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METHOD OF AND DEVICE FOR RECOVERING ENERGY WHEN
COOLING COMPRESSED GASES IN HEAT EXCHANGERS
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Fig. 1

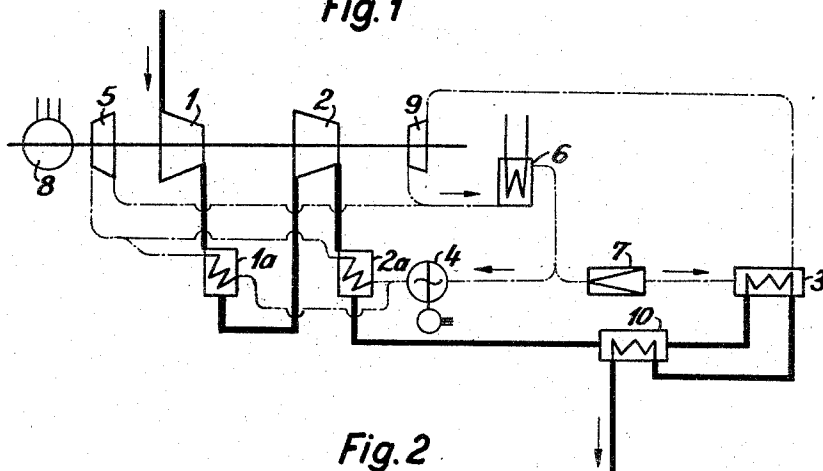
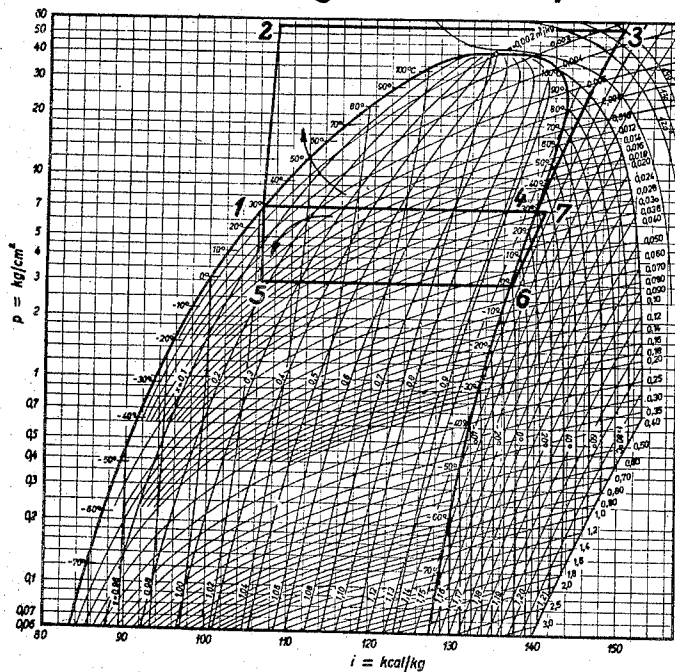


Fig. 2



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METHOD OF AND DEVICE FOR RECOVERING ENERGY WHEN COOLING COMPRESSED GASES IN HEAT EXCHANGERS

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7 Claims. (Cl. 62—87)

The present invention relates to a method of and device for recovering energy from the heat which is freed in heat exchangers during the cooling of gases compressed in one or more stages, which heat exchangers are arranged subsequent to the compression stages.

The cooling of compressed gases in heat exchangers arranged subsequent to the compressors, is effected in most instances by means of cooling water which if it is to be recovered as cooling water frequently is cooled in cooling towers. In such an instance its heat is allowed to escape into the atmosphere without furnishing any useful work.

It is also known to use the compression heat in heat exchangers for the purpose of preheating combustion air, for increasing the natural ventilation in mines, and for heating, drying and other thermal purposes. When in this way exploiting the compression heat for obtaining sensible heat, frequently the drawback is encountered that the consumption of the obtained heat does not coincide with the obtainment of such heat so that the compression heat can be obtained and exploited only in part and is not present when the compressor is stopped.

It is, therefore, an object of the present invention to provide a method and device which will overcome the above mentioned drawbacks.

It is another object of this invention to provide a method of and device for recovering energy which is freed during the cooling of gases compressed in one or more stages, which will make it possible to carry out a circulation of the heat transfer fluid at high pressure. It is still another object of this invention to provide a method and device as set forth in the preceding paragraph which will make it possible to effect an effective recovery of energy by means of relatively small devices and expanding machines and which will work at a high degree of efficiency.

These and other objects of the invention will appear more clearly from the following specification in connection with the accompanying drawings in which:

Fig. 1 is a diagrammatic illustration of an arrangement for carrying out the method according to the invention.

Fig. 2 illustrates the p - i graph.

