Effectiveness of Paper Dryer Journal Insulating Sleeves

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ABSTRACT

Paper dryer journals are often insulated from steam inside the dryer by internal insulating sleeves. An insulating sleeve is a flanged tube that extends through the bore of a paper dryer journal. The flanged end of the sleeve is usually bolted to the inside surface of the dryer head and sealed by a gasket. The opposite end of the sleeve is usually sealed by o-rings in a journal adaptor flange. The insulating sleeve creates an insulating air gap in the annular space between the sleeve and the dryer journal bore. This insulating air gap helps to protect the dryer bearing inner race and maintain oil viscosity to provide long bearing life. This paper quantifies the effectiveness of insulating sleeves. It covers the results of an analysis of the heat transfer from the steam to the dryer bearings and it provides test data to confirm the results of the analysis.

INTRODUCTION

An "insulating sleeve" is a flanged tube that extends through the bore of a paper dryer journal. The flanged end of the sleeve is usually bolted through a gasket to the inside surface of the dryer head and sealed at the opposite end of the journal by o-rings in a journal adaptor flange. This sleeve creates an insulating air gap in the annular space between the outside of the sleeve and the inside of the dryer journal bore. A typical insulating sleeve is shown in Fig. 1. In this example, the dryer has a two-passage rotary steam joint with a stationary syphon. The support tube for the stationary syphon extends from the rotary steam joint to the inside of the dryer through the steam sleeve. The supply steam flows between the syphon support tube and the inside of the insulating sleeve.

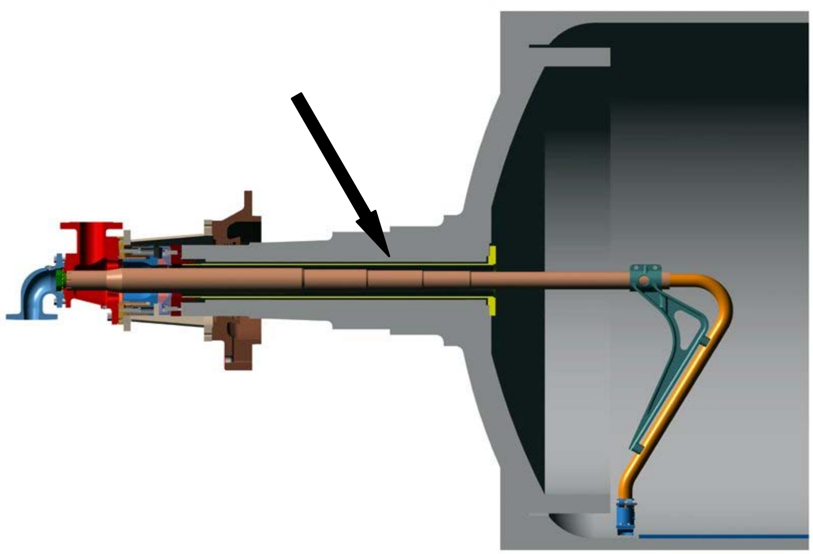

Figure 1. Paper Dryer with Journal Insulating Sleeve (shown in yellow).

BEARING FAILURES

Dryer bearings can fail from lack of lubrication, from contamination, or from cracked bearing races.

Lubrication. Proper lubrication requires that the bearing be supplied with an adequate flow of oil with the proper oil viscosity. Since oil viscosity depends on oil temperature, it is important that the temperature of the oil in the dryer bearing be maintained within a specified range, neither too hot nor too cold. If the oil is too hot, the lubricating film will be too thin. If the oil is too cold, the rollers of the bearing may skid rather than roll and there is increased risk that the oil will not drain from the housing.

Contamination. Oil contamination can be the result of having inadequate oil filtering or having contaminants enter the system after the oil filter banks. Filtering systems should be of the proper micron size, be periodically changed, and not be operated in a by-pass mode. Contaminants that enter the lubrication system downstream from the filters must be flushed from the system by the lubrication oil. This requires an adequate and continuous flow of oil. Contaminants include water as well as rust, paper fibers, and other debris.

Water can enter a dryer bearing housing or gear case through the labyrinth seals between the bearing housing covers and the dryer journals during wash-ups. A typical labyrinth gap is shown in Fig. 2. Water can also accumulate inside the bearing housing by condensation of water vapor in humid air that migrates into the housing.

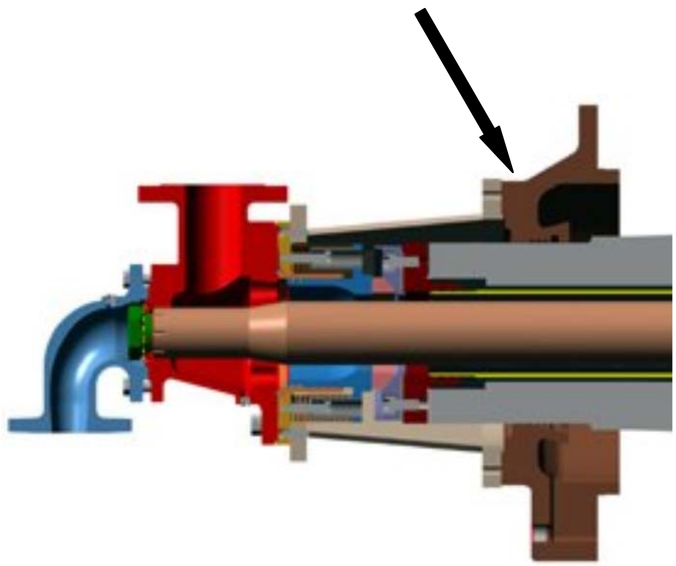

Figure 2. Labyrinth Seals in a Dryer Bearing Housing Cover.

Cracked Inner Race. Under severe operating conditions, the bearing inner race can crack. This "transverse cracking" can be caused by excessive inner race tension, fretting between the race and the journal, stress corrosion, and extensive fatigue spalling. The most common cause of cracked bearing races in paper dryer bearings is excessive inner race tension caused by rapid heating of the dryer journal relative to the dryer bearing. The mechanism is a transient thermal reaction: The dryer journal is heated up first (from the convection of heat from the steam that is in the dryer journal bore and later by conduction of heat from the dryer head to the dryer journal). As the journal heats up, it expands. The bearing inner race also heats up, but it heats up more slowly than the dryer journal and consequently does not thermally expand as quickly.

This results in an increase in tensile stress in the inner race. Depending on the initial stress on the bearing race (the pre-load stress), the relative temperatures, and the bearing race heat treatment, this increase in stress may be enough to cause the race to crack. This type of dryer bearing inner race failure occurs most often:

1. On board machines, where the steam pressures (steam temperatures) are high.
2. On dryers without insulating sleeves (or with insulating sleeves that leak).
3. When the dryer section is being started up from a cold shutdown.
4. Where the steam pressure is increased too rapidly.
5. Where the oil lubrication system does not have an oil pre-heater.

