

Jan. 18, 1966

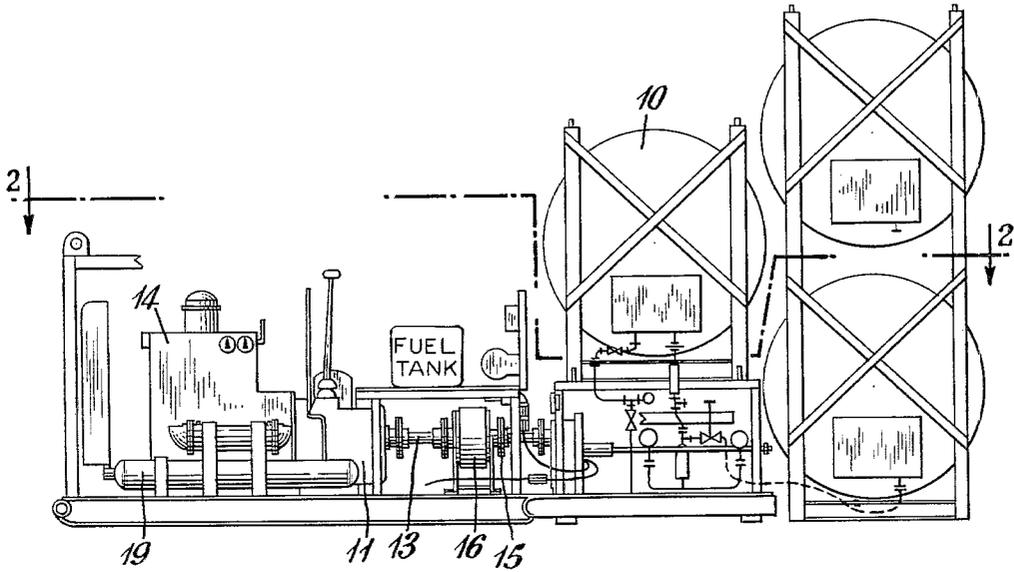
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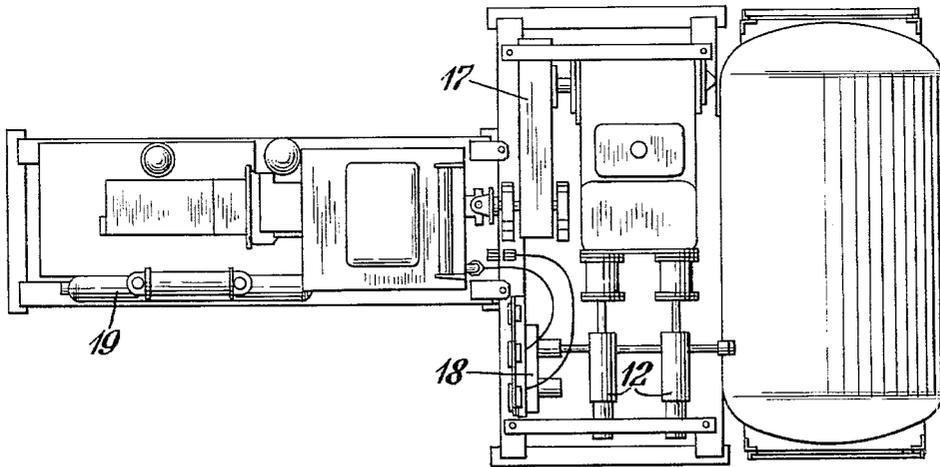
METHOD AND APPARATUS FOR PUMPING AND VAPORIZING LIQUEFIED GAS

