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SUBJECT: Pump-Motor Mixing and Heat Balance Tests of the Byron-Jackson
4000-gpm Pump

TO: I. Spiewak

FROM: H. R. Payne

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SUMMARY

The pump to motor mixing rate of the Byron-Jackson 4000-gpm pump was determined as a function of motor purge flow. A purge rate of 63 liters/hr, which corresponds to a mixing rate of 0.55 liters/hr, is recommended for operation of this pump. Further increases in purge flow did not decrease the mixing rate significantly below this level.

Two runs were made with cooling water bypassing the external motor cooler. These runs indicated that the external cooler was necessary to prevent overheating of the 4000 gpm pump motor. However, the observed heat balance checked the predicted heat balance, indicating that the method of prediction can be applied to the design of motor cooling in other large pumps.

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INTRODUCTION

During the period of operation of the 4000 gpm Byron Jackson pump from August 1957 to December 1957, an investigation of the effect of the purge rate on the rate at which the liquid in the main loop enters the stator cavity was made; a heat balance was conducted on the motor; an overall coefficient of heat transfer for the motor cooling system was determined; and the feasibility of operating the pump without an external motor cooler was investigated.

Knowledge of the rate at which the fuel solution of an aqueous homogeneous reactor enters the motor of a large canned-motor circulating pump, similar to that which will be used in the HRE-3, is of value in determining the expected life of the pump, and whether or not further seal development is necessary. For these reasons, the 4000 gpm Byron Jackson pump was operated at purge rates of 0, 40.8, 63.5, and 136 liters/hour, and the corresponding mixing rate was determined by means of a potassium salt tracer. Mixing flow rates were calculated on the basis of several samples at each purge rate. The maximum mixing flow rate at a purge rate of 136 liters/hour was 0.22 liters/hour (Figure 1).

The external motor cooler (Figure 3) adds to the cost and complexity of the pump. Therefore, it would be advantageous to operate the pump without the cooler. To determine whether the motor cooling system, without the external cooler, is capable of maintaining the temperature of the motor low enough to permit continuous operation for an indefinite time, the pump was operated without cooling water to the external motor cooler. The stator oil temperature at the top of the stator reached a maximum value of 118°C, which is believed to be excessive. This oil is code GX, light white mineral, and has an expected life of 4 years at a temperature of 49°C as a result of the effects of thermal decomposition. The cooling water flow rate to the motor was 37 gpm when the stator oil temperature leveled off at 118°C.

One concept of the 6000 gpm HRE-3 prototype pump is to use a cooling system similar to that of the 4000 gpm pump (Figure 3), but without the external motor cooler. To determine whether heat transfer calculations of sufficient accuracy could be made to predict the feasibility of this arrangement, calculations were made on data taken during operation of the 4000 gpm pump with no cooling water flowing through the external motor cooler. The stator oil temperature at this time was approximately 100°C. This run was made prior to the one in which the stator oil temperature reached 118°C.

PROCEDURE

The mixing runs were conducted by adding a potassium salt tracer to the main loop and taking samples at regular time intervals from the main loop and the motor coolant. The potassium salt solution was added through the main loop sample station with the loop at normal operating conditions (250°C, 1000 psig). Motor coolant samples were taken directly from the piping between the motor and its cooler. Loop samples were taken from the main loop into a bomb and then transferred to a sample bottle.

The loop is constructed for continuous letdown, a part of which flashes to steam. The steam is condensed and during normal operation, this condensate is the purge supply. The remainder of the letdown and the excess condensate flows to the dump tank, which supplies the feed pump.

Due to the carryover of the tracer into the condensate, it was necessary to take purge water directly from the building demineralized water supply, and discard an equal amount of condensate. This resulted in a continuous reduction of the tracer concentration in the system. The rate at which concentration decreased was quite low at steady state conditions.

With a zero purge rate the following formula derived by J. C. Moyers⁽¹⁾ was used to calculate the mixing flow rate between the main loop and the stator cavity:

$$F_m = \frac{V}{t} \ln \frac{C_L - C_{po}}{C_L - C_{pt}}$$

F_m = mixing flow rate, liters/hour

V = volume of the liquid in the back of the pump and the external motor cooler, liters

t = time elapsed since t_o , hours

C_L = potassium tracer concentration in the loop, ppm

C_{po} = potassium tracer concentration in the motor and its cooler at t_o , ppm

C_{pt} = potassium tracer concentration in the motor and its cooler at t , ppm

At purge rates greater than zero the mixing rates were determined at a time when for short time intervals the potassium concentration in the loop and motor could be considered as constant. With this condition and a negligible concentration of potassium in the purge water, the following material balance was used to determine the mixing flow rate:

$$F_m \times C_L = F_m \times C_p + F_p \times C_p$$

F_m = mixing flow rate, liters/hour

F_p = purge rate, liters/hour

C_L = potassium tracer concentration in the loop, ppm

C_p = potassium tracer concentration in the motor and its cooler, ppm

The heat balance and heat transfer calculations were made from data taken with the building cooling water bypassing the external motor cooler. The heat removal in this cooler was considered to be negligible during the

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test. That this was a reasonable assumption was confirmed because the Δt of the motor coolant through the motor cooler was 1°C measured with clamp-on thermocouples on two separate instruments. The motor coolant flow rate used to determine the U (overall coefficient of heat transfer) of that part of the cooling system incorporated in the motor was calculated from data taken at normal operating conditions.