A photograph of a cracked dryer bearing race is shown in Fig. 3. A good indication that the problem is one of differential thermal expansion (which is not quite the same as "thermal shock") is when the inner race cracks, but the bearing surfaces otherwise look fairly good. Insulating sleeves can be a critical part of a program to reduce the occurrence of cracking of bearing inner races.

Figure 3. Cracked Bearing Inner Race (1).
Courtesy Society of Tribologists and Lubrication Engineers.

CRACKED BEARING RACE SOLUTIONS

There are a number of solutions that have been used to reduce and often eliminate problems with cracked dryer bearing races:

Insulating Sleeves. Insulating sleeves can be used to reduce the transfer of heat to the journal from steam flowing through the journal bore. Insulating sleeves tend to reduce the journal steady state temperature, but more importantly, they reduce the rate of change of the journal temperature. The amount of heat that is conducted down the journal from the dryer head is relatively small. A properly sealed insulating sleeve can be very effective in reducing the rate at which the journal is heated.

Although insulating sleeves reduce the transfer of heat, they are not always included in low-pressure dryers. This is because the potential for large differential thermal expansion is less when the dryer steam temperature is less. Excessive superheat, however, can cause rapid heating of the dryer journals, even though the steam pressure is low.

Case-Hardened Races. Dryer bearings can have either case-hardened or through-hardened races. Bearing suppliers can supply both. Case-hardened bearings have more inner race ductility and are more tolerant of differential thermal growth. Through-hardened bearings are more brittle and less forgiving.

Continuous Lubrication. Many mills keep their oil lubrication system in operation, even when the machine is shut down. This practice has a number of benefits: It keeps the bearing surfaces protected from corrosion, it keeps the bearing surfaces lubricated, it flushes out contaminants, and it maintains the drain line temperature so that the bearing housings do not fill up and leak oil out through labyrinth seals when the machine is restarted. If the oil system has a heating system as well as a cooling system, then the bearings will not cool as much when the machine is shut down. If the bearings are warmer to begin with, there is less potential for differential thermal expansion to cause the inner bearing races to crack than when a cold dryer is heated.

Warm-up Rate. The rate at which the dryers are warmed up is also important. The rate of warm-up can be controlled in a number of different ways, but the initial warm up cycle is most critical when the dryer bearings are still cold. It is possible that the ramp-up rate at the beginning of the cycle is too fast, even though the overall warm-up cycle takes a reasonable period of time. An automated warm-up control system can be used to provide consistent and controlled warm-up cycles to prevent rapid heating of the journal and reduce the risk of bearing failures.

INSULATING SLEEVE DESIGN

Insulating sleeves can be made from stainless steel or from carbon steel with the ends plated. They can be threaded into the dryer heads or journal adaptor flanges, sealed with gasketed flanges, or sealed with o-rings, energized cup seals, or various types of packing materials. Figures 1 and 2 show an insulating sleeve with an o-ring seal.

Insulating sleeves are normally carbon steel rather than stainless steel. Stainless steel is less prone to corrosion and steam cutting, but it also has a much larger coefficient of thermal expansion than carbon steel. This means that there will be more axial differential thermal expansion between the sleeve and the dryer journal during transient conditions (start-up, shut-down, pressure changes). The larger thermal expansion puts more demands on the o-ring, packing, or cup seal surfaces, making these surfaces more likely to leak over time.

Insulating sleeves that are threaded into the dryer head or journal adaptor flange can be very difficult to remove. Modern insulating sleeves are typically flanged at one end and sealed with o-rings at the opposite end. The o-ring seal allows for differential thermal expansion while the flanged end provides a robust seal that is easy to disassemble.

“Weep” holes or slots are small passages that vent the air gap between the sleeve and the dryer journal bore. These passages are often provided in the journal adaptor flange or in the seal plate, as shown in Fig. 4. The weep holes vent any small amounts of steam that may leak into the air gap between the sleeve and the bore of the dryer journal. These weep holes also indicate if there is a large leak.

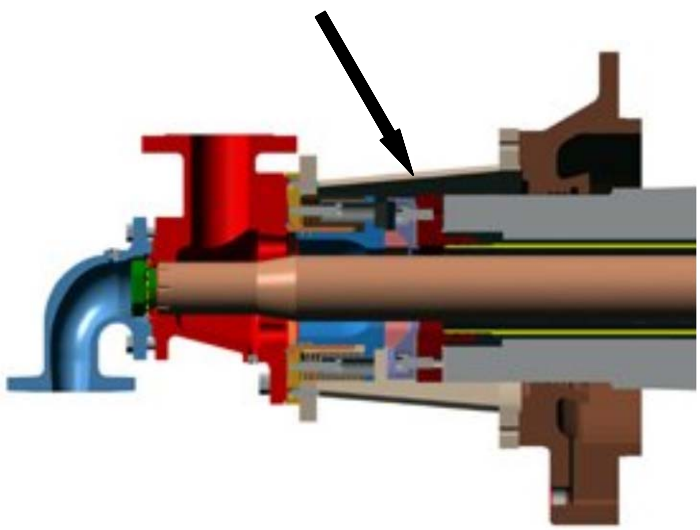

Figure 4. Weep Hole in Journal Adaptor Flange.

Teflon o-rings are often used as the sliding seal for insulating sleeves. Teflon o-rings resist high temperature, but are quite stiff and may not seal completely until the Teflon gets hot and "flows" into position. Some amount of steam may leak into the air gap and then flow out of the weep holes. This slight leakage may be seen leaving the journal, but then stop as the small amount of remaining water is evaporated and vented away. If the weep holes are plugged, however, this water will stay in the air gap and reduce the effectiveness of the steam sleeve. This is discussed in more detail later in this paper.

Weep holes not only vent the occasional steam, but also indicate a real leak. Weep holes can be tapped in advance, to allow them to be temporarily plugged if there is a large leak. These plugs remain in place until a scheduled shutdown when a permanent repair can be made. If the dryer is already hot, there is less risk of radial thermal expansion causing bearing problems, even though the insulating sleeve is not as effective. If the leak is found before the dryer has been heated up to operating temperature, the dryer can be warmed up more slowly than normal, without having to valve off the dryer or shut the machine down to repair the sleeve leak.

If there is a leak, the weep hole can be temporarily plugged, in order to resume production. If a weep hole is temporarily plugged, the dryer should be marked and supervisory personnel should be notified that there is a potential hazard if the dryer is not sufficiently cool for subsequent maintenance. When the machine is later shut down for repairs, the air gap will likely be filled with hot condensate. If the dryer is not sufficiently cooled before the journal adaptor flange is removed, the superheated condensate in the air gap could flash, blowing off the journal adaptor flange when the bolts are taken out. Care must be taken to properly vent this condensate to prevent damage and injury.

THERMAL ANALYSIS

The effectiveness of a dryer journal insulating sleeve at protecting dryer bearings was first analyzed using a finite element heat transfer model. A dryer with an integral head / journal was used for this analysis. The appropriate heat transfer coefficients were applied to all of the boundary surfaces and the inside surface of the head and journal bore were exposed to saturated steam.

