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## (54) METHOD FOR CONVERTING THERMAL ENERGY OF A WORKING MEDIUM INTO MECHANICAL ENERGY IN A STEAM PLANT.

(57) A method for converting the thermal energy of a working medium into mechanical energy in a steam plant with a volume expansion engine in which is used the thermal energy of the working medium which changes, during the working cycle, its state of aggregation. The method provides for isobaric heating of the working medium up to a given temperature, feeding it to the engine, adiabatic expansion of the working medium and its condensation after the discharge from the engine with subsequent adiabatic compression. The heating and the adiabatic compression of the working medium before its feeding to the engine is effected up to the parameters corresponding to its area of critical state, whereas the adiabatic expansion of the working medium in the engine is effected from its area of critical state. The working medium used can be liquids whose difference of enthalpies between the points of critical and atmospheric pressures during the adiabatic expansion equals or exceeds the heat of vaporization.

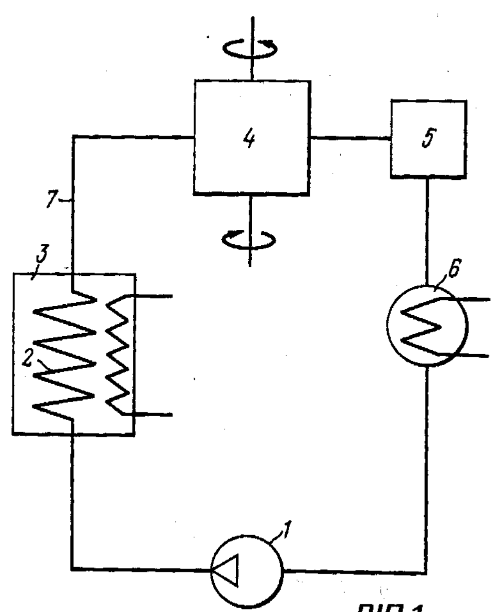


FIG.1

EP 0 485 596 A1

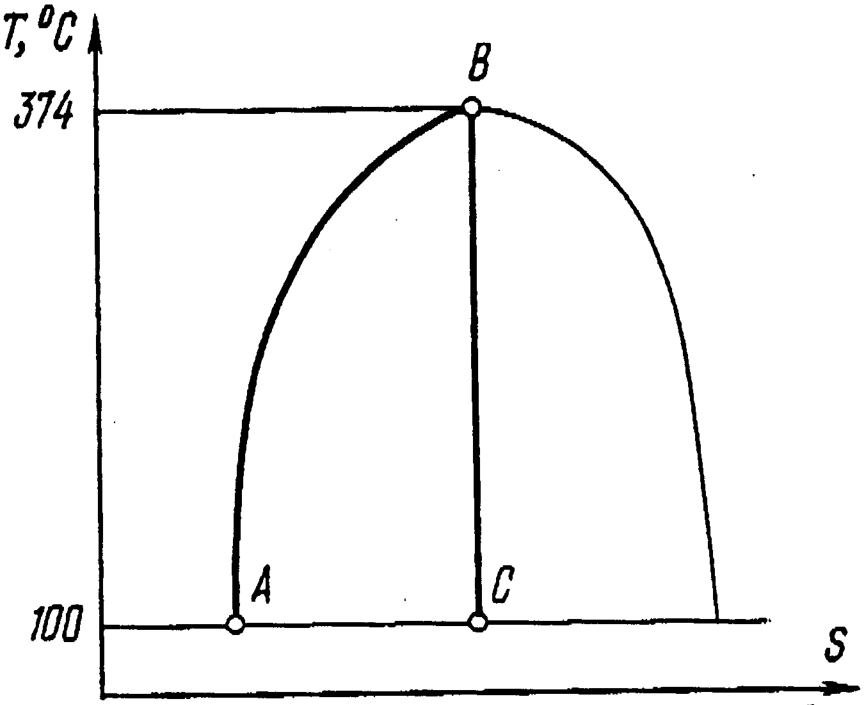


FIG.2

## Field of the Invention

The invention relates to thermal engineering, and in particular, it deals with a method for transforming thermal energy of fluid into mechanical energy in a steam power plant having an expansion engine.

