

July 3, 1945.

K. C. D. HICKMAN ET AL

2,379,436

METHOD AND APPARATUS FOR PRODUCING VACUUM

Filed May 20, 1942

4 Sheets-Sheet 1

FIG. 1.

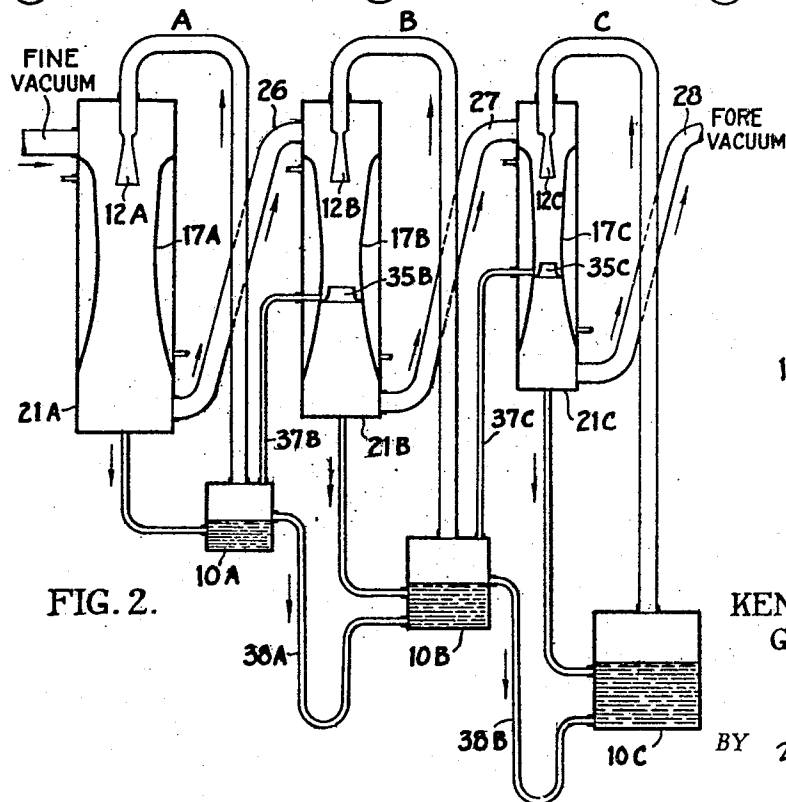
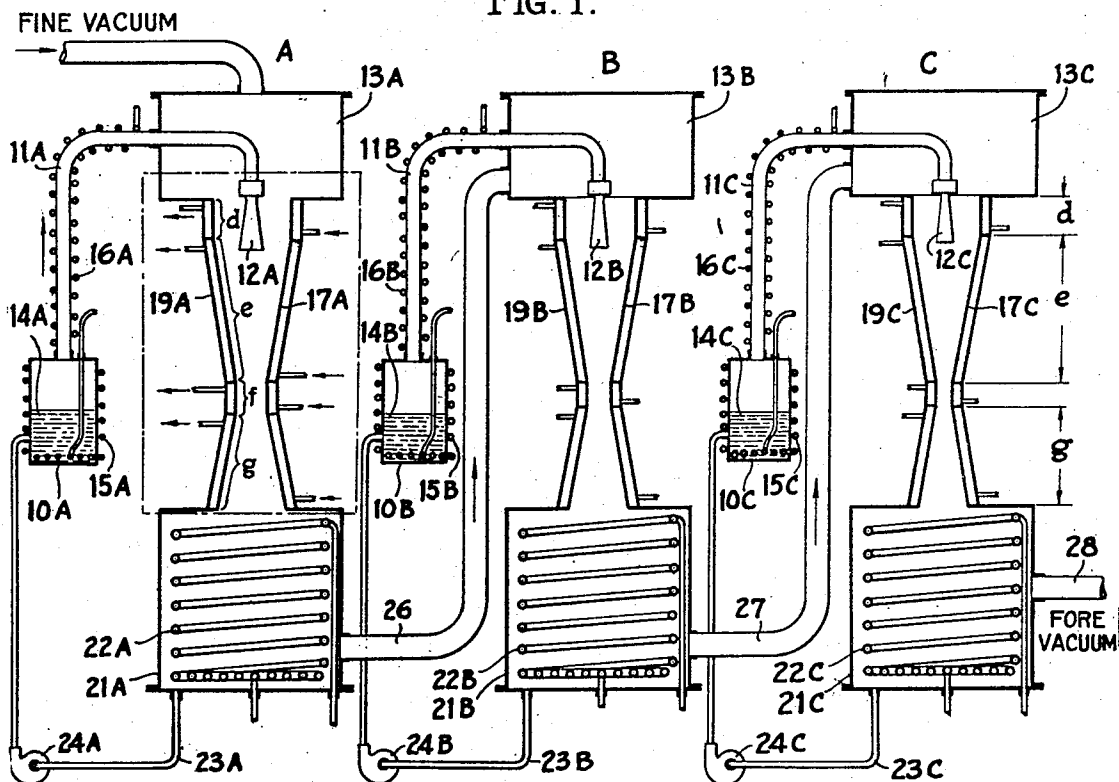
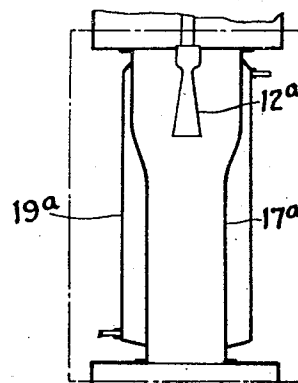


FIG. 1A.



KENNETH C.D. HICKMAN
GEORGE A. KUIPERS
INVENTORS
BY *W.H. Cannon*
ATTORNEY

July 3, 1945.

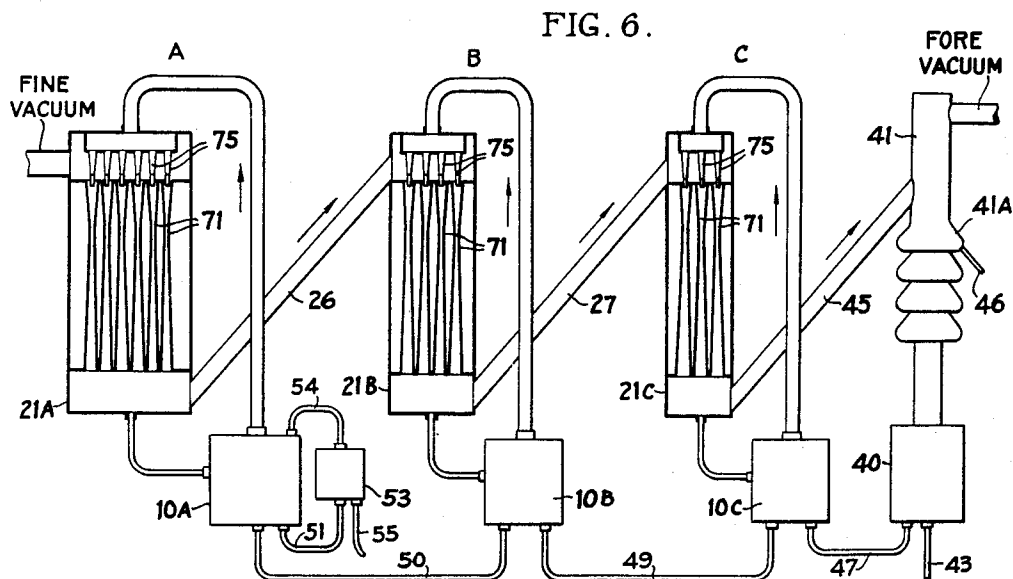
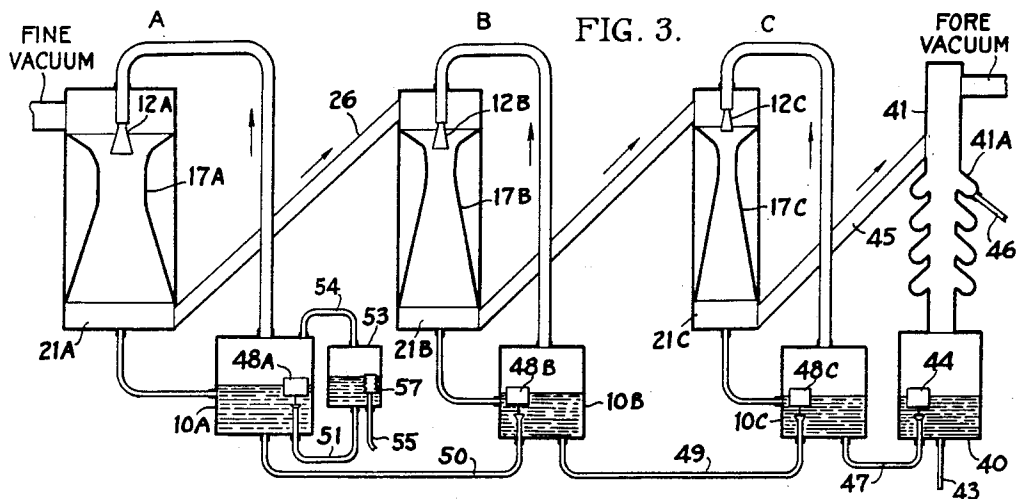
K. C. D. HICKMAN ET AL

2,379,436

METHOD AND APPARATUS FOR PRODUCING VACUUM

Filed May 20, 1942

4 Sheets-Sheet 2



KENNETH C.D. HICKMAN
 GEORGE A. KUIPERS
 INVENTORS

BY *H. M. Perrier*
W. H. Cannon
 ATTORNEY

101

July 3, 1945.

