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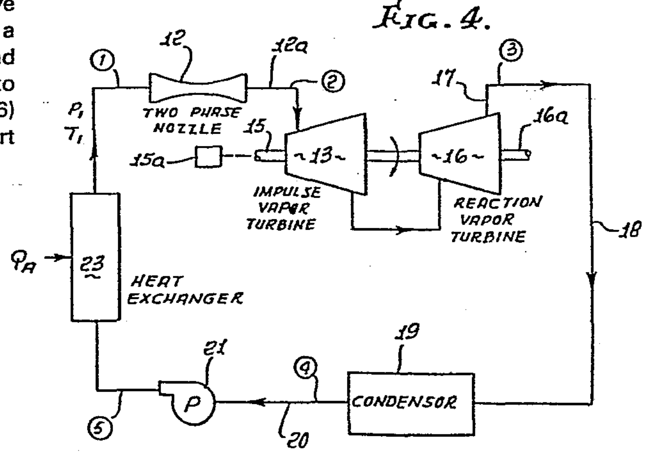
(54) **Method of and apparatus for producing power.**

(57) In apparatus using a fluid which exhibits a regressive vapor dome in a T-S diagram, the following are provided, a two-phase nozzle (12) receiving the fluid in pressurized and heated liquid state and expanding the received liquid into saturated or superheated vapor state, and apparatus (13, 16) for receiving the saturated or superheated vapor to convert the kinetic energy thereof into power.

FIG. 4.



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"METHOD OF AND APPARATUS FOR PRODUCING POWER"

BACKGROUND OF THE INVENTION

This invention relates generally to power production, and more particularly concerns use of a two-phase nozzle in a process employing a fluid exhibiting a regressive vapor dome in the temperature-entropy plane.

Conventional vapor turbines operating in systems utilizing waste heat as energy sources encounter a pinch point problem in transferring the energy from the waste heat to the working fluid. The problem is a result of the heat of vaporization that must be absorbed to vaporize the working fluid as shown in Fig. 1, so that the energy can be transformed into shaft work in a vapor turbine. As a result, there always exists a large temperature difference between the temperature of the exhaust gas and the working fluid (see ΔT_{pp} on Fig. 1). This limits the upper temperature of the working fluid which in turn limits the thermodynamic efficiency of the system.

SUMMARY OF THE INVENTION

It is a major object of the invention to provide a power producing system and process wherein the working fluid exhibits a regressive saturated vapor line, i.e. one wherein the entropy decreases as the temperature of the saturated vapor decreases. Basically, the invention involves the use of a two-phase nozzle in such a system, and includes the steps:

a) receiving the fluid in pressurized and heated liquid state in a two-phase nozzle, and expanding the received liquid therein into a discharge jet consisting of saturated or superheated vapor,

b) and converting the kinetic energy of said vapor jet into power.

In this regard, the use of a fluid with a regressive vapor dome eliminates the above described problem, and as further shown in Fig. 2. The fluid exiting the heat exchanger is in the liquid state. Expansion through a two-phase nozzle from state points 1 to 2 results in a high velocity pure vapor at the nozzle exit.

As will be seen, the working fluid is typically a hydrocarbon or a fluorocarbon, examples being DOWTHERM-A or certain freons and the two-phase nozzle facilitates production of a jet consisting substantially completely of superheated vapor, whereby turbine efficiency can be increased. Overall turbine efficiency is enhanced by provision of both impulse and reaction turbine stages, as will be seen.

The present invention is fluid expansion power apparatus characterized by (a) a two-phase nozzle receiving a fluid in pressurized and heated liquid state, said fluid having a regressive vapor dome in a T-S diagram, and expanding said received liquid into saturated or superheated vapor state, and (b) means receiving said saturated or superheated vapor to convert the kinetic energy thereof into power.

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:-

Fig. 1 is a temperature-entropy diagram;

Fig. 2 is a temperature-entropy diagram;

Fig. 3 is a temperature-entropy diagram; and

Fig. 4 is a schematic showing of a vapor turbine system.

