Mar. 27, 1923. 1,449,504.

R. N. EHRHART.

METHOD OF AND APPARATUS FOR COMPRESSING ELASTIC FLUIDS.

ORIGINAL FILED APR. 3, 1919.

2 SHEETS—SHEET 1.

Fig. 1.

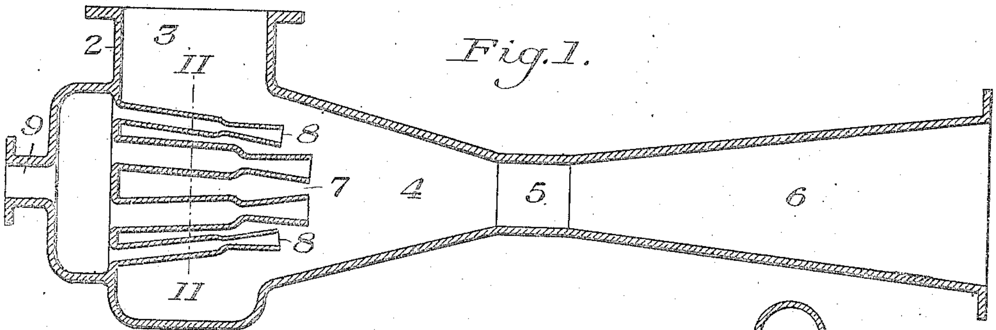


Fig. 2.

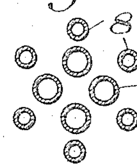


Fig. 5.

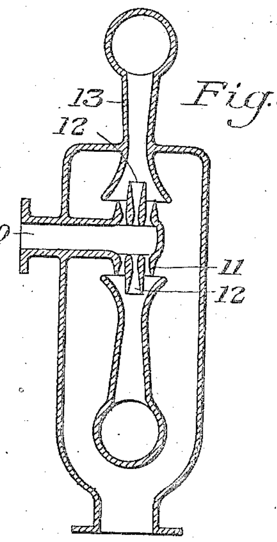


Fig. 3.

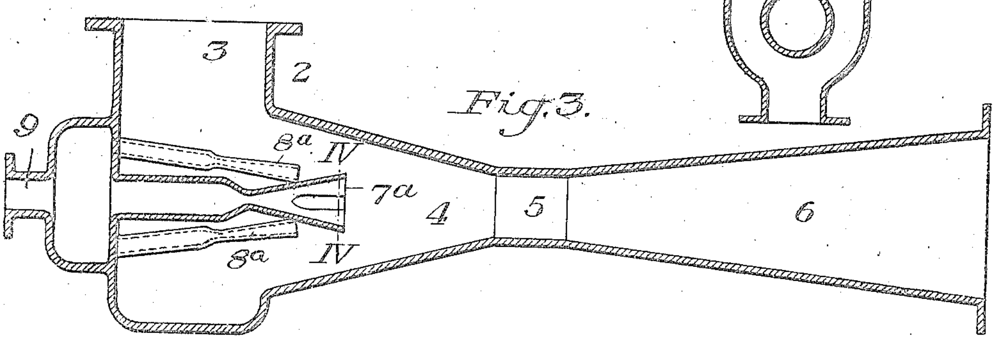
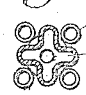


Fig. 4.



WITNESSES

R. A. Baldrson

Francis Trainor

INVENTOR

R. N. Ehrhart

by Bakewell, Byrnes & Parmelee

Attys

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2 SHEETS—SHEET 2.

