THERMOGRAPHIC INSPECTION OF OPERATING PUMPING UNITS IN PERMIAN BASIN OIL FIELDS

Richard E. Witte
Witte Energy Management

ABSTRACT

Thermographic inspection, through the use of portable infrared imagers and non-contact spot radiometers, has been performed on approximately three thousand pumping units in many active Permian Basin oil fields within the past two and one-half years. Infrared imagers with camera adaptability were used to inspect saddle or Sampson post bearings, equalizer or tail bearings, wrist pin bearings, exterior gear box bearings, electric motor and related switch gear on each beam-type pumping unit. In many instances, pole-mounted transformers were scanned for thermal differentials, completing the wellsite inspection.

This technique detects and isolates abnormal variations in the radiant energy emitted from the bearings, motor, switch gear and transformers. Thus, qualitative and quantitative data on each problem bearing or electrical component was precisely established. Thermograms and photographs were taken to document the condition.

INTRODUCTION

As the title of this paper might suggest, it is not immediately clear whether infrared sensing of operating pumping units is an industrial process application, a facilities maintenance application, a thermal engineering study, or part of the evolution of thermal sensing. Certainly, it is a new trend.

BACKGROUND

Since the first pumping unit was installed on an oil well in Pennsylvania in the 1800's, the method of inspection applied to rotating and oscillating parts on beam-type pumping units has remained essentially unchanged. This method requires a "pumper" to apply subjective values acquired through varying experiences to determine by sight, sound and touch that a given bearing is functioning as designed. This imprecise method of bearing inspection is still believed adequate by many in the production end of the oil business today. In fairness, however, the sight-sound-touch method has served the industry quite well, since no other method could economically compete with it. At least not until now.

Today, economic pressure is on the oil companies--both majors and independents--to achieve more efficient and cost effective methods of producing oil. This forced austerity has pushed infrared imaging, or remote sensing, to the forefront as a cost-effective analytical tool in the development of predictive and preventive maintenance programs.

APPLICATION

Infrared inspection of a beam pumping unit consists of:

1. The actual scan using the infrared imager upon immediate shutdown of the unit. For accurate thermal sensing, it is desirable to have the unit in motion a minimum of 15 minutes to friction load the bearings and generate operating thermal energy.

2. Immediate temperature measurement of any thermal anomalies found in the bearings, or in the motor and electrical gear. For this application, a spot radiometer with selectable emissivity was used to establish temperatures.

3. Photographic and thermographic recording of the overheated bearing(s) and electrically energized equipment.

All electric gear required to operate the pumping unit is scanned. This includes the 3-phase 480-volt oil field motor, the control box which contains the main switch, fuse holders, contactor, overload, lightning arrestors, control transformer, undervoltage relays and time clock. The pumping unit is returned to operation while the electrical scan is performed, so that all elements are energized. Temperature anomalies are also measured and recorded, using the noncontact radiometer. If anomalies are present, these are also recorded photographically and thermographically. Since the purpose of the thermal inspection is to identify and isolate problems for the client before these lead to catastrophic failure and lost oil production, voltage and amperage are measured across all overloads in the electrical gear; hence, these measurements are considered an integral part of any thermographic inspection of pumping units.

Due to their exposed locations, pumping units are subject to a wide range of ambient temperatures, wind conditions, and solar variations. Within the Permian Basin of Texas and New Mexico, where the data for this paper originated, air temperatures during actual field inspection ranged from 30^{o} to 110^{o} F. Wind velocities ranged from calm to 30 MPH or higher.

Since no literature existed on infrared scanning of beam-type pumping units three years ago, and little exists today, research both in the field and laboratory and extensive study of literature have produced a data base that allows accurate parameters to be set for replacement or repair of bearings, motors and electrical gear. This statement rests on the assumption that consistent standards of performance are met in the field measurement of temperatures, and subsequent analysis of the physical properties involved.