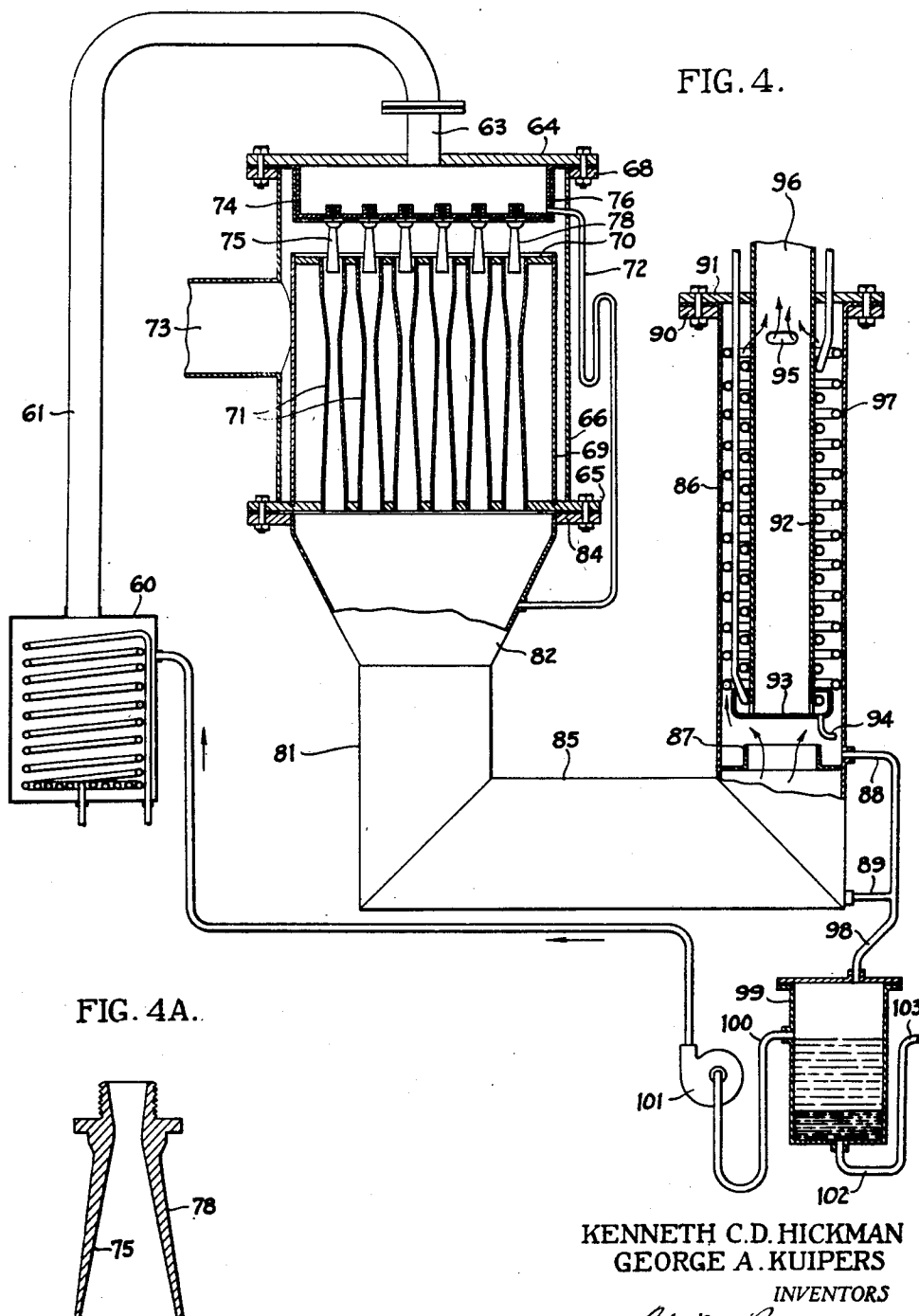
K. C. D. HICKMAN ET AL

2,379,436

METHOD AND APPARATUS FOR PRODUCING VACUUM

Filed May 20, 1942

4 Sheets-Sheet 3



KENNETH C.D. HICKMAN
 GEORGE A. KUIPERS
 INVENTORS

BY *W. H. Cannon*
 W. H. Cannon
 ATTORNEY

July 3, 1945.