Typical results are shown in Fig. 5 and 6. In both figures, the dryer head and journal are shown in cross-section. The temperature profiles are shown in colors indicating the temperature level. In the first figure, the steam pressure is 3.45 bar (50 psia). In the second figure, the steam pressure is 6.9 bar (100 psia). The dryer journal temperatures are quite high in both cases, except in the area of the dryer bearing, where the lubrication oil is removing the heat.

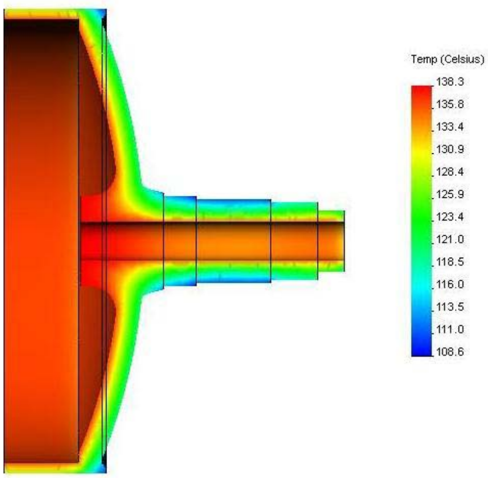

Figure 5. Dryer Journal Temperature Profiles with No Sleeve (3.45 bar steam pressure).

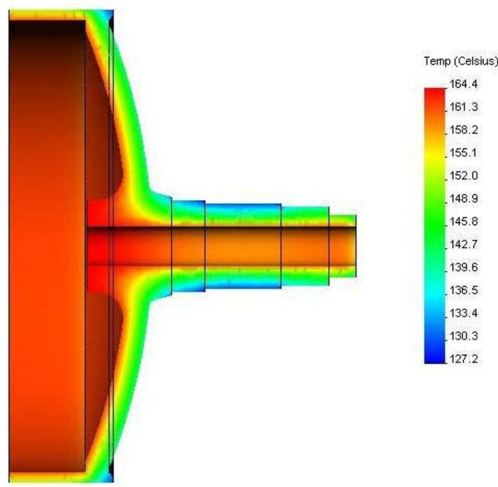

Figure 6. Dryer Journal Temperature Profiles with No Sleeve (6.90 bar steam pressure).

Similar results are shown in Fig. 7 and 8. In these two figures, the dryer journal is insulated by a sleeve that passes all the way through the dryer journal, from the outboard flange to the inboard flange. As before, the first figure represents a dryer operating at a steam pressure of 3.45 bar (50 psia) and the second figure represents a dryer operating at a steam pressure of 6.9 bar (100 psia).

As indicated in the temperature profiles, an insulating sleeve has a small effect on the temperature of the dryer head, but the temperature of the dryer journal is significantly lower along the full length of the dryer journal, particularly in the area of the dryer bearing.

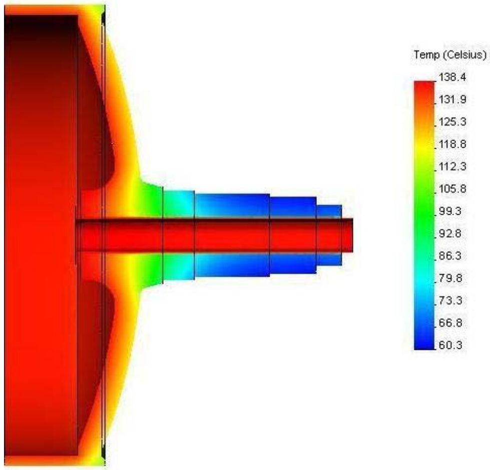

Figure 7. Dryer Journal Temperature Profiles with Sleeve (3.45 bar steam pressure).

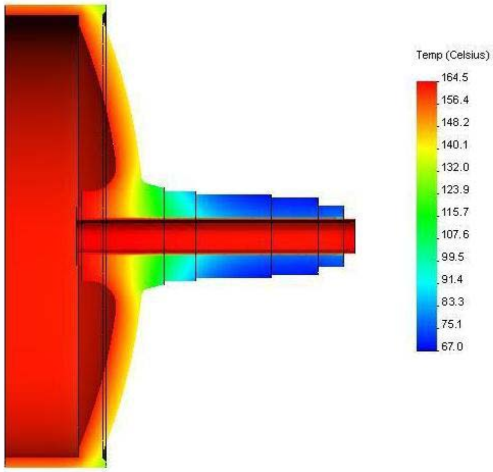

Figure 8. Dryer Journal Temperature Profiles with Sleeve (6.90 bar steam pressure).

The reduction in dryer journal temperature has a corresponding reduction in the amount of heat that must be removed by the oil. This is shown in Table I. This table shows the average temperature of the dryer journal under the area covered by the bearing and housing, and the amount of heat that is transferred to the bearing (and removed by the lubrication oil).

Table I shows two configurations:

- A dryer journal with no insulating sleeve
- A dryer journal with a properly sealed sleeve

Table I. Journal Temperature and Heat Transfer to the Bearing.

Dryer Sleeve Configuration	Dryer Steam Pressure bar (psia)	Journal Temperature under the Bearing °C (°F)	Heat Transfer to the Bearing kW (Btu/hr)
No sleeve	3.45 (50)	110 (230)	2.6 (8840)
No sleeve	6.90 (100)	130 (266)	3.3 (11288)
Sleeve	3.45 (50)	66 (150)	1.0 (3400)
Sleeve	6.90 (100)	71 (160)	1.2 (4080)

The reduction in dryer journal temperature reduces the amount of heat that is transferred through the journal to the oil in the bearing. The amount of heat that was transferred into the bearing housing area is approximately 2.6-3.3 kW when there is no insulating sleeve. With an insulating sleeve, the amount of heat transfer is reduced to 1.0-1.2 kW. This was found to agree well with the experimental measurements that are reported later in this paper.

HEAT TRANSFER ANALYSIS

The transient response of the journal temperature was also evaluated in this analysis. Typical results are shown in Fig. 9. This figure shows the temperature of the dryer journal as a function of time, as the dryer was heated up to 3.45 bar (50 psia), with and without an insulating sleeve in the journal. The curves represent the response to a stepchange in the dryer steam pressure. This is not a realistic assumption, but it was used to highlight the large difference in thermal response. Not only was the steady-state journal temperature reduced with a sleeve, but the rate of temperature change was also greatly reduced. The rate of increase could also be reduced by decreasing the warm-up rate for the dryer. Conversely, for a given warm-up rate, there is less risk of damaging the bearing race if the dryer has an insulating sleeve to protect the inner race.

