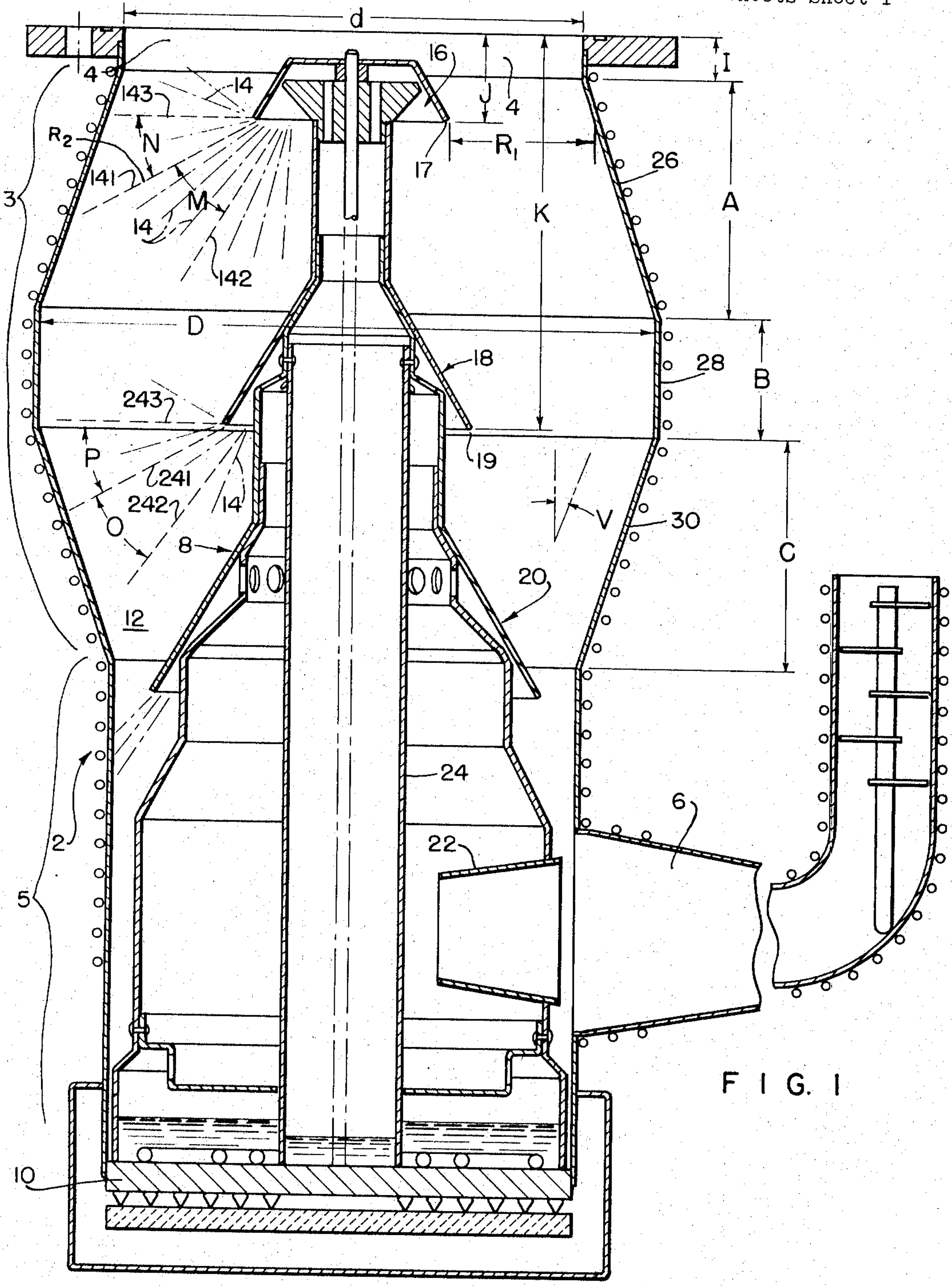
Jan. 16, 1968 A. A. LANDFORS 3,363,830

DIFFUSION PUMP

Original Filed March 11, 1965

3 Sheets-Sheet 1



F I G. 1

DIFFUSION PUMP

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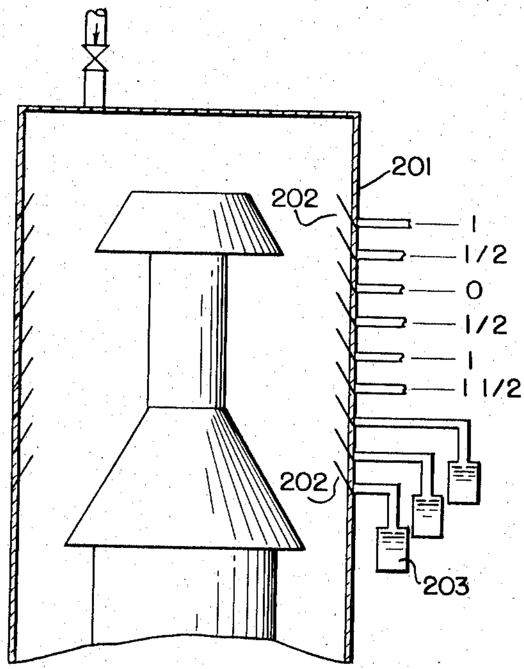