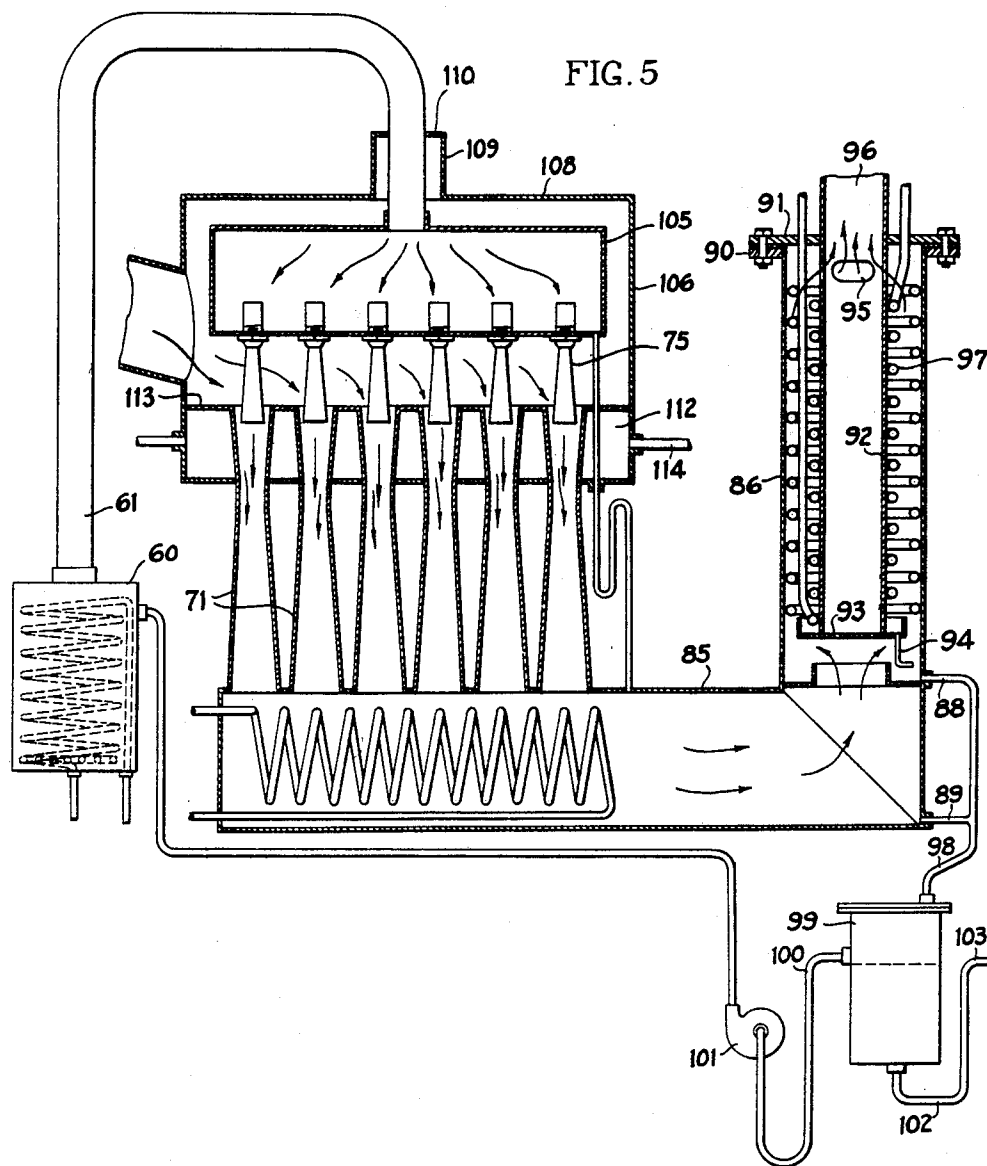
K. C. D. HICKMAN ET AL

2,379,436

METHOD AND APPARATUS FOR PRODUCING VACUUM

Filed May 20, 1942

4 Sheets-Sheet 4



KENNETH C.D.HICKMAN
GEORGE A.KUIPERS
INVENTORS

INVENTORS
BY *N. M. Proulx*
W. A. Cannon
ATTORNEY

Patented July 3, 1945

2,379,436

UNITED STATES PATENT OFFICE

2,379,436

METHOD AND APPARATUS FOR PRODUCING
VACUUMSKenneth C. D. Hickman and George A. Kuipers,
Rochester, N. Y., assignors to Distillation Prod-
ucts, Inc., Rochester, N. Y., a corporation of
Delaware

Application May 20, 1942, Serial No. 443,732

25 Claims. (Cl. 230—101)

This invention relates to a method of producing vacuums and to vacuum pump apparatus for practicing said method.

Among the fluid actuated pumps, those of the steam or water ejector type and of the condensation type are more commonly used in the production of vacuums on an industrial scale.

Of these types, the ejector pump has been very effective down to a limit corresponding with the saturation pressure of water at out-door temperatures which will range from just above freezing to about 30° C. and corresponding with vacuums of about 5 mm. to 40 mm. of mercury. Consequently, vacuum pumps of this type have been limited in their range of practical operation to a lower limit of vacuum pressures of 5 to 10 millimeters of mercury. This condition arises from the fact that the efficiency of a steam or water ejector drops away very rapidly at the lower limit of its range. The rapid decline in the efficiency of the ejector pump at lower pressures, arises from the behavior of the molecules of vapor issuing from the male jet. According to the Maxwellian distribution of thermal velocity, there are always a few molecules which have a greater random velocity than the issuing vapor jet or stream and these molecules, together with others that have accidentally hit projections of the ejector, return against the stream. These returning molecules become part of the load and greatly cut down the efficiency of the ejector as mentioned.

The inefficiency of the steam or water ejector at low intake pressures becomes especially marked when the pump is withdrawing water vapor, as in the case of the evaporation of foods or the drying of textiles or other industrial products. Under those conditions, the ratio between the actuating steam and the load is disappointingly low, since, for every unit of load, the intercondenser of the pump system must handle from 10 to 1000 times as much actuating steam, depending on the lowness of the fine pressure desired. Aside from the expense of operating such a pump, due to the amount of steam and cooling water required, there is the additional disadvantage that each pump is very bulky and a great many of them would be required in any given dehydrating installation. Furthermore, this type of pump is limited to use in those locations where

a large supply of steam and a plentiful supply of cooling water are available. Thus, they would be ill-adapted to form a part of portable apparatus such as would be needed in equipment designed to be taken into the fields for the dehydration of fruit, vegetables and the like.

The condensation type of pump, on the other hand, readily develops vacuums, in the range between .1 of a millimeter down to 10^{-4} or less, but it has a very limited capacity and, therefore, is ill-adapted for use where large volumes of gases must be evacuated. In the condensation pump using a stable organic fluid, no attempt has been made to accelerate the issuing molecules to speeds above the random thermal velocity of the majority of the particles being evacuated. Instead, a gentle stream of vapor is generated and thrust towards the diffuser and all molecules of working fluid which tend to return against the stream are condensed by adjacent cold surfaces. Here the limiting vacuum is directly related to the vapor pressure of the pump fluid at the temperature of the cold condensing surfaces.

From the foregoing explanation, it will be appreciated that the above-mentioned fluid-actuated types of pump have been impractical in the range between 6 mm. and .1 mm., that is, in the range between the lower limit of the ejector pump and the upper limit of the diffusion pump. Thus, these two types of pumps leave a gap in the vacuum "spectrum" which neither has been able to fill with practical or commercial success.

The high velocity mercury ejector as developed by Parsons is capable of effecting evacuation throughout the desired low pressure range. However, the actuating fluid of the Parsons ejector is mercury which breaks up into droplets difficult to collect since they wander into every nook and cranny of the apparatus. The resulting mercury vapor is highly objectionable since it is poisonous and requires a liquid air trap to prevent it from passing into the chamber being evacuated. This mercury type of pump is therefore unacceptable for dehydration uses, especially in the dehydration of foods.

The use of organic actuating fluids in condensation pumps has been proposed where the prevailing boiler pressure therein is low and the actuating vapor issues from the jet as a gently flowing stream.

It has also been proposed, as in the patent to Lewis, 2,028,340, to use petroleum fluids as the actuating mediums in ejector pumps, but this patent points out that these fluids tend to decompose at high boiler pressures. Consequently, the petroleum actuating vapors disclosed in that patent were not accelerated to a speed which for the most part exceeded the relatively great random velocity of certain of the gas molecules.

The main feature of the present invention relates to a novel method of producing high vacuums by forcing a stream of greatly accelerated organic fluid, in aspirating relation to a passage containing the gas to be evacuated, all of which is effected without substantial decomposition of the organic fluid and without the interposition of a cooling trap.

A further feature of the invention relates to the provision of a novel vapor ejector pump system for practicing said method, which system will operate in the range between substantially zero pressure, (10^{-4} or less) and including the range normally effective for a steam or water ejector pump, namely above 6 millimeters, on the fine vacuum side of the pump where a pressure of 5 to 10 or 40 millimeters of mercury prevails on the fore-vacuum side. The pressure of the operating fluid used in the novel pump system is sufficiently in excess of the forepressure to operate the pump and cause water vapor aspirated by the pump to condense in the fore-vacuum at the temperature produced by the cooling water available at the locality.

Another feature of the invention relates to a multi-unit ejector pump in which each unit thereof is operated by a different organic actuating fluid fraction having characteristics best suited for that unit.

An additional feature of the invention relates to the provision in a multi-unit pump using different organic fractions, of apparatus that will automatically separate out from any mixtures of such organic fractions occurring in use, the original fractions and will return each to its appropriate unit.

Still another feature of the invention relates to a novel jet and diffuser arrangement whereby greatly improved results are obtained.

Other features and advantages will appear from the detailed description and claims when taken with the drawings in which:

Fig. 1 is a front elevation, partially in section, of a series-connected, multi-unit pump system in accordance with the present invention; and Fig. 1a is a view of a straight type diffuser jet that can be substituted for one or more of the Venturi type diffuser jets in the system of Fig. 1;

Figs. 2 and 3 are diagrammatic showings of series-connected, multi-unit pump systems respectively provided with different forms of self-purifying apparatus for effecting automatic separation of and distribution of the several actuating fluid fractions to these respective units;

Fig. 4 is a side elevation, partially in section, of a multi-unit pump system in which the units thereof are connected in parallel; and Fig. 4a is a vertical sectional detail view of a male jet used therein;

Fig. 5 is a view, partially in section, of a parallel-connected multi-unit pump system similar to that illustrated in Fig. 4 but differing therefrom in the vapor box and diffuser jet manifold construction as well as in the arrangement for affording selective zonal cooling for the diffuser jets; and

Fig. 6 is a diagram illustrating a series-parallel pump system wherein a plurality of parallel pump constructions of Figs. 4 or 5 can be connected in series in accordance with the arrangements of Figs. 1 and 3.

In Fig. 1 there is illustrated one form of the pump system of the present invention. This system comprises a plurality of pump units, A, B and C connected in series arrangement. Each pump unit such as A, includes a boiler 10A opening into conduit 11A which extends in sealed relation through the wall of an air chamber 13A. Within this chamber, the conduit communicates with a downwardly extending male jet 12A. The boiler 10A contains a stable organic actuating fluid 14A, the nature of which will be hereinafter described.