DETAILED DESCRIPTION

Referring first to Fig. 3, a temperature-entropy curve 10 is shown for a fluid having a regressive vapor dome. The line 10*a* defining the left side of the curve 10 corresponds to saturated liquid, and the regressive line 10*b* defining the right side of the curve 10 corresponds to saturated vapor. Some fluids may exhibit T-S curves such as shown at 10, and examples are the liquid mix known as DOWTHERM-A (a product of Dow Chemical Company, Midland, Michigan); certain fluorocarbons and other hydrocarbon liquid mixes. Typical fluorocarbons are: R 114, R 216 and trifluoroethanol.

Fluids with regressive vapor domes as shown can be expanded from their saturated liquid state (line 10a) through the vapor dome into the superheat region (to line 10b, for example).

In accordance with the invention, a two-phase nozzle 12 is employed as in Fig. 4 to carry out the expansion through the vapor dome, as referred to. Examples of such nozzles are those described in U.S. Patent 3,879,949. Such expansion can take place at high efficiency (such as about 90%) to yeild a vapor jet at 12a with velocities of discharged vapor in the range of about 1000 feet per second. Such jet velocities are not excessive, the latent heat of vaporization of such fluids typically being around 100 B/lbm, where:

B = British thermal unit

lbm = pound mass.

As shown in Fig. 4 the jet is passed to turbine means to convert the kinetic energy of the jet into power. See for example the impulse vapor turbine 13 receiving the superheated vapor jet, and discharging it at 14. A power take-off shaft is indicated at 15, and may be used to drive a pump, generator, etc., indicated at 15a. See also the reaction vapor turbine 16 connected in series with turbine 13 to receive the vapor discharge 14, and discharge the reduced temperature vapor at 17. See point ③ in both Figs. 3 and 4. Both turbines are thereby driven, the power take-off for reaction vapor turbine 16 being indicated at 16a.

In general, in an impulse vapor turbine, the total pressure drop for a stage is taken across elements or blades (stators), whereas in a reaction turbine, the total pressure drop for a stage is divided between stationary blades and rotating blades, these two types of turbines being well known *per se*.

Referring to Fig. 4 the vaporized and discharge fluid 17 is then passed at 18 to a condenser 19, the condensate 20 being re-pumped at 21 to a pressure p_1 equal to the pressure of liquid entering the nozzle 12. Prior to passage to the nozzle, the liquid is heated in a heat exchanger 23 to initial temperature T_1. Heat added to the liquid in exchanger 23 is indicated at Q_A. Also, note corresponding points ③, ④ and ⑤ in Figs. 3 and 4.

The advantages of the described system include:

1) Provision of high efficiency without the

need for boilers or regenerators, enabling the system to operate at high upper cycle temperature for a given heat-source temperature.

2) Spouting (nozzle jet) velocities can be limited to about 1000 ft/sec.

3) Use of conventional turbines, as described.

4) Nozzle efficiency is high (typically greater than 90%) because mostly vapor flows through the diverging section of the nozzle.

A summary of temperatures and efficiencies is set forth in the following table.

TABLE

Fluid		T_1 (°F)	T_2	T_3	$T_{condenser}$
Dowtherm	A	750	500	256	110
"	A	680	401	216	110
"	E	630	240	128	120

efficiency

Fluid		η_η	η_{t_1}	η_{t_2}	η_{cycle}
Dowtherm	A	0.8	0.8	0.8	.267
"	A	0.8	0.9	0.9	.297
"	E	0.8	0.9	0.9	.244

where η_η = nozzle efficiency

η_{t_1} = efficiency of impulse turbine

η_{t_2} = efficiency of reaction turbine

η_{cycle} = overall thermodynamic efficiency of cycle.

CLAIMS:

1. Fluid expansion power apparatus characterized by

a) a two-phase nozzle (12) receiving a fluid in pressurized and heated liquid state, said fluid having a regressive vapor dome in a T-S diagram, and expanding said received liquid into saturated or superheated vapor state, and

b) means (13, 16) receiving said saturated or superheated vapor to convert the kinetic energy thereof into power.