Much of the pumping unit thermal imaging occurs in bright sunlight. This presents special problems in both imaging and photographing the results. The success and accuracy of each inspection thereby relies upon the operator's ability to control the imaging process while large amounts of reflected energy as well as emitted radiation are being received in the imager. Emitted radiation is the only energy component of interest to us in this inspection process. Reflected energy both compounds and confuses the analysis. If the inspection could be conducted at night--as it is in infrared roof surveys--the imaging process could be very much simplified. Of course, this is not practical in most oil fields.

BEARINGS

Heat Dissipation in a Bearing

The problem of determining heat flow from a bearing in a specific application is rather complex. To establish equations with any accuracy that would be applicable in a general sense is not practical. However, the availability of thermal imaging systems has for the first time allowed the visual tracking of those factors affecting the rate of heat dissipation from typical bearing applications.

In general, the factors affecting the rate of heat dissipation include the following:

1. Temperature gradient from bearing to housing. This is affected by size and configuration of the housing and any external cooling such as fan action of rotating parts, or convection due to high air or wind movement.

2. Temperature gradient from bearing to shaft. Any other heat sources such as gears and additional bearings and their proximity to the bearing considered will influence the temperature of the shaft.

3. The heat carried away by a circulating oil system, such as that found in the gear box of a pumping unit.

Bearing Types Used in Beam Pumping Units

Principal bearing types used in the design and manufacture of beam-type pumping units are: (1) Cylindrical roller, (2) spherical roller, (3) ball, and (4) sleeve bearings.

Although steel and bronze sleeve bearings have been used for decades, a recent development in sleeve bearing design is the use of a composite teflon-based material (polytetrafluoroethylene). Teflon can be used at temperatures up to approximately 550^{o} F., limited by the thermal capabilities of the other materials making up the bearing composite. Teflon is strong, impervious, tough, readily machined, and resistant to nearly all chemicals and solvents. It also has a low coefficient of friction, making it ideal for many oil-less or greaseless applications.

For purposes of structural fabrication, teflon bearings have certain desirable properties not possessed by metals. They display excellent characteristics as electrical insulators and also as thermal insulators. It is here that the performance of thermography by analogy becomes high risk. Thermal radiation from a teflon sleeve bearing through the bearing wall is nearly nonexistent when compared to a similar steel sleeve bearing.

The heat generated within the bearing bore of a teflon bearing must escape in some manner, and does. Its exit, however, totally confuses the analogous assumptions made from the extension of empirical data--both visual and numerical--obtained from steel sleeve bearings by thermography. These temperature patterns are a consequence of the physical phenomenon occurring within the bearing systems and establishes the fact that radiation from similar surfaces depends upon other than surface temperature, and that diagnosis of the cause for a particular surface pattern requires a considerable talent and knowledge, not only with the use of thermal sensing systems, but also with the systems being analyzed.

Since teflon is thermally resistant to heat transfer, the energy created by the oscillating or rotating action within the bearing bore is largely removed through the bearing shaft or pin. In turn, this radiant energy moves into the clamps that hold the shaft in place. From the clamps or plates this energy is passed into the atmosphere by radiation and convection. However, the expansion of the bearing shaft that takes place through retention of a larger component of the frictional heat adds another dimension to the proper or satisfactory application of a teflon sleeve bearing. Retention of more energy in the shaft causes a greater change in the expansion of the shaft. As the shaft expands radially, it fills more of the teflon bearing bore. Ideally, the shaft should not make contact with more than 180^{o} of the bearing wall, at the shaft's maximum temperature, since no load-bearing component occurs beyond this point in an oscillating bearing application on a beam pumping unit. However, if tolerance stack-up occurs, along with a high coefficient of expansion in the bearing shaft material, the entire bore of the teflon bearing is filled by the shaft. If the tolerance stack-up is great enough and sufficient pressure is exerted radially on the bearing wall for the total circumference of the bore, a significant increase in temperature will exist. This temperature is not likely to reach the thermal softening level of the teflon; however, the coefficient of friction is greatly increased in the bearing. This may cause the bearing to split, or rotate in the housing. Additional horsepower is required to overcome the friction component. Higher horsepower demands more electric current. The overall result is an increase in the utility charge for operating the well, and reduced life for the bearing.

