AFAPL-TR-65-3

# DEVELOPMENT OF HIGH TEMPERATURE SEAL-LUBRICANT DEPOSIT EVALUATION TECHNIQUES

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# FOREWORD

This report was prepared by Koppers Company, Inc., under USAF Contract No. AF 33(615)-1112. This contract was initiated under Project No. 3044, "Aerospace Lubricants," Task No. 304401, "Turbine Engine Lubrication Engineering". The work was administered under the direction of the AF Aero Propulsion Laboratory, Research and Technology Division, Mr. Leon J. DeBrohun, project engineer.

This report covers work conducted from 1 January 1964 to 30 November 1964.

Three previous reports, ASD-TDR-62-253, "Research on the Lubricant for a Mach 4 Class Engine," ASD-TDR-63-246, "Development of High Temperature Seal-Lubricant Deposit Evaluation Techniques," and APL-TDR-64-78 "Development of High Temperature Seal-Lubricant Deposit Evaluation Techniques" were published under Contract No. AF 33(616)-7893 of the same project.

## ABSTRACT

Testing techniques for evaluating experimental gas turbine lubricants in face-riding main shaft jet engine seals at temperatures representative of high mach aircraft have been under development. Using the ASD Seal Rig, repeatable evaluation techniques were developed for MIL-L-9236 type lubricants that were indicative of performance in engines. The present phase of the program is directed towards refining evaluation equipment and preparing the rig for more advanced research work. During the period covered by this report, internal seal head air heating to 1160°F, preliminary evaluation studies using 0-60-19 and 0-60-18 lubricants, and engineering features of a new seal head design were investigated. An adaptor to permit the use of the seal head with Erdco test equipment is being designed.

This technical documentary report has been reviewed and is approved.

BLACKWELL C. DUNNAM
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RCS AFSC-R47

# 1. Introduction

This report describes the continuation of a research program initiated under Contract AF 33(616)-7893. The objective of the program is to develop techniques for evaluating experimental gas turbine lubricants that will give results indicative of lubricant performance in high mach aircraft using test equipment compatible with the Erdco Universal Tester. A suitable evaluation test, using the "ASD Seal Rig", was developed for MIL-L-9236 type lubricants. The test equipment was redesigned to make it readily adaptable to the Erdco equipment, to incorporate engineering improvements, and to prepare the rig for more advanced lubricant evaluation research. Internal-seal head air heating was the major change required to fulfill the above conditions. A new seal head was designed and constructed and the original seal head was modified to utilize the same internal components as the new design. The modified head was operated and found to be functional except the internal air heater failed to meet design conditions. Complete details of the above work are given in reports ASD TDR 63-246 dated March 1963, and APL TDR 64-78 dated January 1964.

During the period covered by this report, the modified head has been used to establish design requirements for obtaining internal-seal head air temperatures of 1100°F or more. This involved studies using a 5 kilowatt air heater, a 15 kilowatt air heater, and minor seal head design changes to reduce system heat losses. Also included were methods of air temperature control. The studies led to establishing requirements needed to obtain desired air temperatures. Accordingly, design changes were made to the new seal head which is currently being used in a research program to establish (1) reasonable seal-lubricant test life, (2) repeatability of results, and (3) engineering features of the equipment.

Using O-60-19 lubricant, the new seal head (RTD Seal Rig) showed significant differences in test life and deposit formations than those previously obtained for MIL-L-9236 lubricant evaluations. Testing is, therefore, being conducted at a lower temperature level using O-60-18 lubricant in order to more readily establish the parameters necessary for significant lubricant evaluation. As evaluation techniques are established, temperature levels will be increased stepwise to evaluate more advanced lubricants. Concurrent with the evaluation program, an adaptor is being designed that will facilitate the use of the seal head with Erdco equipment.

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## 2. Results and Discussion

### A. Air Heater Design

A cylindrical annulus about 3 inches long with diameters of 5-1/2 and 10-1/2 inches is the maximum space available for the air heater in the seal head. A tubular alloy sheathed single element electrical heater was selected as being the best for this application. This type heater offers advantages because of its ruggedness, relative ease to being fabricated into complex configurations, wide choice of temperature control devices, reasonable life, and relatively high output per space occupied. The single element type was selected in preference to the multi-element electrical heater, often called "ring" or "pancake" heater because it was capable of operating at higher watt densities. Multi-element heaters have the inherent problem of mutually heating adjacent elements within the same sheath. Other electrical heaters such as resistive coating or quartz were not selected due to insufficient output capacity.

Heaters selected were designed for optimum operation at a maximum sheath temperature of 1600°F, however, the manufacturer stated that the heater could be operated with a sheath temperature to 1900°F with some sacrifice of heater life. Life at the higher temperature was expected to be about 2000 hours. Maximum heater output at 1600°F sheath temperature is 80 watts per square inch of surface area, and heaters of different capacities were obtained by having different surface areas.

Heater capacity is obtained by multiplying the square inches of surface area times the maximum watt density rating. This is the heater's maximum output or nominal rating. The heater can deliver this amount of heat provided sheath temperature is kept at or below its maximum rating, in this case 1600 or 1900°F depending on heater life requirements. Obviously at 1900°F ambient surroundings, heater output must be nil, since any output from the heater would cause the sheath to exceed its maximum rating. Each heater has an allowable watt density rating for any given set of conditions. Watt density rating is dominated by (1) air flow over the heater, and (2) ambient temperature of which the latter is the largest contributor. Therefore, heater output must be regulated between the nominal rating and zero dependent on ambient temperature. Since maximum power may be utilized at low temperatures, heaters of this type are capable of rapid warm-up times. As air temperature increases, output power from the heater must be reduced thus limiting their total capacity.