According to the present invention, the cooling of gases compressed in one or more stages is carried out in heat exchangers which are arranged subsequent to the compression stages in such a way that a vapor is employed as heat transfer fluid in the heat exchangers which vapor has a low critical temperature lower than the temperature of the compressed gas to be cooled, but higher than atmospheric temperature. Furthermore, the heat transfer fluid is passed into the heat exchangers at a pressure above the critical pressure. Furthermore, in the heat exchangers the heat transfer fluid is superheated at least

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to such an extent that at least half the expansion of the superheated heat transfer fluid which is fed to an expansion machine occurs within the range of the superheating, thereby causing the heat transfer fluid to perform work.

Thereupon the heat transfer fluid is conveyed to a condenser with subsequent pump in which the condensed heat transfer fluid is placed under tension preferably far beyond the critical pressure. Finally the heat transfer fluid is conveyed by the pump again into the heat exchangers.

The method according to the invention thus makes it possible to carry out the circulation of the heat transfer fluid at high pressure and due to the small vapor volume of the heat transfer fluid inherent thereto it is possible to carry out the method with relatively small devices and expanding machines while the method has a high degree of efficiency.

The method according to the invention may be carried out in different ways as will be seen from Fig. 1. The heavy line in Fig. 1 indicates the course of the compressed gas, while the dot-dash line indicates the path of the heat transfer fluid. The arrangement comprises gas compressors 1 and 2 arranged in series followed by heat exchangers 1a and 2a. The reference numeral 3 designates a deep-cooler designed as heat exchanger, whereas the reference numeral 4 designates a pump driven by an electric motor. The arrangement shown in Fig. 1 furthermore comprises an expansion machine 5, a cooling device 6 cooled by cooling water for the heat transfer fluid, a choke nozzle 7, an electric prime mover 8 for the compressors 1 and 2, a compressor 9 for the heat transfer fluid, and a precooling 10 designed as heat exchanger.

The prime mover 8, the expansion machine 5, the compressors 1 and 2, and the compressor 9 for the heat transfer fluid are arranged on a shaft common to all of them. In this way mechanical transmission losses are avoided.

The operation of the arrangement diagrammatically shown in Fig. 1 is as follows:

The gas to be compressed, for instance long distance gas, passes through the compressor 1—first compression stage—is then cooled in the heat exchanger 1a, is furthermore compressed in the compressor 2—second compression stage—and is again cooled in the heat exchanger 2a. The gas may then be further cooled in the deep-cooler 3 in a manner described further below while the ingredients condensing during the deep-cooling are removed. The thus obtained gas may then be heated again in the precooling 10 where the gas cools the gas being fed to the deep-cooler.

The heat transfer fluid, for instance CF_2Cl_2 , passes at a pressure above the critical pressure from the pump 4 into heat exchangers 1a and 2a where it is evaporated and highly superheated. Thereupon, it passes through the expansion machine 5 in which it expands and performs work while the expansion is effected preferably only within the range of the superheating. The heat transfer fluid is then condensed in the water-cooled cooling device 6 and from there returns to the pump 4. A portion of the condensate may pass through the choke nozzle 7 in which it expands while the temperature is greatly reduced. The heat transfer fluid then passes through the deep-cooler 3 designed as heat exchanger where the compressed gas is deep-cooled and the heat transfer fluid is transformed into gaseous condition. The heat transfer fluid then passes through the compressor 9 for the heat transfer fluid in which it is com-

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pressed and pumped into the feeding line for the heat transfer fluid pertaining to the cooling device 6.

If it is not desired to deep-cool the gas, the choke nozzle 7, the deep-cooler 3, the compressor 9 for the heat transfer fluid and the conduit for the cooling means interconnecting said parts, as well as the precooler 10 may be omitted.

The method according to the invention yields an extremely high exploitation of the compression heat which fact is primarily due to the high superheating of the heat transfer fluid in the heat exchangers 1a and 2a and is also due to the fact that subsequently the heat energy of the heat transfer fluid is obtained as mechanical energy in the expansion machine within the range of expansion preferably only within the range of superheating.

The method according to the present invention makes it possible at relatively low investment costs for the arrangement, which costs are partially compensated for by the reduced size of the prime mover 8 for the compressors 1 and 2, to obtain a permanent reduction in the consumption of energy for the gas compression which reduction has heretofore appeared to be impossible.

Fig. 2 of the drawing illustrates the *p-i* graph for the heat transfer fluid CF_3Cl_2 . The lines 1—2—3—4—1 illustrate an example of the circuit to be passed through by said heat transfer fluid. At point 1 the heat transfer fluid is in liquid condition at approximately 30° C. and at a pressure of 7 kilograms per square centimeter. By means of the pump 4 of Fig. 1, the heat transfer fluid is brought up to a pressure of 55 kilograms per square centimeter (point 2). When the heat transfer fluid passes through the heat exchangers 1a and 2a, its temperature increases steadily to about 140° C. (point 3) and in this way is brought into a gaseous superheated condition. The steady increase in temperature at which the evaporation above the critical point is effected in contrast to the evaporation within the evaporating range, is of particular importance for the heat exchange in countercurrent with the gas to be cooled in the heat exchanger. The said increase in temperature makes possible an even temperature drop from the gas to the heat transfer fluid over the entire path through the heat exchanger, which fact materially simplifies the construction of the heat exchanger, and brings about a reduction in size and in costs.