The boiler may be heated by any suitable means but, as herein illustrated, it is heated by a steam coil 15A having a section thereof located in the bottom of the boiler and another section thereof wound externally about the lateral walls of the boiler. This coil is continued as a section 16A enclosing the conduit 11 so that the vapor generated from the fluid in the boiler will not cool in its travel through this conduit.

The male jet 12A opens into one end of a diffuser jet 17A mounted so that the passages through said jets are in axial alinement. The mentioned end of the diffuser jet communicates with and is sealed to the lower wall of an air chamber 13A which is connected to the fine vacuum pipe. The diffuser jet, although the invention is not so limited, is preferably of the Venturi type having a zone *d* at the neck thereof including a portion just preceding the area of impact therewith of the organic vapor issuing from the male jet. The diffuser jet also has a second zone *e* extending from the first portion to the narrowest part of said jet and it is also provided with a third zone *f* coextensive with the narrowest portion thereof. The diffuser jet further includes a fourth zone *g* coextensive with the remaining flared portion thereof. Each of the zones of the diffuser jet are individually cooled by a water jacket 19A surrounding this jet and communicating with a suitable water supply through the pipes 20A. Thus, the several zones can be selectively cooled to the prescribed temperature best suited for efficient operation. It will be understood that the invention is not limited to cooling all four of these regions but also includes the arrangement where zone *d* only is cooled.

We have discovered that the diffuser jets of the Venturi type utilized in the system of Fig. 1 may be replaced by a diffuser jet of the type, disclosed in Fig. 1a, provided with substantially straight side walls, defining a passage there-through of uniform diameter.

The end of the diffuser jet communicates with a cylindrical condenser 21A sealed to the lower end of this jet. This condenser is cooled in any suitable manner preferably by cooling water circulating through the cooling coils 22A located within the condenser adjacent its bottom and at the side walls thereof. The condenser opens into a pipe 23A having a pump 24A therein for returning the condensed actuating fluid back to the boiler 10A.

The constructions of the pump units B and C are similar to that of unit A so that it will be unnecessary to describe them since in the drawings, the parts of units B and C corresponding to unit A, are designated by the same reference

numerals with the added suffixes B and C respectively.

It should be mentioned that a conduit 26 having one end sealed in a side wall of the condenser 21A communicates with the air chamber 13B of the second pump unit B. Similarly, a conduit 27 connects the condenser 21B of the pump unit B with the air chamber 13C. Also, the condenser 21C communicates with the fore-vacuum pipe 28. It should also be pointed out that the diameters of the male jet 12B and of the receiving jet 17B are smaller than the corresponding parts in the unit A and that the diameters of the male jet 12C and the receiving jet 17C are smaller than the corresponding jets of the pump unit B. In other words, the diameters of the male jets and of the receiving jets progressively decrease in size from the fine vacuum end of the pump system to the forevacuum end thereof.

The actuating fluids to be used in the boilers 10, 10B and 10C in the pump system of Fig. 1 comprise stable organic fluids. While various fluids may be used, it has been discovered that for highest pump efficiency the fluids used should have certain definite characteristics. If the fluid is too volatile it may prevent the establishment of the proper vacuum and in borderline conditions may provide an aureole of partially condensed vapor around the male jet which limits the influx of the gas to be pumped. Furthermore, the vapor of a too volatile pump fluid may be carried away in minute amounts into the forevacuum. It will be appreciated that during the course of a short time of pump operation, the fluid will be revaporized and condensed thousands of times so that the accumulated loss into the forevacuum may be high and the boiler will soon become empty.

When the boiler fluid is of lower volatility than the optimum, the fine pressure may be excellent but the thermal efficiency suffers. More heat must be put into the oil and the temperature of the boiler rises unduly which may cause weakening of the walls, starting of the seams and disintegration of joints and vapor pipelines. When the condition becomes aggravated the temperature rises so high that polymerizing and gumming occurs in the boiler, gaseous decomposition products are evolved and the vacuum is again impaired because of these uncondensibles. With such fluids, it is customary to use lower boiler pressures in order to approximate usual boiler temperatures and this in turn lowers the permissible expansion ratio in the male jet and reduces the entrainment ratio.

In general, the vapor pressure of the fluid should be substantially less than the lowest pressure to be produced at the preferred temperature of the condenser and manifold surrounding the male jet. The vapor pressure of the pumping fluid should be so low that in the apparatus for which it is designed for service, the unrecoverable escape of fluids shall not be greater than, say, 50% in 24 hours.

Where food dehydration is concerned the liquid shall not be hydrolizable by water or water vapor under operating conditions. In general, the vapor shall not be harmfully reactive with the materials handled under the chosen operating conditions.

By way of example, there follows a table of preferred characteristics of, and sources of suitable actuating fluids for specified operating conditions.

List of preferred boiling points and sources of actuating fluids for specified operating conditions

	Fine vacuum produced by pump (mm. Hg)	Forepressure against which pump will operate (mm.)	Source of operating fluid	Boiler	
				Temp. (°C.)	Pressure (cm.)
I.....	.01- .1	.5-2	A, B, C, D, E	210-250	2-8
II.....	.1- .3	2-4	A, B, C, D, E	200-250	4-12
III.....	.3-1.0	4-12	G	180-220	8-20
IV.....	1-4	10-20	F, G	170-220	10-35
V.....	4-10	20-60	F	160-230	20-70

As source of the above oils we have used:

- A—Winter grade crank case oil (WW)
- B—50 W white oil
- C—Light processing oil
- D—Spindle oil
- E—Ice machine oil
- F—Fuel oil No. 1
- G—Fuel oil No. 2

The actuating fluids for the boilers are not these oils but suitable fractions distilled from them to meet the vapor pressure-temperature relations specified. Other fluids meeting these requirements are considered within the scope of this invention. Where the system comprises three pump units connected in series, boiler 10A will preferably utilize a mixture of fractions I and II, boiler 10B preferably will use fractions III and IV, and boiler 10C will preferably employ fraction V.

In the operation of this multi-unit, series-connected pump system, the actuating liquids in the boilers 10A, 10B and 10C are heated to convert them into their vapor phases and to accelerate the flow of these vapors. In the case of the unit A, the actuating liquid in a boiler 10A is heated to a temperature preferably in the range from 200 to 250° C. at a boiler pressure of from 2 to 12 cm. Under these conditions, the liquid in this boiler is converted into a vapor which flows through the conduit 11A and issues from the male jet 12a at a velocity greatly in excess of that ordinarily prevailing in a condensation pump. For example, the velocity of the vapor issuing through the male jet 12a is greater than the random thermal velocity of the majority of the molecules of the gas or vapor being evacuated. This accelerated stream of actuating vapor issues into the diffuser jet 17A in aspirating relation to the passage from the fine vacuum pipe. The walls of this diffuser jet in the mentioned regions d, e, f and g, thereof, are selectively cooled by the several water jackets to provide zonal cooling thereof, since the cool diffuser walls substantially limit the flow of the molecules of the issuing vapor to a forward direction. In other words, the relatively high velocity of the issuing vapor and the constricting action of the cool condenser walls thereon, insure that substantially all of the molecules of the vapor will continue along the principal direction of the vapor stream. From the diffuser, the vapor with the gas to be evacuated entrained therein, passes into the condenser 21A. It should be noted especially that the diffuser jet opens directly into the condenser so that the actuating vapor is not required to pass through any conduit of restricted cross section which would greatly obstruct the forward flow from the mentioned jet. It should also be pointed out that the characteristics of the actuating fluid are such that the vapor will condense readily at the temperature of the usual water supply. From the condenser, the pump

24A returns the condensate through the pipe **23A** to the boiler **10A**. The gas to be evacuated is advanced through the conduit **26** to the pump unit **B**.

The actuating fluid in boiler **10B** of this unit is preferably heated to a temperature of from 170° to 220° C. at a pressure of from 6 to 35 cm. The operation of the pump unit **B** is similar to that of the unit **A** except that the vapor from the boiler **10B** and the male jet **12B**, issues at a higher velocity than the vapor at unit **A**. In this instance also, the condensate from the condenser **21B** is pumped back to the boiler **10B**. The gas to be evacuated is advanced from the condenser **21B** through conduit **27** to the pump unit **C**.

