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Conner et al.

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[54] **PRIME MOVER SYSTEM UTILIZING TRIFLUOROETHANOL AS WORKING FLUID**

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[21] Appl. No.: **75,904**

[52] **U.S. Cl.** **60/36,** 257/67

[51] **Int. Cl.** **F01k 25/10**

[58] **Field of Search** 60/36; 257/67

[56] **References Cited**

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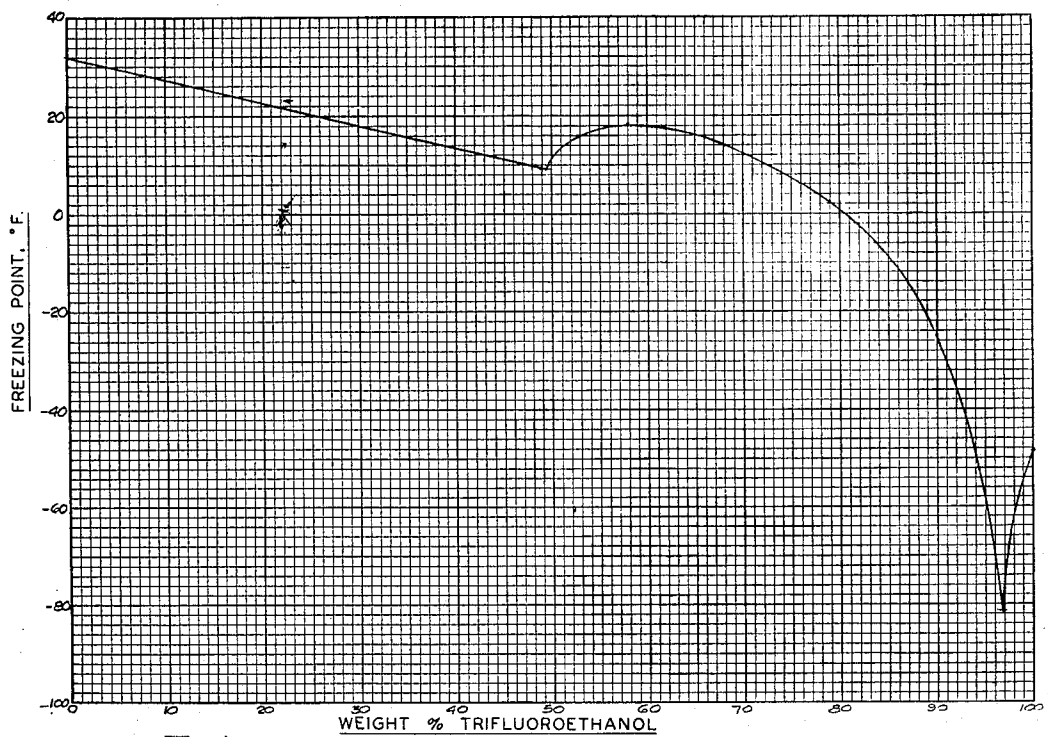
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[57] **ABSTRACT**

An anti-pollution heat engine including a prime mover system wherein the working fluid comprises trifluoroethanol, preferably containing about 3 to 25 percent of water by weight.

