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H. BERGQUIST

2,265,415

THERMO COMPRESSOR

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2 Sheets-Sheet 2

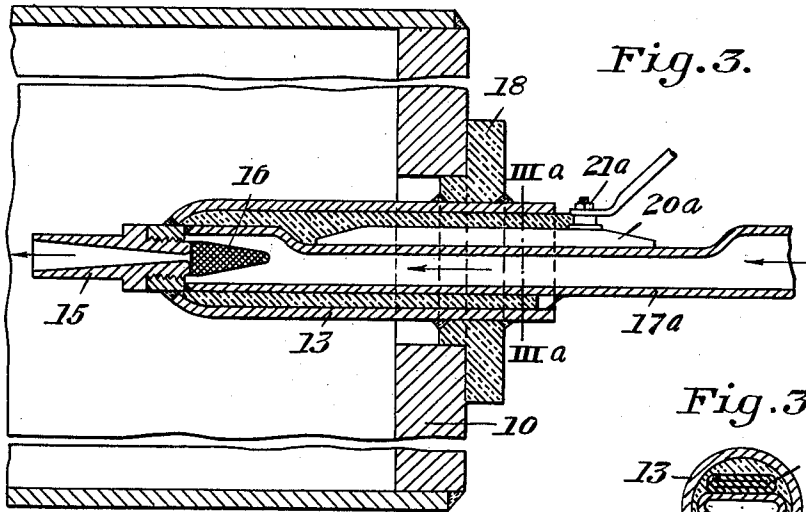


Fig. 3.

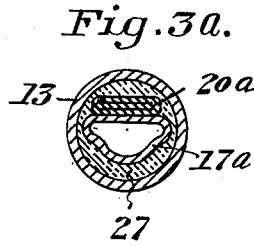


Fig. 30.

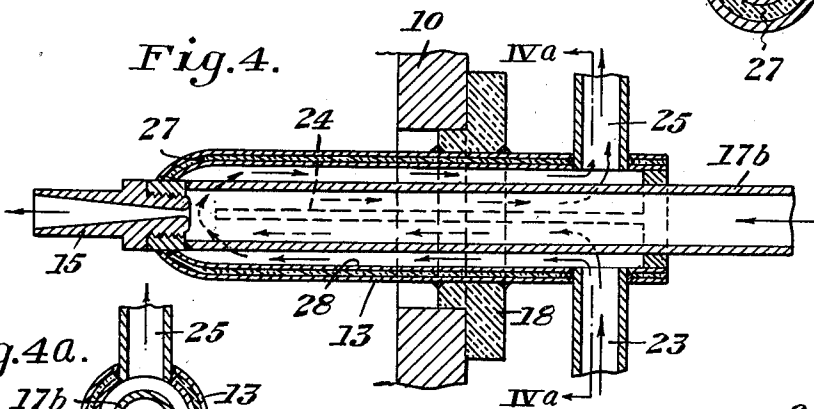


Fig. 4.

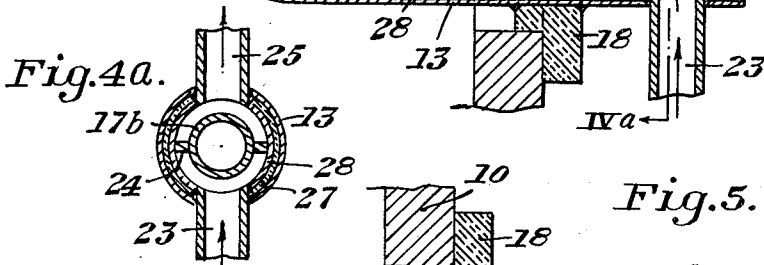


Fig. 4a.

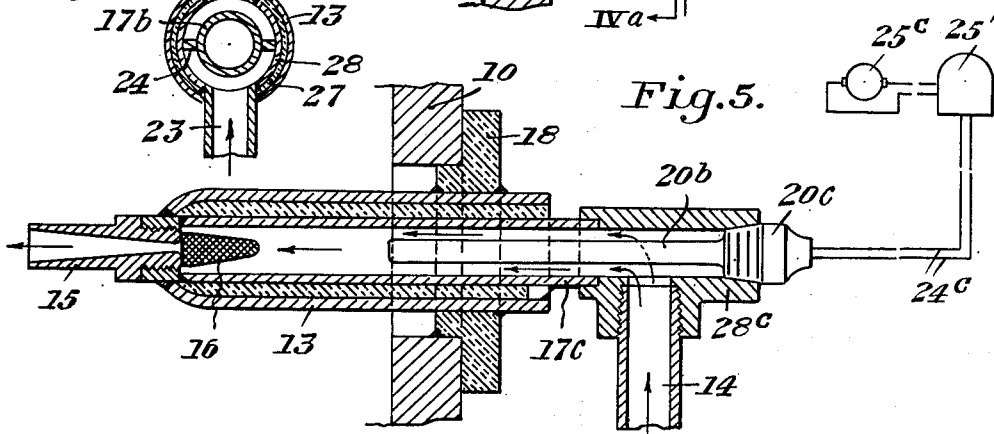


Fig. 5.