The invention may be most advantageously used in steam power plants of vehicles.

The invention may be used in power plants for generating electric energy.

## Background of the Invention

It is known in the thermal engineering to trans - form thermal energy of fluid into mechanical energy, wherein fluid changes its physical state during the transformation cycle. The most widely known method is a so called Carnot's cycle which is a reversible cycle comprising two isothermal and two adiabatic processes. However, the practical application of this method, in particular, to steam power plants of vehicles is difficult because it is necessary to make use of a rather unwieldy compressor for compression of steam at a low pressure with a large specific volume, enormous energy being spent for operation of the compressor.

Also known in the art is a Rankine's cycle which is a closed-loop cycle consisting of heating a fluid, evaporating and overheating steam, adiabatic steam expansion in an engine and condensation of the steam. Heat removal from wet steam in the condenser in this cycle continues until all steam is condensed. It is a liquid having compressibility which is incomparably low in comparison with wet steam compressibility that is compressed rather than wet steam of a low density. Pumps are used to move liquid simultaneously with a pressure increase, the pumps consuming much less energy. However, thermodynamic efficiency of the Rankine's cycle is lower than that of the Carnot's cycle as the degree of admission and average heat supply rate are lower. To enhance the efficiency in the Rankine's cycle, steam is superheated in a steam superheater. In this case the average heat temperature increases, and the degree of admission decreases. As a result, power-to-weight ratio of the steam power plant decreases and its size increases which also makes it difficult to make use of such a cycle in power plants of vehicles.

It is also known to transform thermal energy of fluid into mechanical energy in cycles in which the adiabatic expansion of fluid is carried out both from supercritical and subcritical states of fluid. The critical state of fluid is such a state in which fluid in the liquid state has its own properties materially different from properties of both liquid and vapour. This area is limited on the one hand by the critical point of transition from liquid to vapour and, on the other hand, by a material change in a number of its physical properties.

a part of energy in these cycles is consumed for boiling (vapour formation) of fluid and only the rest of internal energy is consumed for performing useful work thus resulting in a lower efficiency. In addition, density of internal energy in these cycles is low which negatively affects specific performance of power plants using such cycles. These disadvantages make such power plants inacceptable for use as power plants of vehicles.

## Summary of the Invention

The invention is based on the problem of providing a method for transforming thermal energy of fluid into mechanical energy and a steam power plant, wherein, owing to an increase in density and more complety utilization of internal energy of fluid efficiency of the process is so enhanced as to make it effective enough for the implementation in vehicle power plants.

The invention resides in that in a method for transforming thermal energy of fluid into mechanical energy in a steam power plant having an expansion engine, wherein fluid is heated under the isobaric conditions to a preset temperature and supplied to a working chamber of an engine to carry out the adiabatic expansion of the fluid during which useful work of the engine is performed, with subsequent condensing of the exhaust fluid and its adiabatic compression, according to the invention, the fluid is brought to a critical state during heating and is supplied in this state to the working chamber of the engine, the adiabatic expansion of the fluid being carried out immediately from its critical state, the adiabatic compression of the fluid being carried out to a critical pressure.

It is preferred that fluid be in the form of a substance having the difference between enthalpies at points of critical and atmospheric pressures under the adiabatic expansion which is at least equal to the vaporization heat.

The abovedescribed method for transforming thermal energy of fluid into mechanical energy is carried out in a steam power plant having an expansion engine, comprising a fluid heater communicating with an engine for supplying the heated fluid thereto and for expanding it under the adiabatic conditions, and an exhaust fluid condenser, wherein the heater comprises a heater of a liquid fluid for heating it to a critical state, the heater communicating with the engine via a heat insulated line.