Here again the evacuating operation is continued. In this instance, however, the fluid in the boiler is heated at a temperature of from 160 to 250° C. at a boiler pressure of 20 to 70 cm. Under these boiler conditions, the vapor generated in the boiler **10C** is greatly accelerated and it issues from the male jet **12C** at a velocity greater than the acoustic velocity of sound in the actuating vapor. Here also, the condensate formed in the condenser is pumped back to the boiler **10C** for reuse. However, the gas to be evacuated, passes to the fore-vacuum pipe.

From the foregoing description, it will be appreciated that there is provided, a novel method of producing vacuum, effective from atmospheric pressure to extremely low pressures, and yet the use of poisonous and otherwise objectionable actuating fluids, are avoided. In this method, there are utilized organic actuating fluids, preferably derived from the fractional distillation of certain petroleum products, the fluids being heated so that the velocity of the resulting actuating vapors are accelerated to a degree previously considered impossible without thermal decomposition thereof. By using vapor jet velocities in excess of the random thermal velocity of the majority of the vapor molecules and also in excess of the random motion of the gas being pumped, evacuation is effected throughout the vacuum "spectrum," even to the lowest pressures ordinarily sought in industrial processes.

It is a shortcoming of petroleum fluids that they are unlikely to be homogenous. Therefore, in order to avoid the presence of light fractions which impair the vacuum, it is necessary, as a practical matter, to use actuating fluids containing too many heavy fractions for the most economical operation of the pump. Furthermore, the pump, during operation, is likely to become contaminated with material which has an affinity for the pump fluid so that the composition of this fluid will be altered thereby. In accordance with the present invention, it is proposed to provide a multi-stage or multi-unit pump system in which each stage is operated by a fraction most suitable therefor. It is also proposed to include self-purification apparatus in the pump system, which apparatus will automatically separate the various fractions from any mixture of actuating fluids, and which will distribute each of the separated fractions to the pump unit to which it is best suited. This result may be achieved either by fractional condensation or by fractional distillation.

In Fig. 2 there is shown a modified evacuating system in which there is an arrangement for effecting fractional condensation of the actuating fluids and for distributing each separated fraction to its appropriate boiler. This arrangement employs a plurality of pumping units **A**, **B** and **C**

connected in series after the manner of the system shown in Fig. 1. However, the diffuser jets **17B** and **17C** of the units **B** and **C** respectively are provided with gutters **35B** and **35C** at an intermediate point thereof. Each gutter is connected by a pipe **37** to the preceding boiler in the series beginning with the forevacuum end of the system. Thus, the gutter **35C** of the diffuser jet **17C** communicates through the pipe **37C** with the boiler **10B**, similarly the gutter **35B** of the diffuser jet **17B** communicates through the pipe **37B** with the boiler **10A**. It will be noted also that the boilers **10A**, **10B** and **10C** are located at different levels, the elevation of each boiler being determined by the vapor pressure of the actuating fluid therein. Thus, since the vapor pressure of the fluid in the boiler **A** is less than that in boiler **B** and since the vapor pressure of the fluid in the boiler **B** is less than that in boiler **C**, boiler **A** will be at the highest elevation, boiler **B** at an intermediate level and boiler **C** at the lowest level. It will be noted that boiler **10A** communicates with boiler **10B** through a pipe **38A** having a trap therein.

The operation of this modified system in effecting evacuation is the same as that of Fig. 1 and need not be redescribed here. It should be pointed out, however, that the first fluid to condense in the gutter **35C** of the diffuser jet **17C** will be the highest boiling constituent of the vapor and this condensate is conducted through pipe **37C** to boiler **10B** where the fluid is again vaporized and sent to the male jet **12B**. The excess condensate from the jet **17C** over and above that needed in the boiler **10B** flows by gravity through pipe **38B** to boiler **10C**. Likewise, the actuating vapor issuing from the male jet **12B** of pump unit **B** is subjected to partial condensation in the diffuser jet **17B** wherein the highest boiling fraction collects in gutter **35B**. From this gutter, the condensate flows to boiler **10A** where it is reboiled to provide actuating vapor for its jet **12A**. It will be understood that if there is insufficient fluid in the boilers **10A** and **10B**, this deficiency can be made up by adding a cruder fraction of the actuating fluid to the boiler **10C** from which the higher boiling fractions will pass as already described to the respective boilers **10B** and **10A** in the order named.

In Fig. 3, there is illustrated another modified evacuating system in which there is provided means for effecting fractional distillation of the actuating fluids and for delivering each fraction to its proper boiler. In this arrangement also the pump units **A**, **B** and **C** are connected and operated in the manner previously set forth. However, there is also provided a rectifying boiler **40** with a rectifying column **41**. This boiler is provided with an inlet pipe **43** through which fresh oil is continuously available for this boiler as needed. The level of the oil in the boiler is determined by a level-controlled float valve **44** which controls the opening and closing of the inlet pipe **43**. The upper part of the rectifying column communicates with the forevacuum pipe and also with the pipe **45** from the condenser **21C** of the pump unit **C** so that any lighter fractions of vapor not condensed therein will condense in the rectifying column. This column has a gutter **41A** therein in which the undesired lighter fractions collect and can be discharged through the pipe **46**. The rectifying boiler **40** is connected at its bottom portion with the boiler **10C**, through the pipe **47**. The flow of fluid through the pipe **47** is determined by a level-controlled float valve **48C**

101

2,379,436

5

located in the boiler 10C so that a uniform level of liquid is maintained in this boiler. Similarly, the boiler 10C is connected to the boiler 10B by a pipe 49 governed by a level-controlled float valve 48B in the boiler 10B to maintain the desired liquid level therein by controlling the admission of fluid through the pipe 49. In like manner the boiler 10B communicates through pipe 50 with the boiler 10A wherein there is likewise provided a level-controlled float 48A which also maintains a predetermined level in this boiler by controlling the flow of fluid thereto through the pipe 50. The bottom portion of the boiler 10A communicates through a pipe 51 with the bottom portion of a purifying boiler 53 for the nonvolatiles. The upper portion of this boiler or purifier communicates through a conduit 54 with the upper portion or vapor chamber of the boiler 10A, while the bottom of the boiler 53 is provided with a discharge pipe 55, the inlet to which is controlled by a thermostatically operated valve 57. All of the mentioned boilers are provided with heating means not illustrated. It will be understood that the float valves are shown by way of example only and that the leads may be controlled by other well-known means.

The operation of the pump units A, B and C is similar to that already described and need not be repeated except to mention again that the boiler 10C is operated at the highest pressure, boiler 10B at an intermediate pressure and boiler 10A at the lowest pressure. These pressures are, of course, determined by the characteristics of the fractions of actuating fluid used, in accordance with the table previously given. However, with the self-rectifying arrangement herein provided, oil including the fractions suitable for use in the boilers 10A, 10B and 10C is available through pipe 43 so that the float valve 44 maintains a given level of oil in the boiler 40. It is assumed that the level of the actuating oils or fluids in the remaining boilers is at the predetermined point. However, if the level in the boiler 10C is above that required, its float valve 48C will open permitting fluid to flow from boiler 10C to boiler 10B. This, of course, will disturb the level in the boiler 10B which will open its float-controlled valve 48B so that actuating fluid or oil can flow to boiler 10A. The level of the oil in boiler 10A will likewise be disturbed so that float valve 48A will open permitting excess fluid to flow to boiler 53. Similarly float valve 44 in boiler 40 will operate to maintain the level in this boiler. It will be understood that this restoration of the levels in the boilers 10A, 10B and 10C will admit to each boiler, fractions of the fluid other than that best adapted for the operation of the particular pump unit in question. However, the lighter fractions will tend to flow from left to right in the system as illustrated, this flow taking place through a condenser unit or units until the fraction condenses into its appropriate boiler. On the other hand, the heavier fractions will flow from boiler to boiler, from right to left in the system until the non-volatiles accumulate in the purifying boiler 53. When an excess of non-volatiles accumulate in this purifying boiler, the temperature of these non-volatiles will rise to a point where the thermostatically-controlled valve 57 will open the discharge pipe 55 to permit the excess to be discharged through this pipe. In this arrangement, the actuating fluid is cleared of its undesired light volatiles and is also cleared of undesired non-volatiles while the suitable fractions of the purified oil or actuating fluid are auto-

matically distributed to their appropriate boilers in the system. This arrangement insures that each pump unit in the system will be operated at its highest efficiency.