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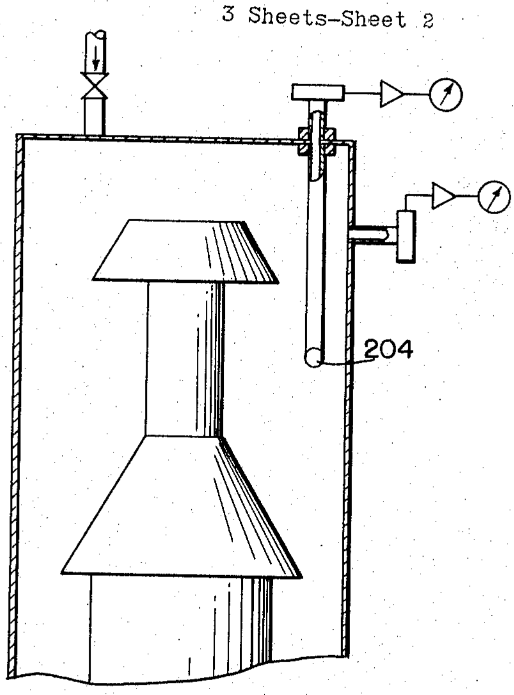

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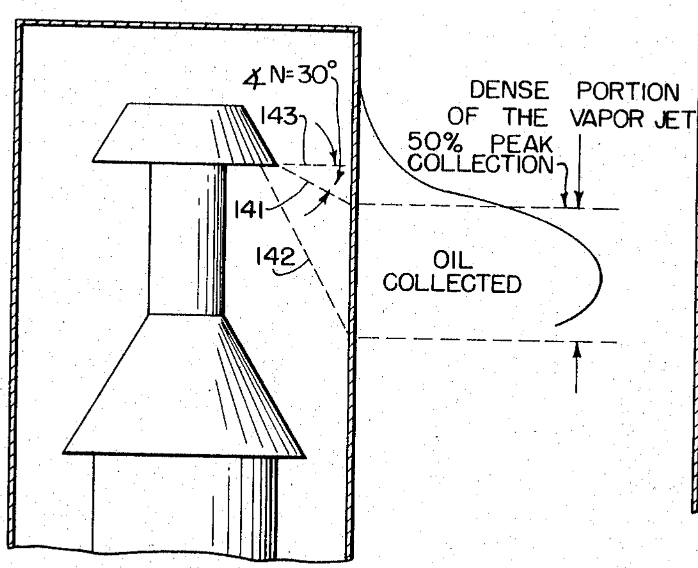

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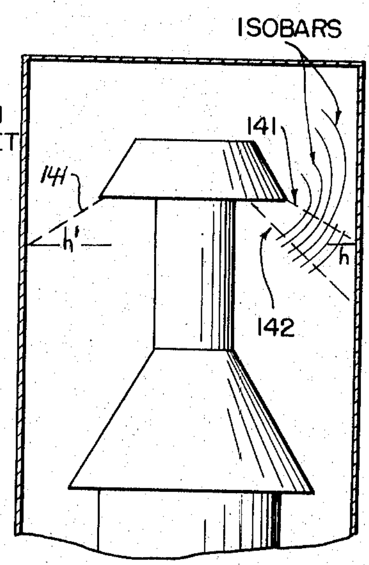

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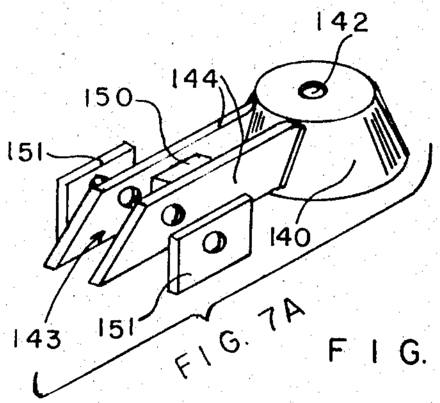