2. Apparatus as claimed in claim 1, characterized in that said means includes an impulse vapor turbine (13) receiving said vapor.

3. Apparatus as claimed in claim 2, characterized in that said means also includes a reaction vapor turbine (16) receiving the vapor discharged from said impulse vapor turbine (13).

4. Apparatus as claimed in any preceding claim, characterized by other means (19, 21, 23) operatively connected with said means for condensing the vapor from said means, for repressurizing and heating same for re-delivery to said nozzle (12).

5. Apparatus as claimed in claim 4, characterized in that said other means comprises a

condenser (19), a pump (21) and a heater (23) connected in series.

6. A method of producing power using a fluid which exhibits a regressive vapor dome in a T-S diagram, the process being characterized by the steps of receiving the fluid in pressurized and heated liquid state in a two-phase nozzle (12), and expanding the received liquid therein into a discharge jet consisting of superheated vapor, and converting the kinetic energy of said vapor jet into power.

7. A method as claimed in claim 6, characterized in that the discharge jet consists substantially completely of said superheated vapor.

8. A method as claimed in claim 6, characterized in that the converting step includes providing turbine stages driven by said vapor jet kinetic energy.

9. A method as claimed in claim 6, characterized in that the converting step includes providing impulse vapor turbine and reaction vapor turbine stages driven by the vapor jet kinetic energy.

10. A method as claimed in claim 8, characterized by condensing the expanded vapor discharged from said turbine stages, and re-pressurising and heating same for recirculation to said nozzle.

11. A method as claimed in claim 9, characterized by condensing the expanded vapor discharged from said turbine stages, and re-pressurizing and heating same for recirculation to said nozzle.

12. A method as claimed in any preceding claim, characterized in that said fluid is a hydrocarbon fluid or a fluorocarbon fluid.

FIG. 1.

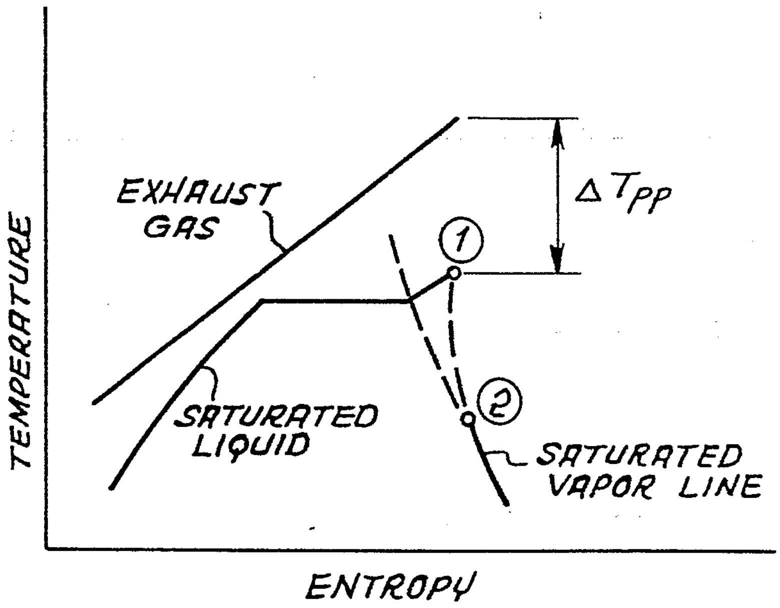

EXHAUST GAS
ΔTPP
1
2
SATURATED LIQUID
SATURATED VAPOR LINE
TEMPERATURE
ENTROPY

FIG. 2.