A further modified form of the invention is shown in Figs. 4 and 4a wherein the pump units or stages are connected in parallel instead of being connected in series as in the arrangements described above. In this modification there is likewise provided a closed boiler 60 adapted to heat the actuating hydrocarbon fluid contained therein to a predetermined temperature. The top of this boiler communicates with a conduit 61 which extends upward and is then arched for communication with a connection nipple 63, attached to the circular cover plate 64 of a diffuser jet manifold. This manifold, in addition to the mentioned cover plate, includes a circular bottom plate 65 of like diameter as the cover plate. The bottom plate has welded thereto, the lower edge of a cylindrical casing 66 of slightly smaller diameter than that of the mentioned plates. The upper end of this casing is welded in the opening of an annular ring 68 which serves as a flange for connecting this casing to the cover plate by means of suitable clamping bolts. There is mounted within the manifold a diffuser jet assembly unit comprising the mentioned bottom plate 65. The unit also includes a second cylindrical casing 69 substantially shorter than and of smaller diameter than the first casing 66. This second casing has its lower edge welded to the bottom plate in coaxial relation with said first casing, while its upper edge is welded to the periphery of a top plate 70. The mentioned top and bottom plates have alined openings therein. In each pair of these alined openings, there is mounted a diffuser jet 71 of the Venturi type with the top and bottom ends of each such jet secured in the mentioned alined apertures by being welded to the respective top and bottom plates. The diffuser jet unit is thus arranged so that cooling water or other fluid can be circulated, by means not shown, through the unit in contact with the outside surface of the diffuser jets without leaking into the actuating fluid which passes through these jets. It will be understood that the several diffuser jets may be provided with zonal cooling, as disclosed in Fig. 1. A fine vacuum pipe 73 communicates with the space inside of the diffuser jet manifold.

It has been mentioned that the boiler communicates through the conduit with the connection nipple 63 on the cover plate 64 of the manifold assembly. This connection nipple opens into a vapor chamber formed by welding the rim of a cup 74 to the underside of the top plate, the cup being approximately of the same diameter as that of the second casing 69 and arranged coaxially therewith. The bottom of the mentioned cup is provided with a number of apertures equal in number and arranged in alignment with the openings in the top plate. In each of the these apertures in the cup bottom, there is screwed a flaring male jet 75 (Fig. 4a) with its lower end preferably extending into the upper end of one of the receiving jets. It will be noted that the upper end of each of the male jets projects well above the bottom of the mentioned cup. However, a pipe 72 with a liquid trap therein, communicates with the bottom of the cup so that if any of the actuating vapor condenses in the vapor box, this condensate will be discharged therethrough to the hot condenser. Inasmuch as the upper ends of the male jets project well above the bottom of the vapor box,

the condensate cannot enter therein to clog them but instead the jets will remain "dry" thereby insuring the most efficient operation of the pump.

It should be particularly pointed out that the walls of the vapor box are so positioned that there is an extremely long metallic path between the male jets 75 and the diffuser jets 71. Furthermore the walls of the vapor box are covered with heat insulating material 76 to prevent thermal losses. Additional provisions against such thermal losses may comprise supplying the walls of the vapor box with additional heat such as by heating coils (not shown) and by polishing or mirroring of the outside surface 78 of each of the male jets.

The bottom plate of the diffuser manifold has clamped thereto, the upper end of a hot condenser. This hot condenser comprises a vertically extending cylindrical pipe 81 provided with a flaring portion 82 and having its upper end of a diameter substantially equal to the diameter of the inner casing of the diffuser jet assembly. The upper edge of this flaring portion is welded in a ring 84 which serves as a flange to be clamped by suitable clamping bolts to the bottom plate of the manifold. A suitable gasket interposed between these parts seals them together. The lower end of the hot condenser opens into a cylindrical, horizontal reservoir 85. Preferably, the lower end of the cylindrical pipe and the left end of the boiler are mitered and welded together in accordance with the usual elbow construction. Likewise, the right end of the reservoir has joined thereto the vertical chimney 86 of a cold condenser unit, the chimney and reservoir being likewise joined together by the mentioned elbow construction. The chimney at a point just above the top of the reservoir has welded therein a horizontal ring 87 with an integral upstanding flange which provides a suitable gutter for the collection of condensate formed on the inner wall of the chimney. This gutter is provided with a discharge conduit 88 which may be connected in parallel with a discharge conduit 89 provided at the bottom of the reservoir. The upper end of the mentioned chimney is welded to a ring 90 providing a connection flange, adapted to be clamped to an annular cover plate 91, the ring having an opening therein of a diameter substantially smaller than the diameter of the mentioned chimney. A tube 92 of approximately the diameter of this opening is welded to the underside of the cover plate 91 to communicate with said opening. The mentioned tube is slightly shorter than the chimney and its lower end is closed by a circulate plate 93 formed with an upstanding outer flange to provide a gutter at the lower end of the tube. This gutter collects condensate forming on the outside or the outer wall of the tube 92, and is provided with a discharge conduit 94 opening into the first mentioned gutter. The tube near its upper end is provided with an aperture 95 so that the annular flue between the chimney and the tube communicates with the opening in the cover plate, which opening leads into the fore-vacuum conduit 96. The mentioned annular flue space is provided with a cooling coil 97 for the circulation of cooling medium therethrough, certain of the turns of this coil contacting the outer wall of this tube and other turns thereof contacting the inner wall of the chimney so that

both the chimney and the tube will serve to condense the vapors.

It has been mentioned that the condensate from the cold condenser as well as from the hot condenser and the reservoir are discharged into conduits 88 and 89 which lead to the common pipe 98 and thence into the top of the oil separator 99. This separator comprises the usual receptacle provided at a point spaced from the top thereof with an oil outlet pipe 100 leading to a gear pump 101 which advances the oil back into the boiler 60. The bottom of the oil separator is provided with a pipe 102 through which water is discharged. This pipe is provided with a riser that extends to a point 103 just slightly below the oil discharge pipe.

In the operation of this parallel connected multi-unit pump system, the boiler 60 is heated to vaporize the actuating fluid therein. This actuating fluid preferably has the characteristics of the fluid designated IV in the mentioned table. Consequently, the fluid in the boiler will be heated to a temperature in the range from 170 to 220° C. at a boiler pressure of 10 to 35 cm. With the boiler heated to the mentioned temperature, the vapor or actuating fluid will be accelerated so that it issues through the male jets 75 at a velocity greater than the random thermal velocity of the gas being pumped. The accelerated vapor issuing from each male jet streams into its related diffuser jet 71 and in so doing, entrains some of the gas to be evacuated. The wall of each diffuser jet is cooled by zones as in Fig. 1 or uniformly throughout the major portion of its length, with the result that these cooled walls will reduce the tendency of the vapor molecules to diverge thereby insuring that substantially all of the vapor stream will continue to flow along the principal direction of movement of the stream. This restriction of the divergence of the molecules of the vapor stream together with the high velocity at which the stream issues from the male jet, assures substantially no retrograde flow of any part of the actuating vapor. As a result of this condition, the present ejector type of pump functions with remarkable efficiency even in the low pressure range usually restricted to condensation and mercury actuated pumps.

After passing through the diffuser jets, the actuating vapor with evacuated gas entrained therein flows into the hot condenser 81 wherein some of the vapor is condensed and collects in the reservoir 85. The uncondensed portion of the vapor as well as the entrained gas passes into the cool condenser wherein the remainder of the vapor is condensed, the gas, of course, passing out of the cold condenser into the forevacuum conduit 96. The vapor condensate accumulating in the reservoir and the cold condenser flows to the oil separator 98 where the oil is separated from the water therein. The oil in the top portion of the separator is returned by the gear pump 101 to the boiler 60, the water in the bottom of the separator, of course, flows through the pipe 102 to a suitable drain. By employing the hot condenser, the major portion of the actuating fluid is condensed at relatively high temperature so that it can be returned to the boiler with a minimum loss of heat. However, the cold condenser is necessary to recover the remainder of the fluid at a lower temperature with somewhat more dissipation of heat. Nevertheless, this condenser arrangement effects a substantial improvement in thermal efficiency.

In Fig. 5 there is illustrated a further modified form of pump system in which the several pump units or stages are connected in parallel, like the pump system of Fig. 4. However, the pump system of this modification differs from that disclosed in Fig. 4 in the arrangement of the vapor box and the diffuser jet manifold whereby additional vacuum insulation prevents leakage of heat between these parts. Furthermore, the diffuser jet manifold differs from corresponding manifold illustrated in Fig. 4 in that there is here provided selective zonal cooling of the liquid and air type. The parts of Fig. 5 which are of the same construction as those in Fig. 4 are identified by the same reference characters.