FIG. 7A

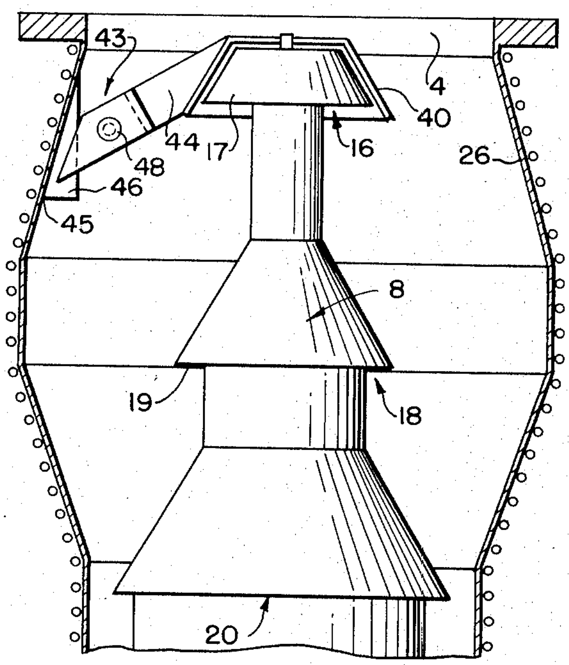

FIG. 6

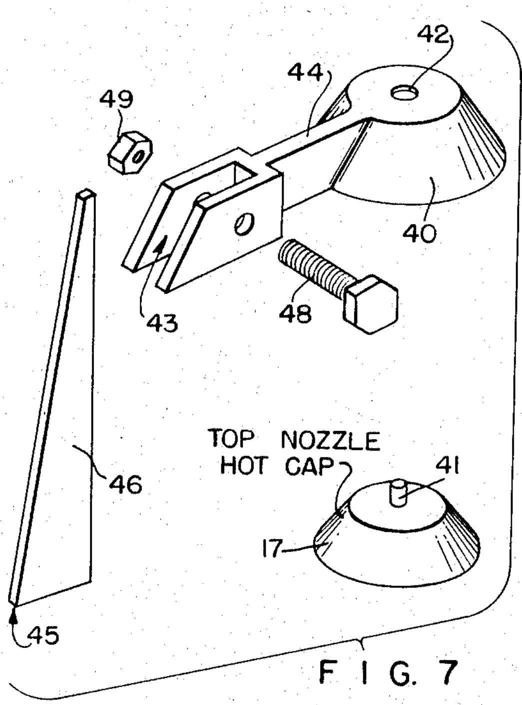

FIG. 7

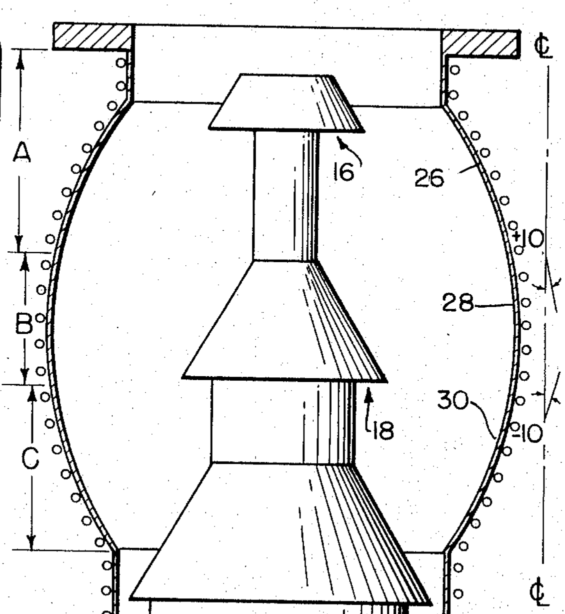

FIG. 8

3,363,830
DIFFUSION PUMP

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Continuation of application Ser. No. 439,033, Mar. 11, 1965. This application Feb. 16, 1967, Ser. No. 619,885
13 Claims. (Cl. 230—101)

ABSTRACT OF THE DISCLOSURE

A diffusion pump with an expanded casing portion surrounding the upper portion of the vapor jet assembly with the top jet from the topmost vapor jet nozzle of the assembly discharging against the expanded casing and the ratio of inlet-nozzle distance to nozzle-casing distance is less than one. This new relationship of casing and vapor jet assembly provides much greater pumping speed than prior art pumps of the same nominal inlet size.

This application is a continuation of application, Ser. No. 439,033 filed Mar. 11, 1965 and now abandoned.

The present invention relates to vapor vacuum pumps and more particularly to diffusion pumps used for producing high vacuum in many laboratory and industrial processes.

It is the principal object of the invention to provide an improved diffusion pump having increased speed compared to prior art pumps.

It is a further object of the invention to provide an improved diffusion pump having increased speed without a corresponding penalty in throughput loss, pump size increase, expense of construction, pump fluid and power usage or in the cost of mating vacuum system components.

It is a further object of the invention to provide an improved diffusion pump which readily accommodates an anti-backstreaming cold cap.