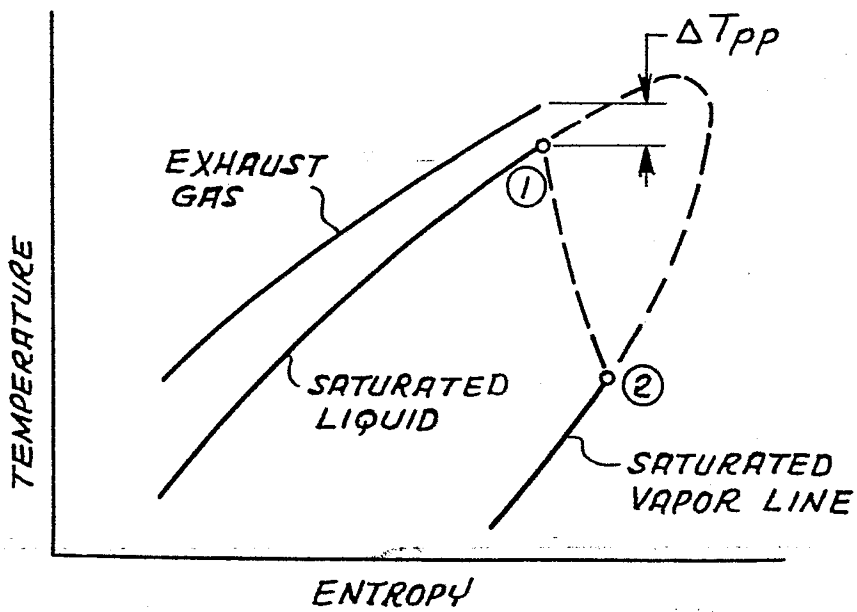

ΔTPP
EXHAUST GAS
1
2
SATURATED LIQUID
SATURATED VAPOR LINE
TEMPERATURE
ENTROPY

FIG. 3.

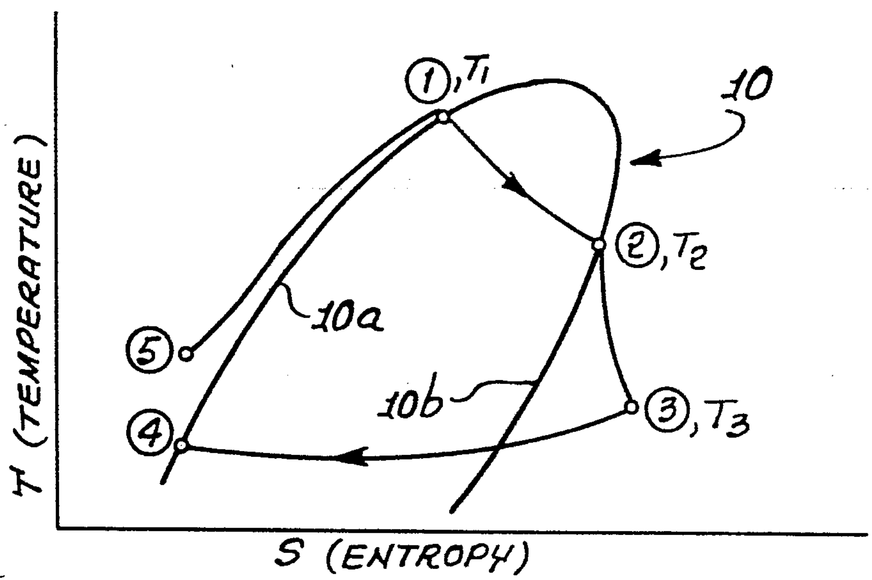
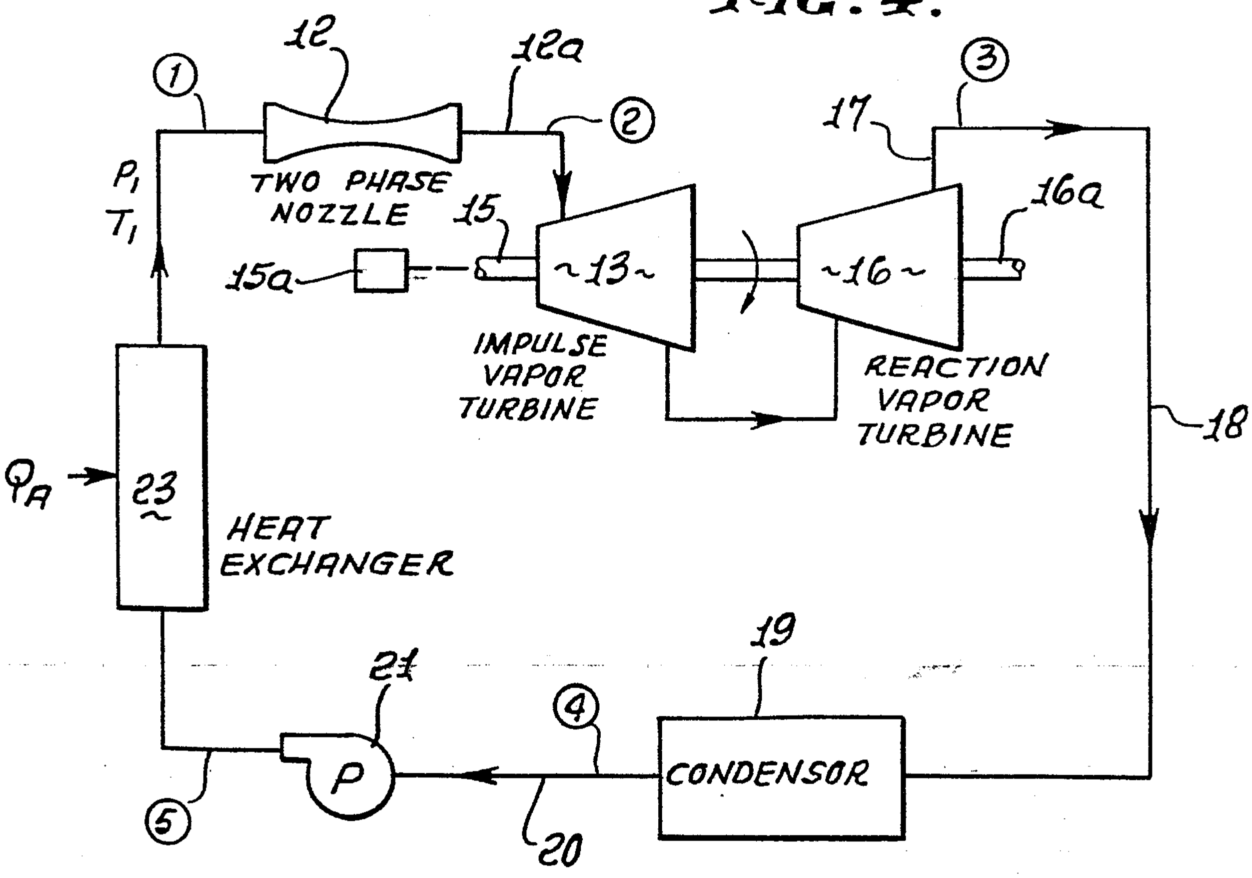