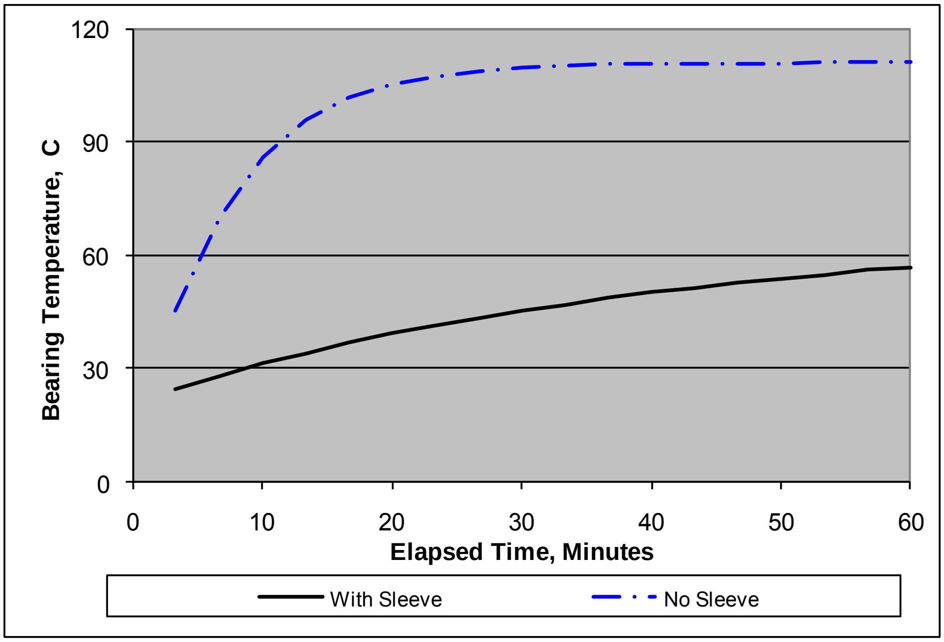

Figure 9. Transient Analysis of the Dryer Journal Temperature Response.

EXPERIMENTAL FACILITIES

The effectiveness of the dryer journal insulating sleeve was also measured directly, to confirm the above analytical results. One of two pilot dryers at the Kadant Johnson Research Center in Three Rivers Michigan was used for these tests. This dryer is 1.8 m (72") in diameter with an 8.76 m (345") in face. The front and back dryer heads each have integral journals. The dryer is rated for 11 bar steam pressure (160 psig), it has a maximum operating speed of 2000 mpm (6560 fpm), and it has a condensing capacity of approximately 50 kg/hr-m^2 (10 lb/hr-ft^2). For these tests, the dryer was equipped with a set of dryer bars for high heat transfer rates. The steam was supplied to the dryer through a dual flow rotary steam joint with a cantilever stationary syphon. A photograph of this dryer is show in Fig. 10.

Figure 10. Pilot Dryer Testing Facility.

Figure 11. Pilot Dryer Tending Side Bearing.

The dryer is mounted on spherical roller bearings. The drive side bearing is fixed. The tending side bearing is mounted in a housing that sits on rockers. Both dryer bearings of the pilot dryer are connected to a forced lubrication system, with the ability to measure the oil flow rate, the temperature of the oil entering the bearing housing, and the temperature of the oil leaving the bearing housing. A photograph of the tending side dryer bearing is shown in Fig. 11. This photograph shows the location of the oil temperature measuring points.

A photograph of the oil flow rate measurement system is shown in Fig. 12. The flow rate of the lubrication oil was controlled at 2.1 liter/min (0.55 gpm) for the tending side bearing and 1.7 liter/min (0.45 gpm) for the drive side bearing. The specific gravity of the oil was 0.88, giving a mass flow rate of the oil to the tending side bearing of 1.83 kg/min (4.04 lb/min).

Figure 12. Dryer Bearing Lubrication System.

TAPPI Technical Information Paper 0420-08 recommends that the oil flow rate on the steam joint side (the tending side on the pilot dryer) be 2 liter/min. The oil circulation system has a heater and a cooler. The oil supply temperature was controlled at 36 °C (97 °F). The dryer was set up to record the journal / head temperatures with an imaging infrared camera as the dryer steam pressure was increased and as the dryer speed was increased.

TESTING PROCEDURES

The effectiveness of the insulating sleeve was evaluated using measurements of both steady state and transient conditions, as outlined in the following sections.

The thermal response of the dryer heads, the rate of heat transfer to the bearing housings, and the steady-state operating heat transfer rates were monitored and recorded. In each case, the dryer was heated up from a cold condition, representing the start-up of a dryer following a cold shutdown.

The dryer was allowed to cool for a minimum of 16 hours between tests. The oil flow rate and supply temperature were held constant for all of these tests. For all tests, the supply oil temperature was controlled within 2.5 °C of the operating temperature of approximately 36 °C (97 °F).

Tests were run with two different steam pressures: 3.45 bar and 6.9 bar (50 psia and 100 psia). These steam pressures correspond to the conditions used in the above thermal analysis. Separate tests were conducted without an insulating sleeve, with an insulating sleeve that was not tightly sealed, and with a properly sealed insulating sleeve.

The dryer warm-up was controlled automatically using a dryer management steam control system. A fixed ramp rate is applied to the steam pressure control valve until the blow through steam reaches saturation. This indicated that all of the air had been removed from the dryer.

The steam pressure ramp rate is then increased until the pressure is close to the operating set-point, then the control system is switched to PID control, to bring the dryer steam pressure up to the intended operating pressure. This warm-up sequence takes approximately one hour.

At the beginning of each test, the dryer speed was kept constant at a low start-up speed of 150 mpm (500 fpm). After the dryer head temperature had reached its maximum value, the dryer speed was increased in steps, up to 1830 mpm (6000 fpm) in order to establish the effect of speed on the heat load to the lubrication oil.

The dryer head and journal temperatures were measured during the warm-up cycle using an AGEMA ThermoVision infrared camera. A photograph of the dryer journal is shown in Fig. 13. This photograph shows the end of the dryer shell, the dryer head and integral journal, and the bearing housing.

One of the thermal vision images of this same area is shown in Fig. 14. The temperature contours were recorded electronically, with the results displayed on temperature plots.

The dryer shown in these images had no insulating sleeve. The dryer was initially cold, then heated with steam to a pressure of 3.45 bar (50 psia). The thermal image shown in Fig. 14 was taken after the dryer journal temperature had stabilized.

Although the entire length of the journal could not be captured with this technique, the temperature plot clearly shows that although the temperature of the dryer journal is less than the temperature of the dryer head, it is still quite hot, even close to the dryer bearing housing.