10 Claims, 4 Drawing Figures



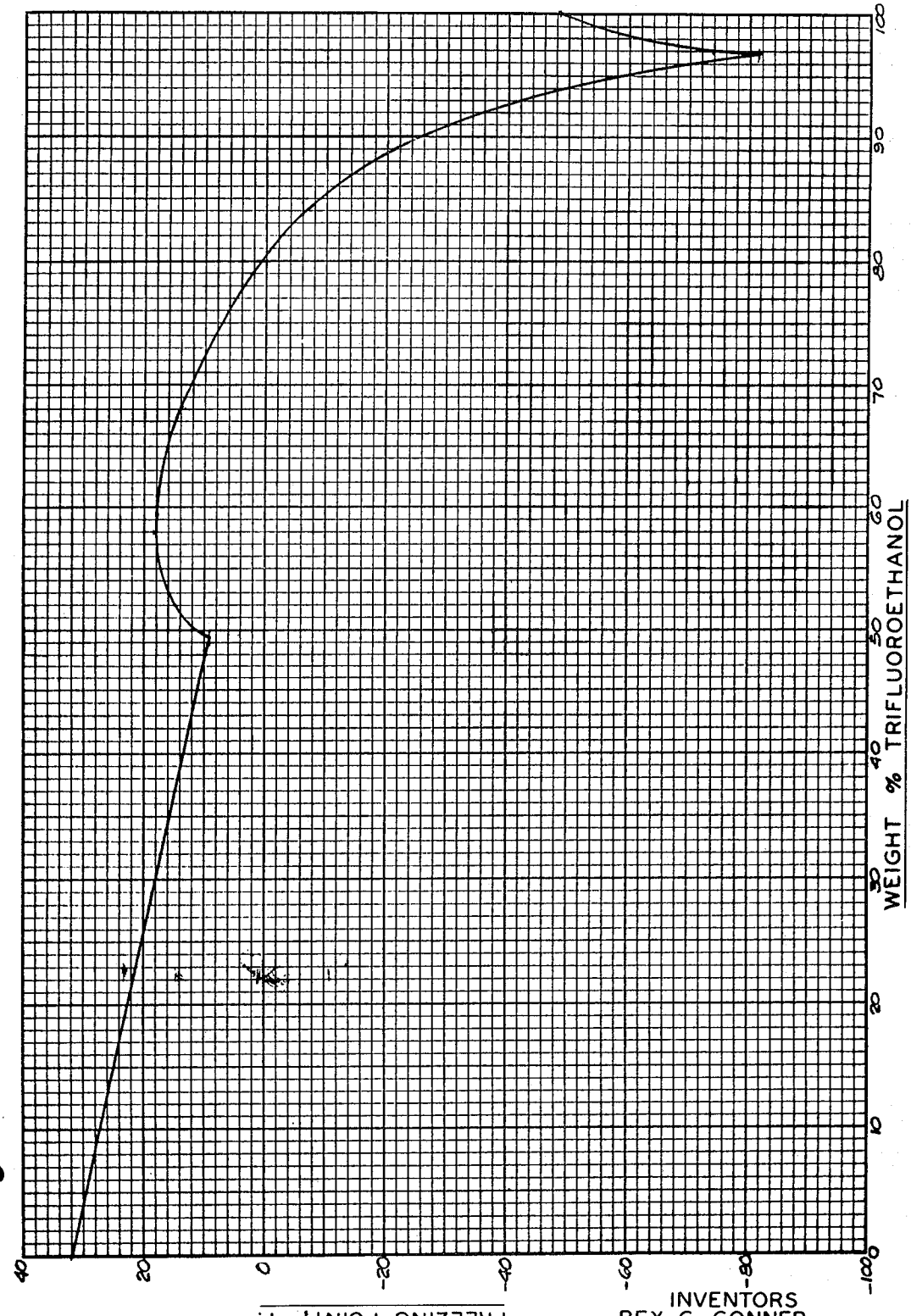


Fig.1

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Fig.2

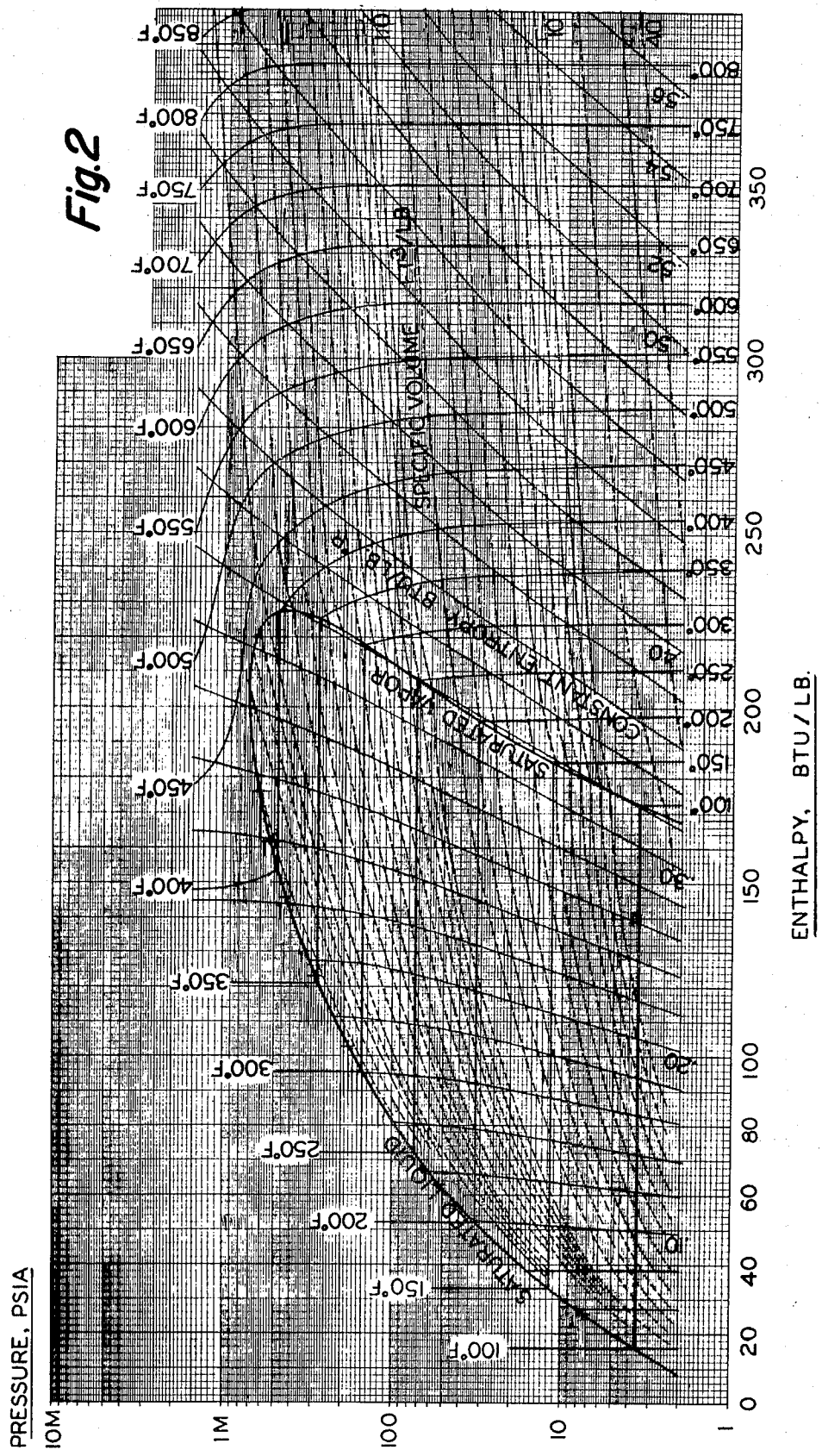

PRESSURE, PSIA
10M
1M
100
10
1
0
20
40
60
80
100
150
200
250
300
350
ENTHALPY, BTU/LB.
SATURATED VAPOR
SATURATED LIQUID
CONSTANT ENTROPY, BTU/LB°R
SPECIFIC VOLUME, FT³/LB
100°F
150°F
200°F
250°F
300°F
350°F
400°F
450°F
500°F
550°F
600°F
650°F
700°F
750°F
800°F
850°F