These objects are served by a novel construction of the diffusion pump casing wherein the upper part of the casing is expanded in the region thereof surrounding the upper portion of the vapor jet assembly. That is, the casing starts from a normal inlet and then expands outwardly and then downwardly and inwardly (with an intervening cylindrical portion in a preferred and distinct embodiment). The first, and preferably the first and second, uppermost vapor jet nozzles discharge their vapors into this expanded portion. Except for this casing feature and the cooperation of respective casing and nozzle heights, the casing may be of conventional design and the vapor jet assembly and boiler within the casing may be of conventional design. Yet, I have achieved speed increases higher than 25%–50% (compared to prior art pumps of the same nominal inlet size) in the operation of pumps with such expanded casings. The increase in speed is attained without increasing the size of the inlet opening beyond the limits for matching the exit of accessory components. Thus, less costly pump accesories such as small baffles or valves may be fitted over the inlet. For instance, a (nominal) 4-inch pump made according to my invention can provide almost as high a speed as a conventional 6-inch pump. Yet, the 4-inch pump can be used with a 4-inch size rather than 6-inch cold trap.

The invention accordingly comprises an improved diffusion pump having a novel arrangement of casing and vapor jet assembly, which provides an improved interaction thereof to afford higher pumping speeds without a corresponding penalty in throughput or costs of construction or use. The scope of application of the structural combination of my invention is set forth in the claims at the end of this specification.

Other objects, features, and advantages will be in part obvious and will in part appear hereinafter.

A detailed description of the invention, including my best known embodiment, is given in the following detailed specification to be read in conjunction with the accompanying drawings wherein:

FIG. 1 is a sectional view of a diffusion pump according to the preferred embodiment of the invention.

FIGS. 2–5 are schematic diagrams of experimental models used to indicate the dense portion of the jet, particularly the upper boundary of the dense portion of the jet.

FIG. 6 shows the preferred pump of FIG. 1 equipped with a cold cap.

FIG. 7 is an exploded view of the parts of FIG. 6, and

FIGURE 7*a* is an exploded view of an alternate cold cap.

FIG. 8 is a sectional view of a modified construction of the preferred embodiment.

Referring now to FIG. 1, the diffusion pump comprises a vertically arranged tubular casing **2** with an inlet **4**, and exit foreline **6**, a vapor jet asembly **8**, and a boiler **10** at the bottom of the casing for supplying pumping vapors to the interior of the vapor jet assembly. The casing has an upper expanded portion **3** and a lower cylindrical portion **5**. The vapor jet assembly **8** comprises a stepped construction from bottom to top with a series of annular jet nozzles along its length. The annular nozzles **16**, **18**, **20** emit fluid from the interior of the vapor jet assembly downwardly and into the annular pumping space **12** defined between the casing and the centrally located vapor jet assembly. The annular jet nozzles can be as described in the Patent 3,141,606 or can have a variety of forms known in the prior art, including a series of orifices around the periphery of the vapor jet assembly or an annular opening provided between two vertically spaced components. The vapor jet assembly can be built from tube spinnings or machined components. The assembly also comprises ejector nozzle **22**, and a fractionating tube **24** which conducts pump vapor from the boiler to the first uppermost jet nozzle **16**, bypassing the lower jet nozzles. The chain lines **14** indicate portions of the annular vapor jets emerging from the uppermost jet nozzle **16** and the second uppermost jet nozzle **18**. While the vapor jet emerges from the nozzles over a wide angle, the major portion or dense portion of the vapors are within the regions M and O which are shown between dashed lines **141** and **142** for nozzle **16** and between lines **241** and **242** for nozzle **18**. The regions M and O are where the compression occurs for the most part. The dashed line **141** is the upper boundary of the dense portion of the jet from nozzle **16**. The location of line **141** is defined as a vector extending from the lip of a nozzle at an angle N with respect to a horizontal plane **143** passing through the lip of the nozzle. Similarly, for nozzle **18**, line **241** is located with reference to a horizontal line **243**.

In the nozzle, **16**, shown in FIG. 1, the upper boundary of the dense portion is located at an angle N of 20–35° (and typically 30°), with respect to horizontal, throughout the pressure range of the pump. In nozzle **18**, the corresponding angle P is within the same range. The manner of determining the upper boundary (line **141**) of the dense jet portion for any given nozzle is described in the following paragraph.

Referring to FIG. 2, there is shown a test apparatus comprising a diffusion pump with a vapor jet nozzle **161**. The casing **201** is provided with gutters **202** and collection tubes **203** at 1 inch intervals along its length. The pump is operated and the amount of oil collected in the tubes is measured. Also, pressure measuring probes **204** (FIG. 4) are inserted at various locations in the annular pumping space between the vapor jet assembly and the pump casing. An oil collection curve for the pump is given in FIG. 3 and the plot of pressures and isobars obtained from pressure measurements is indicated in FIG. 5. The boundary **141** corresponds to a line drawn from the nozzle lip to the horizontal plane h where 50% of peak oil collection is achieved (FIG. 3) and also corresponds to a line drawn from the nozzle lip to the horizontal plane h' where pressure abruptly rises from a minimum valve. The planes h and h' are found to roughly coincide. The boundaries of the dense jet portion in FIG. 5 also correspond to the region where the isobars are most nearly parallel and are spaced close to each other and where downward vectors from the nozzle are perpendicular to the isobars. Neither method has a high degree of precision, but the location of the dense jet portion given thereby is adequate for the present purpose of matching the vapor jet assembly to the expanded portion of the casing. In this particular case the upper boundary **141** of the dense jet seen to have an angle N with respect to horizontal of 30°, as determined from both FIG. 3 and FIG. 5.