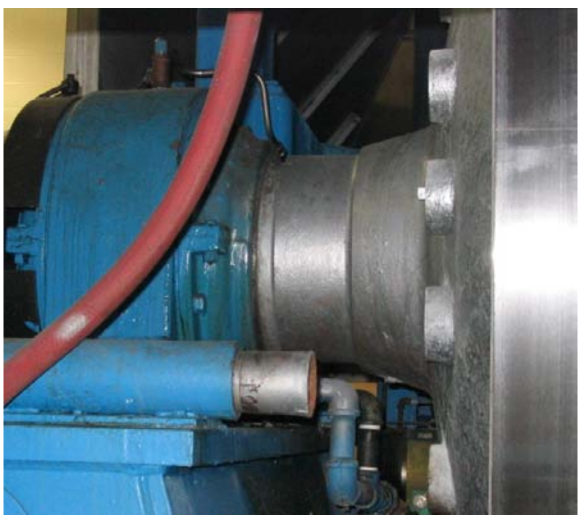

Figure 13. Dryer Tending Side Journal

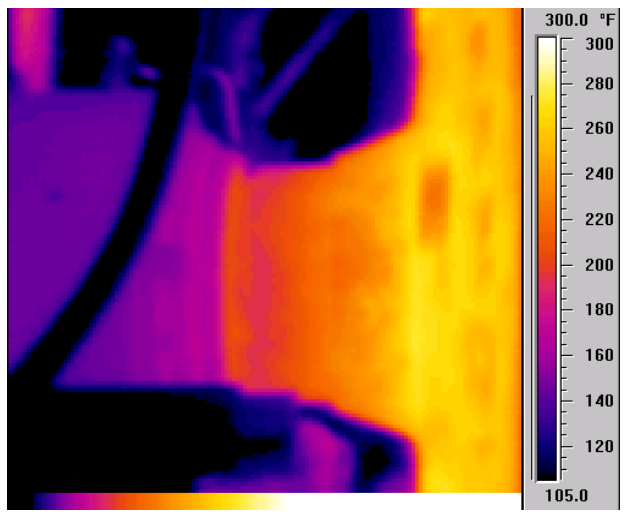

Figure 14. Thermal Image of Tending Side Journal.

TEST RESULTS – NO INSULATING SLEEVE

In the first test, the pilot dryer did not have a journal insulating sleeve installed. The cold dryer was heated with steam, with the steam pressure rising to 3.45 bar (50 psia).

The temperature-time response for the dryer journal was determined as the dryer was warmed up, using the average of three mid-frame temperature points taken near the bearing housing cover with the thermal imaging camera. The results are shown in Fig. 15. The dryer journal heated up from approximately 27 °C to 109 °C (80 °F to 228.4 °F) in about one hour, and then stabilized at that level.

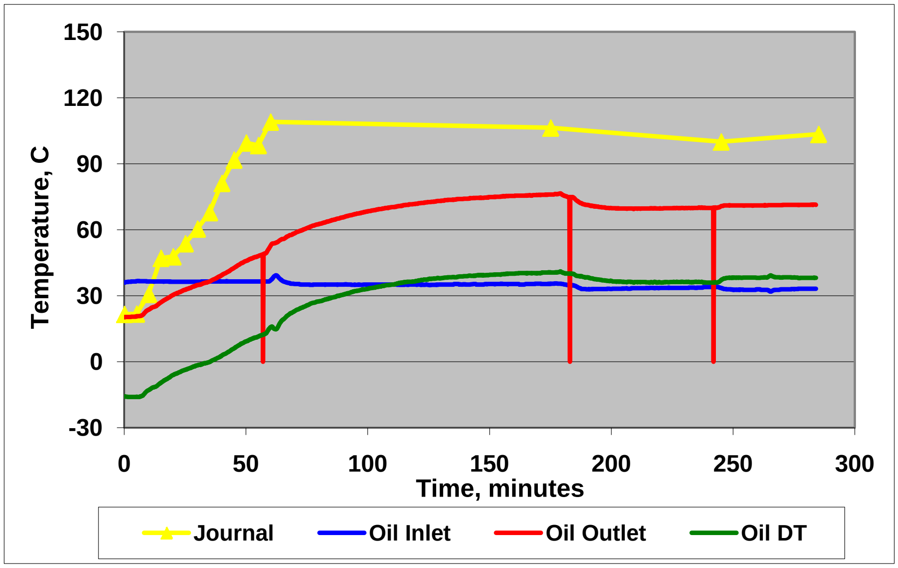

Figure 15. No Insulating Sleeve (3.45 bar steam pressure).

The oil supply and oil outlet (drain) temperatures were also recorded during these tests. These values are shown on this same graph. The supply oil temperature was maintained at approximately 36 °C (97° F). Note that the supply oil served to warm up the bearing for the first 35 minutes, but began removing heat from the bearing as the journal temperature increased.

The oil temperature increased as the amount of heat transferred through the dryer journal to the bearing increased. The temperature of the oil leaving the bearing housing increased from room temperature 21 °C (70 °F) until it eventually reached 76 °C (168 °F). The rise in the oil temperature lagged behind the rise in the temperature of the dryer head, reaching its maximum value after about 3 hours.

The amount of heat that was picked up by the lubrication oil is proportional to the rise in the temperature of the oil. The temperature rise is also shown in Fig. 15. A negative temperature rise indicates that the oil is heating the bearing. A positive temperature rise indicates that the oil is cooling the bearing. The maximum rise in this test was 40.4 °C (72.7 °F).

This graph also indicates points of speed change by vertical lines on the outlet oil temperature curve. The four test speeds are shown: 150 mpm, 610, 1220, and 1830 mpm (500 fpm, 2000, 4000, and 6000 fpm). The change in speed is seen to have a small effect on the amount of heat removed by the oil.

Similar results are shown in Fig. 16 for the same dryer configuration (no insulating sleeve). In this case, the dryer was again cold, then heated with steam to a pressure of 6.9 bar (100 psia).

The journal heated up from approximately 24 °C to 129 °C (76 °F to 263 °F) in about one hour, and then stabilized at that level. This temperature is approximately 19 °C (34 °F) above the journal temperature for the previous lower pressure test (also with no journal insulating sleeve). The difference in the steam temperature was 26 °C (46 °F), so the increase in journal temperature does not directly track the steam temperature.

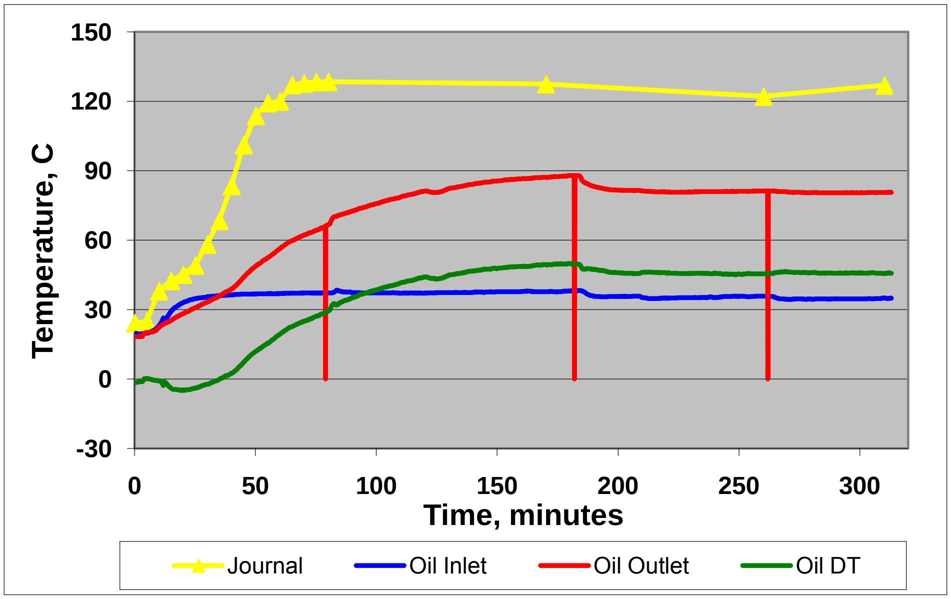

Figure 16. No Insulating Sleeve – 6.90 bar steam pressure.