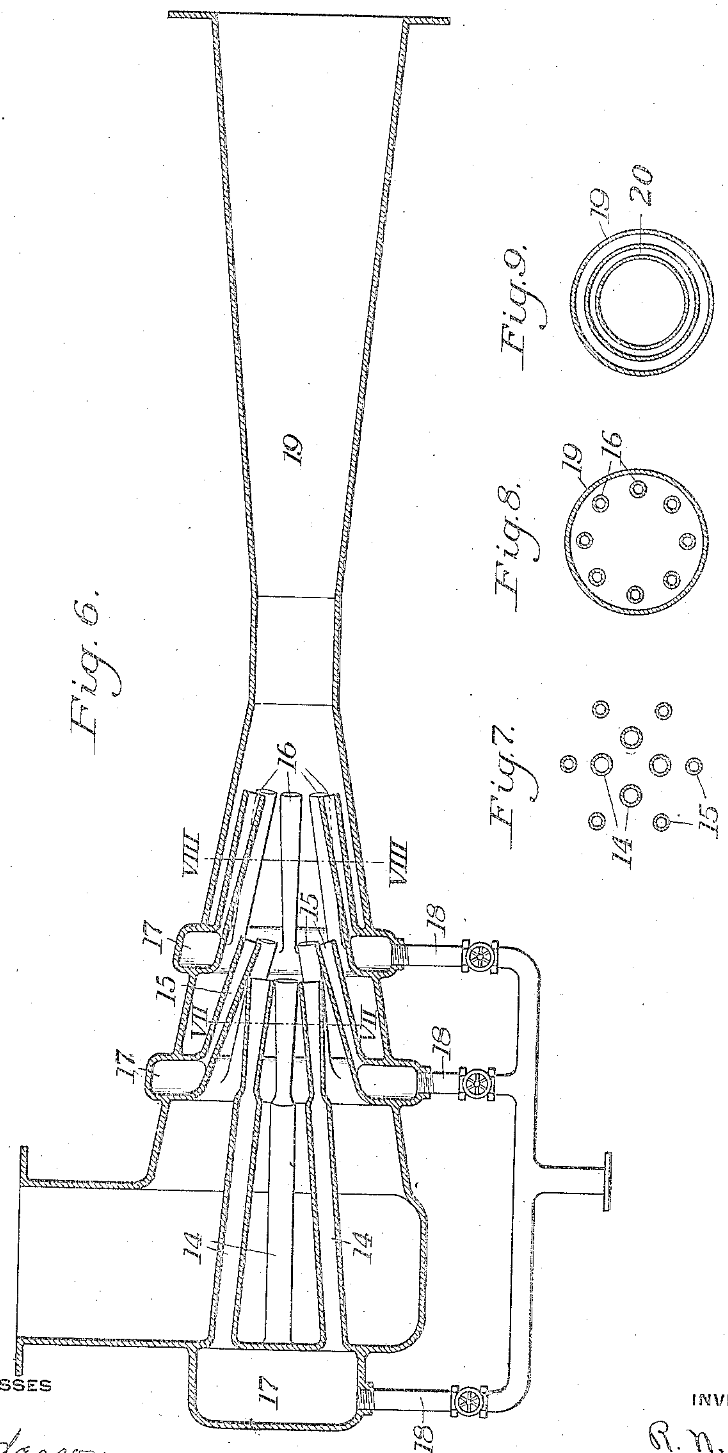

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

WITNESSES

R A Balderson
Frances Trainor

INVENTOR

R. N. Ehrhart,
by Bakewell, Byrnes & Parmelee
Attys

Patented Mar. 27, 1923. 1,449,504

UNITED STATES PATENT OFFICE.

RAYMOND N. EHRHART, OF PITTSBURGH, PENNSYLVANIA, ASSIGNOR TO ELLIOTT COMPANY, OF PITTSBURGH, PENNSYLVANIA, A CORPORATION OF PENNSYLVANIA.

METHOD OF AND APPARATUS FOR COMPRESSING ELASTIC FLUIDS.

Application filed April 3, 1919, Serial No. 287,255. Renewed August 22, 1922. Serial No. 583,642.

To all whom it may concern:

Be it known that I, RAYMOND N. EHRHART, residing at Pittsburgh, Allegheny County, Pennsylvania, have invented a new and useful Improvement in Methods of and Apparatus for Compressing Elastic Fluids, of which the following is a full, clear, and exact description, reference being had to the accompanying drawings, forming part of this specification, in which:

Figure 1 is a longitudinal section of an ejector embodying my invention;

Figure 2 is a section on the line II—II of Figure 1;

Figures 3 and 4 are views like Figures 1 and 2, respectively, but showing a modification; Figure 4 being on the line IV—IV of Figure 3;

Figure 5 is a longitudinal section showing a further modification of my invention, showing it constructed and arranged in an annular manner;

Figure 6 is a similar view on a larger scale and showing still another modification;

Figures 7 and 8 are sections taken respectively on the lines VII—VII and VIII—VIII of Figure 6; and

Figure 9 is a transverse section showing a modified form of nozzle.

My invention has relation to a method of and apparatus for compressing elastic fluids, and more particularly to a novel steam ejector apparatus suitable for use as a vacuum pump for condensers, and to a novel method of operating the same.

Steam ejectors suitable for high ratios of compression, such as are required in connection with pumping air from steam condensers, have heretofore been made in two stages, it having been generally regarded as impossible to maintain the high vacuum required in condenser service unless such ejectors were made of at least two stages. It has heretofore been thought impossible for a single-stage ejector to compress over the required range, but that two or more stages in series were required, each ejector of the series consisting of an inlet port, a set of propelling nozzles and a diffusion structure which converts the velocity created by the propelling nozzles into increased pressure.