The width of the dense jet portion and the location of its upper boundary can vary for different nozzles. But the above procedure can be used to locate the upper boundary for any given nozzle within a few degrees precision. Once this boundary is found, the structural criteria given below can be applied to arrange the casing and vapor jet assembly with respect to each other in a manner to realize the advantages of the present invention.

Referring again to FIG. 1, it can be seen that in this embodiment of the invention the entire upper boundary **141** of the dense jet portion of nozzle **16** is vertically within the bulge portion of the casing and there is sufficient free space above boundary **141** to allow gas molecules coming through inlet **4** ready access to the dense jet. Also, the upper boundary **241** of the principal compression region of nozzle **18** is vertically within the bulged portion of the casing. Consistent with these criteria, the lips **17** and **19** of these nozzles are located vertically within the expanded portion **3** and sufficiently high that the upper dense jet boundaries **141** and **241**, associated with these nozzles, intercept the casing in the expanded portion.

Referring to FIG. 1, it will be recognized that the upper dense jet boundary **141** and the second uppermost dense jet boundary **241** form essentially conical areas exposed to gas molecules coming from above. It is preferred that the area (A_1) of the conical surface formed by boundary **141** be equal to or slightly larger than the area (A_2) of the conical surface formed by boundary **241**. The ratio of these areas (A_1/A_2) should be between 1.0 and 1.5.

It is a more general condition of the pump construction that the upper nozzle **16** is sufficiently close to the inlet **4** and that the casing is expanded in the region of the upper nozzle so that the molecules entering the inlet are efficiently captured by the dense jet from nozzle **16**. In terms of construction features, this required relationship can be expressed with reference to J which is the distance from the inlet **4** to lip **17** of nozzle **16** and R_1 which is the distance from the lip **17** to the wall of the pump in a horizontal plane or R_2 which is the distance from the lip **17** to the wall of the pump along a straight line taken at an angle of 30° to a horizontal plane, the said plane extending through lip **17** and the said line extending from lip **17** to the wall below the plane. The ratio J/R_2 is less than one and, also, the inherently larger ratio (J/R_1) is preferably less than one. This condition is to be taken together with the conditions of a pump casing expanding or flaring outwardly from the inlet region and the dense portion of the upper jet striking the expanded region. These conditions provide a situation wherein the probability of a gas molecule entering the pump is greater than the probability of a gas molecule leaving the pump and wherein the vapor jet from the upper nozzle efficiently captures the gas molecules to be pumped and increases the pumping speed.

The inlet diameter of the pump is indicated by the letter d and the maximum diameter of the bulged portion of the pump casing is indicated by the letter D. The lower portion **5** of the casing preferably has the same diameter as the inlet. Preferably, the maximum diameter D should be between 1.1 and 1.5 times the inlet diameter d and the expanded portion should occupy a vertical height at least as great as one-half the maximum diameter D and no greater than the maximum diameter D. The expanded portion **3** is located immediately under the inlet **4** (i.e., a small dimension I on the order of 1–2 inches and, in any case, less than J) and is divided into three vertical sections:

(1) An upper conical section **26** which tapers downwardly and outwardly and occupies a vertical length A along the casing,

(2) A central cylindrical section **28** which occupies a length B,

(3) A lower conical section, section **30** which tapers downwardly and inwardly and occupies a vertical length C.

The lip **17** of nozzle **16** is located within the section **26** and the section **26** is sufficiently long (dimension A) that it intercepts the upper boundary **141** of the dense jet portion from nozzle **16**. The lip **19** of nozzle **18** is located substantially at the junction of sections **28** and **30** and section **30** is sufficiently long (dimension C) that it intercepts the upper boundary **241** of the dense jet portion from nozzle **18**. Another consequence of a large dimension C is that section **30** presents a gradually inclined face to the jet from nozzle **18** rather than an essentially upwardly facing wall. The requirement for a gradual slope for the section **30** is that the section preferably have a slope angle V between 15° and 45°. It is also possible to have the section **30** extend almost to the boiler of the pump and in this condition the angle V could be less than 15°. But the forepressure tolerance of such a modified pump would not be as good as the forepressure tolerance of the preferred embodiment. Each of the dimensions A, B, C, should preferably be at least one-fifth the total vertical height of the portion **3** (i.e. A plus B plus C).