Closer control of manufacturing tolerances must inevitably result where dissimilar materials are matched in load-bearing applications if bearing life and efficiency are to be increased. Thermal imaging should obviously take an important place in this process, with economic gains for everyone.

GREASE LUBRICATION

Grease life in a bearing is governed by such factors as speed, load, humidity, type of service and frequency of lubrication. Bearing life is, therefore, directly responsive to the attention given to selection of a grease and its frequency of application under operating conditions. The actual temperature of the bearing while running is the most critical factor to be considered in choosing a grease. In applications typical of beam-type pumping units, where subzero to elevated temperatures, high loads, severe dirt, high humidity and other extreme conditions are encountered, accelerated deterioration of the grease may occur.

Rolling bearing greases are usually a mixture of lubricating oil and soap base. The latter merely acts to keep the oil in suspension. When moving parts of a bearing come in contact with the grease, a small quantity of oil will adhere to the bearing or shaft surfaces. Oil is, therefore, removed from the grease near the rotating parts. The oil that is picked up by the bearing is gradually broken down by oxidation or lost by evaporation, centrifugal force, etc. Bleeding of the grease should, therefore, take place so as to continue to supply a small quantity of oil. But the bearing cannot function properly unless the supply of oil keeps up with the demand. This process cannot go on indefinitely. In due course, the grease will oxidize or the oil in the grease near the rotating parts may be depleted. High temperature and ultimate bearing failure results.

In greasing rolling bearings the use of high pressure equipment is not only unnecessary but is generally undesirable unless used with great care. Unfortunately, most oil field pumping units are serviced with high pressure grease apparatus. High pressure may damage the bearings, blow out the seals, cause unnecessary loss of grease, create danger of overheating due to overgreasing and produce unsightly conditions around the bearing. All of these conditions are known to exist on many pumping units in Permian Basin oil fields.

SUMMARY

The significance of infrared inspection of bearings on oil field pumping units is that a bearing does not fail instantaneously. It is a progressive failure, one which generates a higher temperature differential (Δt) as the rate or speed of failure increases. However, once a certain temperature level is achieved within the bearing, catastrophic failure becomes imminent. Thermography thus provides an early warning system for bearing failure.

Problems in electrically energized components of pumping units usually appear as hot spots due to localized thermal overloads, phase imbalance, weak components, mechanical overload, poor electrical connections, or corrosion. Thermographic inspection provides a rapid and highly accurate isolation of these hot spots and thermal overloads. Thermograms provide the visual evidence required for maintenance correction.

There are multiple benefits to be achieved through the use of thermographic inspection of pumping units and other electrical and mechanical equipment in the operating oil field. Among others, these benefits are:

1. Early detection of overheated bearings, electric motors and energized equipment--often far in advance of failure--can substantially reduce repair costs.

2. Repairs to electric gear frequently lowers power consumption, thereby reducing monthly utility charges.

3. Reduces downtime through fewer catastrophic failures.

4. Allows scheduled maintenance, at reduced costs, where problems do not require immediate correction.

5. Aids development of both predictive and preventative maintenance programs.

6. Lowers lost production costs.

7. Allows comparative analysis of performance and costs between field units, or between two or more fields.

8. Rate of inspection--the number of pumping units inspected per day--is high compared to other methods.

9. Cost effectiveness and accuracy exceeds any other type inspection now available.

CONCLUSION

The application of thermography to beam-type oil field pumping units should not be considered standard, straight-forward thermal imaging. The wide range in bearing systems, materials, load, size, speed and atmospheric conditions places an ethical requirement on all individuals who elect to enter this industrial area of thermal imaging. Precise knowledge of temperatures, their causes and effects on the systems under study, demands an intellectual commitment to scientific and professional standards. The conceptual simplicity of thermography belies the complex, multidimensional, multidisciplinary nature of the subject.