Heating and carrying out the adiabatic compression of fluid before supplying it to the engine to parameters corresponding to the area of its critical state and carrying out the adiabatic expansion of fluid from the area of its critical state, using fluid in the form of a substance having the difference between enthalpies at po - ints of critical and atmospheric pressues under the adiabatic expansion at least equal to the vaporization heat, make it possible to achieve a material increase in the isobaric heat capacity of fluid. It should be noted that fluid allows energy to be concentrated to a higher density in the critical state area, the density of energy being out of proportion to a change in fluid temperature. This effect cannot be achieved in areas corresponding to subcritical and supercritical states of the same liquid.

When fluid is expanded from the area of the critical state, the transformation occurs without boiling since latent vaporization heat at the critical point is zero. Therewere, the inicial parameters of vapour (temparature and pressure) have the same values as those of the injected liquid fluid. During the expansion of fluid the stored energy absorbed during the supply of heat in the critical state area is released. As a result, work of expansion begins substantially during the isothermal process with the continual transition to the adiabatic process, and it is known that heat supplied inder the isothermal expansion of fluid is fully transformed into useful work.

Therefore, the method according to the invention allows the ability of liquid to absorb and store thermal energy in the critical state area without a proportional temperature increase and pressure change to be implemented, whereby efficiency of the process is substantially improved.

## Brief Description of the Drawings

The invention will now be described with reference to specific embodiments illustrated in the accompanying drawings, in which:

Figure 1 shows a diagrammatic view of a steam power plant for carrying out a method according to the invention;

Figure 2 is a diagram illustrating working cycle of the plant as relationship of temperature ($^T$) v. entropy (S) using water as fluid;

Figure 3 is a diagram illustrating working cycle of the plant as relationship of T v. S using carbon tetrachloride as fluid.

## Best Mode of Carrying out the Invention

Figure 1 shows a diagrammatic view of a steam power plant for carrying out a method for transforming thermal energy of fluid into mechanical energy according to the invention.

A steam power plant comprises a pump 1, a fluid heater in the form of a straight-flow heat exchanger 2 having a thermal accumulator 3, an expansion engine 4, a separator 5, and a condenser 6.

The fluid heater is in the form of a heater for heating a liquid fluid to its critical state. The heater comprises the heat exchanger 2 which is connected to the engine by means of heat insulated line.

The method is carried out in the following manner. Fluid is heated under the isobaric conditions to a preset temperature by bringing it to a critical state. As mentioned above, fluid in the area of the critical state is still in the liquid state but has properties which are materially different from those of both liquid and vapour. The area of the critical state is limited on the one hand by a critical point of liquid transition to vapour, and on the other hand, by a material change in a number of physical properties.

Investigations showed that heating and the adiabatic compression of liquid to an area corresponding to its critical state where temperature and pressure strictly correspond to each other ensure a material increase in the isobaric heat capacity of the liquid. For example, it is equal to 507.5 kcal/kg. deg. for water. A substantial heat capacity increase at the lower limit curve (T v. S diagram) begins 10-15°C in advance of the critical point. After the critical point, the liquid suddenly turns into a gas and looses those properties.

A high-density energy is concentrated in the unit of liquid volume in the area corresponding to its critical state, i.e. to a small volume of liquid there is imparted energy the value of which is out of proportion to a change in its temperature. This effect does not take place in areas corresponding to supercritical and s subcritical states of the same liquid.

Good result can be achieved using fluids in the form of substances, preferably liquids for which the difference between enthalpies at points of critical and atmospheric pressures under the adiabatic expansion is at least equal to the vaporization heat.

The use of fluid in the form of substances for which the difference between enthalpies at points of critical and atmospheric pressures is at least equal to the vaporization heat makes it possible, in combination with the abovementioned distinguishing features, to ensure maximum efficiency of the cycle which is determined as the ration of supplied heat to the heat removed in the cycle.