The supply oil temperature was maintained at the same level as in the previous test. Again, the supply oil initially served to warm up the bearing then began removing heat as the journal temperature increased. The temperature of the oil leaving the bearing housing eventually reached 88 °C (190 °F). This is 12 °C (21 °F) hotter than the previous test that was run at 3.45 bar (50 psia). The oil temperature lagged behind the temperature of the dryer head, again taking about 3 hours to reach its maximum value.

TEST RESULTS – PARTIALLY SEALED INSULATING SLEEVE

In the next group of tests, a complete insulating sleeve was installed in the pilot dryer, but the sleeve was installed with a small leak past the o-ring seal and the weep hole was plugged so that steam that leaked past the seal could not escape. During this series of tests, approximately 1 liter of condensate collected in the annular area between the insulating sleeve and the dryer journal bore. The results of the test are shown in Fig. 17.

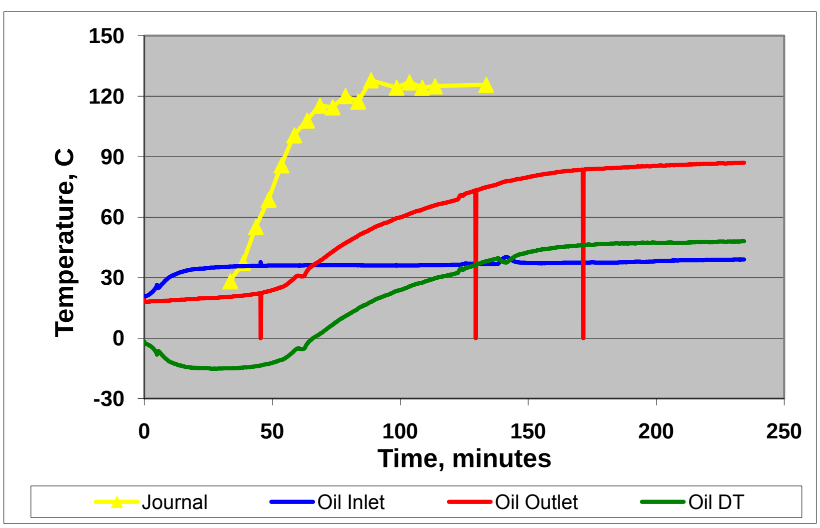

Figure 17. Partially Sealed Insulating Sleeve – 6.90 bar steam pressure.

In this test, the dryer was again initially at room temperature, then heated with steam to a pressure of 6.9 bar (100 psia). The journal heated up from approximately 27 to 128 °C (80 °F to 262 °F) in about one hour, and then stabilized at that level. This is the same journal temperature reached by the dryer warming up to the same steam pressure without any insulating sleeve at all. That is, the partly-sealed sleeve provided little improvement over the dryer that had no sleeve at all.

In this test, the supply oil warmed up the dryer bearing for the first 35 minutes, then the dryer warm-up sequence was started. The oil system continued to heat the bearing for another 30 minutes, then began removing heat as the journal temperature increased. Although the oil outlet temperature lagged behind the temperature of the dryer head, it eventually reached 87 °C (188 °F). This is just slightly cooler than the oil outlet temperature when the dryer had no insulating sleeve.

TEST RESULTS – COMPLETELY SEALED INSULATING SLEEVE

The insulating sleeve was then removed and re-installed in the dryer, but this time the weep hole was opened and a proper seal was provided to prevent steam from migrating into the annular area between the insulating sleeve and the dryer journal bore. The results of these tests are shown in Fig. 18.

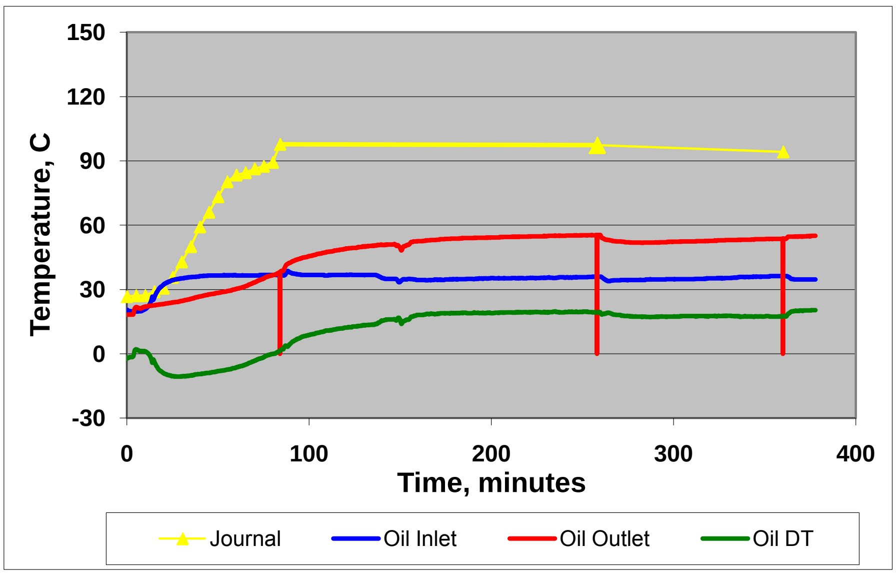

Figure 18. Completely Sealed Insulating Sleeve – 6.90 bar steam pressure.

In this test, the journal heated up in about one hour from approximately 27 to 98 °C (80 °F to 208 °F) and stabilized at that level. This is 30 °C (54 °F) cooler than the temperature reached with a dryer with no insulating sleeve or with a sleeve that was not properly sealed.

Once again, the oil warmed up the bearing at the beginning of the cycle, then began removing heat. The temperature of the oil leaving the bearing housing never exceeded 55 °C (131 °F). This is 33 °C (59 °F) below the temperature of the outlet oil when the dryer did not have an insulating sleeve. The oil temperature rise again lagged behind the temperature of the dryer head. The stable oil temperature and journal temperature values are much lower for the dryer with a properly sealed sleeve than for the dryer without a properly sealed sleeve.

The amount of heat that was transferred to the lubrication oil system in the dryer without an insulating sleeve (or with an inadequately sealed sleeve) was reduced by nearly 60% by the installation of a properly sealed journal insulating sleeve. This is a clear indication of the effectiveness of an insulating sleeve.