INVENTOR

Hugo Bergquist
By
Thomas L. Miller
his attorney

UNITED STATES PATENT OFFICE

2,265,415

THERMO COMPRESSOR

Hugo Bergquist, Swissvale, Pa., assignor to Elliott Company, Jeannette, Pa., a corporation of Pennsylvania

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5 Claims. (Cl. 230—95)

This invention relates to thermo compressors, and more particularly, to thermo compressors of an ejector type for producing a high vacuum.

As will be appreciated, an ejector operates entirely on a kinetic plan in that it expands a propelling gas, usually steam, through divergent nozzles in such a manner that the pressure energy of the steam is converted into velocity energy. Such velocity is relatively high. The gas mingles with and entrains the vapors to be evacuated and imparts to them a portion of its velocity, at the same time being slightly decelerated, all prior to entering a diffuser. After entrainment, the mixture of entrained gas and propelling gas passes into a convergent-divergent diffuser, where its velocity energy is to a great extent converted into static pressure, thus overcoming the vacuum created at the diffuser inlet.

Very low pressures or vacuums are today useful, for instance, in chemical processing in connection with vitamin distillation or in the evacuation of rectifier bulbs, radio tubes, incandescent lamps, etc. In this connection, I have been able to provide a thermo compressor having a useful capacity of at least .15 millimeter of mercury down to a minimum of at least .06 millimeter at shut-off conditions. To obtain a high vacuum, a series of vacuum ejectors are connected in such a manner that one discharges progressively into the others. Where applied to high vacuum work, a final stage of ejector combination, such as a fourth stage, will normally be a relatively large structure capable of handling a relatively small quantity of material in terms of pounds per hour but an enormous number of cubic feet per hour. It resembles a conventional lower vacuum booster ejector except that it is nozzled for a relatively small quantity of steam. This fourth or last stage accomplishes such a small amount of compression that it is not able to raise the absolute pressure to a point where vapors are normally condensable by a following condenser. Thus, the ejector will usually discharge directly into the suction of the third stage and the third stage will be followed by a condenser for condensing vapors or propelling steam; the same procedure will be generally followed for the second and first stages.

This is the practice since natural water supplies are normally used as the cooling medium and it is necessary to get an absolute pressure corresponding to a temperature that is available in the water supply. Since the suitable cooling water temperature is not generally available at least between the third and fourth stages, the

condenser is generally omitted as above outlined. Where vapors handled have a very low pressure and a relatively high condensing temperature at that pressure, an inter-condenser can be applied between the fourth and third stages.

The propelling steam nozzle of the fourth or last stage discharges into the region of pressure corresponding to a suction pressure of such stage which, as pointed out above, may be as low as .15 millimeter. The atmosphere or gas being evacuated may consist of high superheated water vapor, sub-cooled water vapor, gases, or any number of volatile substances of complex chemical constitution, or a mixture of such gases or vapors.

It will be apparent that the ejector pressures which are being particularly considered are in the regions corresponding to ice rather than to water, since water freezes at .23" of mercury (5.8 mm.). I have found that a globule of water ejected into such a region will promptly freeze into ice as will many other substances having lower and higher freezing points. The ice thus formed, particularly under intermittent operation, tends to evaporate off. As an example, I have found that a steam nozzle of 7 or 8" in length projecting into a high vacuum ejector and emitting steam at 250° temperature will have ice formed upon it. Ice may also occur upon other parts of the ejector if there is any impingement of vapor upon the cold part. As pointed out above, the ice will then evaporate if the liquid admission is intermittent, but it may persist for hours when additional liquid impinges and freezes at the same rate that the ice is evaporated.

Propelling steam for the nozzles may be taken at any pressure that leaves sufficient energy in it after it is expanded through the nozzle to suction conditions in the ejector. This is true since the energy range of steam upon expanding to increasingly lower pressures has its greatest value in the region below zero pounds gauge instead of the region above zero pounds gauge. In practice, it is customary to take steam at a few pounds pressure, but nozzles can be proportioned to take it at any pressure available provided the bore does not become so small as to be stopped by dirt in the steam.