The preferred method of constructing the expanded portion **3** of the casing is by the die bulging technique described in Crane, "Plastic Working in Presses" (Wiley, New York, 3rd edition, 1961, pages 101–105). In using this technique, the junctions of the sections will have a larger radius than obtainable by spinning. Depending on the die used, the sections may be straight, as in FIG. 1, or slightly curved. As an alternative method of construction, the casing may be made of multiple spinnings which are welded or clamped (e.g. via flanges) to each other. A pair of spinnings with a single weld joint in the section **28** is one suitable form of construction. Another alternative construction is a tube **2** with the expanded portion **3** formed by spinning on a collapsible mandrel.

However, the die bulging technique is a distinctly advantageous process in terms of cost and it is a specific feature of this invention that peak speeds and throughput are obtainable by configurations within the forming capabilities of the die bulging while larger or more complex expanded portions, which must be built by costlier methods, yield diminishing returns in terms of additional speed and throughput improvement.

Example

A nominal six inch pump was made according to the preferred embodiment of the invention described herein. The conical section **26** had a vertical dimension A of 4 inches. The cylindrical section **28** had a vertical dimension B of 2 inches and the conical section **30** had a vertical dimension C of 3 inches. The inlet diameter d of the pump was 7¾ inches, as in conventional nominal "6 inch" pumps and the lower portion of the casing had a diameter of 7¾ inches. The diameter D of the section **28** was 10¼ inches. The uppermost nozzle **16** had a lip diameter of 3 inches and the lip **17** was located 1.75 inches (dimension J) from the inlet opening **4**. The second uppermost nozzle **18** had a lip diameter of 4 inches and the lip (indicated at **19**) was 4⅛ inches from the lip of nozzle **16**; i.e., 6⅜ inches from the inlet (dimension K). The lip of nozzle **20** has a 6¼ inch diameter and is located 11 inches from the inlet. The expanded portion **3** started about one inch below the inlet opening (dimension I) and ended about 10 inches below the opening.

The nozzle throats were .070 inch. The pump was charged with 400 cc. DC–704 oil, operated for 5 hours at 2200 watts and then shut down. Then the pump was operated again and displayed the following characteristic:

Inlet pressure:	Speed, l./sec.
2×10^{-3} torr	1500
1.5×10^{-3} torr	2200
1×10^{-3} torr (1 micron)	2400
9×10^{-4} torr	2450
7×10^{-4} torr	2570
5×10^{-4} torr	2550
3×10^{-4} torr	2500
1×10^{-4} torr	2570

The pump had a forepressure tolerance of .64 torr at an inlet pressure of 9×10^{-4} torr and .70 torr at an inlet pressure of 1×10^{-4} torr.

It can be seen that the pump of the above example which meets all the above-described structural conditions provides a substantial volume above the boundary **141** for capturing gas molecules. It is also significant that the downwardly facing inner surface of section **26** tends to feed gas molecules into the dense jet from nozzle **16**. That is, gas molecules striking the inner surface of surface of section **26** will have a greater tendency to be rejected from the wall in a direction normal to the wall than in any other direction. There are several construction features related to this phenomenon. The closeness of section **26** to the pump inlet, the slope of section **26** and its length (A) and relation to nozzle **16** all assure that a large number of gas molecules will strike the section **26**. These features also assure that the primary target for these molecules coming from the inner surface of section **26** will be the jet from nozzle **16**, providing a more efficient use of the jets.

A principal expression given above for the structural framework, in which this efficient use of the pumping jets is provided, is that the casing expands outwardly immediately below the inlet (a small dimension I). Another and related expression is that the upper nozzle **16** is discharging its jet into one expanded portion and that there is sufficient room for the jet to capture gas molecules in the expanded portion (dimension I smaller than dimension J). In connection with such an expanded portion, it has also been stated as a preferred relationship that the ratio (J/R_1) be less than one. The preferred three-section form of the expanded portion casing has been described above. But it will now be apparent that many other constructions of the expanded portion, meeting one or all of the above expressions, can be made to realize one or more of the advantages afforded by the present invention.

I have also found, as described above, that a wider high speed range, consistent with stability and good forepressure tolerance, is obtained by arranging the second uppermost jet nozzle **18** within the expanded portion and discharging its jet against the expanded portion. the preferred structural framework in which the two nozzles are discharging into the expanded portion is described above with respect to the ratio (A_1/A_2) and the length and shape of the expanded portion 3, particularly of section **30** of the expanded portion.

The preferred technique of forming the expanded portion 3 (dibulging) produces a seamless casing with a bulge having flat or slightly curving form and radius of curvature of about ¾ inch at the junctions of the sections. By "slightly" curving, I mean that the radius of curvature at any given location along a section of the bulge portion is larger than the expanded radius of the casing at the same location. Where the expanded portion has slightly curving walls, the beginning and end of "cylindrical" section **28** may be defined as the last points along the casing where the angle between the tangent of the casing and the vertical axis of the pump is less than plus or minus 15°. A pump with slightly curving walls along the expanded portion of the casing is shown in FIG. 8. The relationship of the nozzle heights and the expanded portion are the same as in FIG. 1.