In this modified parallel-connected pump system, there is also included a boiler 60 having suitable means for heating an organic actuating fluid contained therein. This boiler communicates through the conduit 61 with the top of the cylindrical vapor box 105. The bottom of this vapor box has openings therein in which male jets 75 are mounted to extend downward. The vapor box is completely enclosed within the cylindrical diffuser jet manifold 106, also, preferably cylindrical in shape and mounted in coaxial spaced relation to the vapor box.

This novel mounting arrangement provides virtually complete vacuum insulation of the vapor box. In this novel arrangement, the cover 108 of the diffuser jet manifold has a central opening therein of substantially larger diameter than the downward extension of the conduit 61 which passes concentrically therethrough. Since the top of the manifold must be sealed, a cylindrical sleeve 109 mounted concentrically with respect to the conduit 61 has its lower edge welded to the margin of the cover plate at its central opening. The upper edge of the sleeve 109 is welded to the outer edge of an annular plate 110, the inner edge of which is welded to the conduit 61 which passes therethrough. By way of example, in actual construction, the cover plate 108 may be one-half an inch thick, the sleeve 109 one-sixteenth of an inch thick and the annular plate 110 may be one-quarter of an inch thick. It will be noted that the flat cover and the flat plate are relatively thick for strength while the sleeve which obtains its strength mainly by reason of its shape and mounting, is relatively thin to offer an extremely poor heat conducting path between the conduit 61 and the manifold walls.

Each male jet 75 opens into a diffuser jet 71, while the upper portions of these diffuser jets project in sealed relation through the bottom wall of the diffuser jet manifold where they are enclosed by a fluid cooling chamber 112. This cooling chamber is defined by the bottom and by a portion of the side wall of the diffuser jet manifold as well as by a perforated plate 113, having its periphery welded to the side wall of the manifold. The upper edges of the diffuser jets are sealed in the perforations in the plate 113. Portions of a pipe 114 communicating with this cooling chamber are included in a liquid circulation system whereby the upper portion of each diffuser jet extending approximately to its restricted region may be liquid cooled to any desired temperature. The portion of the diffuser jets extending below the diffuser manifold may be cooled by circulating air thereabout.

In this form of the invention, the lower ends of the diffuser jets open into the reservoir 85. The left-hand portions of this reservoir is provided with a cooling coil whereby a substantial

portion of the actuating vapor is condensed while the remainder thereof proceeds to the cold condenser, as previously described in connection with the system of Fig. 4.

This last described modification operates with a high degree of efficiency throughout the desired vacuum range and with a minimum of heat losses.

The modified form of the invention illustrated in the diagram of Fig. 6, comprises a series-parallel connected multi-unit pump system in which three of the parallel-connected pumps as disclosed in Figs. 4 and 5 have substituted for the units A, B and C in the arrangement of Fig. 3. It should be pointed out that the number of male and diffuser jets in each unit A, B and C progressively decreases from the fine vacuum end of the system to the forevacuum end thereof. The operation of this pump system will be substantially similar to that disclosed in Fig. 3.

The expression stable organic liquid as herein used, means a liquid which does not substantially change its chemical structure or physical characteristics, other than color, over relatively prolonged periods of use even when subjected to the rigorous conditions encountered as a high boiling and highly accelerated actuating medium for a jet.

The present invention thus provides for the use of high-velocity ejectors and high-boiling organic fluids so chosen and designed that the decomposition ordinarily associated with high-boiling organic liquids is avoided while the high working efficiency equal to the well-known Carnot cycle, hitherto unobtainable with organic fluids, is in fact substantially realized. This invention includes the provision of fluids, ejector and diffuser jets with entrainment ratios in excess of 100:1 and approaching substantially 5: and 10:1 thus realizing from 1-50% of the work available according to the second law of thermodynamics. The relation between the existing art and the present invention will best be appreciated from the following example. With Burch's invention of the oil-operated condensation pump, speeds of the order of 100 liters per second and pressures of 10^{-4} mm. were readily available. A "large" Burch condensation pump would thus compress one-twenty-thousandth of an inch of air per minute. That condensation pump employed a shallow pool of organic liquid in a carefully constructed boiler in which every precaution was taken not to overheat the oil. A small fraction of a liter of oil and a few hundred watts input of electricity furnished the power and working fluid. According to the present invention, it is contemplated to employ substantially commercial boiler practice, utilizing a boiler of 1 to 1000 H. P. capacity filled with the properly selected fluids, piping the vapor of said fluids in large pipes, according to advanced power house practice, around many floors of a large factory, to the multiple jet assemblies described herein and returning the condensate by pipe line and high power mechanical pump to the boiler. It is contemplated that a 500 H. P. installation will entrain over 2000 lbs. of water vapor at 1 mm. pressure per minute thus bringing the technology of a high vacuum oil pump to industrial use on a scale never heretofore contemplated.

What we claim is:

1. The method of producing vacuums to extremely low pressures which method comprises heating a source of relatively stable organic liquid to convert it into its vapor phase, acceler-

ating the molecules of said vapor, and causing said accelerated molecules to issue as a jet in aspirating relation to an opening communicating with the space to be evacuated, the speed of said issuing molecules being greater than their random velocity.

2. The method of producing any degree of vacuum from 60 mm. to .001 mm. which method comprises heating to a temperature in the range from 160° to 250° C., a relatively stable organic liquid, having a vapor pressure at a temperature in said range of approximately 2 to 70 cm. of mercury to convert it into its vapor phase, accelerating the molecules of said vapor, and causing said accelerated molecules to issue as a jet in aspirating relation to an opening communicating with the space to be evacuated.

3. The method of producing vacuums to extremely low pressures which method comprises heating a source of relatively stable organic liquid to convert it into its vapor phase, causing said vapor to issue as a jet into a restricted passageway communicating with the space to be evacuated, the velocity of the molecules of vapor issuing as said jet being greater than their random velocity, and selectively cooling different zones about said passageway whereby there is a substantial reduction in the tendency of the vapor molecules comprising said jet to deviate from the principal direction of movement of the jet.

4. The method of producing vacuums to extremely low pressures in successive stages which comprises providing highly accelerated jets of vapor, generated from relatively stable organic liquids, at successive points along and in aspirating relation to the stream of gas or vapor being evacuated, and condensing said organic vapors to their liquid phases, said liquids having successively lower boiling points from the fine vacuum portion of the stream to the fore vacuum portion thereof.

5. A vacuum pump system comprising a plurality of ejector units connected together and operating jointly to produce low pressure, each unit including a male jet and a diffuser jet arranged in aspirating relation, and fluid actuating means for said units, including a fluid derived by fractional distillation of petroleum, said fluid having a boiling point of 200° to 250° C. at pressures of 2 to 12 centimeters of mercury.

6. A vacuum pump system comprising a plurality of ejector units connected to operate in parallel relation, each unit including a male jet and a diffuser jet arranged in aspirating relation, and fluid actuating means for said units, said means including an organic fluid having a vapor pressure less than 5 mm. of mercury absolute pressure at the temperature of one of said diffuser jets.

7. A vacuum pump system comprising a plurality of ejector units connected to operate in series-parallel relation, each unit including a male jet and a diffuser jet arranged in cooperative relation, and fluid actuating means for said units, said means including at least one organic fluid having a vapor pressure less than 5 mm. of mercury absolute pressure at the temperature of one of said diffuser jets.

8. A vacuum pump system comprising a plurality of ejector pump units connected in series, each unit including a male jet, a diffuser jet into one end of which said male jet opens, a chamber sealing the adjacent ends of said jets from the atmosphere but communicating with space to be evacuated, a boiler communicating with said

male jet, an actuating fluid for each boiler, said diffuser jet also communicating with other space such as the chamber of a succeeding pump in the series, the actuating fluids in said boilers increasing in vapor pressures from the fine vacuum end of the pump system to the fore-vacuum end thereof.

9. A vacuum pump system comprising a plurality of ejector pump units connected in series, each unit including a male jet, a diffuser jet into one end of which said male jet opens, a chamber sealing the adjacent ends of said jets from the atmosphere but communicating with space to be evacuated, a boiler communicating with said male jet, an actuating fluid for each boiler, said diffuser jet also communicating with other space such as the chamber of a succeeding pump in the series, the actuating fluids in said boilers being hydrocarbons increasing in vapor pressures from the fine vacuum end of the pump system to the fore-vacuum end thereof.

