

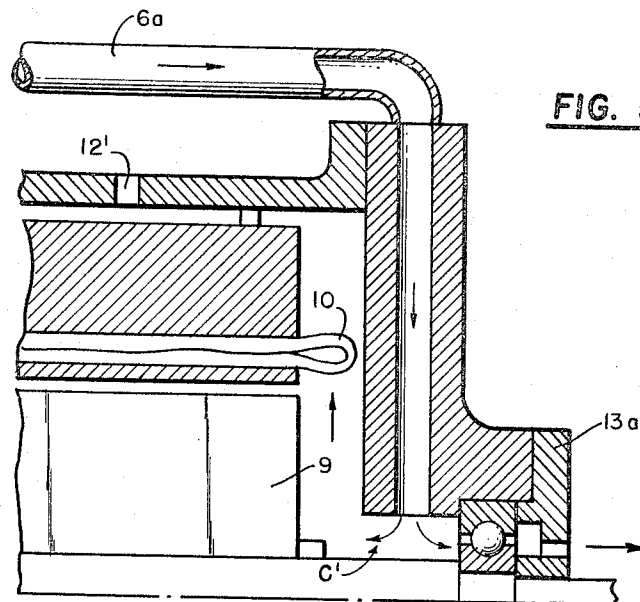
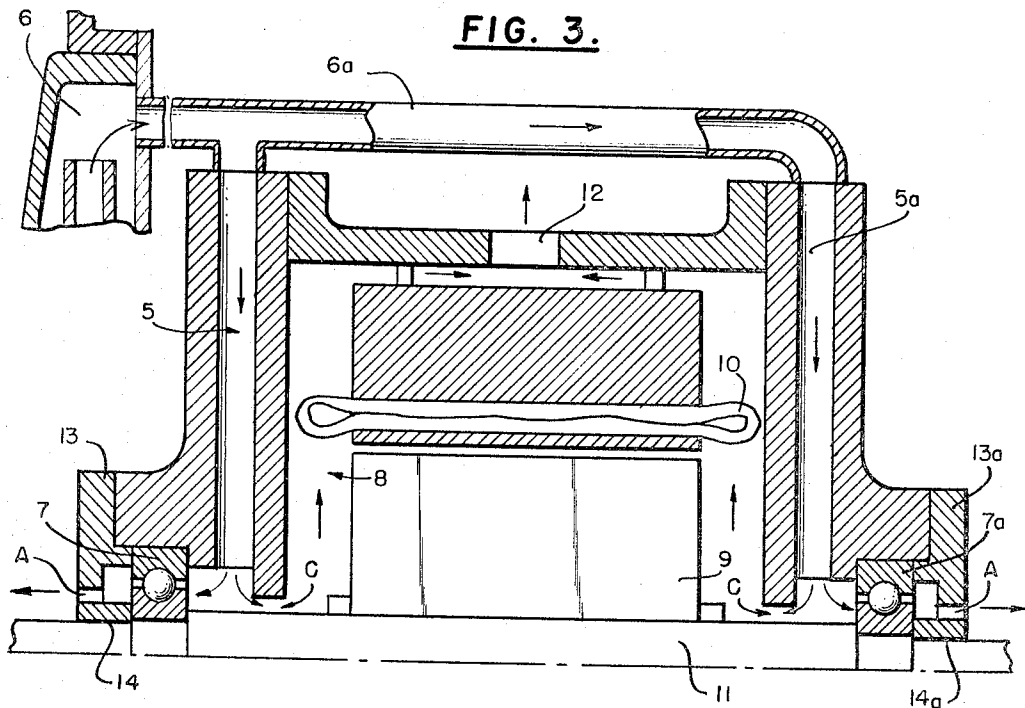
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J. W. HUNT
SUBMERSIBLE PUMPS

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2 Sheets-Sheet 2



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SUBMERSIBLE PUMPS

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This invention relates to the pumping of very cold fluids, and particularly to the pumping of liquid gases, from very large tanks in which the pumps are submerged.

The rapidly-growing large-scale use of liquid gases such as liquefied natural gas (LNG) presents the problem of rapidly pumping quantities of this material from very large tanks or reservoirs, often measuring over 100 feet deep and from 50 to over 100 feet across. The liquid gas is usually maintained at substantially atmospheric pressure, and in the case of LNG, is typically at a temperature close to -260° F. (the boiling point of the liquid at atmospheric pressure). Electric motor drive pumps are frequently employed, in which both pump and electric motor are submerged in the liquid near the bottom of the storage tank or reservoir. The present invention is concerned with the proper lubrication and operation of such motor-driven units.