An anti-backstreaming cold cap of conventional design may be added to the nozzle **16**. The effects on the cold cap on pump speed are about proportionally the same as when cold caps are added to prior art pumps. For instance, with a cold cap added, the pump of Example 1 has a speed of about 2400 litres/second at low inlet pressure (e.g. .1 micron). It is believed that the direction of boundary **141** is changed, but not appreciably. For purposes of this specification location of nozzle **16** means the location of lip **17** whether or not a cold cap is disposed around the nozzle. Similarly reference to the location of nozzle **18** means location of lip **19**.

It is another specific feature of the invention that it readily accommodates the cold cap. Cold caps are well known in the diffusion pump art for limiting backstreaming from jet nozzles, (see e.g. Power, U.S. Patent 2,919,-061). A cold cap consists of a ring or cap surrounding the jet nozzle and extending below the nozzle lip and having means to cool it by conductive or radiating heat transfer to a heat sink, such as the cooled pump casing **2**.

A pump according to my invention mounted with a cold cap is shown in FIG. 6. The casing **2** and vapor jet assembly **8** of FIG. 6 are the same as in FIG. 1. A cold cap **40** is mounted over the hot cap of nozzle **16** and spaced from nozzle **16**. A conduction rib **44** extends from the cold cap towards section **26** of the expanded casing portion. A bracket **46** is mounted on the casing and the conduction rib is tightly clamped against the bracket by a nut **48**.

Referring now to FIG. 7, the cold cap arrangement is shown in exploded form. The cold cap **40** and rib **44** are a single aluminum casting and the rib terminates at its outer end in a U form **43**. The thickness of the rib **44** is ¹⁄₁₆ inch and its width is one inch. The thickness allows the rib to be bent for locating its end **43** with respect to bracket **46**. Additional degrees of freedom of movement are afforded by the short length of the rib.

A nut **49** is provided for cooperation with bolt **48** to ensure that the legs of the rib end **43** press against the bracket **46** for good heat transfer under vacuum. Tightening this nut and bolt arrangement also locates the cold cap **40**. No vertical spacers are necessary between cold caps **40** and nozzle **16**. Radial spacing is provided by a ceramic cylinder **41** mounted on top of the hot cap of nozzle **16** and a hole **42** in cold cap **40**. The legs of the U-form rib end **43** straddle the bracket when the parts are assembled. The bracket is welded to the casing along the top and side edges, but not along the bottom edge **45**. Thus, the only escape path for gases is into the dense portion of the jet from nozzle **16**.

Referring again to FIG. 6, it should be noted that the cold cap parts **40, 43, 44, 48** are easily insertable and removable through the inlet **4** of the pump, The bracket **46** is completely recessed in the expanded portion of the casing so that it does not interfere with removal of the vapor jet assembly **8** through the inlet for maintenance and subsequent re-insertion. The importance of this feature is that it allows a tight clearance between the vapor jet assembly and casing. In the boiler region of the pump, this clearance is on the order of ¹⁄₃₂ of an inch. The tightness of this clearance makes a better seal for condensed oil dripping down the wall of the pump and reduces backstreaming originating in the seal at the boiler region of the pump.

Other features, known per se to the art, can be readily incorporated in the improved pump of my invention such as a foreline baffle, a quench coil in the boiler for rapidly terminating a pump cycle or a splash baffle.

An alternative form of cold cap assembly is shown in FIG. 7A. The conduction rib is subdivided into two parallel ribs **144** with a bridging spacer **150** forming the U-form rib end which may be considered as the end of either of the ribs **143**. A brass bracket is brazed to the pump casing along its entire outer surface. The ribs **144** are silver soldered to the cold cap **140**. They have sufficient flexibility to provide freedom of movement with respect to the bracket before tightening the nut and bolt. Steel blocks **151** are used with the nut and bolt to provide wide area contact between the bracket and U-form rib end. After tightening the nut and bolt the ceramic cylinder is lifted out through a hole **142** in the cold cap which is then covered over. The floating cold cap holds its position throughout pump operation without being suported from the nozzle **16**. Backstreaming rates in a six inch pump have been reduced to below .01 cc./hour using the cold cap.

Within the scope of my invention there are several permissible variations from the preferred embodiment which can be made while retaining one or more of the distinct advantages of the preferred embodiment. Some of these have been described above. It will be apparent to those skilled in the art that several other vapor jet nozzle-expanded casing combinations can be made which will be equivalent to the described embodiments. It is therefore intended that the above description and accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An improved diffusion pump comprising a vertically arranged tubular casing with an open circular inlet at its upper end and a boiler at its lower end, the casing flaring outwardly below the inlet to provide an expanded portion, said expanded portion having an upper section opening outwardly and a lower conical section opening upwardly and outwardly, a vapor jet assembly located centrally within the casing and comprising a vertical series of jet nozzles for emitting vapor jets downwardly and outwardly toward the casing, the casing and vapor jet assembly being so arranged that the uppermost jet nozzle of the assembly is vertically within the said upper expanded portion of the casing and the ratio

$$J/R_2$$

is less than one, where J is the axial distance from the inlet opening to the lip of the uppermost nozzle and R_2 is the distance from said nozzle lip to the casing, taken at an angle of 30 degrees to a horizontal plane, the diameter of the casing at both the inlet and region of the boiler being essentially the same.