## B. Seal Head Air Heating

Internal seal head temperatures were studied using the modified seal head. The area between the test seal and the back seal, the air compartment, was utilized for air heater location in the seal head. The shaft extends axially through the geometric center of the air compartment. Air circulation is provided by an impeller located to the shaft. Both seals are protected from direct radiation by shields. Ports are located in the air compartment for make-up air to the system, electrical leads to the heater, thermocouples for heater skin and air temperatures. Air temperature inside the head is measured by a shielded thermocouple located between the heater and the seal head housing. Make-up air enters the head at ambient temperature under pressure. The outer periphery of the seal head, except for the area near electrical lead-in lines to the heater, was covered with two-inch thick insulation.

In all air temperature studies the rig was operated at 7000 rpm shaft rotation, oil flow of 1 gpm, and at air pressures and leakages typical of evaluation testing conditions. Test oil heaters were not used so that the only source of heat was from the internal air heater. Heater skin and other internal seal head temperatures not readily accessible were measured by using temperature indicating paint. Operating temperatures were increased stepwise in order that maximum heater skin temperature would not be exceeded. The heater was inspected after each test to determine its operating temperature from indicating temperature paints. The results from each run were used to determine the next step in any test series.

### Five KW Heater Testing

The first heater tested had a five KW nominal rating and consisted of one continuous element wound in a spiral manner so as to present 3 coils in a plane parallel to the seal. The tests were conducted using stainless steel shields to protect both seals from direct radiation. Air entered the chamber directly to the heater compartment between the two shields. Heater capability was determined from eight runs and is graphically shown as Figure 1. An internal air temperature of 500-600°F was the maximum the heater could safely attain. At this air temperature, the heater sheath temperature was near its maximum of 1900°F, and heater output was measured to be 2.4 kilowatts. Of this amount of heat, 0.4 kilowatts was utilized to heat the make-up air and the remainder of 2.0 kilowatts was lost to the system. Heat shields reached the same temperature as the internal air during these tests.