In the design and use of a submersible pumps driven by an electric motor, it has been recognized that the cooling and/or lubrication of motor bearings by the fluid to be discharged can provide a considerable simplification and advantages. When a conventional liquid is to be discharged under conditions well below the boiling range, the means of realizing this objective call for no particular ingenuity and no special difficulties are encountered. When, however, the liquid to be discharged is at or near its boiling point as, for instance, in the case of liquefied hydrocarbon gases, special difficulties may arise which cannot be met by the use of equipment presently available.

In particular when discharging liquefied hydrocarbon gas mixtures by wholly or partly submersible pumps, inadequate lubrication of bearings presents considerable problems. It will be evident that the generation and accumulation of any significant heat in the motor bearings or in the motor is undesirable. It will also be obvious that the use of ordinary lubricants including greases is not feasible because at the temperatures prevailing such ordinary lubricants solidify. When relying for lubrication on the liquid medium to be discharged, the risk of lubricant failure or of only partially effective lubrication is much greater than is desirable. The present invention has for its objective the elimination of these hazards.

According to the present invention, a liquid at or near its boiling point can safely be discharged with the aid of a submersible pump wholly or partially immersed in the liquid by arranging a sufficient flow of said liquid across the motor bearings under such conditions as to avoid formation of vapor in the bearing housings while cooling and lubricating the bearings. Advantageously, liquid is delivered to the housings at the pump discharge pressure through passages connected to the pump discharge. Clearly if the flow of cooling and lubricating fluids were excessive, the pump efficiency would decline. On the other hand, the pump should not be so arranged that there is an appreciable pressure drop in the bearing housings. The minimum flow below which vapor formation in the bearing housings arises can be reduced to a simple formula which is hereafter set forth in detail. From this formula calculation of the gap or orifice on the discharge side of the bearing housings to permit an effective flow across the bearings can readily be effected.

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The provision of cooling within the motor housing by means of the liquid to be discharged is a desirable ancillary feature of this invention and such means involve a further passage way into the motor housing and an outlet so restricted as to ensure a satisfactory flow of coolant liquid through this housing without impairing the flow of fluid through the bearing housings. An alternative and preferred approach involves restricting the flow of coolant fluid at the inlet point to the motor housing so that the liquid passing into the housing vaporizes and effects cooling action by absorption of latent heat. In this way, a considerable reduction in the volume of liquid passing into the motor housing is effected without sacrifice of cooling efficiency. Also the pressure of the fluid in the motor housing is appreciably reduced. The dimensioning of the orifice or gap on the down-stream side of the bearing housings and of the inlet orifice to these housings turns in part on the type of bearings which are used. In the case of ball or roller bearings the free area will be greater than with sleeve bearings. With the latter fluted passages or other channels in or around the bearings may be found necessary in order to ensure access of a sufficient flow of cooling lubricant without substantial pressure drop.

The specific nature of the invention, as well as other objects and advantages thereof, will clearly appear from a description of a preferred embodiment as shown in the accompanying drawings, in which:

FIG. 1 is a pressure-enthalpy diagram for the liquid being discharged;

FIG. 2 is a diagrammatic sectional view of an in-ground storage facility with pumping means according to the invention;

FIG. 3 is a half-section through the motor and the bearing of the pump motor shown in FIG. 1, using roller bearings;

FIG. 4 is transverse sectional view of a sleeve bearing according to the invention for use with the motor of the preceding figures; and

FIG. 5 is a partial view of an alternative form of the invention in which no restriction is employed in the passage to the motor housing.

In determining the necessary cooling flow through the bearing housings the problem can more readily be appreciated by reference to the pressure enthalpy diagram for the liquid being discharged. Referring now to FIG. 1, this shows a typical pressure-enthalpy diagram for a liquid being discharged, the curve A representing the bubble point line for the liquid and line B representing the pump compression path from pump suction level p_s to pump discharge level p_1 . The fluid is in the single liquid phase under the various pressure-enthalpy relationships found above curve A, whereas below this line fluid will be present in two phases. It will at once be evident that the rise in enthalpy of liquid flowing over the bearings must not be such as to yield a pressure-enthalpy state falling on or below curve A, in order that the fluid remain present in the liquid state at all times as a lubricant. If the rate of production Q_b of frictional heat in the bearing housing is determined, a flow rate in excess of that given by the formula $Q_b/(h_s - h_1)$, wherein h_s is the enthalpy at the bubble point temperature corresponding to pump discharge pressure and h_1 is the enthalpy of the liquid at pump discharge, ensures both adequate lubrication and a sufficient cooling without formation of vapor in the housing. A flow of fluid significantly greater than is requisite to attain these objectives of course involves a sacrifice of pumping efficiency which needs to be avoided.