Fig.3

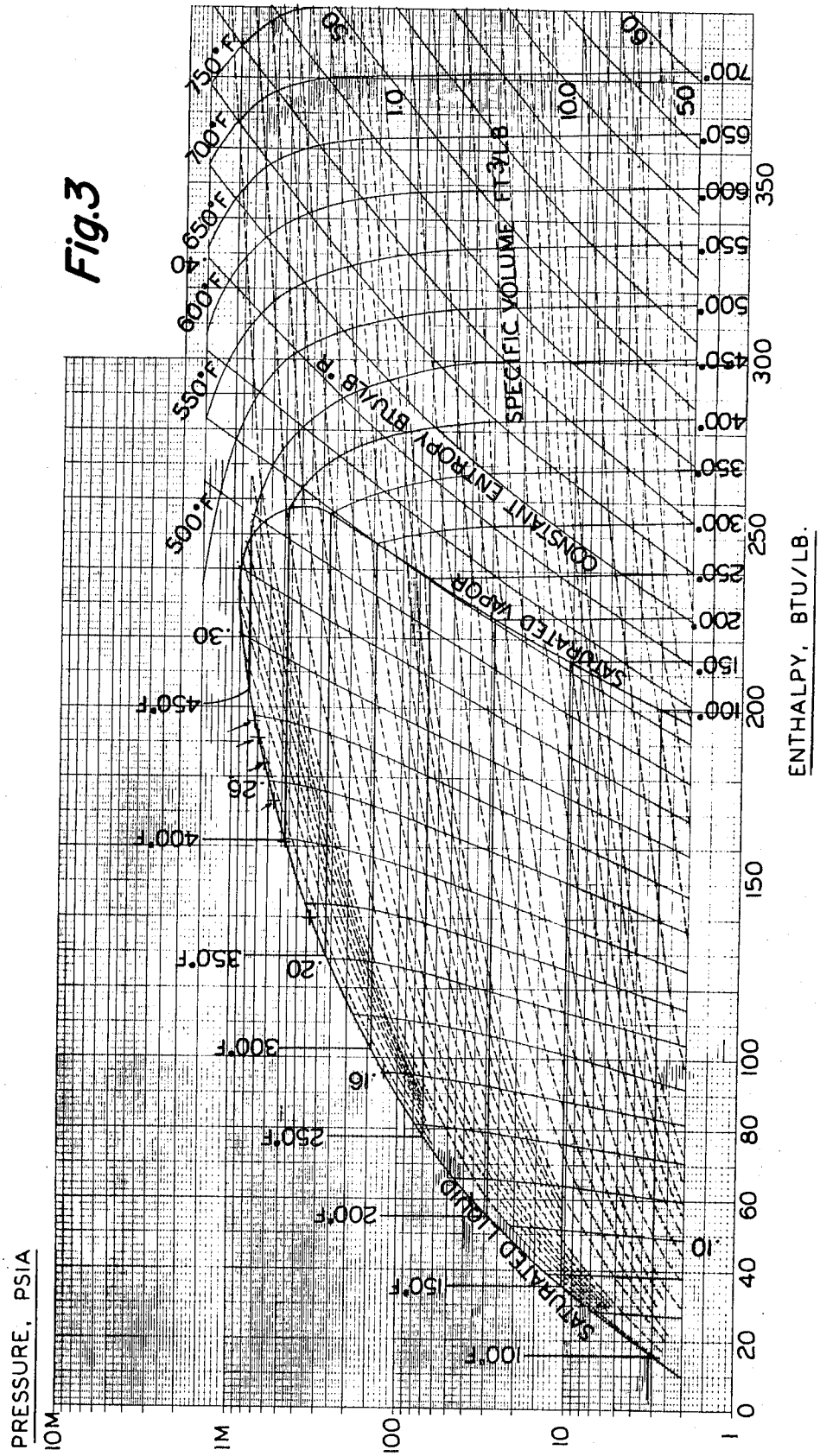