T (TEMPERATURE)
S (ENTROPY)
1, T1
2, T2
3, T3
4
5
10
10a
10b

FIG. 4.


1
2
3
4
5
12
12a
P1
T1
TWO PHASE
NOZZLE
15
15a
13
16
16a
17
IMPULSE
VAPOR
TURBINE
REACTION
VAPOR
TURBINE
18
QA
23
HEAT
EXCHANGER
19
CONDENSOR
21
P
20

European Patent Office

EUROPEAN SEARCH REPORT

0149288

Application number

EP 84 30 0202

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. ³)
Y	DE-A-1 551 260 (SIEMENS AG) * Page 2, lines 6-23; page 7, line 3 - page 8, line 17; figures 1,2 *	1-12	F 01 K 25/00

Y	US-A-4 086 772 (WILLIAMS) * Abstract; column 2, lines 50-55; column 4, line 47 - column 5, line 15; column 5, lines 50-67; figures 1-3 *	1-12	

Y	DE-A-3 006 286 (B.B.C. AG) * Page 3, lines 2-8 *	2,3,9	

A	US-A-3 234 734 (BUSS et al.) * Column 1, lines 22-30; figure 1 *	1,4-6, 10,11	**TECHNICAL FIELDS SEARCHED (Int. Cl. ³)**
	---		F 01 K F 01 D
A,D	US-A-3 879 949 (HAYS et al.) * Abstract *	1,2,4-8,10, 11	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	31-08-1984	ATTASIO R.M.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document