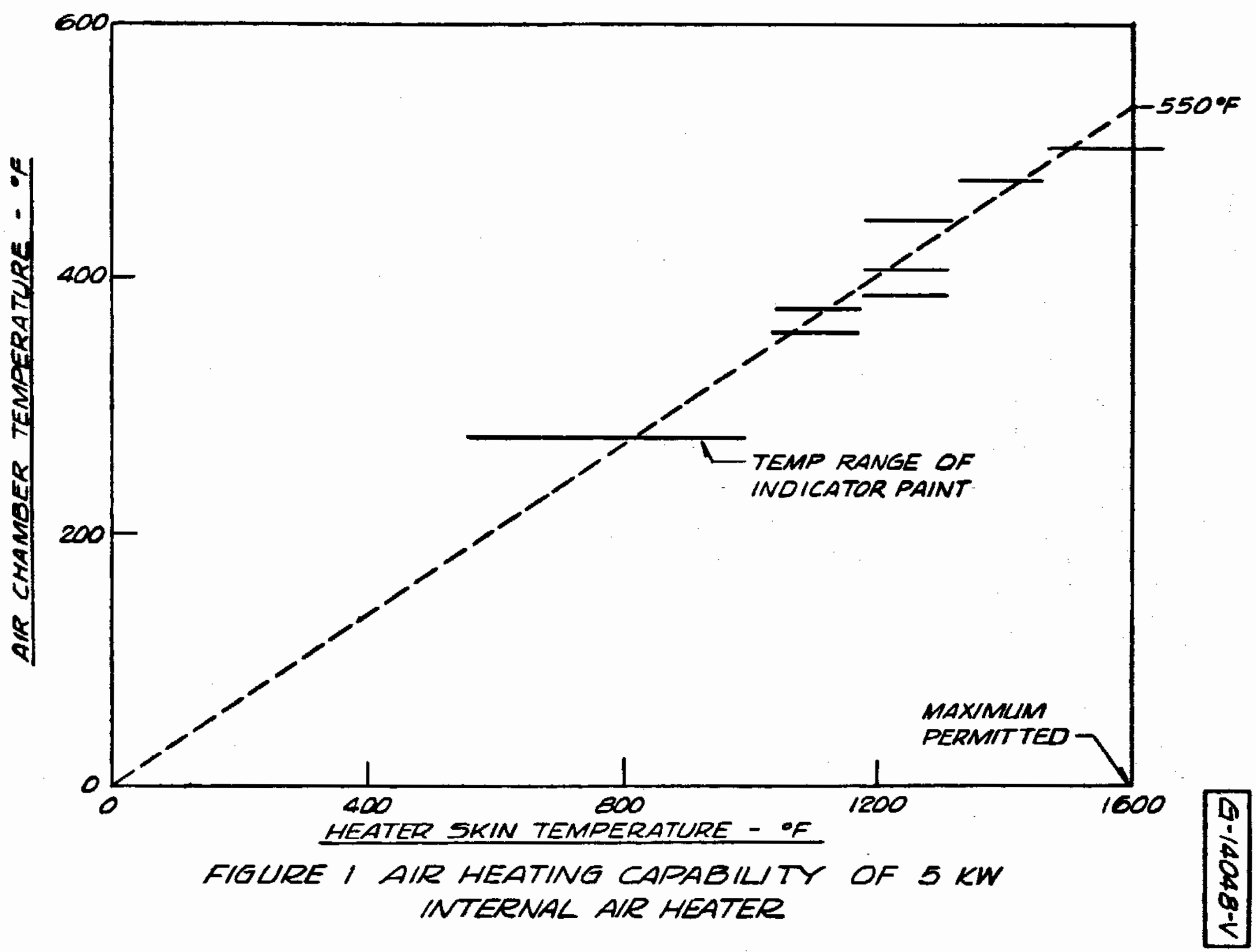


FIGURE 1 AIR HEATING CAPABILITY OF 5 KW INTERNAL AIR HEATER

Fifteen KW Heater Testing

The first obvious conclusion from the five KW heater tests was that heater output would have to be increased or system heat losses reduced if an air temperature of 1100°F or more was to be reached. In the same manner of testing, a 15 KW heater was next evaluated. This heater had the same general operating characteristics as the 5 KW heater except it had three times the surface area, thus increasing its nominal rating by a factor of three. The 15 KW heater consisted of a continuous spiral element formed into a configuration of three rows, each row having three rings in a plane parallel to the seal. Total surface area of the heater being 180 square inches.

Testing at conditions equivalent to the 5 KW testing and utilizing the same seal head arrangement, the capability of the 15 KW heater was determined from seven runs. The results are shown graphically in Figure 2, which indicates an air temperature of slightly under 1000°F to be maximum for the 15 KW heater as used in the seal head design. Although the nominal rating of the heater had been tripled, the output capability of the heater was only increased from 2.4 to 5.2 kilowatts at maximum operating conditions. This increase was reflected in an almost double air temperature capability but was still below the required 1100°F operating temperature.

Heater output was determined by current-voltage measurements of electrical power to the heater. From these data the amount of heat required to produce an air temperature for the seal head was possible. The data are shown as Figure 3. As the extrapolated data indicate, heater output of about 6.5 KW would be required to obtain 1100°F air temperature for the seal head as designed. This was 1.3 KW more than the present heater was capable of delivering and would require a heater having a nominal rating of about 20 KW or more when taking into account heater watt density rating at higher air temperatures. This coupled with the fact that the 15 kilowatt heater was considered the largest practical size that could be fabricated for the space available, increased temperatures would have to be approached by reducing heat losses from the seal head.

Flow rates and temperature differences of air and oil to and from the seal head were made to determine heat losses and distribution from the seal head. Data obtained had limited accuracy due to temperature measurement variation and the inability to separate interrelated variables. Corrections were applied for heat gained by the oil from air leakage and from shaft rotation, therefore, oil system heat gained accounts for only heat transferred through metal components. The results summarized as Figure 4 indicate that 35 per cent of the heat is used for air heating, 35 per cent is transferred to the oil system via metal components, and the remaining 30 per cent is lost somewhere other than the air or oil systems. The study indicated that sufficient gains could be made to obtain an air temperature of 1100°F or more by reducing heat losses from the seal head.