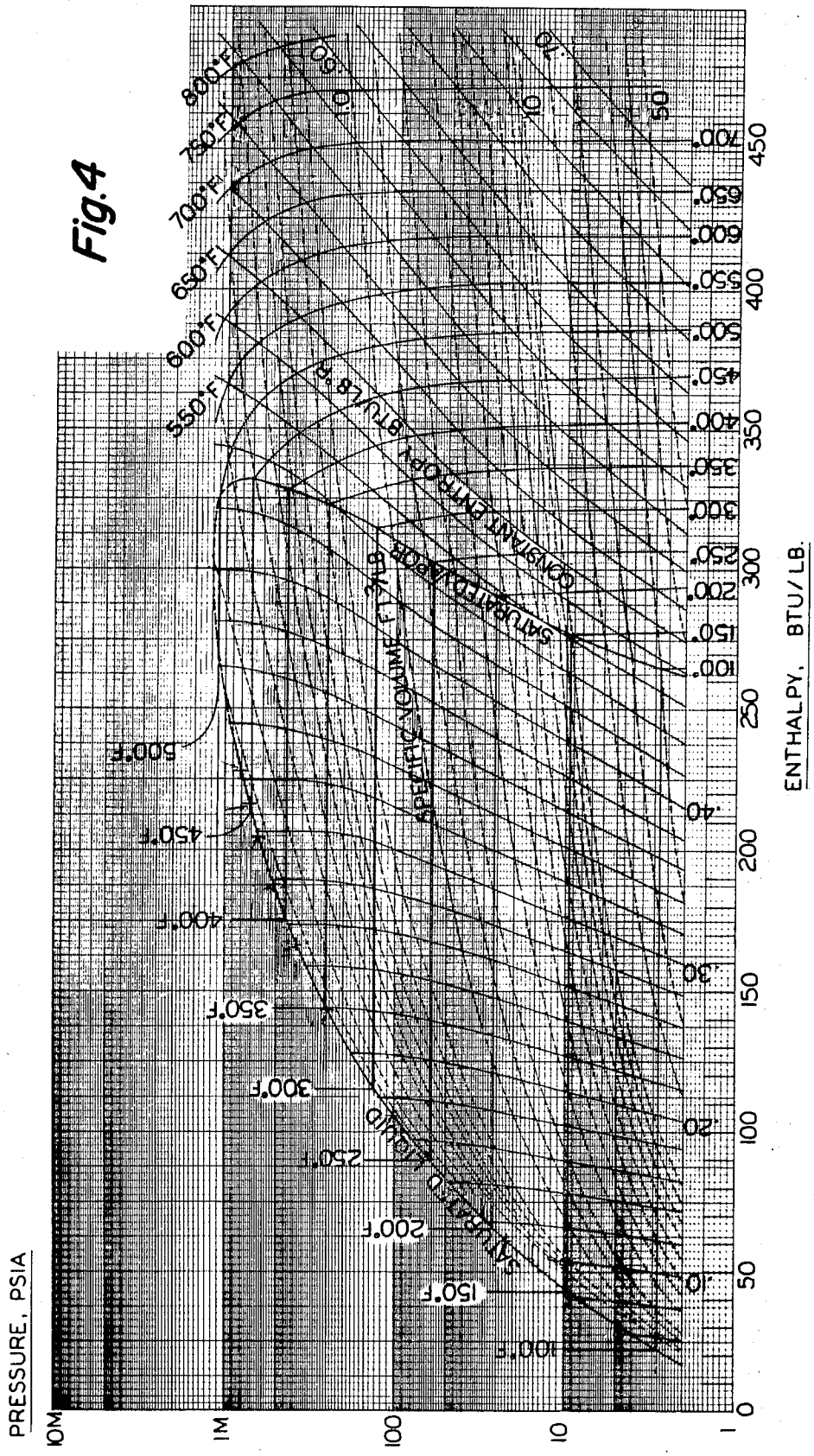