RESULTS

There was considerable scatter in the results of the mixing flow rates determined from the experimental data; however, a plot of the maximum mixing flow rate vs. the purge rate (Figure 1) gives the type of curve expected of a thermal barrier and shaft seal arrangement of the kind in this pump (Figure 2). The high mixing flow rate at zero purge is attributed to the circulation path around the outside of the thermal barrier and through the shaft seal. Dimensional tolerances will greatly affect the mixing flow rate with an arrangement of this kind. For this pump a purge rate of 63 liters/hour or more appears adequate. The range of the mixing flow rates obtained at each purge rate is shown in Table I.

The following are the results of the heat balance and heat transfer calculations made on the pump motor.

$$Q_m = P_1 (1 - e_m) \times 3413$$

$$Q_m = \text{heat losses in the motor from the electrical power input to be removed by the cooling water, Btu/hour}$$

$$P_1 = \text{electrical power input, kw}$$

$$e_m = \text{motor efficiency} = 0.78 \text{ (manufacturer data)}$$

$$Q_m = 298 (1 - .78) 3413 = 224,000 \text{ Btu/hour}$$

$$Q_{cw} = Q_m + Q_{tb} - Q_p$$

$$Q_{cw} = \text{heat to be removed from the motor by the cooling water, Btu/hour}$$

$$Q_{tb} = \text{heat transferred through the thermal barrier of the pump, Btu/hour}$$

$$Q_p = \text{heat removed by the purge flow, Btu/hour}$$

$$Q_{cw} = 224,000 + Q_{tb} - 39,000$$

$$Q_{cw} = 185,000 + Q_{tb} \text{ Btu/hr}$$

Sufficient data were not available to determine Q_{tb} .

The heat losses in the motor are removed from it by the motor coolant as it passes down through the spiral passage between the stator and the pressure shell, through the thrust bearing, and up through the annulus between the rotor and the stator. During normal operation the heat is transferred from the motor coolant in the external cooler, and through the pressure shell enclosing the motor. In this experiment only that transferred through the pressure shell was removed by the cooling water except for a small amount conducted from the hydraulic end through the upper section of the casing. The U for the heat transfer from the motor coolant to the cooling water through the pressure shell at the above conditions was calculated to be $51.6 \text{ Btu/hour ft}^2\text{-}^\circ\text{F}$. This is based on the outside area of the pressure shell covered by the cooling water spiral. The major heat transfer resistance was metal conduction. It is assumed that the average film coefficient is applicable over the full area.

$$Q_{cw1} = U A \Delta t$$

$$Q_{cw1} = \text{heat transferred by forced convection from the motor coolant to the cooling water through the pressure shell, Btu/hour}$$

$$\Delta t = \text{average motor coolant temperature} - \text{average cooling water temperature} = 130^\circ\text{F}$$

$$Q_{cw1} = 51.6 \times 26.1 \times 130 = 175,500 \text{ Btu/hour}$$

The heat removed by the cooling water determined from the data was:

$$Q_c = W c_p \Delta t$$

$$Q_c = (383 \times 60) \times 1 \times 7.2 = 165,500 \text{ Btu/hour}$$

CONCLUSIONS

For the 4000 gpm Byron Jackson pump, a purge rate of 63 liters/hour or more appears to be desirable.

The purge was supplied by a 1 LB Scott and Williams pulsator giving a pulsating purge. A constant pressure purge supply could possibly reduce the mixing flow rate. More consistent results might also be obtained if an effective entrainment separator could be used to eliminate solids from the condensate before the condenser.

The heat balance and calculations on the motor cooling indicate that results of sufficient accuracy for design purposes can be obtained by calculation.

The external motor cooler is necessary for satisfactory operation of the 4000 gpm Byron Jackson pump.

TABLE I

Results of Mixing Runs	
Purge Rate L/Hr.	Mixing Rates L/Hr.
0	13.2 to 35.7
40.8	0.30 to 2.59
63.5	0.027 to 0.545
136	0.055 to 0.218

Figure 1

Figure 2. Mixing and Purge Flow Paths Between Loop and Motor in the Byron Jackson 4000 GPM Pump

Figure 3. 4000 GPM Pump Motor Cooling System

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