I have found that if wet steam containing definite amounts of moisture is used in propelling through a nozzle, the results are very poor and vacuum operation impractical. I have also found that it is very difficult if not impractical to supply steam, gas, etc., that are in a true sense dry, and for this reason, I found it advisable to carry

a small amount of superheat in the steam. In this manner, no moisture whatever will come to the nozzle to be projected through it. Although from a theoretical standpoint, steam expanding from any practical gauge pressure through a nozzle into regions of vacuum would theoretically attain the temperature of the region into which it discharges, I have determined that in actual practice, it would have to do this in an extremely small fraction of a second due to its high velocity of travel. The steam actually passes so rapidly through the nozzle, through the entraining space, and into the compression diffuser that receives the propelling steam including the mixture being evacuated, that it does not have time to cool and thus, goes through the ejector without attaining theoretical equilibrium. Such variation between the theoretical and the actual is of aid in carrying out my invention.

It should also be noted that condensation of steam does not occur immediately but it can exist as steam in a region where it may be supercooled or superheated. The time factor is highly influenced by nuclei upon which condensation can take place. In the absence of nuclei, it is advisable to retain superheat or supercooling for much longer periods. It is thus apparent that dry superheated steam expanded through a nozzle under conditions of an ejector does not have time to condense, passes through the ejector in a condition of superheat, and in this condition is highly effective as a propelling medium. Heretofore, in ordinary compressor units, superheat has been avoided upon the belief that the overall efficiency is decreased. I have definitely determined that the overall efficiency is increased and a new low scale of obtainable vacuums is made possible by a suitable utilization of superheat. In conclusion, my determinations are based upon the discovery that dry steam expanding through a nozzle under conditions of an ejector does not have time to condense, passes through the ejector in a condition of superheat, and in this condition is highly effective as a propelling medium. On the other hand, the vacuum range is limited and the results are highly unsatisfactory where high vacuum ejectors are actuated with wet steam. That is, the water in the steam in passing through the ejector nozzle by its presence possibly tends to interrupt the flow of the propelling steam, or it disintegrates and furnishes nuclei of condensation, in addition to causing icing conditions.

I have further determined that with small quantities of steam such as an ejector utilizes, it is difficult to obtain steam of a high enough initial superheated temperature to make it usable. Superheat added is destroyed by conduction of the conveying piping prior to its entrance to the nozzle, and for this reason, I find it advantageous to provide means for superheating the steam immediately adjacent or prior to the entrance point or nozzle. Such a means can be employed to inexpensively provide the desired superheat in effective and controllable manner that will best suit the operating conditions of a thermo compressor or compressors.

I have also found it advantageous to eliminate unnecessary conduction and radiation to obtain a maximum efficiency of heat utilization. Then, too, the location of the superheating agency or means is important in view of another factor which I have discovered, namely, that the expansion range of the ejector nozzle is such that no amount of initial superheat that is practical will produce a significant amount of superheat in

the nozzle discharge at the pressure at which it discharges provided the steam had time to come into equilibrium with the atmosphere in such region.

From the above discussion, it will appear that for obtaining high vacuums under practical conditions, I preferably provide a relatively high velocity of the energizing fluid, preferably superheat the fluid adjacent to or near its entrance point, limit heat losses, prevent the formation of nuclei, eliminate wetness and prevent theoretical temperature equilibrium results. And in view of such considerations, it has been an object of my invention to provide new and improved procedure for providing low vacuum pressures.

Another object of my invention has been to determine the factors heretofore limiting the production of vacuum by thermo compression means such as an ejector and to determine a practical solution of the problems involved in view of such discovered factors.

Another object has been to provide a new and improved form of thermo compressor mechanism, and more particularly, to provide mechanism for producing a low range of vacuum pressures in a practical and effective manner.

These and many other objects of my invention will appear to those skilled in the art from the drawings, the specification, and the claims.

In the drawings:

Figure 1 is a side view in elevation partially in section and showing an ejector apparatus employing my invention;

Figure 2 is a front view in elevation taken along the line II—II of Figure 1 showing a modified or additional heating arrangement;

Figure 2A is a similar view on line IIA—IIA of Figure 1;

Figures 3, 4, and 5 are sectional views in elevation taken through devices constructed in accordance with the principles of my invention; and

Figures 3a and 4a are sections taken along the lines IIIa—IIIa and IVa—IVa, respectively, of Figures 3 and 4, respectively.