SUMMARY OF STEADY STATE RESULTS

For each test condition, the dryer was allowed to reach thermal stability (that is, the dryer journal and oil outlet temperatures were stable). The dryer head temperature, oil outlet temperature, and heat transfer quantity were then recorded. The heat transfer rate was calculated from the oil flow rate and oil temperature rise as follows:

$$Q = m\, c_p\, (T_{out} - T_{in}) \qquad (1)$$

where:

Q = Heat transfer rate from the bearing, kW (Btu/hr)
m = Mass flow rate of oil, kg/min (lb/hr)
c_p = Specific heat of oil, 0.47 calorie/g-C (0.47 Btu/lb-F)
T_{out} = Temperature of the oil leaving the bearing housing, °C (°F)
T_{in} = Temperature of the oil leaving the bearing housing, °C (°F)

The results are shown in Table II. These results compare very well to the results of the theoretical analysis.

Table II. Steady State Results.

No.	Type	Pressure bar/psia	Steam Temp C/F	Journal Temp C/F	Oil Outlet Temp C/F	Rise in Oil Temp C/F	Oil Heating kW/Btu/hr
1	No Sleeve	3.45 / 50	138 / 281	109 / 228	76 / 168	40 / 73	2.49 / 8510
2	No Sleeve	6.90 / 100	164 / 327	127 / 261	88 / 190	50 / 90	3.20 / 10925
3	Leaky Sleeve	3.45 / 50	138 / 281	105 / 221	72 / 162	34 / 61	2.16 / 7360
4	Leaky Sleeve	6.90 / 100	164 / 327	128 / 162	87 / 188	48 / 87	3.10 / 10580
5	Sealed Sleeve	3.45 / 50	138 / 281	82 / 179	50 / 123	16 / 28	1.08 / 3680
6	Sealed Sleeve	6.90 / 100	164 / 327	98 / 208	55 / 131	20 / 35	1.21 / 4140

The results are also summarized in Fig. 19 and Fig. 20. Figure 19 shows the effectiveness of the dryer journal insulating sleeve in reducing the temperature of the dryer journal. The dryer journal temperature increases with increasing steam pressure, but is reduced significantly by a properly sealed sleeve. In steady state, a properly sealed insulating sleeve will reduce the dryer journal temperature by 27-29 °C (49-53 °F).

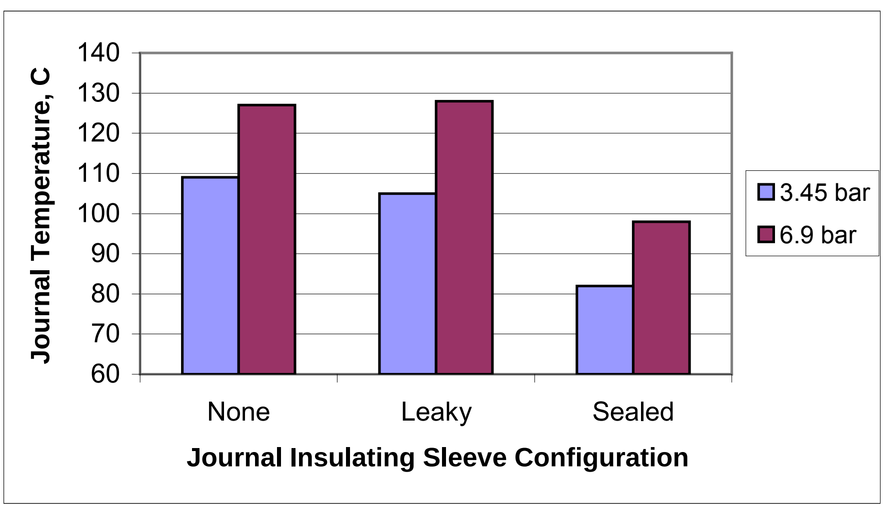

Figure 19. Effect of Journal Insulating Sleeve on Journal Temperature.

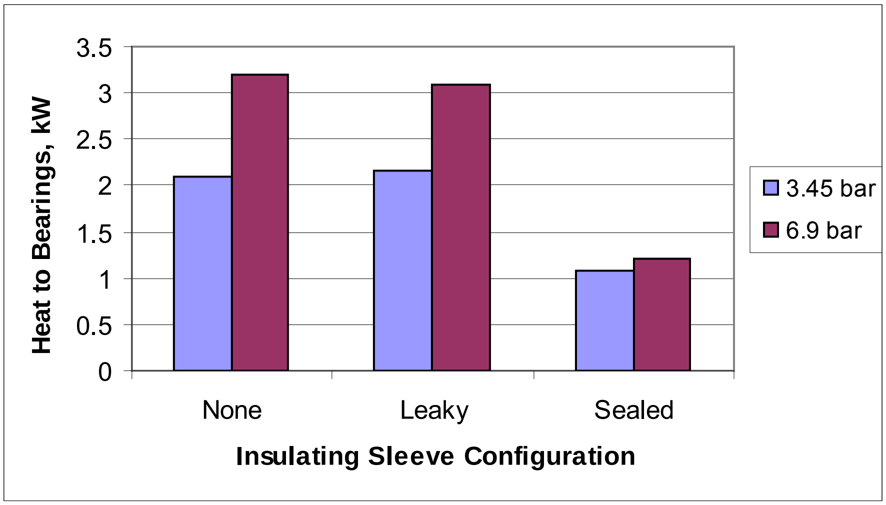

Figure 20. Effect of Journal Insulating Sleeve on Reducing Heat Transfer.

Figure 20 shows the effectiveness of the dryer journal insulating sleeve in reducing the amount of heat that must be removed from the dryer bearings. The amount of heat that is transferred to the dryer bearing (and removed by the lubrication oil) increases with increasing steam temperature. The amount of heat is reduced, however, by the addition of an insulating sleeve. The reduction in heat transfer was 57-62%. This is a significant reduction in the amount of heat that must be removed from the bearing housings and provides a corresponding reduction in the rise in oil temperature. Little benefit is found from an insulating sleeve that is leaking.

As the dryer is warming up, the oil removes an increasing amount of heat. This rate of heat transfer eventually stabilizes. The time constant for this rise was established using the measured oil temperature rise, beginning when the oil began removing heat. An exponential curve fits the data quite well, as shown in Fig. 21.

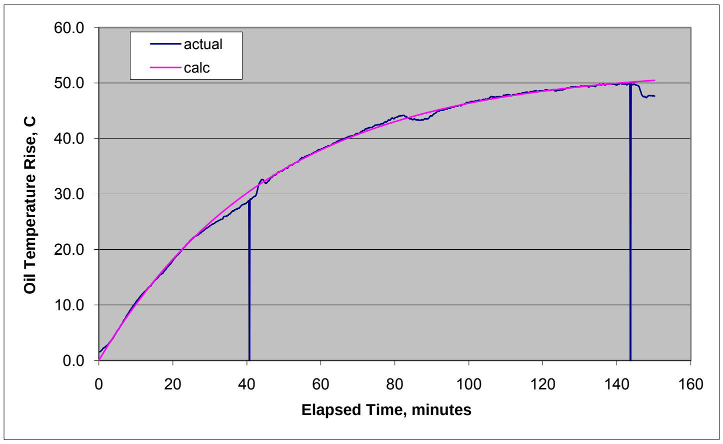

Figure 21. Oil Temperature Rise – 6.90 bar steam pressure.