I have discovered that a single-stage ejector can be made which will operate to produce high ratios of compression and which is eminently suited to the same service to which the highly developed multistage ejectors are now applied. I accomplish this by a certain arrangement of the propelling nozzles and diffusion structure. For maintaining such vacua as are incident to condensers serving steam turbines and the like, I find that in general it is necessary to provide such a single-stage ejector with two nozzles or groups of nozzles, one nozzle or group handling a greater quantity of propelling fluid than the other nozzle, or group; and the first named nozzle or group projecting further into the converging element of the diffusion structure than the other nozzle or group.

Where an extremely high vacuum, or state of rarefication is desired, as in certain branches of the chemical industry, and the like, I prefer to divide the first named or accelerating nozzles into two or more nozzles or groups of the same, each projecting a different distance into the diffusion structure, and the sets that project furthest into the diffusion structure passing the greater amount of propelling fluid.

Certain other novel proportions and arrangements of parts hereinafter described are also believed to be essential.

Referring first to that form of my invention shown in Figures 1 and 2, the numeral 2 designates the inlet portion of the ejector having the inlet port 3, and to which is connected the converging-diverging diffusion structure in which 4 is the converging portion, 5 the throat, and 6 the diverging portion. 7 designates the group of nozzles which project farthest into the diffusion structure, and 8 the nozzles which project to a less extent into the diffusion structure. 9 is a steam-supplying connection.

In the modification shown in Figures 3 and 4, the nozzle 7^a having the greatest projection is shown as having a cruciform discharge portion, the perimeter of whose outlet is greater than that of a circle having the same cross sectional area. The other and shorter nozzles 8^a are preferably equal in number, to the number of lobes or wings on the non-circular nozzle, the space between such lobes or wings acting as guides for the streams of fluid entrained by the shorter nozzles.

I prefer to proportion the diffuser with a slight angle of 6 to 10 degrees, although my invention is not limited to these angles. I also prefer to use an angle of about 6 degrees in the divergence of the passages of the propelling nozzles. The nozzles which project farthest into the converging portion of the diffuser should pass materially more steam than the group of nozzles which do not extend so far into the diffusion structure. For the best results, the first named nozzles should pass at least twice as much steam as is passed by the preceding set. I find that it is desirable to proportion the organized ejector so that the steam and entrained fluid from the first or lesser group of nozzles is delivered to the next group at relatively high velocities. In other words, I use the first group of propelling nozzles for delivering impelling fluid at an accelerated velocity to the next group of nozzles, instead of delivering it at low velocity with substantially all its energy in the form of pressure as is done in the multistage ejectors with which I am familiar.

In this way, I eliminate important losses which exist in multistage ejectors, and I conserve the velocity coming from the first nozzles, whereas in the multistage ejectors, the velocity energy is changed to pressure energy inefficiently, and then re-accelerated into velocity in the next stage, with further serious shock losses. I find that this conservation of velocity materially affects the efficiency of the whole mechanism, since the stream lines are not disturbed, and the continuous flow at high velocity is conducive to high efficiencies.

In practice, a group of nozzles should deliver steam to the succeeding nozzles at speeds in excess of 750 feet per second, and from this up to 2,000 feet per second.

Certain dimensions of the parts such, for example, as the length and outlet diameter of the diverging portion of the diffuser and the size and shape of the inlet port, may vary over wide limits, without materially influencing the efficiency of the apparatus. Certain other dimensions must, however, be within certain limits in order to obtain the desired results. For instance, the throats of the propelling nozzles and the throat of the diffuser must bear a certain relation to each other, and the nozzle throat must be proportioned to pass an amount of steam which bears, within certain limits, a definite relation to the area of the minimum cross section of the diffuser. I also find that the effective flow area at the point where entrained fluid and motive steam from the nozzles acting on the entrained fluid is delivered to the nozzles next acting on the entrained fluid must be properly proportioned; this being due to the fact that the last named nozzles must receive the entrained fluid and the motive fluid from the first named nozzles at a certain velocity. This area bears a certain relation, within limits, to the areas of the throats of the first named nozzles.