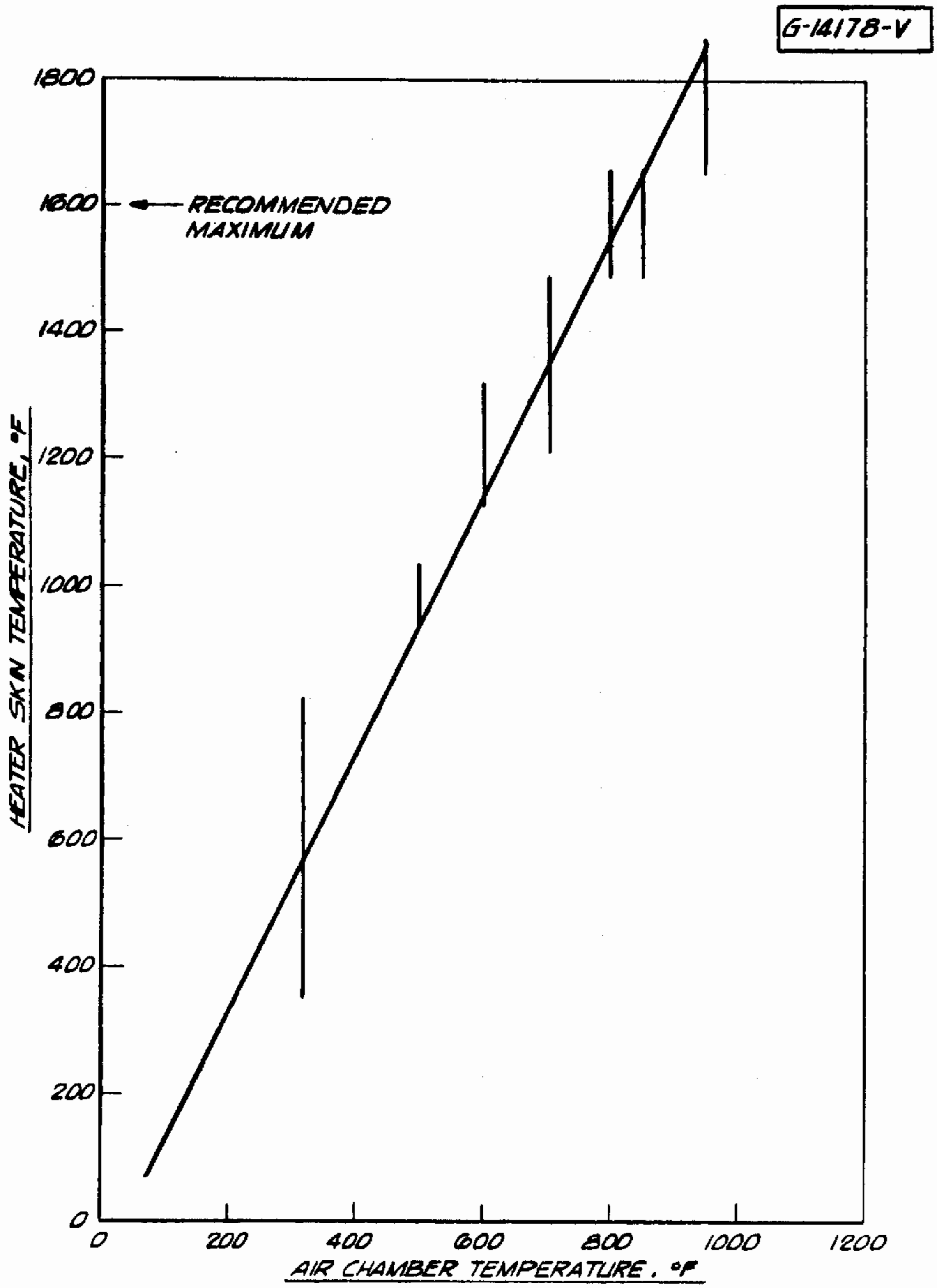


FIGURE 2 AIR HEATING CAPABILITY OF 15 KW INTERNAL HEATER

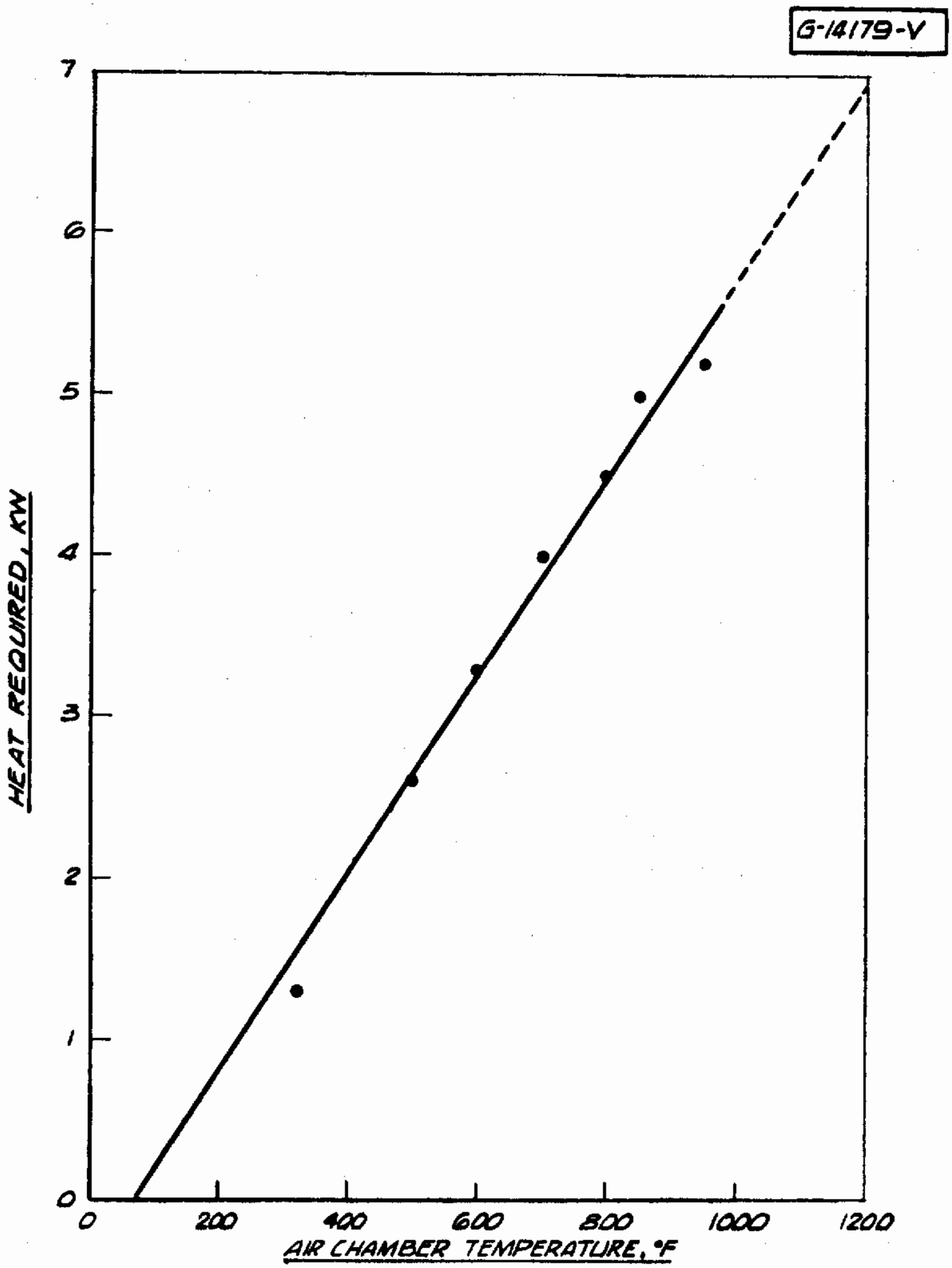


FIGURE 3 AIR HEATING REQUIREMENTS FOR SEAL TEST RIG

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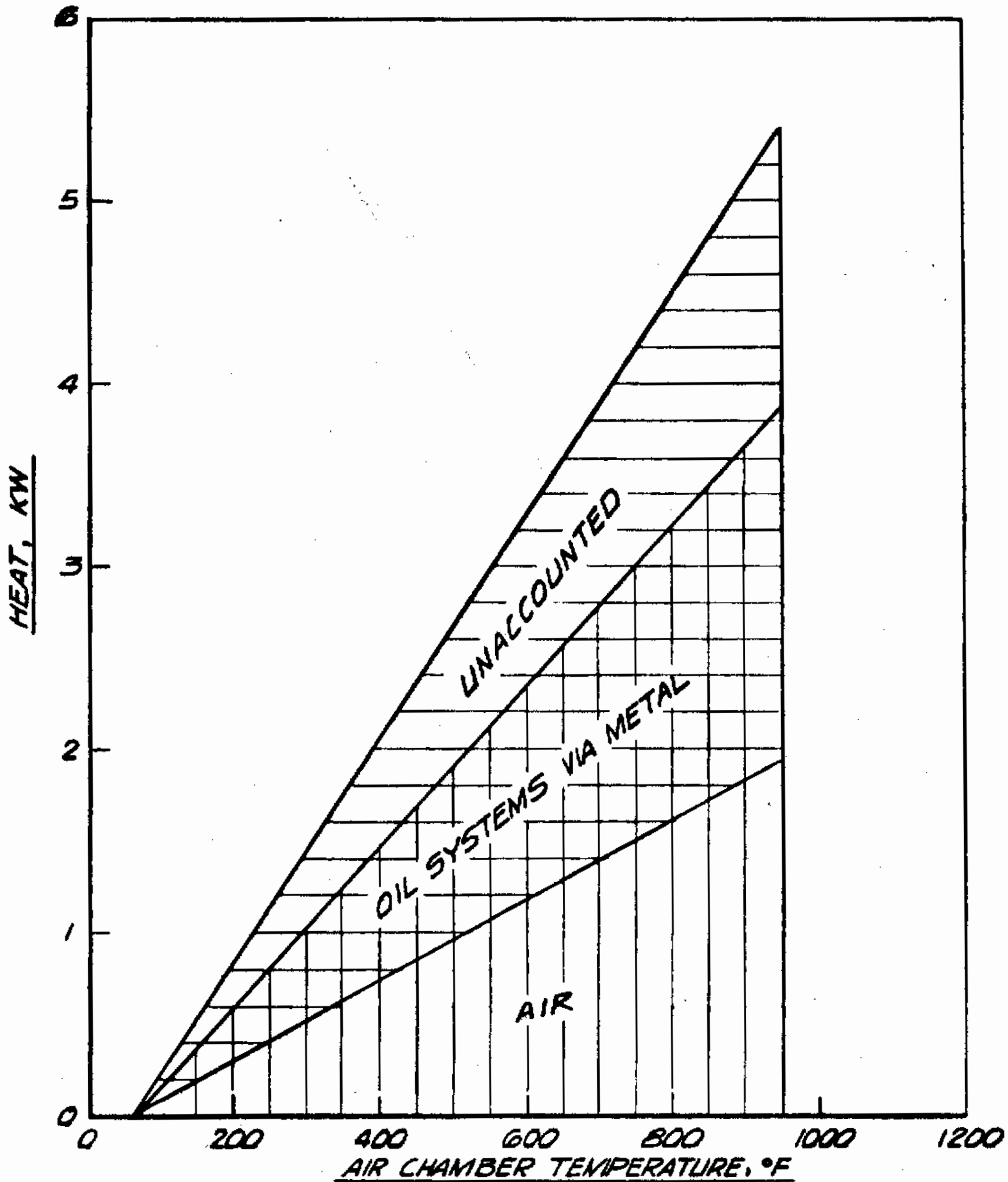


FIGURE 4 DISTRIBUTION OF HEAT FROM INTERNAL HEATER

Heat Loss Studies

The initial approach for studying system heat losses was to make design changes to the seal head and note the effect of the change on the heat balance of the system. In this manner, the most effective design changes could be achieved, since for lubricant evaluation purposes it is desirable for the test seal to receive heat from the air system. Due to interrelated variables, this approach would have required an unjustified effort. A more direct approach to increasing air temperature was used. Design changes were made to the seal head and the effectiveness of the changes were established on the basis of input heat required and maximum air temperature capability of the 15 KW heater when operated at maximum sheath temperature. This approach required a series of tests, in order not to exceed heater sheath temperature, therefore, it was not practical to study the effect of each proposed design change independently. The more expedient course was to study several design changes at one time. Design changes were made on the basis of previous data and theoretical expectations, provided they did not substantially alter the seal head so as to require major alterations. Testing conditions and techniques were the same as used in air heater studies.

The first significant air temperature increase was obtained by making two internal seal head design changes:

1) The shaft components, front hub, back hub, and impeller, were modified in order to reduce their bearing surface area on the shaft. Annular voids were machined into each part so that contact with the shaft was limited to 3/8 inch bearing surface on the ends of each component.