Filed May 15, 1964

3 Sheets-Sheet 1



*Fig. 1.*



*Fig. 2.*

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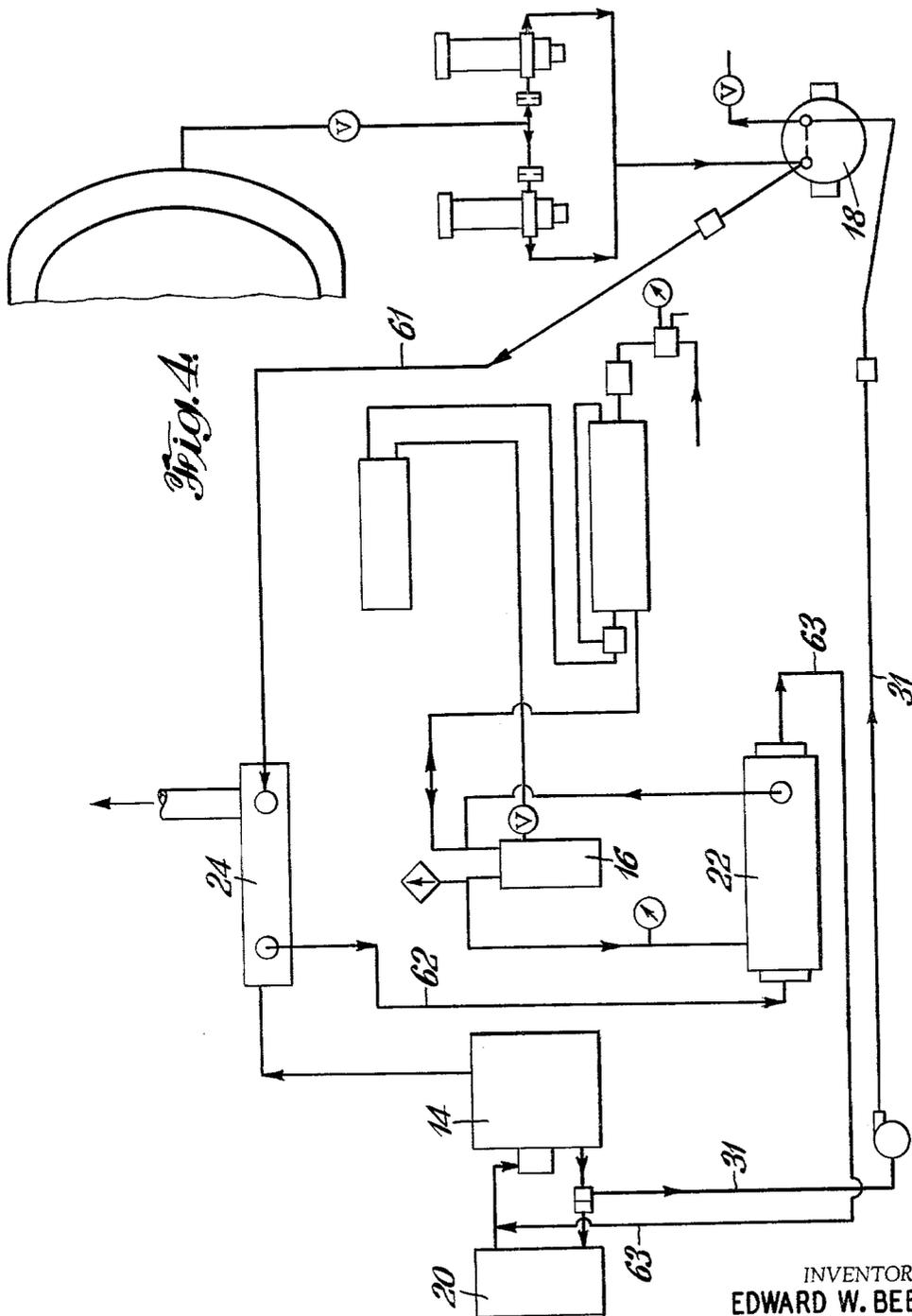


FIG. 4

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**METHOD AND APPARATUS FOR PUMPING AND VAPORIZING LIQUEFIED GAS**

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 Filed May 15, 1964, Ser. No. 367,690  
 15 Claims. (Cl. 62-53)

This invention relates to a method and apparatus for pumping a liquefied gas to a high pressure and vaporizing and warming such gas to above its liquefaction temperature. While not limited thereto, the invention is particularly valuable for use in remote locations, such as in oil well servicing operations.