REFERENCES

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2. Courville, George E., Professionalism in Commercial Infrared Sensing-an Update, Energy Division, Oak Ridge National Laboratory (Thermosense V), Proc. SPIE 371, pp. 32-35, 1982.

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EXAMPLES OF INFRARED IMAGING

The following examples of overheated bearings on beam-type pumping units are representative of bearing failures found through thermal imaging. A brief description of each in-process failure is presented with each pair of photograph-thermograms.

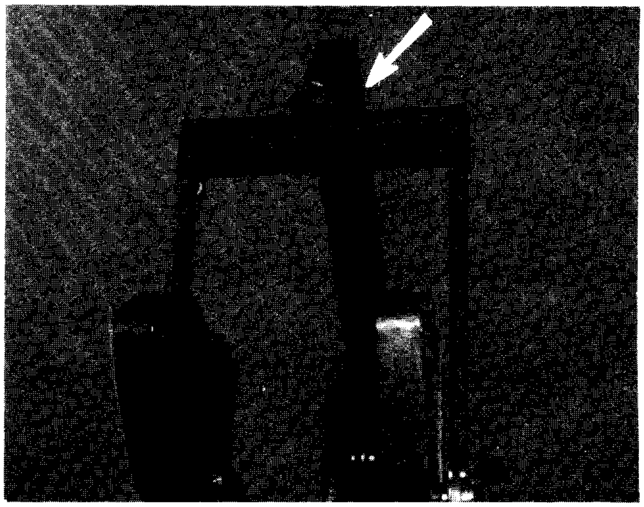

Fig. 1-Photograph of tail bearing.

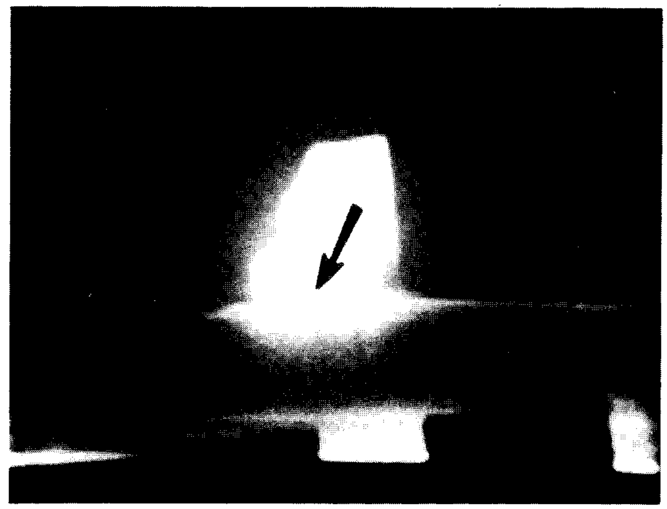

Fig. 2-Thermogram of tail bearing.

Figures 1 and 2 present a case for thermal imaging as a quality control or warranty device. The subject pumping unit was 45 days old. The temperature in the bearing was found to be 60° F. above ambient. Failure was imminent. The manufacturer was notified, the bearing replaced at no cost to the customer, saving him approximately $2,000.