10. A vacuum pump system comprising a plurality of ejector pump units connected in series, each unit including a male jet, a diffuser jet into one end of which said male jet opens, a chamber sealing the adjacent ends of said jets from the atmosphere but communicating with space to be evacuated, a boiler communicating with said male jet, an actuating fluid for each boiler, said diffuser jet also communicating with other space such as the chamber of a succeeding pump in the series, the actuating fluids in said boilers being fractions derived by the distillation of petroleum, the fractions in said boilers having successively lower boiling points from the fine vacuum end of the pump system to the forevacuum end thereof.

11. A vacuum pump system comprising a plurality of ejector pump units connected in series, each unit including a male jet, a diffuser jet into one end of which said male jet opens, a chamber sealing the adjacent ends of said jets from the atmosphere but communicating with space to be evacuated, a boiler communicating with said male jet, an actuating fluid for each boiler, said diffuser jet communicating with other space such as the chamber of a succeeding pump in the series, said actuating fluids comprising fractions distilled from petroleum and having boiling points in the range from 250° C. at a pressure of 2 cm., to 160° C. at a pressure of 20 cm.

12. A vacuum pump system comprising a plurality of ejector pump units connected in series, each unit including a male jet, a diffuser jet into one end of which said male jet opens, a chamber sealing the adjacent ends of said jets from the atmosphere but communicating with space to be evacuated, a boiler communicating with said male jet, an actuating fluid for each boiler, said diffuser jet also communicating with other space such as the chamber of a succeeding pump in the series, said actuating fluids comprising fractions distilled from petroleum and having boiling points in the range from 250° C. at a pressure of 2 cm. to 160° C. at a pressure of 20 cm., the fraction in at least one of said vacuum pump units having a vapor pressure less than 5 mm. of mercury absolute pressure at the temperature of the diffuser jet of said last mentioned unit.

13. In a vacuum pump system, a boiler adapted to vaporize an actuating fluid contained therein, a vapor box into which said boiler discharges vapor, male jets communicating with said box and projecting outward therefrom, a diffuser jet manifold in which said vapor box is mounted in spaced relation to the bottom and side walls of

said manifold whereby thermal leakage from said box to said manifold is greatly reduced, and diffuser jets, each diffuser jet having one end thereof communicating with said manifold in alined cooperative relation with a male jet.

14. In a vacuum pump system, a boiler adapted to vaporize an actuating fluid contained therein, a vapor box into which said boiler discharges vapor, male jets communicating with said box and projecting outward therefrom, a diffuser jet manifold in which said vapor box is mounted in spaced relation to the top, bottom and side walls of said manifold whereby said box is thermally insulated from said manifold and diffuser jets, each diffuser jet having one end thereof communicating with said manifold in alined cooperative relation with a male jet.

15. In a vacuum pump system, a boiler adapted to vaporize an actuating fluid contained therein, a vapor box into which said boiler discharges vapor, male jets mounted in air tight relation in openings in the bottom of said box with the upper ends of said male jets projecting above the upper surface of said bottom, a diffuser jet into which each male jet opens, a diffuser manifold providing a sealed chamber enclosing the lower end of said male jets and the upper end of said diffuser jets, a conduit communicating with said manifold and with the space to be evacuated, and means for discharging condensate which forms on the mentioned surface of said vapor box.

16. An ejector pump unit comprising a male jet, a source of actuating organic vapor supplied to said jet, a diffuser jet of the Venturi type into which said male jet opens, a chamber enclosing the adjacent ends of said jets, an inlet pipe for gas to be evacuated, opening into said chamber in aspirating relation to adjacent ends of said jets, condensing means with which said diffuser jet communicates, and means for applying liquid cooling to the diffuser jet from the mentioned end thereof to substantially its narrowest portion.

17. An ejector pump unit comprising a male jet, a source of actuating organic vapor supplied to said jet, a diffuser jet of the Venturi type into which said male jet opens, a chamber enclosing the adjacent ends of said jets, an inlet pipe for gas to be evacuated opening into said chamber in aspirating relation to adjacent ends of said jets, condensing means with which said diffuser jet communicates, and means for selectively cooling various zones along said diffuser jet by applying thereto liquids at different predetermined temperatures.

18. The method of producing vacuums to extremely low pressures in successive stages which comprises providing highly accelerated jets of vapor, generated from relatively stable organic liquids, at successive points along and in aspirating relation to the stream of gas or vapor being evacuated, the pressure of the vapor at one of said jets being in excess of two cm. of mercury and condensing said organic vapors to their liquid phases, said liquids having successively lower boiling points from the fine vacuum portion of the stream to the fore vacuum portion thereof.

19. The method of evacuating a receptacle which comprises heating to a temperature in the range of approximately 160 to 250° C., a relatively stable organic liquid having a vapor pressure at a temperature of 160 to 250° C. of about 2 to 70 cm. of mercury, to convert the stable organic liquid into its vapor phase causing said vapor to pass through an expansion

nozzle whereby it becomes accelerated to exceedingly high velocity, and entraining gases from the receptacle to be evacuated in the high velocity jet of stable organic vapor thus formed.

20. The method of evacuating a receptacle which comprises heating to a temperature in the range of approximately 160 to 250° C., a relatively stable organic liquid having a vapor pressure at a temperature in said temperature range of about 2 to 70 cm. of mercury, to convert the stable organic liquid into its vapor phase, causing said vapor to pass through an expansion nozzle whereby it becomes accelerated to a velocity exceeding the random velocity of the majority of the molecules of said vapor, and entraining gases from the receptacle to be evacuated in the high velocity jet of said stable organic vapor thus formed.

21. An ejector pump unit comprising a male jet, a source of relatively stable actuating organic vapor supplied to said jet, a diffuser jet of the Venturi type into which said male jet opens, a chamber enclosing the adjacent ends of said jets, an inlet pipe for gas to be evacuated, opening into said chamber in aspirating relation to adjacent ends of said jets, condensing means with which said diffuser jet communicates, and means for applying cooling fluid to the diffuser jet from the mentioned end thereof to substantially its narrowest portion.

22. An ejector pump unit comprising a male jet, a source of relatively stable actuating organic vapor supplied to said jet, a diffuser jet of the Venturi type into which said male jet opens, a chamber enclosing the adjacent ends of said jets, an inlet pipe for gas to be evacuated opening into said chamber in aspirating relation to adjacent ends of said jets, condensing means with which said diffuser jet communicates, and means for selectively cooling various zones along said diffuser jet by applying thereto fluids at different predetermined temperatures.

23. An ejector pump unit comprising a boiler a relatively stable organic liquid contained in said boiler to be vaporized thereby, said liquid having a vapor pressure at a temperature in the range from 160 to 250° C. of about 2 to 70 cm. of mercury, a male jet communicating with said boiler, a diffuser jet of the Venturi type into which said male jet opens, a chamber enclosing the adjacent ends of said jets, an inlet pipe for gas to be evacuated, opening into said chamber in aspirating relation to the adjacent ends of said jets, condensing means with which said diffuser jet communicates, and means for applying fluid cooling to the diffuser jet from the mentioned end thereof to substantially its narrowest portion.

24. An ejector pump unit comprising a boiler a relatively stable organic liquid contained in said boiler to be vaporized thereby, said liquid having a boiling point higher than that of water, a male jet communicating with said boiler, a diffuser jet of the Venturi type into which said male jet opens, a chamber enclosing the adjacent ends of said jets, an inlet pipe for gas to be evacuated opening into said chamber in aspirating relation to the adjacent ends of said jets, condensing means with which said diffuser jet communicates, and means for selectively cooling various zones along said diffuser jet by applying thereto fluids at different predetermined temperatures.

25. An ejector pump unit comprising a boiler a relatively stable organic liquid contained in

said boiler to be vaporized, said liquid having a vapor pressure at a temperature in the range from 160 to 250° C. of about 2 to 70 cm. of mercury, a male jet communicating with said boiler, a diffuser jet of the Venturi type into which 5 said male jet opens, a chamber enclosing the adjacent ends of said jets, condensing means

with which said diffuser jet communicates, and means for selectively cooling various zones along said diffuser jet by applying thereto fluids at different predetermined temperatures.

KENNETH C. D. HICKMAN.
GEORGE A. KUIPERS.