From point 3 to point 4 the adiabatic expansion occurs in the expansion machine 5. From point 4 back to point 1 the condensation in the cooling device 6 occurs through the range of the wet vapor.

The lines 1—5—6—7—1 illustrate an example for the circuit passed through by the branch current which may be branched off ahead of the pump 4 and employed for deep-cooling the gas. While the heat content *i* is maintained, the branch current expands in the nozzle 7 to a pressure of 3 kilograms per square centimeter and to a temperature of approximately -1° C. (point 5) while a partial evaporation occurs. The branch current is completely evaporated (point 6) in the deep-cooler 3 by heat exchange with the compressed gas whereupon the branch current by means of the compressor 9 is again compressed to a pressure of 7 kilograms per square centimeter and is heated up to approximately 30° C. (point 7) and finally is again liquefied in the cooling device 6 (point 1). In a similar manner, the above described circuits can be carried out with carbon dioxide, propane, isobutane, or ethane.

It is, of course, understood that the present invention is, by no means, limited to the particular arrangement shown in the drawing but also comprises any modification within the scope of the appended claims.

What I claim is:

1. A method of recovering energy from the heat which is freed in heat exchanger means during the cooling of

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compressed gases, which includes the steps of: employing a heat transfer fluid which has a critical temperature lower than the temperature of said compressed gases but higher than atmospheric temperature and conveying said heat transfer fluid in liquefied form to said heat exchanger means at a pressure higher than the critical pressure, superheating said heat transfer fluid in said heat exchanger means to at least such an extent that at least half the expansion of said superheated heat transfer fluid when subsequently expanding occurs within the superheated range, expanding said superheated heat transfer fluid to thereby cause the same to perform work, condensing said expanded heat transfer fluid, placing said heat transfer fluid under a pressure higher than the critical pressure, and again conveying said heat transfer fluid to said heat exchanger means.

2. A method of recovering energy from the heat which is freed in heat exchanger means during the cooling of compressed gases, which includes the steps of: introducing into said heat exchanger means at a pressure higher than the critical pressure a liquefied heat transfer fluid having a critical temperature lower than the temperature of said compressed gases but higher than atmospheric temperature, superheating said heat transfer fluid in said heat exchanger means to such an extent that said superheated heat transfer fluid will be able to expand within the range of superheating when being expanded to perform work, expanding said superheated heat transfer fluid within said range of superheating in an expansion machine to obtain useful work, condensing said expanded heat transfer fluid, placing the heat transfer fluid under a pressure higher than the critical pressure thereof and thereupon re-introducing said heat transfer fluid into said heat exchanger means.

3. A method according to claim 2, which includes the steps of: prior to placing said heat transfer fluid under a pressure higher than the critical pressure thereof, branching off a portion of said heat transfer fluid, passing said branched off heat transfer fluid through a choke nozzle, deep cooling said compressed gases discharged from said heat exchanger means by said heat transfer fluid passed through said choke nozzle, thereupon compressing said heat transfer fluid, and finally rejoining the thus compressed branched off heat transfer fluid with the heat transfer fluid discharged from said expanding machine.

4. An arrangement for recovering energy from the heat which is freed in heat exchanger means during the cooling of compressed gases, which comprises in combination: first conduit means for said compressed gas, said conduit means having interposed therein heat exchanger means arranged for receiving said compressed gas, and cooler means connected to said heat exchanger means and provided with a discharge; and circuit means for the circulation of heat transfer fluid which includes condensing means for receiving vaporous heat transfer fluid and condensing the same, second conduit means passing from said condensing means through said heat exchanger means to cool the compressed gas in the latter whereby said heat transfer fluid which is conveyed to said heat exchanger means at a pressure higher than its critical pressure is superheated, an expansion machine having an inlet and an outlet, third conduit means leading from said second conduit means at said heat exchanger means to said inlet for causing the superheated heat transfer fluid to expand in said expansion machine while performing work within the range of superheating, and fourth conduit means leading from said outlet to said condensing means for conveying heat transfer fluid thereto.

5. An arrangement according to claim 4, in which said first conduit means includes compressor means preceding said heat exchanger means, and a shaft common to and drivingly connected with said compressor means and said expansion machine.

6. An arrangement according to claim 4, which includes a shunt shunting said condenser means and com-

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prising a restrictor, a deep-cooler arranged in series with said restrictor, and compressor means for said heat transfer fluid, said compressor means for said heat transfer fluid being arranged in series with said restrictor and said deep-cooler and communicating with said condenser means for delivering compressed heat transfer fluid thereto.

7. An arrangement according to claim 4, in which the heat transfer fluid of said first conduit means comprise a

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deep-cooler having an outlet, a pre-cooler interposed between said heat exchanger means and said deep-cooler, and discharge conduit means connected to said deep-cooler outlet and passing through said pre-cooler.

References Cited in the file of this patent**UNITED STATES PATENTS**

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