PRESSURE, PSIA
10M
1M
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10
1
ENTHALPY, BTU/LB.
0
20
40
60
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200
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300
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100°F
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350°F
400°F
450°F
500°F
550°F
600°F
650°F
700°F
750°F
SATURATED LIQUID
SATURATED VAPOR
CONSTANT ENTROPY BTU/LB
SPECIFIC VOLUME FT³/LB
.10
.16
.20
.26
.30
1.0
10.0
50
60
100
150
200
250
300
350
400
450
500
550
600
650
700

Fig.4


PRESSURE, PSIA
ENTHALPY, BTU/LB.
800°F
750°F
700°F
650°F
600°F
550°F
500°F
450°F
400°F
350°F
300°F
250°F
200°F
150°F
100°F
SATURATED VAPOR
SATURATED LIQUID
CONSTANT ENTROPY
BTU/LB
SPECIFIC VOLUME, FT³/LB

PRIME MOVER SYSTEM UTILIZING TRIFLUOROETHANOL AS WORKING FLUID

The present invention relates to prime mover systems for the conversion of heat into work by the expansion and condensation of a heated pressurized vapor.

Conventional internal combustion engines operate by explosive consumption of a fuel in a cylinder so as to move a piston which in turn rotates a shaft, often to drive a vehicle. Because of the varied conditions of explosion due to changes in load, e.g., during acceleration, idling or normal driving, combustion frequently varies from the ideal, the consumption of the fuel being incomplete so that incompletely oxidized substances are discharged into the atmosphere with attendant pollution.

A vapor cycle heat engine operating to drive an expander, e.g., a turbine, piston engine, or the like, wherein heated pressurized water vapor is used as the working fluid in a prime mover system, commonly called an external combustion engine, is quite efficient in its combustion of fuel, i.e., the fuel is substantially fully consumed; in addition, it is relatively flexible in the nature of the fuels which may be used. However, using water as the working fluid necessitates very high temperatures and pressures to achieve reasonable efficiencies for the conversion of heat energy to work and this in turn requires special safety measures and special equipment, including expensive alloy metals. In addition, at steam temperatures above 650° F. conventional lubricants and gasketing materials break down.

In an effort to overcome the problems with steam, other working fluids have been proposed but they introduce other problems of their own, e.g., breakdown of the fluid upon prolonged heating, chemical reaction with metal materials of construction and with conventional gasketing materials, limited efficiency, toxicity, flammability, or the like.

It is accordingly an object of the present invention to provide novel working fluids in prime mover systems utilizing external combustion to put thermal energy into the fluid for conversion to motive power.

A further object of the invention is to provide a safe working fluid for a vapor cycle engine such as the Rankine Cycle engine for a vehicle, boat or other power equipment, powered by an efficient, inexpensive, safe, low emission, prime mover system which can be powered by the consumption of a variety of readily available fuels such as fuel oil, diesel fuel, kerosene, gasoline, natural gas, propane, butane, alcohol, oil, and the like, or solid fuels, to minimize pollution of the atmosphere.

In accordance with the present invention, there is provided a conventional prime mover system such as a Rankine Cycle engine to provide mechanical work, except that the working fluid comprises trifluoroethanol. The working fluid, in addition to trifluoroethanol, may include up to about 40 percent by weight of water and advantageously includes at least about 1 percent, preferably about 3 to 25 percent by weight, of water.

Trifluoroethanol is distinguished by its thermal stability alone as well as in aqueous solution, so that it can be used for a long time in a closed circuit without replacement or replenishment. Not only is trifluoroethanol thermally stable in pure form and even more stable in the presence of water, but it is safe as well. As determined by ASTM D-92-52 it has no fire point, i.e., it will not support its own combustion; if an open flame is held in contact with 100 percent trifluoroethanol it may be consumed but if the flame is removed the trifluoroethanol will not continue to be consumed. In addition, its miscibility with water, and also most common organic solvents, makes it easy to remove it from unwanted locations in the event of spills or accidents. It satisfies Manufacturing Chemists Association standards for non-toxicity upon inhalation or dermal contact.

The thermal properties of trifluoroethanol and of aqueous trifluoroethanol especially suit them for use as working fluids. As can be seen in FIG. 1 there are two local minima in the freezing point curves of trifluoroethanol-water. Thus, the addition of any trifluoroethanol to water reduces its freezing point. On the portion of the curve above 60 percent trifluoroethanol it can be seen that if the freezing point is reached, some water-enriched trifluoroethanol will freeze so that the residual liquid will become enriched with trifluoroethanol thus moving the liquid composition down the curve to the right. While there will be some frozen solids in the liquid, it will be a slush and will not freeze solid until the temperature falls below the eutectic at −82° F. Consequently, aqueous trifluoroethanol containing from about 60 to 97 percent by weight trifluoroethanol will all have final solidification temperature of −82° F., permitting their use even in Arctic climates, i.e., the systems will not freeze solid during periods of non-use at ambient temperatures.