Phase transitions occur during vapour cycles, and fluid passes through the liquid state. Majour heat removal in such a cycle occurs during condensation. Therefore, the lower the latent vaporization heat of a substance, the lower is the amount of heat to be removed during the cycle.

Substances with a low latent vaporization heat under atmospheric pressure generally have a positive or zero heat capacity at the upper limit saturation in the T v. S curve so that a point of the atmospheric isobar will be in the superheated vapour area or on the upper limit curve. Accordingly, the amount of heat removed during the cycle with such properties of the substance will be substantially equal to the latent vaporization heat of the substance.

Values of enthalpies at the critical point determine the property of a given substance and maximum amount of heat supplied to the liquid, and the difference between enthalpies at points of the critical state of the substance and point of the atmospheric isobar determine the amount of heat that can be transformed to work.

Therefore, the ratio of difference between the enthalpies to the latent vaporization heat determines properties of substances which are vital for efficiency of the cycle.

The method for transforming thermal energy into mechanical energy of fluid in a steam power plant having an expansion engine will now be described with reference to practical examples.

Example 1

Fluid was in the form of water. An axial piston pump 1 (Figure 1) was used to compress fluid to a pressure of 225.6 kg/cm$^2$ (point A in Figure 2) which corresponded to the critical water pressure, whereafter the fluid was heated in a straight-flow heat exchanger 2 having a thermal accumulator 3 to 374 ° C which corresponded to a temperature of the critical state area (point B in Figure 2). Fluid was injected in this state into a working chamber of a rotary expansion engine 4 which is disclosed in details in a copending application filed by the same applicant.

Fluid was adiabatically expanded in the working chamber of the engine 4 owing to internal energy of fluid to atmospheric pressure at 100 ° C (from point B to point C in Figure 2). The liquid was thus converted to vapour with a dryness of 0.5 at the end of the expansion. The vapour dryness was determined by means of the separator 5 (Figure 1).

The exhaust vapour was fed to the water-cooled condenser 6. Fluid in the liquid state was compressed to a critical pressure of 225.6 kg/cm$^2$ (point A in Figure 2) after leaving the condenser 6, and the cycle was repeated. Efficiency of the cycle was determined as follows: heat supplied for carrying out the cycle was determined as the amount of heat consumed for melting the known mass of the energy storage substance of the thermal accumulator 3 by measuring temperatures of the beginning and end of crystalization of the substance.

The heat removed in the condenser 6 was determined by measuring the amount of fluid circulating in the system during crystallization of the energy storage subs - tance of the thermal accumulator 5 taking into account dryness of vapour and the amount of condensed liquid.

The efficiency was calculated as follows:

$$\eta = \frac{Q_1 - Q_2}{Q_1},$$

wherein

$Q_1$ is the heat supplied to the heater 2 during the cycle;

$Q_2$ is the heat removed in the condenser 6.

The cycle efficiency in this Example was 38%, where -as this efficiency at the same temperature but under a pressure below the critical state can be maximum 30% (the Rankine's cycle).

Example 2

Fluid was in the form of carbon tetrachloride ($CCL_4$). The sequence of steps, methods of measurements and calculation as well as equipment were the same as those used in Example 1. The difference resided in the fact that the fluid was compressed to a pressure of 45 kg/cm$^2$ (point A in Figure 3) which corresponded to the critical pressure for carbon tetrachloride and heated to 283 ° C which corresponded to a temperature in area of the critical state of this liquid (point B in Figure 3).

The adiabatic expansion of fluid in the working chamber of the engine 4 to atmospheric pressure occured at 76.8 ° C (from point B to point C in Figure 3). Liquid was converted to vapour with a dryness of 0.9 at the end of the expansion. Efficiency of the cycle was 42% in this example. It should be noted that the tests have been conducted under laboratory conditions, and a higher efficiency can be achieved in the practical implementation of tie method.