Referring to FIG. 2, the storage facility is an in-ground reservoir 15 of the type shown in U.S. Patent No. 3,159,006, although it may equally well be a large ship's tank of the type shown in U.S. Patent No. 3,085,536. Such

reservoirs are typically over 100 feet deep and it will be understood that the entire operation is a large-scale one involving heavy and very expensive equipment, so that the maintenance of high efficiency and reliable operation are very important factors economically and practically.

Liquid gas 16 is drawn from the tank through pipe-line 17 by means of a pump 18 driven by an electric motor 19 through conventional control (not shown). A vent 20 is provided, usually equipped with pressure-controlled valve means to maintain the vapor pressure within the reservoir at slightly above atmospheric pressure.

The invention will now be particularly described by reference to FIG. 3 which shows a half-section through the motor and bearings of the pump.

In the motor end bell are formed passages 5 and 5a by which cooling medium being discharged can flow from pump discharge 6 through line 6a to the inlet side of ball bearing housings and of the motor housing 8. The rotor 9 supported on shaft 11 and the stator windings 10 provide a sufficient clearance in the housing 8 for the flowing of cooling medium which is permitted to leave the housing via an outlet 12. The respective outer and inner race retainers for the bearings are shown at 13, 13a and 14, 14a and are arranged to provide an annular gap labelled A, dimensioned to achieve the objectives of the present invention.

Considering first the bearing housing, the cooling medium at the inlet side of the housings is at pump discharge pressure and the entry to the housing permits a flow above that needed for lubrication under liquid phase conditions. The gaps at A, on the other hand, restrict the flow of coolant medium but are still sufficient to permit a flow in which the frictional heat is absorbed without formation of vapor in the bearing housings. With the restriction to flow set up by gap A, vapor formation of fluid passing through the bearing housings may only occur down-stream from gap A. It will be evident from FIG. 1 that if the pressure drop between inlet and the housing itself were appreciable the pressure enthalpy state of fluid around the bearings might lie on a point below curve A in FIG. 1, and possibly somewhere near the point 3; this needs to be avoided.

Preferably, the inlet gap to the motor housing is restricted as shown at C in FIG. 3, to cause a substantial pressure drop across restriction C. In this case, a relatively large outlet 12 is provided so that there is substantially no restriction of the flow at this point. Thereby the fluid in the housing after absorbing sundry heat generated therein is present in whole or in part in the vapor state and effectively cools by the absorption of latent heat. A greatly reduced flow of coolant in the housing is thus required and the presence of vapor in the housing is in no way harmful. However, as shown in FIG. 5 at C', the restriction at this point may be omitted if desired and liquid cooling alone for the motor may be employed, with the quantity of liquid being controlled by the dimensioning of the motor housing outlet 12', serving in this case as a restriction.

FIG. 4 shows the manner in which a sleeve bearing 7b can be used instead of the ball bearings shown in FIG. 3, to support the motor shaft 11a. In order to provide access of a sufficient flow of cooling lubricant through an adjacent bearing without excessive pressure drop, fluted passages 7c can be provided in the bearing surface, the passages being designed to provide a proper flow of fluid in accordance with the principles indicated above.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of my invention as defined in the appended claims.

I claim:

1. A submersible pump unit for discharging a liquefied hydrocarbon gas or gas mixture at or near its boiling point comprising

- (a) a pump having an outlet for discharging fluid under pressure,
- (b) a motor having a shaft connected to said pump for driving same, and having bearings for said shaft,
- (c) passage means from the outlet of said pump to said bearings, said passage means being dimensioned to conduct fluid from said pump outlet to said bearings at substantially the outlet pressure of the pump,
- (d) flow means in the bearings for conducting said fluid from said passage means through the bearing at substantially the outlet pressure of the pump,
- (e) flow restriction means in the direction of flow beyond said flow means, for restricting the flow of fluid through said bearings to an amount sufficient for lubrication of the bearings.

2. The invention according to claim 1, the relation between the size of the flow and passage means and the size of the restriction for a given pressure being such as to produce a flow just in excess of the value determined by the formula $Q_b/(h_s - h_1)$, where

Q_b is the rate of production of frictional heat in the bearing;

h_1 is the enthalpy of the liquid at pump discharge; and

h_s is the enthalpy at the bubble point temperature corresponding to pump discharge pressure.

3. The invention according to claim 1, said motor having an enclosed housing, and passage means for conducting fluid from the outlet of the pump at outlet pressure to the interior of the housing.

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