Referring particularly to Figure 1, I have shown an ejector apparatus having a mixing chamber housing 10 provided with a converging-diverging discharge nozzle or element 11 and having an inlet 12 for the gas or fluid to be evacuated.

An ejector nozzle 13 is removably mounted on an inlet tube 17 and provided with a suitable strainer 16. Steam from a main line 34 is bled off through a steam chest or "T" 31 having suitable mounting flanges 33, through a strainer 32, past a control valve 30, to the inlet tube 17. The inlet tube 17 is shown provided with a steam gauge connection 19 and is shown as mounted to extend through a gland or gasket 18 into the mixing chamber 10. The steam thus introduced into the tube 17 is superheated by a suitable agency such as electrical heating elements or grids 20 having electrical connections or terminals 21. It will be seen that the steam entering tube 17 passes longitudinally along and over and between the heating grids 20 in such a manner that it is heated to dryness by conduction, convection, and radiation.

In Figure 2, I have shown an alternative or additional heating agency 22 that is mounted about the gland or gasket 18 adjacent the entrance to the mixing chamber. Although this element may be gas or electrically heated, I have for the purpose of illustration shown a steam coil type of heat transfer agency. In Figure 2 I have shown an electric element 22a.

Referring particularly to Figures 3 and 3a, I have shown a steam inlet tube 17a having an encircling tube 13 positioned about a portion of such tube and extending into a mixing chamber 10. A nozzle 15 is suitably mounted at or adjacent the end of the tube combination provided by the tubes 17a and 13. The inner tube 17a is partially offset, as shown in Figures 3 and 3a, to provide a mounting for an electrical heating element 20a. The element 20a has suitable electric connections 21a. Insulation 27 is interposed between the element 20a and the inner and outer tubes 17a and 13, respectively.

In the embodiment of my invention shown in Figures 4 and 4a, I have provided an inner tube 17b, an intermediate tube 28, and an outer tube 13. Suitable insulation 27 (such as asbestos, glass wool, an air space, etc.) may be interposed between the tubes 28 and 13 and substantially horizontally or longitudinally-extending baffle means 24 is substantially centrally positioned to extend along the spacing between the inner tube 17b and the intermediate tube 28 to direct a heating fluid such as steam entering from an inlet tube 23, along the bottom side of the tube 17b towards the front thereof to a point adjacent the entrance to the nozzle 15, then upwardly through a front offset portion of such fin-like baffling 24 and backwardly and longitudinally along the upper half of the energizing steam tube 17b to an outlet pipe 25. It will thus be seen that the energizing steam entering through tube 17b is heated chiefly by radiation and conduction from a suitable fluid heating agency introduced through the pipe 23 and having a return flow with respect to such tube.

In the embodiment of my invention shown in Figure 5, I provide insulation between the tube 17c and the outer tube 13. The energizing steam introduced through inlet 14 into a supplemental heat chest 28c is then conducted into the main tube inlet 17c and to the ejector nozzle 15. A heating element 20b shown as an electrical element, is provided with a screwhead 20c for mounting in a longitudinally extending position within the chambers formed by the tube 17c and the chest 28c. In this manner, the steam is heated by conduction and radiation as well as convection, and is permitted to pass along and about the heating element 20b. The heating element is provided with electrical connections 24c leading to an energizing agency 25c through an automatic control device 25'. The unit 20b preferably includes a thermostatic metal having expansion and contraction qualities such that it will automatically "break" the electrical contact to the heating element through the control 25' when the temperature tends to go above a desired operating temperature range and will automatically "make" contact below such temperature; any suitable commercial form of thermostat can be employed. It will be apparent that any suitable heating agencies may be employed in the various embodiments of my invention, for example, electrical, gas, steam, etc.

In Figure 1 of the drawings, I have indicated the normal fluid flow from the nozzle 15 by the letter b. In some cases, the propelling steam may be cooled down until, for example, at the suction of the third stage, it is so cool that fluid passing through the nozzle in the third stage, which may include a part of the operating steam in the first stage, will freeze at the location indicated by a in Figure 1. In installations where there is a possibility of ice formation at the point

a, I preferably provide some suitable form of heating element such as a calrod element 22a, see Figure 2A, that may be mounted externally about the housing 10 as shown. Of course, any suitable form of heating agency or element may be employed in this connection. The element 22 of Figure 2 or the element 22a of Figure 2A will heat the interior of the ejector adjacent the point a by conduction and thus prevent icing at this point.