High pressure nitrogen gas is becoming increasingly useful for oil well servicing operations, such as fracturing oil sand formations, etc. Because the equipment used must be compact, safe and reliable, existing pumping equipment for delivering pressurized and vaporized liquid nitrogen is not entirely satisfactory, particularly from the safety and maintenance considerations. The major portion of the heat required to vaporize and warm the high pressure liquefied gas is normally supplied from engine waste heat. However, the engine power output needed to pump the liquefied gas to the desired discharge pressure usually does not provide all the waste heat needed to vaporize and warm the pressurized liquefied gas to above its liquefaction temperature. Therefore an additional source of heat is normally required, particularly at high pumping flow rates.

A principal difficulty with the prior art pumping systems has been the use of liquid fuel-fired heaters as an auxiliary heat source to supplement the use of engine waste heat in vaporizing and warming the pumped liquefied gas to above its liquefaction temperature.

These liquid fuel-fired auxiliary heaters are not reliable enough to meet the present needs of the industry which require a safe, dependable, relatively maintenance-free system for vaporizing and warming pumped liquefied gas over a wide range of flow conditions.

It is the principal object of this invention to provide a method and apparatus for pumping a liquefied gas to a high pressure and for vaporizing and warming such gas to above its liquefaction temperature, without the use of auxiliary fuel-fired heaters.

Another object is to provide a liquefied gas pumping and vaporizing system which is well suited for use in remote locations and is safe, dependable and relatively maintenance free in comparison to the prior art systems in use.

Other objects and advantages will be apparent to one skilled in the art, from the following disclosure and claims.

In the drawings:

FIG. 1 is a front elevational view of a liquefied gas pumping and vaporizing apparatus suitable for practicing the present invention;

FIG. 2 is a plan view of the apparatus shown in FIG. 1 and is taken along the lines 2-2 of FIG. 1;

FIG. 3 is a diagrammatic sketch illustrating a flow system according to a preferred embodiment of the invention; and

FIG. 4 is a diagrammatic sketch illustrating a flow system according to another embodiment of the invention.

According to one aspect of the present invention wherein a liquefied gas is pumped to a high pressure by means of a liquefied gas pump driven by an internal combustion engine having a coolant jacket, an improved method is provided for vaporizing and warming the liquefied gas to above its liquefaction temperature. The improvement comprises absorbing heat from the coolant

jacket, heat from the exhaust gases from the engine, and heat from a frictional braking device driven by the engine and transferring a substantial portion of such absorbed heat into the liquefied gas.

The heat is absorbed from the engine coolant jacket by the engine coolant and at least a part of this coolant is circulated in heat exchange relation with the liquefied gas to vaporize and warm it to above its liquefaction temperature. The engine coolant, which has now been reduced in temperature by the heat exchange with the liquefied gas, is preferably heated by circulating it in heat exchange relation with the fluid from the frictional braking device. Thereafter the engine coolant is preferably still further heated by circulating it in heat exchange relation with the heated exhaust gases from the engine. Thereafter the heated engine coolant is returned to the engine coolant jacket to be further heated while cooling the engine.

Alternatively, it may be desirable in certain applications to circulate the portion of the engine coolant which has been used to vaporize and warm the liquefied gas in heat exchange relation with the engine exhaust gases before circulating it in heat exchange relation with the fluid from the frictional braking device. From a heat transfer efficiency standpoint this alternative procedure would usually be limited to applications where the temperature of the engine exhaust gases was lower than the temperature of the fluid from the frictional braking device.

The engine coolant, which may consist of water or a mixture of water and ethylene glycol, is preferably maintained within a temperature range of 140° F.-200° F. To prevent excessively high engine coolant temperatures a portion thereof may be diverted through a radiator and returned to the engine coolant jacket. The portion diverted may be controlled by a thermostatic valve in a conduit parallel with the conduit supplying engine coolant for heat exchange with the high pressure liquefied gas.

