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VACUUM DIFFUSION PUMP

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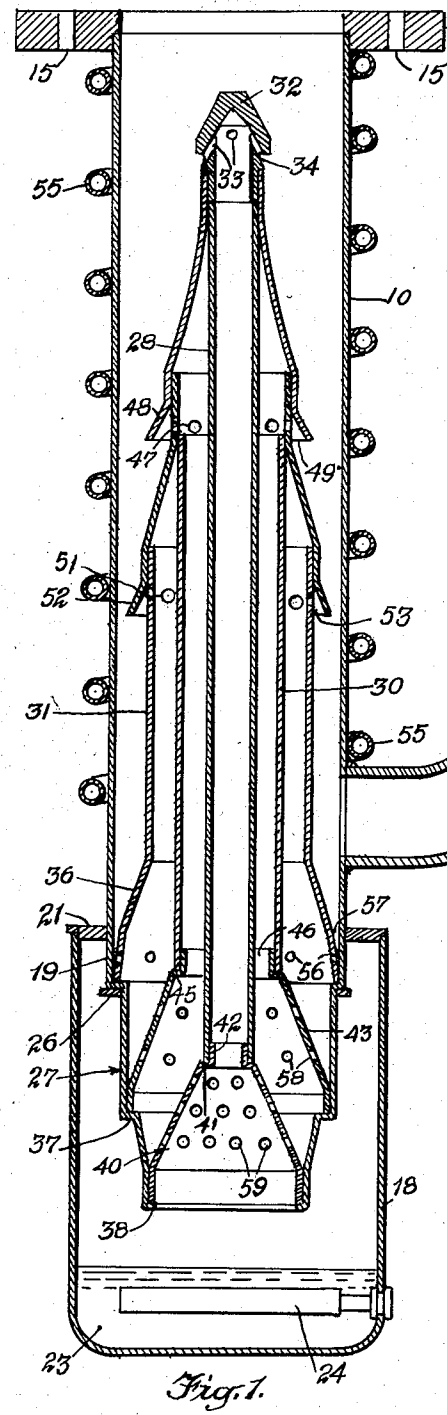


Fig. 1.

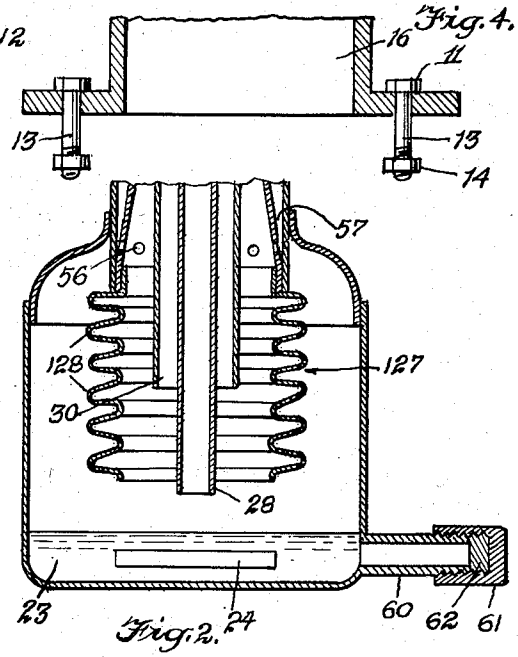


Fig. 2.

Fig. 4.

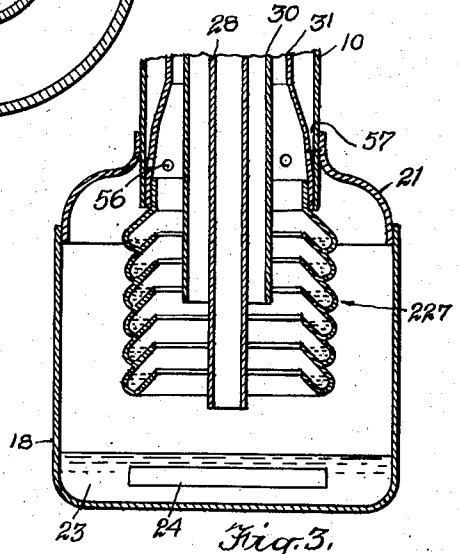


Fig. 3.

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VACUUM DIFFUSION PUMP

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5 Claims. (Cl. 230—101)

This invention is a multi-stage, vacuum diffusion pump and more particularly a vapor condensation pump that fractionates the pumping liquid and directs its least volatile fraction to the nozzle ring nearest the pump's intake end and its most volatile fraction to the nozzle ring farthest removed from that end, and at the same time provides an adequate supply of vapor to the individual jets and at effective pressure.

Due to their lower vapor pressures, the substitution of organic liquids for mercury as the pumping fluid in vapor condensation pumps made it possible to attain lower pressures and to pump gases at a much faster rate, and for most purposes simplified the problem of trapping vapors that back-stream from the pump.