I also find that the proportioning of the impelling nozzles is a matter of great importance. The outlet areas of the nozzles compared with the areas of the minimum cross section should be much greater in the accelerating than in the compressing nozzles, and if the accelerating nozzles be divided into two or more groups extending different distances into the diffusion structure, I find that the relation

$$\frac{\text{Outlet area}}{\text{Minimum area}}$$

should decrease successively for the nozzles extending further into the diffusion structure.

For convenience in describing the proportioning of the parts, I term the first nozzles or those projecting the shortest distance into the diffuser the "accelerating" nozzles, and those projecting the farthest distance into the diffuser the "compressing" nozzles. The minimum cross-sectional area of the nozzles is termed the "throat" area, and the area at their outlet I call the "outlet" area. That portion of the diffuser nearest the accelerating nozzles I term the "collector;" that portion immediately adjacent to the termination of the compressing nozzles, I call the "mouth," and the "mouth area" of the diffuser, is the area of the converging tube at this point less the area taken up by the compressing nozzles. That portion of the diffuser which has the smallest diameter I term the "throat."

For the nozzles handling the propelling fluid, I call the relation

$$\frac{\text{Outlet area}}{\text{Throat area}}$$

the "ratio of divergence."

Calling the aggregate areas of the accelerating nozzle throats "A," and the aggregate areas of the compressing nozzle throats "B," the mouth area "C," the diffuser throat area "D," and the absolute steam pressure of the motive fluid "P," I find that the following relation must be maintained for reasonable efficiency:

a. $$\frac{(A+B)115}{P} \text{ equals } KD$$

where "K" is a factor varying between the limits .08 and .16 *b*.

b. $$\frac{A\times 115}{P} \text{ equals } QC$$

where "Q" is a factor varying between the limits .02 and .04. I further find that the aggregate area of the throat of the accelerating and compressing nozzles should vary inversely as the steam pressure, other things remaining the same.

I also find that the distance the nozzles project into the diffusion structure bears an important relation to the efficiency of the apparatus. Calling the distance from the outlet of the compressing nozzles to the diffuser throat "M," I find that for good efficiency the following relation must be held:

M equals Y x dia. of diffuser throat where "Y" is a factor varying between the limits 2 and 2.7. Calling the distance from the outlet of the accelerating nozzles to the diffuser throat "N," I find that for good efficiency the following relation must hold:

N equals z x dia. of diffuser throat, where "Z" is a factor varying between the limits 4 and 5.9.

I can also construct my ejector in annular form, as shown in Figure 5. The same method of proportioning area dimensions and steam flow applies to this annular form as to the axial ejector shown in Figures 1 and 3. Figure 5 shows my ejector in annular form. For comparison with the axial type of ejector, I call the minimum distance between the sides of the diffuser structure the diameter of the diffuser throat. In this figure, 10 designates the steam inlet, 11 the shorter nozzles, 12 the longer nozzles, and 13 the diffuser structure.

In Figures 6, 7 and 8, I have shown another form of my invention having three successive groups of nozzles 14, 15 and 16. Each group has its nozzle connected to a header 17, having a steam-supply connection 18. All the nozzles discharge into the converging portion of a single diffuser structure 19. This arrangement has the advantage of making it unnecessary to carry the compressing nozzles through or around the accelerating nozzles, which is more or less difficult, owing to the limited space available and the number of nozzles required.

Instead of a plurality of nozzles in each group, I may use a single nozzle 20, having an annular discharge, as shown in Figure 9, this being the equivalent of a group of nozzles.

As a specific instance of an ejector embodying my invention and the results attained thereby, I give the following:

With an ejector having the aggregate throat areas of the accelerating nozzles equal to .0197 square inches, and outlet area equal to .6 square inches, the aggregate area of the throats of the compressing nozzles equal to .098 square inches, an outlet area of .88 square inches, the mouth areas equal to .665 square inches and the diffuser throat area equal to .95 square inches, I find that, when supplied with steam at 115 pounds absolute pressure, it will compress 15½ pounds of air per hour from a pressure of one inch of mercury to substantially atmospheric pressure, 43 pounds of air from a pressure of two inches absolute to substantially that of the atmosphere, and 67 pounds of air from three inches of mercury to substantially that of the atmosphere. I also find that while the above proportions give the best results, I can vary areas at each point mentioned by approximately 20% and still maintain a reasonable efficiency.

I claim:

1. The herein described method of compressing an elastic fluid, which consists in utilizing the ejector action in a single stage of a plurality of jets, the rearmost of which deliver impelled fluid at a velocity of from 750 to 2000 feet per second to the succeeding jets, substantially as described.