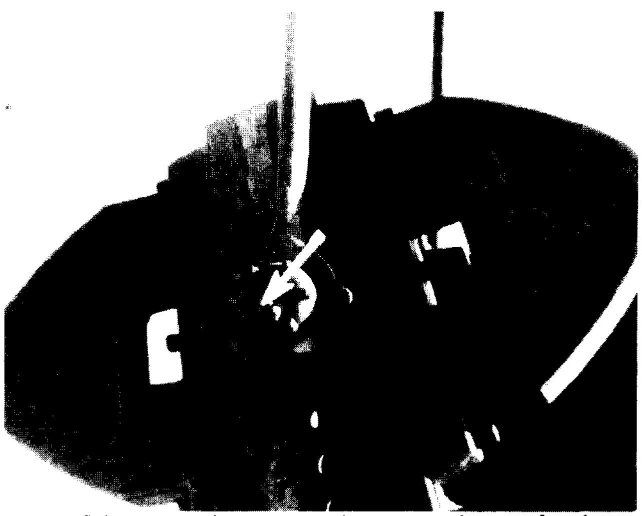

Fig. 3-Photograph of wrist-pin bearing.

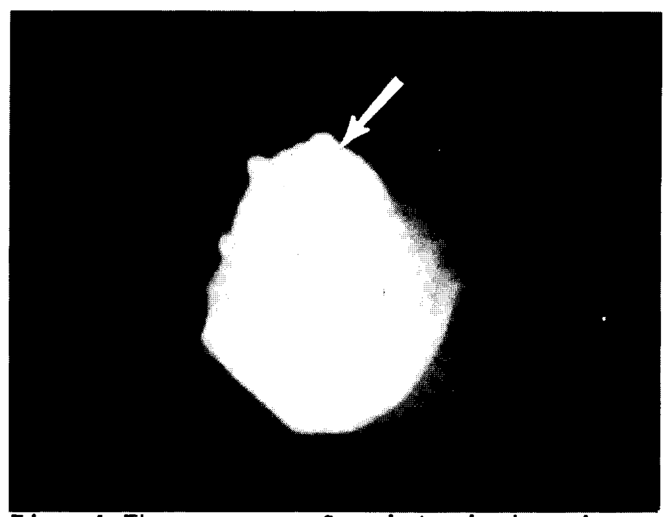

Fig. 4-Thermogram of wrist-pin bearing.

Figures 3 and 4 present in-process failure of a wrist-pin bearing. Thermal imaging saved this customer approximately $10,000 in repairs and lost oil production. Catastrophic failure of a wrist-pin bearing can cause a pumping unit to destroy itself. Temperature in the bearing was 40° F. above ambient.

Fig. 5-Photograph of saddle bearing.

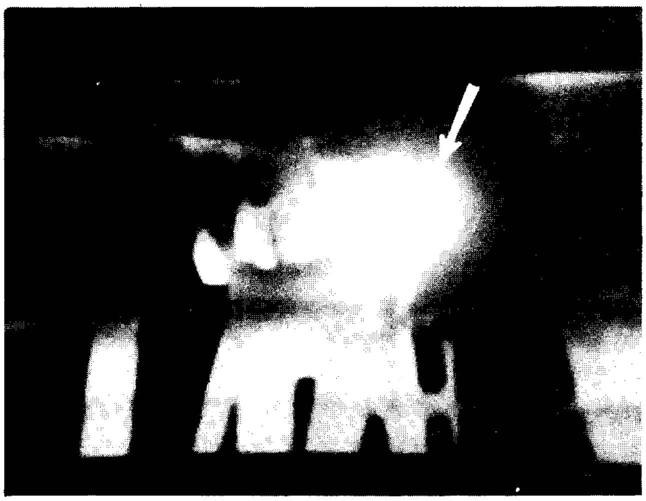

Fig. 6-Thermogram of saddle bearing.

Figures 5 and 6 graphically display failure of one bearing on the saddle while the other continues to operate at normal temperatures. Temperature in the bearing is 33^{o} F. above ambient.

This saddle bearing example (below) is typical of the temperature pattern and heat transfer that occurs in a teflon-base sleeve bearing. This bearing replaced a steel sleeve bearing.

