1982).

ACKNOWLEDGEMENTS

The authors want to thank Dresser Industries for sharing their valuable experience on the design of coupling enclosures. Also, many thanks to the Bendix Corporation for allowing us to include their method of calculating enclosure temperatures.