When I speak of "immediately" in the specification and claims, I have particular reference to the introduction of the reheated steam into the small throat area of the propelling nozzle 15 before it has lost its dryness or, in other words, before the effectiveness of the reheating operation has been lost by condensation of a portion of the energizing fluid or steam.

Although for the purpose of illustration, I have shown representative embodiments of my invention, it will appear to those skilled in the art that many substitutions, additions, subtractions, and modifications may be made without departing from the spirit and scope of the invention as indicated by the appended claims.

I claim:

1. In a low vacuum-producing thermo compressor adapted to operate at a relatively high velocity and below the pressure region of ice, a mixing chamber, a steam ejector nozzle for introducing propelling and energizing condensable fluids such as steam into said mixing chamber, means connected for supplying energizing steam at a suitable pressure to an inlet end of said ejector nozzle, said nozzle having a portion with a small throat opening at the inlet end thereof, such portion of said nozzle expanding towards a discharge end of said nozzle for converting pressure energy of the steam into velocity energy, and heating means operably disposed along said supply means upstream of the small throat opening of said nozzle, said heating means having an effective heat transfer area sufficient to insure at least dryness of the steam being supplied to the small throat opening of said nozzle.

2. In a low vacuum-producing thermo compressor adapted to operate at a relatively high velocity and below the pressure region of ice, a mixing chamber, a steam ejector nozzle for supplying energizing and propelling condensable fluids such as steam to said mixing chamber, means connected for supplying energizing steam of at least a few pounds pressure to an inlet end of said nozzle, said nozzle having a throat portion provided with a relatively small bore at the inlet end thereof, said throat portion diverging outwardly from the small bore towards a discharge end of said nozzle to convert pressure energy at an inlet end of said nozzle into relatively high velocity energy at the discharge end sufficient to prevent the steam from coming into temperature equilibrium with the atmosphere of said mixing chamber and sufficient to provide a pressure in said mixing chamber of as low as .15 millimeter absolute, and heating means operably positioned along said steam supply means, said heating means having a portion upstream of the small bore of the inlet end of said nozzle, said upstream portion of said heating means having an effective heat transfer relationship with the steam being supplied such that the steam will be heated to a heat sufficient to insure at least dryness before entering the inlet of said nozzle and during its movement through the small bore of said nozzle throat portion.

3. In a low vacuum-producing thermo compressor adapted to operate at a relatively high velocity and at a relatively low pressure region below the region of ice, a mixing chamber, a steam ejector nozzle for supplying energizing and propelling condensable fluids such as steam to said mixing chamber, means connected for supplying energizing steam at a suitable pressure to an inlet end of said nozzle, said nozzle having a throat portion of relatively small bore at the inlet end thereof, such throat portion diverging outwardly towards a discharge end thereof to convert pressure energy of the steam into relatively high velocity energy at the discharge end, heating means disposed along said connected supply means in a direction of steam travel therealong, a downstream end portion of said heating means being positioned upstream of the inlet end of said nozzle, said heating means being adapted to heat the steam being supplied to the inlet end of said nozzle to a superheat sufficient to insure at least dryness of the steam during its movement through the small bore of said nozzle throat portion, said throat portion being constructed and arranged to provide a velocity flow into said mixing chamber sufficient to prevent the steam from coming into temperature equilibrium with the atmosphere of said mixing chamber.

4. In a method of preventing erratic propulsion effect of an energizing fluid such as steam caused by the formation of moisture in an expansion throat of an ejector operating below the pressure

region of ice which consists of, adding sufficient heat to a condensable energizing fluid such as energizing steam of suitable pressure to insure dryness thereof, and then immediately moving the reheated dry steam through a relatively small propelling nozzle throat area, and converting pressure energy of the heated steam into relatively high velocity energy by passing the steam through such small throat area and then expanding the steam through and along an outwardly diverging area towards the discharge end of the nozzle.

5. In a method of preventing erratic propulsion effect of an energizing fluid such as steam caused by the formation of moisture in an expansion throat of an ejector operating below the pressure region of ice which consists of, providing an energizing and propelling fluid such as steam of suitable pressure and temperature, adding sufficient heat to insure dryness of the steam, and then immediately moving the reheated dry steam through a relatively small propelling nozzle throat area, and then expanding the steam from such small throat area and through and along an outwardly diverging area towards the discharge end of the nozzle, and providing a relatively high velocity of flow sufficient to prevent the steam discharging from the nozzle from coming into temperature equilibrium with the atmosphere of a mixing region.

HUGO BERGQUIST.