According to another embodiment, the temperature of the engine coolant circulating through the radiator may be controlled by a thermostatically operated shutter positioned across the major heat transfer surface of the radiator.

According to still another embodiment of the invention, the engine is operated at a constant throttle position while the output of the liquefied gas pump driven by the engine is controlled by regulating the frictional drag force applied to the engine by the frictional braking device.

Preferably, the constant throttle position is the maximum throttle position of the engine.

According to a preferred embodiment of the invention, apparatus is provided for pumping a liquefied gas to a high pressure and for vaporizing and warming the gas to above its liquefaction temperature. The apparatus comprises, in combination: a container for storing liquefied gas, a liquefied gas pump for receiving liquefied gas from the container and for pumping it to a high pressure and conduit means for connecting the container with the inlet of the gas pump. A first heat exchanger is provided for vaporizing and warming the liquefied gas, and conduit means are provided for connecting the inlet of this heat exchanger with the discharge outlet of the gas pump. The outlet of the heat exchanger has valved conduit means for controllably discharging the vaporized and warmed high pressure gas. The liquefied gas pump is driven by an internal combustion engine having a coolant jacket, by connecting drive means. A coolant pump is employed to circulate engine coolant through the engine coolant jacket. Conduit means are also provided for connecting this pump with the first heat exchanger for circulating at least a portion of the engine coolant there-

through in heat exchange relation with the liquefied gas. A fluid frictional braking device is also connected to the engine to absorb power therefrom to heat the fluid. Conduit means are provided for circulating this heated fluid from the braking device to a second heat exchanger. Conduit means are also provided for connecting the outlet of the first heat exchanger with the inlet of this second heat exchanger for circulating the engine coolant portion from the first heat exchanger in heat exchange relation with the fluid from the frictional braking device. A third heat exchange is provided for absorbing heat from the engine exhaust gases. Conduit means are employed for connecting the third heat exchanger with the exhaust gas outlet of the engine. Conduit means are also employed for connecting the inlet of the third heat exchanger with the outlet of the second heat exchanger for circulating the engine coolant portion from the second heat exchanger in heat exchange relation with the engine exhaust gases passing through the third heat exchanger. Finally, conduit means are provided for connecting the outlet of the third heat exchanger with the engine coolant pump for returning the engine coolant to be recirculated through the coolant jacket.

Referring to FIGS. 1 and 2 of the drawings, liquefied gas, e.g., liquid nitrogen, stored in insulated container 10 is pumped to a high pressure such as, for example, 5000-15,000 p.s.i. by liquefied gas pump 12. An example of a suitable gas pump for use in practicing this invention is disclosed and claimed in U.S. Patent 3,016,717; however, other types of liquefied gas pumps may be used with success. The liquefied gas pump is driven by internal combustion engine 14 through geared transmission 11, coupling 13, frictional braking device 16, coupling 15 and chain drive 17. The high pressure liquefied gas is pumped to first heat exchanger 18 where it is vaporized and warmed to above its liquefaction temperature. A portion of the engine power is absorbed by the fluid frictional braking device 16 and is absorbed in the form of heat by the fluid. A portion of this heat is removed from the fluid in second heat exchanger 19 by heat exchange with at least a part of the engine coolant, after which it is returned to the braking device. An example of a suitable fluid frictional braking device for use in practicing this invention is Thompson Products No. R-20-RD 31-B11. The fluid used in this device is oil.

Referring now to FIG. 3, a continuous flow of coolant is circulated through the coolant jacket (not shown) of engine 14 by coolant pump 28. At least a part of the heated engine coolant leaving the engine is diverted through conduit 31 to a first heat exchanger 18. If the coolant temperature rises too high, a thermostatic valve 21, in a conduit parallel to conduit 31, opens to permit a portion of the engine coolant to be circulated through radiator 20 whereupon it is cooled and returned to the engine coolant jacket. The engine coolant is preferably maintained within a temperature range of 140-200° F. If desired, even closer control of the engine coolant temperature can be achieved by the use of a shutter 25 positioned across the major heat transfer surface of radiator 20. The shutter may be operated by a motor 27 in response to a thermostatic switch 23.