Table 1, which follows, shows the critical temperatures and pressures for trifluoroethanol and various blends with water, as computed:

TABLE 1

% trifluoroethanol by weight	Critical Temperatures, ° F.	Critical Pressures, psia
100	440	715
97	465.5	930
90	512	1200
85	535	1460
60	600	2160

While the physical properties of steel start suffering above 600° F. and deteriorate quite significantly above 750° F., it can be seen that trifluoroethanol or its aqueous blends can be converted from liquid to vapor without exceeding these temperatures. Pressures of 300 to 1,500 psia, which are readily usable without special measures, are also quite satisfactory for cycling of the working fluid between liquid and vapor states. Aqueous or pure trifluoroethanol is non-corrosive with most metals including iron, steel, copper and aluminum even at elevated temperatures. Tests at elevated temperatures, as evidenced by a change in thickness, indicate minimal attack on fluoroelastomers (Viton A) and neoprene which are conventional gasket materials.

FIGS. 2, 3 and 4 show pressure -enthalpy curves for 100 percent trifluoroethanol, 97-3 trifluoroethanol-water and 90-10 trifluoroethanol-water by weight, respectively. From a comparison of these curves it is apparent that the addition of a small amount of water as in FIG. 3 and a larger amount of water as in FIG. 4, compared to 0 percent water in FIG. 2, increase con-

siderably the enthalpies of the system both at atmospheric pressure and at pressures of about 300 to 1,500 psia to which the instant fluids are intended to be raised during superheating in the course of operation. This increase in enthalpy in turn evidences not only an increased heat capacity but also a greater efficiency in converting heat to work in each cycle of heating a portion of fluid in a reservoir, vaporizing it, in most cases superheating it, expanding it so as to move a member and perform work, the expanded vapor cooling, condensing and returning by means of a pump to the reservoir.

As noted, aqueous trifluoroethanol is an even better working fluid than trifluoroethanol alone. Even though the mole percent of water in the solution increases substantially, the boiling point of the mixture rises very slowly, e.g., while the trifluoroethanol content of an aqueous mixture drops from 100 mole percent to 20 mole percent, the boiling point only rises from 165° to 178° F. At the same time, the pressure and temperature at which a Rankine Cycle may operate are increased, e.g., 3 percent water on a weight basis permits operating a Rankine Cycle at 700 psia and 470° F whereas the maximum pressure and temperature of a cycle using 100 percent trifluoroethanol are 600 psia and 440° F. In this manner, the maximum possible efficiency of less than 22.5 percent for a 100 percent trifluoroethanol cycle is raised to more than 25 percent with only 3 percent of water by weight added to the trifluoroethanol.

Since ordinary steel cannot be used at temperatures in excess of 750° F and since a condenser pressure of 15 psia is most desirable for many purposes, a Rankine cycle operating at such a condenser pressure and with water-steam under conditions so as not to exceed 750° F would at best be only about 20 percent efficient, even though the maximum steam pressure would only be about 190 psia. This efficiency is markedly less than that attainable with 100 percent trifluoroethanol or aqueous trifluoroethanol.

The following examples illustrate various aspects of practicing the invention:

EXAMPLE 1

An 97–3 trifluoroethanol-water mixture by weight enters a boiler at 165° F. and leaves as a vapor at 438° F. and 700 psia. The vapors are superheated to 470° F. at that pressure and then are expanded through the blades of a turbine whose shaft is caused to rotate and perform work. The expanded vapor cools and condenses, falling back to 165° F. and 15 psia, at which point the liquid is punped back into the boiler. The efficiency of the cycle is about 25 percent.

Substantially similar results are achieved if the expansion of the gas takes place against a reciprocating piston which is slidably mounted between two positions, the expansion causing the piston to move to its second position and rotate a crank-shaft in doing so, the shaft driving a prime mover. Similarly the expansion can be utilized to rotate a helical screw.

The prime mover system may be used for automobile vehicles, boats or for purposes other than motive power such as in electric generators, powered equipment, and the like, wherever other such systems or internal combustion engines have heretofore been used. The motive power, when involved, may drive any shaft including especially the drive shaft of vehicles such as automobiles.

EXAMPLE 2 — THERMAL STABILITY

In a series of runs stainless steel bombs were partially filled with trifluoroethanol or trifluoroethanol-water, each bomb was evacuated, sealed and the temperature raised to the indicated level. The initial pressure was calculated for the mean elevated temperature of the run, using the ideal gas law. At various time intervals the bombs were cooled to room temperature and, without opening, the pressure in the gas space was measured on a coarse gauge which could not give numerical readings in excess of 60 psig. Where the pressure in the gas space was relatively low after short treatments the bombs were reheated and the experiments continued. In Runs A, measurements were made after 17, 109, 119, 253 and 452.5 hours, and in Runs B after 40, 68.6, 97 and 115, about 200., 241.5, 419 and 481 hours. The pressure upon cooling was taken as an index of the extent of decomposition. The results are reported in Table 2.