Efficiency of the cycle was improved in Example 2 in comparison with Example 1 because the latent vaporization heat for carbon tetrachloride is 195.2 kJ/kg, and this figure in 2262.5 kJ/kg for water, i.e. it is 11.6 times as low in comparison with water, and the difference between enthalpies at the critical point and at the point at the end of the adiabatic expansion to atmospheric pressure for carbon tetrachloride is 209.5 kJ/kg and about 513.7 kJ/kg for water.

Therefore, heating and adiabatically compressing fluid before supplying to the engine to parameters corresponding to the area of its critical state make it possible to achieve a more complete utilization of internal energy of liquid, hence, to improve efficiency of the cycle.

Industrial Applicability

The use of substances having the difference between enthalpies at points of critical and atmospheric pressures under the adiabatic expansion whien is least equal to the vaporization heat, in combination with the above distinguishing features makes it possible to ensure maximum efficiency of the cycle and makes effective the employment of such a cycle in vehicle steam power plants having an expansion engine.

## Claims

1. A method for transforming thermal energy of fluid into mechanical energy in a steam power plant having an expansion engine, comprising heating fluid under the isobaric conditions to a preset temperature, supplying it to a working chamber of the engine to carry out the adiabatic expansion of the fluid during which useful work is performed by the engine, with subsequent condensing of the exhaust fluid and its adiabatic compression, characterized in that the method includes bringing the fluid during heating to a critical state and supplying the fluid in this state to the working chamber of the engine, the adiabatic expansion of the fluid being carried out immediately from its critical state, and the adiabatic compression of the fluid being carried out to a critical pressure.

2. A method according to claim 1, characterized in that the fluid comprises substances having the difference between enthalpies at points of critical and atmospheric pressures under the adiabatic expansion which is at least equal to the vaporization heat.

3. A steam power plant for transforming thermal energy of fluid into mechanical energy in an expansion engine (4), comprising a heater communicating with the engine (4) for supplying the heated fluid thereto and a condenser (6) for exhaust fluid, characterized in that wherein the heater is in the form of a heater for heating a liquid fluid to a critical state thereof, the heater communicating with the engine by means of heat insulated line (7).