Liquefied gas from container 10 is delivered through conduit 40 to the inlet of liquefied gas pump 12 whereupon it is pumped to a high pressure and discharged through conduit 41 to first heat exchanger 18 wherein it is circulated in heat exchange relation with at least part of the heated engine coolant flowing from conduit 31. The high pressure liquefied gas is vaporized and warmed to above its liquefaction temperature in heat exchanger 18 and the resulting high pressure gas is controllably discharged through conduit 42 and valve V therein to its point of use or to an intermediate storage tank (not shown). If desirable, an auxiliary coolant pump 30 may be provided to supplement engine coolant pump 28.

The portion of the engine coolant circulated through first heat exchanger 18 and cooled by the liquefied gas passed in heat exchange therewith is preferably pumped to second heat exchanger 22 through conduit 32 wherein it is heated by heat exchange with heated fluid entering heat exchanger 22 through conduit 50 from frictional braking device 16.

The heated engine coolant portion leaving heat exchanger 22 is pumped into third heat exchanger 24 through conduit 33 whereupon it is passed in heat exchange relation with exhaust gases from engine 14 and still further heated. The engine exhaust gases are passed into heat exchanger 24 through conduit 35 and are thereafter discharged into the atmosphere through pipe 37. The heated engine coolant from third heat exchanger 24 is then returned through conduit 34 to coolant pump 28 for recirculation through the coolant jacket of engine 14.

It is preferable to operate engine 14 at a constant throttle position while controlling the output flow from the liquefied gas pump 12 by regulating the frictional drag force applied to the engine by the braking device 16. The frictional drag force applied by the brake retarder is dependent upon the fluid pressure maintained in it. This pressure may be controlled by regulating air pressure applied to hydraulic piston 26 through supply line 29. The air pressure can, if desired, be regulated in response to the temperature of the pumped engine coolant measured at some convenient point.

Another operating procedure is to remove thermostatic valve 21 and use the braking device to maintain the preferred minimum engine coolant temperature of 140° F. while controlling the preferred maximum engine coolant temperature of 200° F. by motorized shutters 25 in front of the radiator 20.

Referring now to FIG. 4, an alternative pumping and vaporizing system is illustrated. According to this embodiment, the portion of the engine coolant circulated to first heat exchanger 18 through conduit 31 is thereafter pumped to third heat exchanger 24 through conduit 61 for heat exchange with the engine exhaust gases before it is passed to second heat exchanger 22 for heat exchange with the fluid from the frictional braking device 16. After the coolant is heated in third heat exchanger 24 by the engine exhaust gases, it is pumped through conduit 62 to second heat exchanger 22 wherein it is heat exchanged with fluid from the braking device 16. Thereafter, the heated engine coolant is returned through conduit 63 to coolant pump 28 for recirculation through the engine.

The relative portions of the total heat supplied from the engine jacket, exhaust gas, and the braking device will vary according to the pumping flow and discharge pressure requirements. For example, at high pumping flow rates or discharge pressures when the engine speed and power output are high, most of the heat required to vaporize and warm the product will come from the engine and exhaust gas and only a small amount is required from the braking device. At low pump flow rates or discharge pressure when the pump power requirement is also small, surplus engine shaft power may be supplied and dissipated in the braking device to produce sufficient heat to vaporize and superheat the compressed liquid product to a temperature above about -40° F. (usually the minimum temperature that oil well casings or usual gas consumption equipment withstand safely without damage). The pump flow rate may be controlled by varying the engine speed in combination with the selection of appropriate transmission gear ratios, while pump discharge pressure may be controlled by the discharge valve or by the pressure level of the system being pumped.