2) The stainless steel shields, protecting the seals were replaced with heat insulating material. The shield protecting the back seal was constructed so that it extended to the inside diameter of the seal head housing. The original shield had an outside diameter equivalent to that of the seal leaving an annular gap between the shield and seal head housing. This change, therefore, resulted in two additional changes to the system. One, the heater compartment was reduced in size and two, make-up air was now forced to enter the seal head between the back seal and the shield protecting the seal. Therefore, air leakage through the back seal was essentially unheated air and air entering the heater compartment would be partially preheated.

These changes resulted in a maximum temperature of 1150°F with a heater sheath temperature of 1900°F and a 30-minute warm-up period to reach maximum conditions. The effect of change No. 1 only, i.e., using the original stainless steel heat shields but cut-away shaft components, had little effect on maximum air temperature but did increase warm-up times by a factor of three. Although the desired 1100°F air temperature was obtained, the heater had to be operated at near maximum design conditions. It was, therefore, desired to make additional changes that would reduce the burden on the air heater.

The heater compartment of the seal head was internally insulated from the system. Final design changes were:

1) The bearing surface area of shaft components was reduced, as previously described, to 0.15 inch bearing surface on the ends of each component.

2) Heat insulating shields as previously described.

3) The annular area between the outer most heater coil and the inside diameter of the test chamber was insulated with one inch thickness of kaowool.

The results of these changes on internal air heating are summarized on Figures 5 and 6 which compare air heating for the fully insulated seal head with seal head as initially designed. In both cases the 15 KW heater used and the rig operated at typical test conditions. A temperature of 1160°F was possible with a warm-up time of less than 15 minutes, heater sheath temperature less than 1800°F, and about 5 KW input power to the heater.

The results of the study established design changes required to obtain 1100°F air temperature. The head was not operated for extended duration after being fully insulating since design changes for initial evaluation were made with materials on hand rather than selected materials of an engineered design. This phase will be studied concurrently with other evaluations utilizing the new seal head.