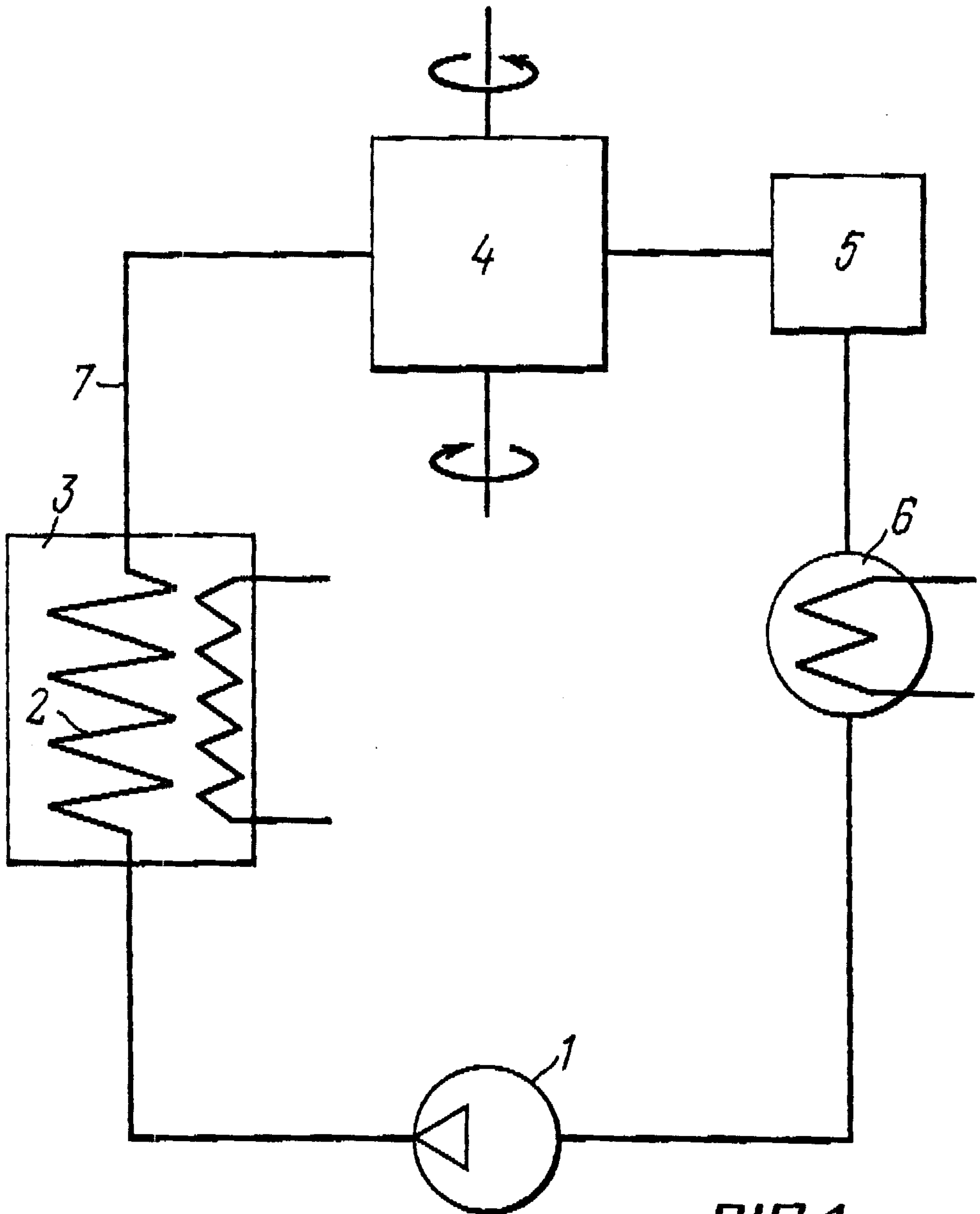


FIG.1

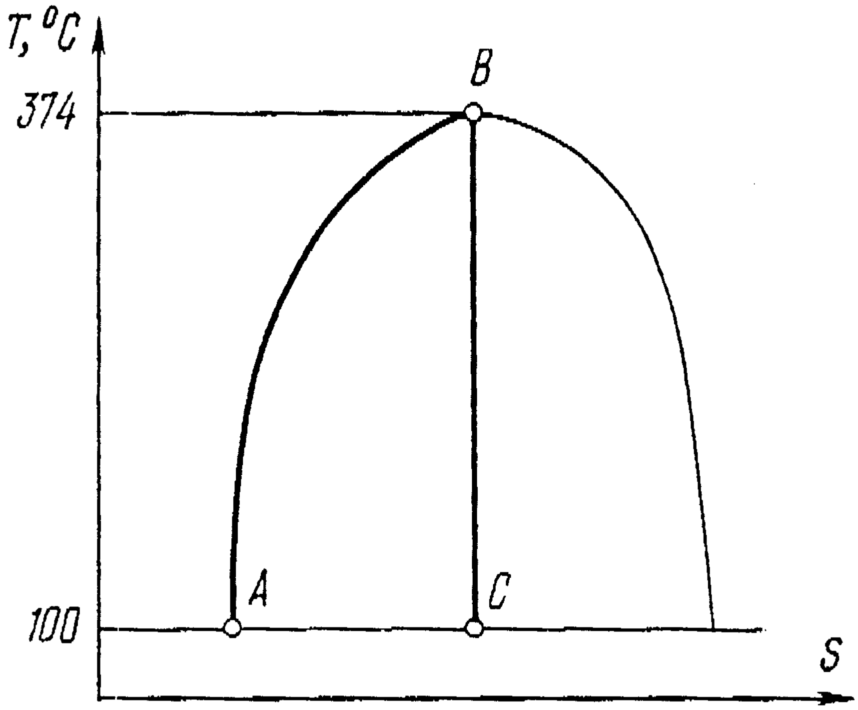


FIG.2

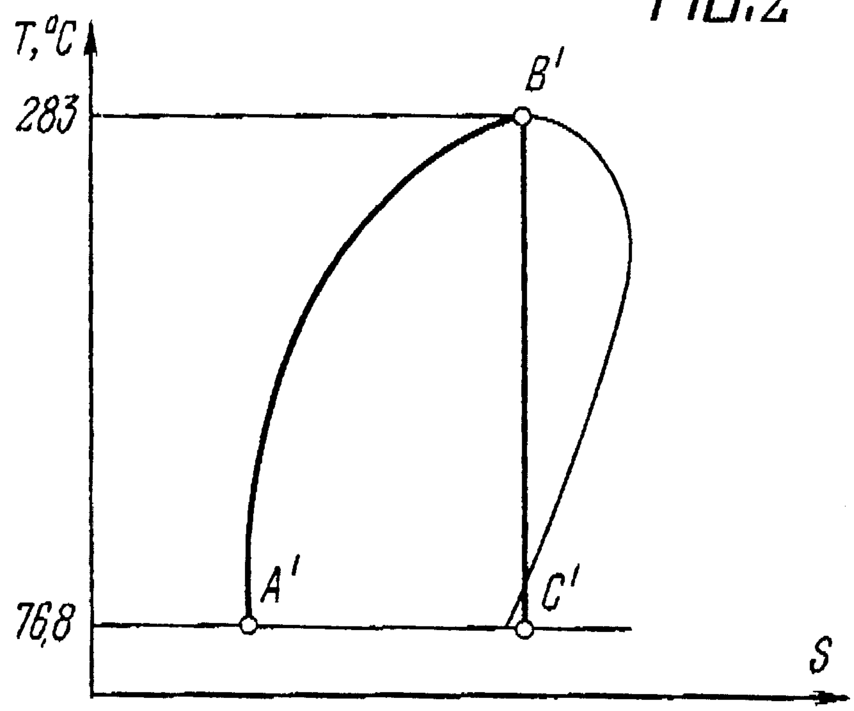


FIG.3

# INTERNATIONAL SEARCH REPORT

International Application No PCT/SU 89/00131

**I. CLASSIFICATION OF SUBJECT MATTER** (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

$IPC^5$ F 01 K 3/00, 13/00

**II. FIELDS SEARCHED**

Minimum Documentation Searched [7]

| Classification System | Classification Symbols |
|---|---|
| $IPC^4$ | F 01 K 3/00, 13/00, 15/00 |

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

**III. DOCUMENTS CONSIDERED TO BE RELEVANT** [9]

| Category * | Citation of Document, [11] with indication, where appropriate, of the relevant passages [12] | Relevant to Claim No. [13] |
|---|---|---|
| A | GB, A, 2153442, (SOLMECS CORPORATION NV), 21 August 1985 (21.08.85), see figure 2 | 1-3 |
| A | DE, B2, 1426895, (BRONICKI, LUCIEN, HARISHON, REDHOVOTH), 28 May 1975 (28.05.75), see figure 2 | 1-3 |
| A | DE, A1, 3505532, (SPOLANSKI VADIM), 28 August 1986 (28.08.86), see claim 1 | 1-2 |

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

**IV. CERTIFICATION**

| Date of the Actual Completion of the International Search | Date of Mailing of this International Search Report |
|---|---|
| 10 January 1990 (10.01.90) | 16 February 1990 (16.02.90) |
| **International Searching Authority** | **Signature of Authorized Officer** |
| ISA/SU | |