Engine coolant temperature will be maintained automatically within the desired range by the thermostatic valve and/or radiator shutters which prevent excessively high coolant temperature. If coolant temperature from the engine jacket drops too low (below 120° F.) or if the compressed gas delivery temperature drops too near

the  $-40^{\circ}$  F. minimum, more heat can be produced in the braking device by forcing more oil into it.

An important operating feature provided by the braking device is to place the engine on maximum throttle, then use the braking device for pump speed control. This arrangement provides convenient speed control and also ample heat without use of spark retardation on the engine to burn fuel inefficiently in order to produce added heat. Spark retardation is undesirable, since it tends to cause burned engine exhaust valves, pistons, etc. and produce increased engine maintenance costs.

What is claimed is:

1. In the method of pumping a liquefied gas to a high pressure wherein a liquefied gas pump is driven by an internal combustion engine having a coolant jacket, the improvement which comprises vaporizing such liquefied gas and warming it to above its liquefaction temperature by absorbing heat from said coolant jacket, heat from the exhaust gases from said engine, and heat from a frictional braking device driven by said engine, and transferring a substantial portion of such absorbed heat into such liquefied gas.

2. In the method of pumping a liquefied gas to a high pressure wherein a liquefied gas pump is driven by an internal combustion engine having a coolant jacket, the improvement which comprises vaporizing such liquefied gas and warming it to above its liquefaction temperature by passing at least part of the heated engine coolant in heat exchange relation with such liquefied gas, thereafter passing the cooler engine coolant portion in heat exchange relation with the fluid from a frictional braking device driven by said engine to further heat such engine coolant portion, thereafter passing such engine coolant portion, in heat exchange relation with the heated exhaust gases from said engine to still further heat such engine coolant portion, and thereafter passing such engine coolant portion through said engine coolant jacket to still further heat said coolant while cooling said engine.

3. In the method of pumping a liquefied gas to a high pressure wherein a liquefied gas pump is driven by an internal combustion engine having a coolant jacket, the improvement which comprises vaporizing such liquefied gas and warming it to above its liquefaction temperature by passing at least part of the heated engine coolant in heat exchange relation with such liquefied gas, thereafter passing the cooler engine coolant portion in heat exchange relation with the heated exhaust gases from said engine to further heat said engine coolant portion, thereafter passing said engine coolant portion in heat exchange relation with the fluid from a frictional braking device driven by said engine to still further heat said engine coolant portion and thereafter passing said engine coolant portion through said engine coolant jacket to still further heat said coolant while cooling said engine.

4. In the method as claimed in claim 2, the improvement for preventing excessively high coolant temperatures circulating through said engine coolant jacket which comprises diverting a portion of the engine coolant through a radiator and returning such portion to said coolant jacket.

5. In the method as claimed in claim 4, the improvement which comprises controlling the proportion of engine coolant diverted to said radiator by a thermostatically operated valve in a conduit parallel with the conduit supplying engine coolant for heat exchange with the liquefied gas.

6. In the method as claimed in claim 4, the improvement which comprises controlling the temperature of the engine coolant circulating through said radiator by a thermostatically operated shutter positioned across the major heat transfer surface of said radiator.

7. In the method as claimed in claim 2, wherein the engine coolant circulating through said coolant jacket is maintained within a temperature range of  $140^{\circ}$  F.  $-200^{\circ}$  F.

8. In the method of pumping a liquefied gas according to claim 1, the improvement which comprises operating said engine at its maximum throttle position while controlling the output from said pump by regulating the frictional drag force applied to said engine by said braking device.

9. In the method of pumping a liquefied gas according to claim 1, the improvement which comprises operating said engine at a constant throttle position while controlling the output from said pump by regulating the frictional drag force applied to said engine by said braking device.