Nevertheless, the use of organic liquids has several significant disadvantages; among them:

(*a*) the partial decomposition of the organic liquids by heat, as in thermal cracking, and in some cases by reaction with the gases and vapors being evacuated, introduces into these liquids contaminating products having higher vapor pressure, and with known undesirable reduction in otherwise attainable vacuum;

(*b*) this decomposition under heat often is limited to cracking the organic liquids to others of lower molecular weight and does not proceed as far as to complete thermal decomposition (which leaves behind merely carbon) with consequent elimination of the undesirable breakdown products; and

(*c*) finally while most of the random oil vapor migrating away from the intake of an oil diffusion pump is easily trapped (by condensation) at temperatures much higher than those that must be used with mercury, yet it is extremely difficult to trap every bit of oil vapor.

For many applications in producing high vacuum with oil diffusion pumps, the foregoing disadvantages have been overcome at least partially by the fractionating pump, for example, as in the multi-jet, vertical, oil diffusion pump. In it, as the oil in the bottom of the pump is heated to boiling by the heater, the resulting vapor is impelled up through the chimney and is ejected from it and down through the jets at the several elevations to condense on the inside of the cooled enclosing casing of the pump, along which it flows down to return to the boiler. The pumping action is provided by the action of the jets in compressing any gas or vapor molecules or both entrained in the jet streams and ejecting them down toward the bottom of the pump where they are sucked out through the exhaust arm by the mechanical fore pump. This jet action removes the gas molecules diffusing into the ejector vapor stream and the depletion in the vicinity of the stream causes more rapid diffusion of the gaseous molecules from the more remote zones. This results in a continuous pumping action making possible a high degree of evacuation.

Evidently, the ultimate vacuum attainable by such a pump must bear a direct relationship to the vapor pressure of the pumping fluid at the lowest temperature existing between the intake of the pump and the zones or

systems to be evacuated. Thus, any deviation from purity of the pump fluid, whether by contamination or decomposition, if it results in the presence of higher vapor pressure substances, will reduce the pump's efficiency. Such decrease in purity will not only limit the ultimate vacuum attainable, but also seriously reduce the pumping speed at the lower pressures. This latter difficulty usually is most serious at pressures below ten to the minus four millimeters of mercury.

Attempts have been made to overcome particularly the disadvantages caused by the presence of impurities in the pumping fluids, in the form of substances having higher vapor pressure than the pumping fluid, whether originating from decomposition or merely as contaminants. These attempts are best exemplified by the fractionating pump covered by U.S. Patent No. 2,112,037 to Louis Malter.

While the Malter fractionating pump and modifications of it provided advantages over the simple vertical, multi-jet pump, nevertheless several shortcomings and disadvantages were observed and experienced even with these fractionating pumps. For example:

(*a*) in them the fractionation, or division of the pumping fluid into a number of vapor streams having different vapor pressures, is achieved merely by selective boiling off from individual annular areas of a relatively deep pool of liquid at the bottom of the pump. Such a pool can vary in depth from one-half to three quarters of an inch in the small pumps, for example, one of four inches pumping chamber diameter and smaller, to two inches and even deeper in the larger pumps;

(*b*) then the partition of the boiler into several concentric annuli makes it difficult to maintain the proper pressure and adequacy of supply of vapor to the individual jets;

(*c*) when such a pump stops operating, all of the different fractions of liquid mix together in such a way that when the pump is re-started, it must be operated for a considerable period before the pumping fluid has cycled sufficiently to establish once more the optimum pumping conditions attainable with the particular pump; and

(*d*) the partitions in the Malter boiler prevent the use of any heating elements in the body of pumping liquid across the bottom of the boiler.

These and other shortcomings and disadvantages in multi-jet fractionating, diffusion pumps, for example, those exemplified by the Malter vacuum diffusion pump, are overcome by the structural and operating features of the multi-jet, fractionating, diffusion vacuum pump of the invention.

In the pump of the invention, a plurality of coaxial cylinders or tubes, spaced apart radially from one another, are enclosed within and spaced away from, and are co-axial with, the vertical pumping chamber, thus forming a series of coaxial pumping vapor conduits which together constitute the chimney. At its upper end, each of these conduits terminates in an ejector jet directed downward into the pumping zone (defined below). For most operations three of such conduits suffice. The space between the outermost of these and the inner surface of the pumping chamber is conveniently designated as the pumping zone or area. Its lower end is sometimes referred to as the condensate collection area.

The bottom of the condensate collection area (constituting the lower end of the pumping zone) is closed off from direct access to the interior of the boiler. This can be done in several ways. A convenient closure is made by bringing the lower end of the pumping cylinder and the outermost vapor conduit together, for example, by providing the lower end of that conduit with a downward and outward flare sufficient to close the interval.