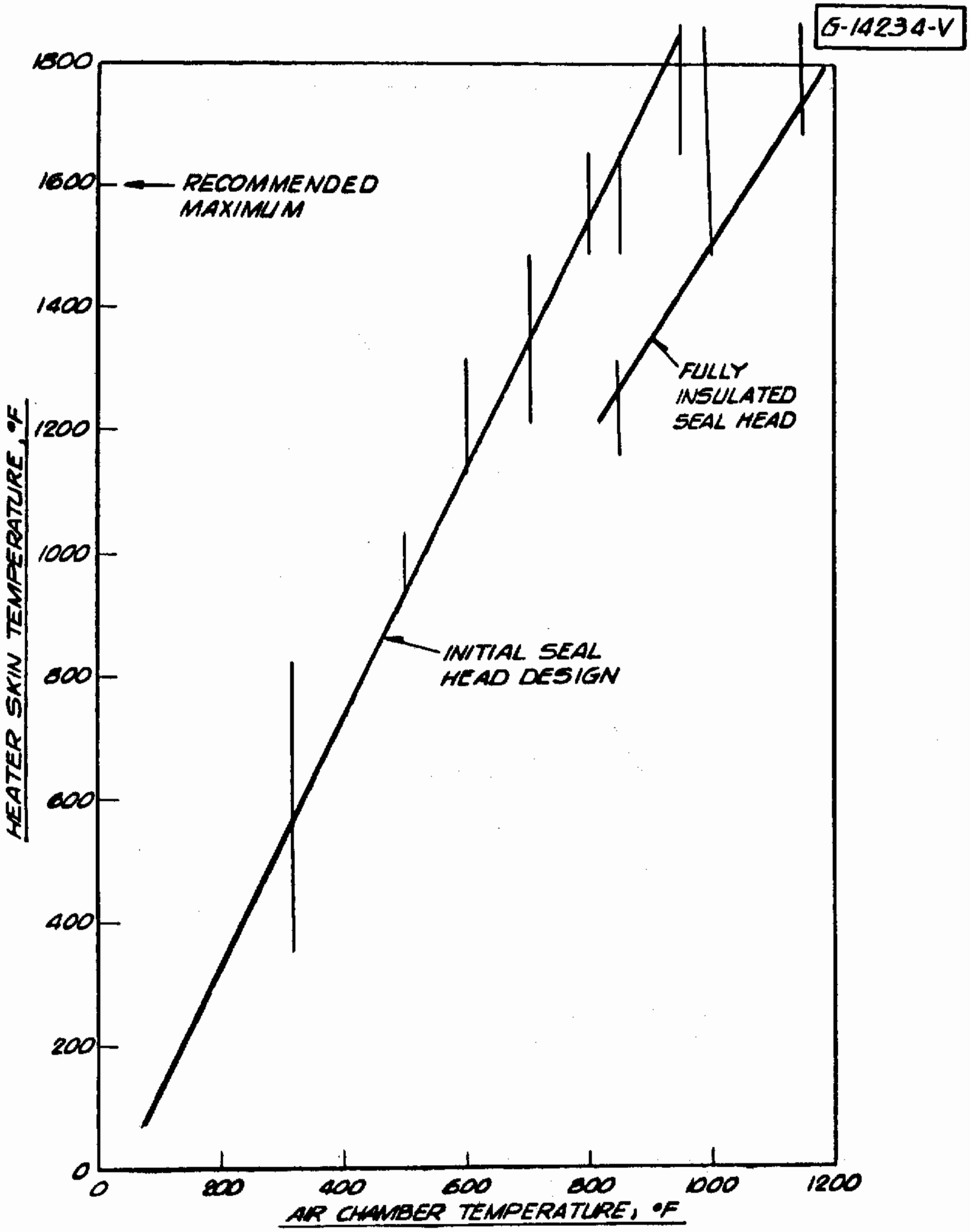


FIGURE 5 FINAL AIR HEATING CAPABILITY OF 15 KW INTERNAL HEATER

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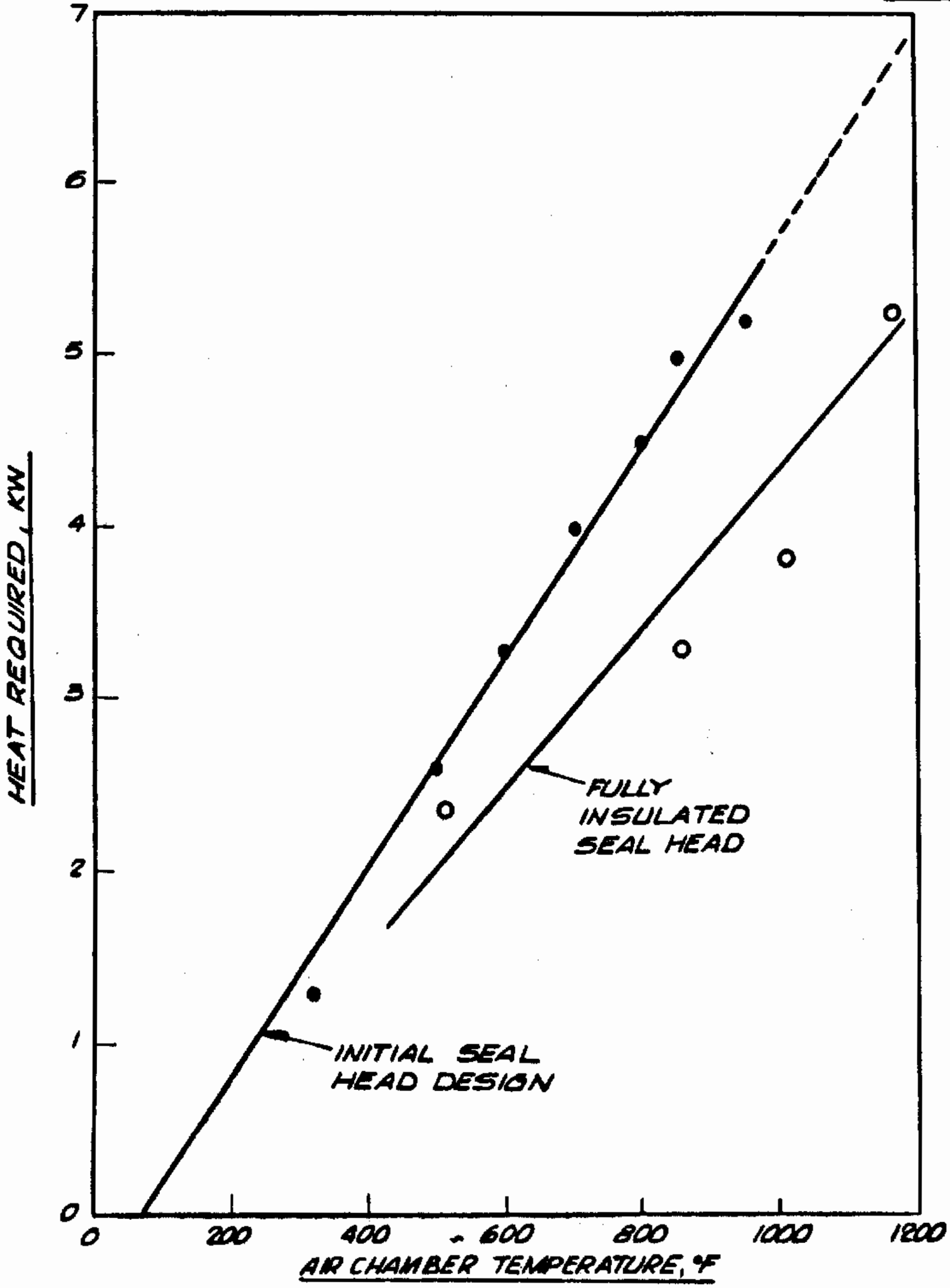


FIGURE 6 FINAL AIR HEATING REQUIREMENTS FOR SEAL TEST RIG

Air Temperature Control

Air temperature was controlled by regulating input energy to the air heater element. Heater control was possible by any combination of the following devices:

1) Percentage on-off timer control.

2) On-off indicator controller using a thermocouple in contact with the heater sheath.

3) Continuously variable voltage to the heater-power stat control.

Of these three control devices and combinations of them, control by the power stat alone provided the most satisfactory operation. Using this control, air temperature variation was less than 5°F except when large fluctuations in air leakage occurred. Other control methods, involving on-off mechanisms caused variations in air temperature as high as 50°F. The on-off controller utilizing a thermocouple in contact with the heater skin has been used as a safety feature to prevent overheating of the heater sheath. The thermocouple does not indicate true skin temperature but rather a temperature between air temperature and heater sheath temperature. Its relationship to maximum heater sheath temperature has been consistent enough to permit the controller to serve as a safety overheat protection device.