2. An improved diffusion pump comprising a vertically arranged tubular casing with an open circular inlet at its upper end and a boiler at its lower end, the casing having a lower cylindrical portion and an upper expanded portion between said inlet and lower portion, a foreline extending transversely from the casing, means for cooling the casing, a vapor jet assembly located centrally within the casing and comprising a vertical series of annular jet nozzles for emitting vapor jets downwardly and outwardly towards the casing, the expanded portion of the casing having an upper conical section opening downwardly and outwardly, a central cylindrical section and a lower conical section opening upwardly, the uppermost jet nozzle being vertically within the said upper expanded portion and the uppermost jet nozzle and expanded

casing portion being constructed and arranged so that the ratio

$$J/R_2$$

is less than one where J is the distance from the inlet to the lip of the upper nozzle and R_2 is the distance from the nozzle to the casing at on angle 30 degrees to a horizontal plane.

3. The pump of claim **2** wherein the expanded portion is formed by die bulging of a portion of a cylindrical tube.

4. The pump of claim **2** wherein the maximum diameter of the expanded portion is between 1.1 and 1.5 times the casing inlet diameter and wherein the vertical height of the expanded portion is at least one-half the maximum diameter.

5. The pump of claim **4** wherein the vertical height of the expanded portion is at least one half the maximum diameter thereof and no greater than the maximum diameter thereof.

6. The pump of claim **2** wherein each of the sections occupies at least one-fifth the total height of the expanded portion.

7. The pump of claim **2** wherein the second jet nozzle is vertically located at the junction of the central and lower sections of the expanded portion so that the lower section intercepts the dense jet from the second nozzle.

8. The pump of claim **2** with a cold cap mounted over the uppermost jet nozzle and having a conduction rib extending to the pump casing and means for securing the rib to the casing.

9. The pump of claim **8** wherein the means for securing the rib comprises a contact member mounted on the upper conical section of the casing's expanded portion entirely within said expanded portion and wherein the rib has a U-form rib end for straddling the contact member, and means for pressing the legs of the U-form rib end against the contact member.

10. An improved diffusion pump comprising, in combination:

(a) a vertically arranged tubular casing with an inlet opening at its upper end and an inlet flange surrounding the opening and a boiler at its lower end, the casing having a lower casing portion at the boiler region of essentially the same cross section area as the inlet opening and an upper expanded casing portion between said inlet and lower portion, the said expanded portion of the tubular casing being expanded outwardly below the inlet flange to a maximum cross section area substantially larger than the inlet area and returning inwardly at said lower casing portion;

(b) a column form vapor jet assembly having a maximum cross section area less than the inlet area and being located centrally within the casing and comprising a vertical series of jet nozzles for emitting vapor downwardly and outwardly towards the casing;

(c) the casing and vapor jet assembly being constructed and arranged so that the uppermost jet nozzle discharges its dense vapor jet into the expanded portion of the casing with said dense vapor jet clearing the upper section of the expanded casing portion to allow a gas capture area in the upper section of the expanded portion;

(d) the casing and vapor jet assembly being constructed and arranged so that the ratio

$$J/R_2$$

is less than one where J is the axial distance from the inlet opening to the lip of the uppermost nozzle and R_2 is the distance from said nozzle lip to the casing taken at an angle of 30 degrees to a horizontal plane; and

(e) the casing and vapor jet assembly being constructed and aranged so that the second uppermost jet nozzle is located vertically within the expanded casing portion and discharges its dense vapor jet into said expanded portion.

11. The pump of claim **1** wherein the casing and vapor jet assembly are so arranged that the ratio

$$J/R_1$$

is also less than one, where J is the axial distance from the inlet opening to the lip of the uppermost nozzle and R_1 is the distance from said nozzle lip to the casing, taken in a horizontal plane.

12. The pump of claim **2** where in the uppermost jet nozzle and expanded portion are constructed and arranged so that the ratio

$$J/R_1$$

is also less than one where J is the distance from the inlet to the lip of the upper nozzle and R_1 is the distance from the nozzle to the casing in a horizontal plane.

13. The pump of claim **10** wherein the said expanded portion of the tubular casing is expanded outwardly immediately below the inlet flange and wherein the casing and vapor jet assembly are so constructed and arranged so that the ratio

$$J/R_1$$

is also less than one where J is the axial distance from the inlet opening to the lip of the uppermost nozzle R_1 is the distance from said nozzle lip to the casing taken in a horizontal plane.

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