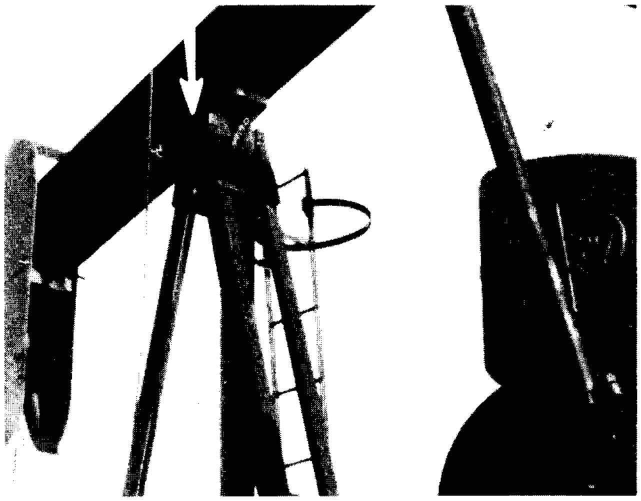

Fig. 7-Photograph of teflon saddle bearing.

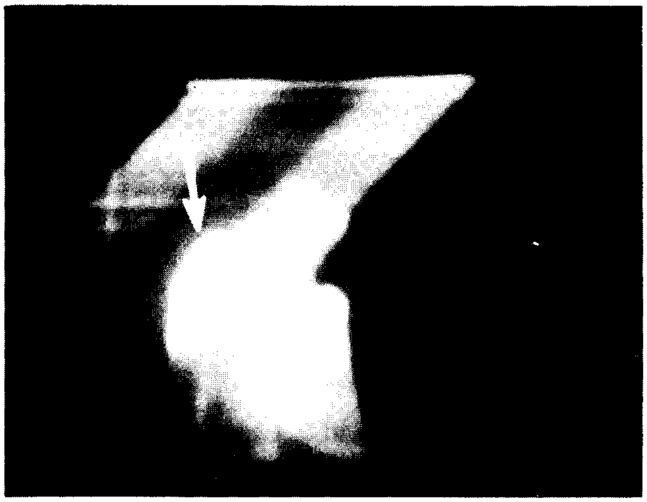

Fig. 8-Thermogram of teflon saddle bearing.

The left clamp supporting this saddle bearing has a 49^{o} F. temperature above ambient metal, while the right clamp has a 37^{o} F. rise. The higher temperature is on the cooler side of the unit, indicating greater wear on the left. Recommendation: Replace bearing.

Developing problems in electrically energized components can be quickly and accurately isolated by thermal imaging. Following are two examples that show how infrared inspection represents "Manaaement through Insight."

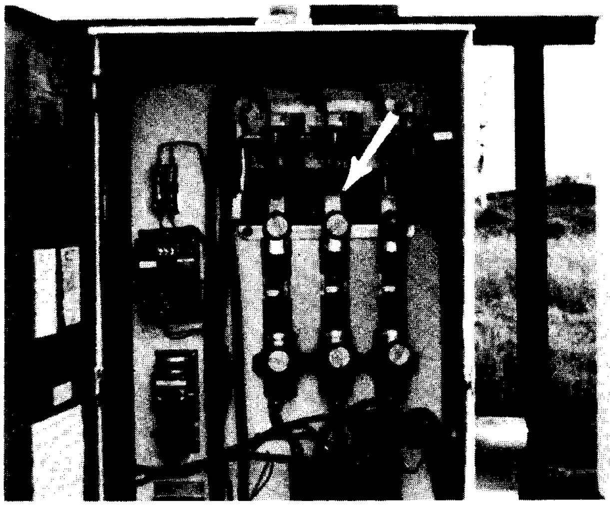

Fig. 9-Photograph of control box.