10. Apparatus for pumping a liquefied gas to a high pressure and for vaporizing and warming such gas to above its liquefaction temperature which comprises, in combination: a container for storing liquefied gas, a liquefied gas pump for receiving liquefied gas from said container and pumping it to a high pressure, conduit means connecting said container with the inlet of said pump, a first heat exchanger for vaporizing and warming the liquefied gas, conduit means connecting said first heat exchanger with the discharge outlet of said pump, and valved conduit means for controllably discharging vaporized and warmed high pressure gas from said first heat exchanger; an internal combustion engine having a coolant jacket, means for drivably connecting said engine to said liquefied gas pump, a coolant pump for circulating coolant through said engine coolant jacket, conduit means for connecting said coolant pump with said first heat exchanger for circulating at least a portion of the engine coolant through said first heat exchanger in heat exchange relation with the liquefied gas; a fluid frictional braking device connected to said engine to absorb power therefrom to heat said fluid, a second heat exchanger for removing a portion of the heat from said fluid, conduit means for circulating fluid from said braking device through said second heat exchanger, conduit means for connecting the outlet of said first heat exchanger with the inlet to said second heat exchanger for circulating the engine coolant through said second heat exchanger in heat exchange relation with fluid from said braking device; a third heat exchanger for still further heating the engine coolant from said second heat exchanger, conduit means for connecting the exhaust gas outlet of said engine with said third heat exchanger, conduit means for connecting the outlet of said second heat exchanger with the inlet of said third heat exchanger for circulating the engine coolant through said third heat exchanger in heat exchange relation with the exhaust gases from said engine, and conduit means for connecting the outlet of said third heat exchanger with said coolant pump for returning the engine coolant to be recirculated through said coolant jacket.

11. Apparatus according to claim 10 wherein a radiator is connected in parallel with said conduit means connecting said coolant pump with said first heat exchanger, for cooling the portion of engine coolant not circulated to said first heat exchanger, and conduit means connecting the outlet of said radiator with the inlet of said coolant pump.

12. Apparatus according to claim 11 wherein a thermostatically operated valve connected to the inlet of said radiator controls the proportion of engine coolant passing through said radiator.

13. Apparatus according to claim 11 wherein said radiator has a motorized shutter positioned across the main heat transfer surface thereof, said shutter being operative in response to a thermostatic device connected thereto, said thermostatic device being connected to a conduit conducting engine coolant.

14. Apparatus according to claim 10 wherein an auxiliary booster pump is connected in series with said coolant pump for circulating at least a portion of the engine coolant through said heat exchangers.

15. Apparatus for pumping a liquefied gas to a high pressure and for vaporizing and warming such gas to

above its liquefaction temperature which comprises, in combination: a container for storing liquefied gas, a liquefied gas pump for receiving liquefied gas from said container and pumping it to a high pressure, conduit means connecting said container with the inlet of said pump, a first heat exchanger for vaporizing and warming the liquefied gas, conduit means connecting said first heat exchanger with the discharge outlet of said pump, and valved conduit means for controllably discharging vaporized and warmed high pressure gas from said first heat exchanger; an internal combustion engine having a coolant jacket, means for drivably connecting said engine to said liquefied gas pump, a coolant pump for circulating coolant through said engine coolant jacket, conduit means for connecting said coolant pump with said first heat exchanger for circulating at least a portion of the engine coolant through said first heat exchanger in heat exchange relation with the liquefied gas; a fluid frictional braking device connected to said engine to absorb power therefrom to heat said fluid, a second heat exchanger for removing a portion of the heat from said fluid, conduit means for circulating fluid from said braking device through said second heat exchanger; a third heat exchanger for heating the engine coolant from said first heat exchanger, conduit means connecting the ex-

haust gas outlet of said engine with said third heat exchanger, conduit means for connecting the outlet of said first heat exchanger with the inlet of said third heat exchanger for circulating the engine coolant through said third heat exchanger in heat exchange relation with the exhaust gases from said engine; conduit means for connecting the outlet of said third heat exchanger with the inlet of said second heat exchanger for further heating the engine coolant by circulating it through said second heat exchanger in heat exchange relation with the fluid from said braking device, and conduit means for connecting the outlet of said second heat exchanger with said coolant pump for returning the engine coolant to be recirculated through said coolant jacket.

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