The time constant was determined for each of the tests using the following format to describe the oil temperature rise, where t_0 = time constant:

$$\Delta T = (T_{out} - T_{in})_{max} \; [1 - \exp(-t/t_0)] \qquad (2)$$

The results are shown in Table III. This table compares the response for each of the configurations. It also shows the time delay before the oil began cooling the bearing. The time is measured from the point at which the steam supply valve begins to open. For this dryer, with an insulating sleeve installed, the time constant for the rise in oil temperature was 2460 seconds (41 minutes).

Table III. Time Constant and Heating Delay.

No.	Type	Pressure bar/psia	Time Constant, seconds	Heating Delay, seconds
1	No Sleeve	3.45 / 50	2160	2400
2	No Sleeve	6.90 / 100	2820	2280
3	Leaky Sleeve	3.45 / 50	2880	3060
4	Leaky Sleeve	6.90 / 100	3000	3960
5	Sealed Sleeve	3.45 / 50	2940	4440
6	Sealed Sleeve	6.90 / 100	2460	4680

The time constants determined from these tests do not indicate any clear difference, although the final temperature levels were significantly lower with an insulating sleeve installed. The insulating sleeve was also found to provide a measurable increase in the time required for the dryer bearing to heat up above the oil temperature. This longer time delay helps in reducing the stress on the inner bearing race due to differential thermal expansion. The time delay is shown graphically in Fig. 22.

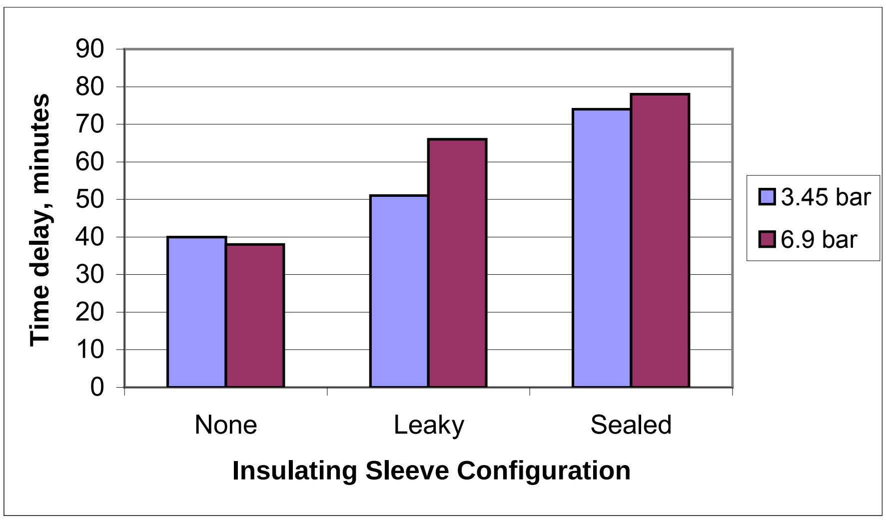

Figure 22. Effectiveness of Insulating Sleeve on Bearing Heating Time Delay.

DRYER SPEED EFFECTS

For each of the test configurations and steam pressures, the dryer speed was increased progressively until it reached 1830 mpm (6000 fpm). The outlet oil temperature and dryer journal temperature were recorded during this time. Select data is shown in Fig. 23.

The dryer speed did not appear to have a significant effect on the amount of heat that is removed from the dryer bearings. As a general observation, it appears that increasing dryer speed has a minor cooling effect on the dryer head and journal, with a corresponding reduction in the amount of heat that must be removed from the bearings.

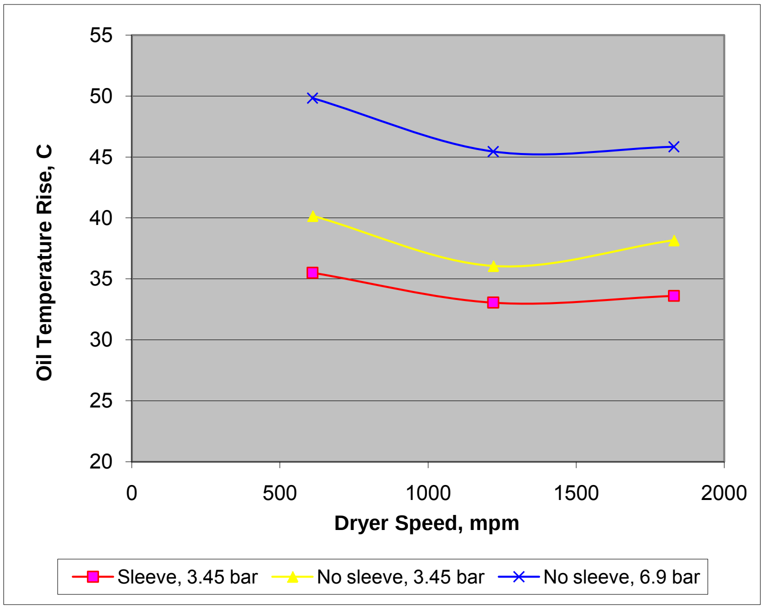

Figure 23. Effect of Dryer Speed on Bearing Heat Load.

SUMMARY

When a paper dryer is warmed up, the dryer journal temperature increases, the temperature of the inner bearing race increases, the temperature of the oil in the bearing increases, and the amount of heat that is removed by the lubrication oil increases.

A properly sealed insulating sleeve greatly reduces the operating dryer journal temperature, the temperature of the bearing race, the temperature of the lubrication oil, and the amount of heat that must be removed by the oil. The rate of increase of the temperatures is highly dependent on the rate at which the dryer is warmed up. This can be reduced by proper and consistent warm-up procedures.

The effectiveness of the sleeve depends on how well it is sealed. A non-vented and improperly sealed sleeve contributes very little to the reduction of heat transfer. Even a relatively small leak can result in significant loss in the effectiveness of the sleeve, resulting in an increase in race temperature and an increase in heat transfer to the bearings and oil lubrication system.

If the heat flow to the bearing is less than 2.6 kW (9000 Btu/hr), then it may be acceptable to operate a dryer without an insulating sleeve, particularly if the warm-up procedures are carefully controlled. If a sleeve is installed, it will reduce the heat flow to the bearing to way below this limit, even if the steam pressure is as high as 11 bar (160 psig). Above this heat transfer limit, the viscosity drops too much, the oil can begin to carbonize, and the thermal response of the dryer journal may be too fast.

Since the dryer journal temperature and the heat transfer rate are both lower at lower operating dryer steam pressures, it may be acceptable to operate without a journal insulating sleeve, provided the operating steam pressures are kept below some threshold and the rate of warm-up is carefully controlled. If the dryer journal does not have an insulating sleeve, the dryer steam pressure would normally be limited to about 5 bar (75 psig). This pressure is equivalent to the steam temperature of 160 °C (320 °F).

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