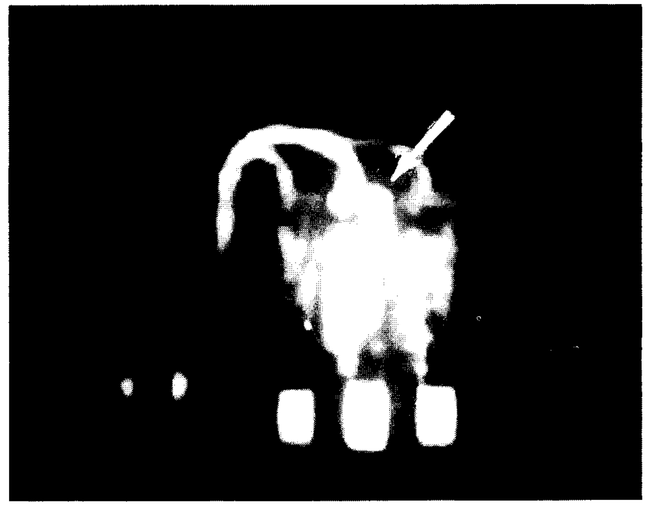

Fig. 10-Thermogram of control box.

Figures 9 and 10 illustrate how a simple electrical component such as a hot fuse, fuse clip and contactor can result in a partial system failure that can cause extensive damage to the electric motor and subsequent lost production. Failure of the fuse or melt-down of the middle line can, and often will, allow the motor to operate single-phase. If not caught by an alert pumper, the motor ultimately burns out.

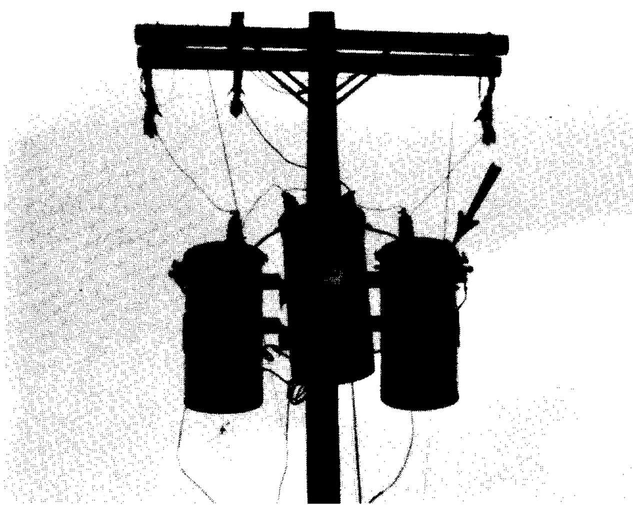

Fig. 11-Photograph of two malfunctioning transformers.

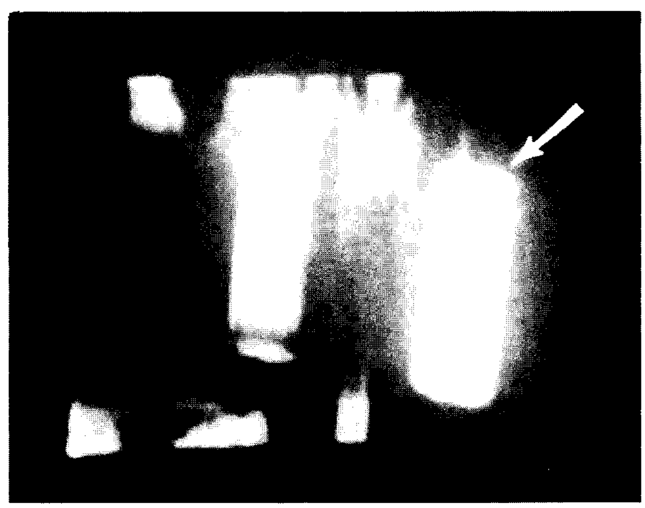

Fig. 12-Thermogram of the same transformers.

Whether the transformers are owned by the oil company or the utility company, the cost of energy being wasted into the atmosphere is being paid for by the oil company, dependent upon the meter location. In most cases, the oil producer pays. Two of these transformers are in trouble, the right unit operating at a 36^{o} C. higher temperature than the center one. Failure of the right unit could allow the motor to operate single-phase, potentially causing motor failure if not discovered first.