TABLE 2

Run	TFE content in wt. % of TFE-H_2O Solution	Temp., °C.	Initial Pressure PSIG, Calculated at Mean Temp.	Time, Hours	PSIG, when cooled
A-1	100	390–480	4500	17	>60
2	84.6	314±3	6000	452.5	0.5
3	84.6	344±3	6300	119	0
4–*a*	84.6	350–369	6800	109	0
–*b*			6800	253	10
B–1	100	300–320	3700	97	21
2	100	310–325	3700	68.6	0.75
3	100	318–338	3800	40	>60
4	100	334–348	3800	113.4	>60
5	100	302–327	1200	481	0
6	100	334–348	615	113.4	*
7	97	300–345	3700	205.8	>60
8	97	302–327	1400	481	0
9	94	302–327	1500	481	0
10	90	330–350	5400	419	0
11	90	330–350	615	419	0
12	88	302–327	1800	481	0
13–*a*	75	320–345	7600	241.5	2
–*b*			7600	196	0
14	60	330–349	5700	115.5	0
15	60	330–349	615	115.5	0

* Not recorded

While the results are somewhat approximate, by comparing, for example, runs **B1** and **B5** which were effected at about the same temperatures, it can be seen that there appears to be a degrading action resulting from pressure, although the pressures in both of these runs are, of course, greater than would normally be encountered in ordinary equipment. The extremely high pressures are generated as a result of the small amount of vapor space and the high temperatures. A similar pressure effect can be seen by comparing runs **B4** and **B6**. The presence of water, however, has a thermally stabilizing effect which more than compensates for any negative pressure effect. Thus, comparing run **B5** with runs **B8**, **9** and **12** it can be seen that the aqueous product is no less stable than the 100 percent

trifluoroethanol of B5 although one would have expected water to have a degrading effect. Moreover, run B2, B3 and B4 in comparison with run B10, for example, shows that the latter is more stable, notwithstanding the higher pressures generated and the higher operating temperatures.

It will be appreciated that the instant specification and example are set forth by way of illustration and not limitation, and that various modifications and changes may be made without departing from the spirit and scope of the present invention.

What is claimed is:

1. In a prime mover system wherein heat is converted to mechanical work, the system including a closed circuit containing a reservoir of working fluid, means for vaporizing and heating the fluid to a temperature of about 400° to 750° F, an expander which converts heat to mechanical work, a condenser and a pump for returning condensate from said reservoir to said means for vaporizing and heating the fluid, the improvement wherein said fluid consists essentially of trifluoroethanol containing about 1 to 40 percent of water by weight.

2. A system according to claim 1, wherein said fluid comprises about 3 to 25 percent of water by weight.

3. A system according to claim 1, wherein the expander is a turbine, piston engine or helical screw.

4. A vehicle driven by a prime mover system according to claim 1.

5. In the conversion of heat into motive power by vaporizing and superheating a portion of the fluid in a reservoir and then allowing said fluid vapor to expand, condense and return to said reservoir, said expansion moving a member, the improvement which comprises heating said fluid to a temperature of about 400° to 750° F., said fluid consisting essentially of trifluoroethanol containing about 1 to 40 percent of water by weight.

6. A process according to claim 5, wherein said fluid is heated to about 400° to 600° F.

7. A process according to claim 5, wherein, the fluid vapor prior to expansion is under a maximum pressure of about 300 to 1,500 psia, the tendency toward decomposition fostered by said pressure being counteracted by the stabilizing effect of said water.

8. A process according to claim 7, wherein said fluid comprises about 3 to 25 percent of water by weight.

9. A process according to claim 6, wherein said moving member is a reciprocating piston and drives a vehicle.

10. A process according to claim 9, wherein said moving member is a turbine blade and drives a vehicle.

* * * * *