2. The herein described method of compressing an elastic fluid, which consists in utilizing the ejector action in a single stage of a plurality of jets from diverging propelling nozzles, some of which extend well into the converging portion of the diffuser, the rearmost of which deliver impelled fluid at a velocity of from 750 to 2000 feet per second to the succeeding jets and maintaining a smaller volume flow in each jet than in the succeeding jet, substantially as described.

3. A single stage ejector having an inlet port through which the evacuated fluid enters, a converging-diverging diffusion structure, and diverging propelling nozzles, a portion of which extend well within the converging member of the diffuser, said nozzles having different ratios of divergence, substantially as described.

4. A single stage ejector having an inlet port through which the evacuated fluid enters, a converging-diverging diffusion structure, and diverging impelling nozzles, a portion of which extend well within the converging member of the diffuser, said nozzles having different ratios of divergence with those having a lesser ratio of divergence extending further into the diffusion structure, substantially as described.

5. A single-stage ejector having an inlet port through which the evacuated fluid enters, a converging-diverging diffusion structure, and diverging propelling nozzles extending different distances into the converging portion of said structure, some of said nozzles being constructed to pass a greater volume of steam per unit of time than the other of said nozzles, substantially as described.

6. A single-stage ejector having a converging-diverging diffusion structure, and two sets of nozzles of at least one nozzle each, one set terminating nearer the throat of the diffuser than the other set and well within the converging portion of the dif-

fuser, the nozzles of the first named set being constructed to pass a greater quantity of the steam than the nozzles of the last named set, the last named set being constructed and arranged to deliver impelled fluid to the first named set at a velocity of from 750 to 2000 feet per second, substantially as described.

7. The herein described method of compressing an elastic fluid which consists in utilizing the ejector action in a single stage of a plurality of jets, the rearmost of which deliver impelled fluid at a velocity of from 1000 to 1750 feet per second to the succeeding jets, substantially as described.

8. An ejector having a diffuser, and a plurality of nozzles, one of said nozzles having a plurality of wings or lobes and having its outlet nearer the smallest diameter of the diffuser than the other nozzles, said other nozzles being equal in number to and arranged between the wings or lobes of the first named nozzle, substantially as described.

9. A single-stage steam ejector comprising a diffusion structure, accelerating nozzles and compression nozzles and in which the parts are constructed and arranged to embody the formula

$$\frac{(A+B)\times 115}{P} \text{ equals } KD,$$

in which A represents the aggregate areas of the accelerating nozzle throats, B the aggregate areas of the compressing nozzle throats, D the diffuser throat area, P the absolute steam pressure of the motive fluid employed, and K a factor which varies between the limits .08 and .16, substantially as described.

10. A single-stage steam ejector, comprising a diffusion structure, accelerating nozzles and compression nozzles, and in which the parts are constructed and arranged to embody the formula

$$\frac{A\times 115}{P} \text{ equals } QC,$$

in which A is the aggregate areas of the accelerating nozzle throats; P the absolute steam pressure of the motive fluid employed C the mouth area of the diffusion structure, and Q a factor varying between the limits .02 and .04, substantially as described.

11. A single-stage steam ejector comprising a diffusion structure, accelerating nozzles and compressing nozzles, and in which the parts are constructed and arranged to embody the formula M equals Y× diameter of diffuser throat, in which M is the distance from the outlet of compressing nozzles to the throat of the diffuser, and Y is a factor varying between the limits 2 and 2.7, substantially as described.

12. A single-stage steam ejector, comprising a diffusion structure, accelerating and compressing nozzles, and in which the parts are constructed and arranged to embody the formula N equal Z times the diameter of the diffuser throat, in which N is the distance from the outlet of the accelerating nozzles to the throat of the diffuser, and Z is a factor varying between the limits 4 and 5.9, substantially as described.

13. An ejector having a diffuser with a single diverging element, and a plurality of nozzles terminating at different distances from the throat of the diffuser, at least some of the nozzles projecting well within the converging element of the diffuser and having different ratios of divergence, substantially as described.

14. In a single-stage ejector, a diffuser structure, and at least two nozzles, one of which projects well into the converging end of the diffuser, said last mentioned nozzle receiving fluid partially compressed within a range of from 750 to 2000 feet per second, substantially as described.

15. In a single-stage ejector, a diffuser structure and two sets of nozzles, one of which sets projects well into the converging end of the diffuser, said last mentioned set of nozzles receiving fluid partially compressed within a range of from 750 to 2000 feet per second, substantially as described.

In testimony whereof, I have hereunto set my hand.

RAYMOND N. EHRHART.