C. New Seal Head Testing

Having established the necessary requirements for obtaining the desired air temperature using the modified seal head, more refined insulating components were designed and constructed for the new RTD seal head. Internal insulation consisted of three components: (1) front heat shield, (2) back heat shield, and (3) a solid annular ring surrounding the heater. Johns-Manville Marinite was selected as an insulating material. An air inlet line was added to the new head so that make-up air would enter the head between the back seal and the back heat shield. With these design modifications and the use of cut-away shaft components, the RTD seal head was ready for evaluation testing to determine repeatability of test results, comparison of results with previous lubricant evaluations, and functional operation of equipment. These items are being studied concurrently.

To date, five runs have been conducted and are summarized on Table I. Runs 66, 67, and 68 were made using 0-60-19 lubricant at conditions comparable to previous evaluations[1/] at series 3-A-2 conditions, except inlet oil for series 3-A-2 conditions was controlled at 390°F. Run 66 was termi-

1/ Development of High Temperature Seal-Lubricant Deposit Evaluation Techniques ASD-TDR-63-246 March 1963.

## TABLE I

### Summary of Runs With New Test Head

| Run No. | Lubricant No. | Test * Conditions | Run Life hrs. | Deposit Rating | Comments |
|---|---|---|---|---|---|
| 66 | 0-60-19 | A | 14.5 | 75 | Secondary seal failure |
| 67 | 0-60-19 | A | - | - | Contamination from front shield |
| 68 | 0-60-19 | A | - | 40 | |
| 69 | 0-60-18 | B | 70 plus | 210 | Tests terminated Before seal failure |
| 70 | 0-60-18 | B | 15 plus | 98 | |

| * | A | B |
|---|---|---|
| Shaft, rpm | 7000 | 7000 |
| Seal Air Pressure, psi | 30 | 30 |
| Oil Flow, CPM | 1 | 1 |
| Oil Jets to Seal | 2 | 2 |
| Air Temperature, °F | 1050 | 900 |
| Bulk Oil, °F | 425 | 350-390 |
| Inlet Oil, °F | 420 | 345-380 |
| Heat Shield | Marinite | Stainless Steel |

nated after 14.5 hours due to secondary seal failure, however the deposit level at failure was lower than those previously attained. A rig test life of 5 hours was previously obtained for 0-60-19 lubricant. Runs 67 and 68 were attempted to determine repeatability of the test rig, however, deterioration of the front heat shield resulted in seal contamination. There was enough indication that lubricants would run for excessively long periods of time before failure in the new seal head and that deposit formations were not entirely satisfactory for lubricant evaluation. It was decided to establish favorable test conditions at a lower test level using 0-60-18 lubricant to establish the parameters necessary for useful seal-lubricant evaluations.

To avoid seal contamination and increase the air side seal temperature, the marinite shield was replaced with the original stainless steel shield. Using this arrangement, Run 69 was made with 0-60-18 lubricant. The run was terminated, prior to seal failure, after 70 hours of operation. The high deposit rating was due to unusual sludge deposit formation. Air temperature was 900°F, bulk oil temperature 350°F for the first 35 hours and 390°F for the last 35 hours. Previous evaluations of 0-60-18 lubricant at these conditions would indicate seal failure should have occurred at 15-25 hours, if air side seal temperatures were equivalent. Contamination has been eliminated, however, testing conditions still had to be adjusted in order to obtain more reasonable test rig life for the lubricant.

The stainless steel heat shield was reduced in size to expose more of the seal area to direct radiation, and perforated with holes to improve air circulation near the seal. Run 70 was made using this heat shield arrangement and 0-60-18 lubricant. The test was terminated, prior to failure, after 15 hours. Deposit formations were very light indicating seal failure would not have occurred for many hours. Temperature indicating paint showed the air side seal surface to be only 600°F when the air temperature was 900°F. These results indicated that the seal was not being sufficiently heated by the air system. Run 71 is now in progress without a shield between the heater and the test seal.

The desired result is to increase the oil film temperature on the seal. If this cannot be accomplished by increased air side seal temperatures, then testing at reduced oil flows to accomplish the same results will be attempted.

## D. Miscellaneous

Preliminary layout drawings for the Erdco-Koppers seal head adaptor have been approved and detailed design of the adaptor is in progress.

## 3. Summary and Conclusions

1) Seal head air temperatures exceeding 1100°F have been obtained by using the 15 kilowatt air heater and making minor seal head design changes to reduce heat losses from the air chamber by means of internal insulation.

2) Continuously variable voltage to the air heater element is a very satisfactory method of air temperature control. An on-off controller used with heater sheath temperature is useful as an overheat protection device.

3) Lubricant evaluations using the new seal head have indicated that the test seal is too well insulated from the air system resulting in lower seal temperature, less deposits, and excessively long test rig life for lubricants.

## 4. Future

Repeatability, reasonable test rig life, and continuous operation of seal head components will be concurrently established using the new seal head. Studies will be conducted, first at a lower temperature level, using 0-60-18 lubricant or equivalent, to establish conditions required for satisfactory seal-lubricant evaluations. Increased seal deposits will be attempted by exposing more of the seal to the air heating system and by reducing oil flow to the seal to increase film temperatures, if required. As conditions are established at lower temperature levels, evaluations will proceed to higher temperature lubricants. Lubricant evaluations will be coordinated and compared with other evaluation tests and results.