Then from that closure these extends downward into the interior of the boiler a tubular, descending condensate trickler, flume or cascade to a level near that of the bottom end of the inner conduit. Several different modifications of this condensate trickler are possible, and a few of them are shown in the drawings and described below. Orifices of convenient design, distribution and sufficient total area, in the bottom of the conduit side of the condensate collection zone, allow the condensate to reach the inner surface of this tubular trickler. The height of the boiler is such that whatever form the descending condensate trickler has, the bottom end of the trickler will not reach the top surface of the boiling pool of pumping liquid but will leave a reasonable gap above it.

Accordingly, all of the descending condensate en route to return to the boiler is compelled to run down the inner surface of the tubular condensate trickler in the form of a relatively thin film. At the same time vapors rising from the surface of the boiling pool of liquid and passing the outer surface of the condensate trickler are restrained from entering the vapor conduits and reflux in that part of the boiler. As a result, the descending condensate receives heat by direct contact with vapors rising from the pool of boiling liquid on their way to the vapor conduits and also receives heat conducted through the wall of the trickler from vapors surrounding the trickler and consequently not in the flow path to the vapor conduits.

Since separation of the different vapor-pressure components of a liquid mixture can be much more easily and more effectively accomplished by evaporation from a thin film, the conditions just described approximate the ideal for the fractional distillation of the different vapor-pressure constituents of the pumping liquid. Since the most volatile constituents are distilled off first and thus abound at the highest level, the outermost or first pumping vapor conduit has its lower (or entrance) end higher than that of the other conduits, and these constituents enter it. Accordingly, it is the shortest of the conduits and its ejector jet is the lowest of the jets blowing into the pumping zone. The next volatile constituents abound at a lower level and enter the next inner or second vapor conduit whose entrance end is below that of the outermost or first conduit. The second vapor conduit has a height greater than that of the first so that the jets at the top of the second conduit are directed into the pumping chamber at a level above that of the first mentioned jets. And so on similarly with the next less volatile constituents, depending on the number of vapor conduits and corresponding jets in the pump. Then the conduit carrying the topmost jet receives the vapors rising directly from the boiling pool where the pumping liquid has been rid of its more volatile constituents.

As to its more specific details, the invention is illustrated by, but not restricted to, the embodiments discussed in the following description in relation to the accompanying drawings, wherein:

Figure 1 is a vertically transverse section diametrically through the axis of the chimney and also of the exhaust (or fore) pump arm, and omitting the usual cap or top plate that fits over, and closes off, the top of the pumping chamber and has the inlet port through which the interior of that chamber communicates with the space or body to be evacuated;

Each of Figures 2 and 3 is a similar section (replacing that portion of Figure 1 below the level of the bottom of the exhaust pump arm) through another boiler showing in each figure a respectively different modification of the structure enclosed within the vapor space of the boiler, for distributing the descending condensate in the form of a descending film exposed to fractioning interaction with the vapors rising directly from the boiling pool of pumping liquid and for indirect heat exchange with other portions of the vapors refluxing in the boiler; and

Figure 4 is the cap or top plate to be bolted on to the top of the puming chamber.

In the drawings, the pumping chamber **10** is closed at its upper end by the cap plate **11** secured vacuum tightly to the outward extending annular flange **12** by locking the series of bolts **13** and nuts **14** in the corresponding bolt holes **15**. By way of the upward extending inlet port **16**, the interior of pumping chamber **10** communicates with the space to be evacuated.

Pumping chamber **10** rises vertically above, and co-axially with, the boiler **18** and has its lower end **19** protruding part way through, and terminating below, the vacuum tightly secured closure cap **21** of the boiler **18**. Through the exhaust (or fore) arm **22**, extending outward from the lower end of chamber **10** and shortly above cap **21** of the boiler, the gases evacuated from the space being evacuated by the pump are withdrawn by the rough pump (not shown).

The lowermost part of the boiler encloses a continuous, undivided liquid-space, which sustains the pool **23** of pumping liquid. Supported, and likewise powered, from either one side (as in Fig. 1) or the bottom (as in Figs. 2 and 3), of boiler **18**, a suitable immersion heater **24** extends into, and, for best effect is completely submerged in, the pumping liquid **23**.

Around the bottom end of pump chamber **10** there is secured an annular, supporting and suspending flange **26** (Fig. 1) having a rim extending inward. From the lower end of chamber **10**, there depends co-axially with said chamber a cylindrical skirt to serve as a condensate trickler, flume or cascade, down which the return condensate trickles. Three different modifications of the condensate trickler are shown in the drawings and as a whole are designated respectively **27** (Fig. 1), **127** (Fig. 2) and **227** (Fig. 3). These are described in detail separately hereinafter.

Enclosed within pump chamber **10** and co-axial with it are three pumping vapor conduits, of which the innermost is designated as inner conduit **28**, the outermost one as vapor conduit **31**, and the intermediate one as intermediate conduit **30**. While the modifications included in the drawings have only three vapor conduits, more may be used, or even only two, depending on the particular job and performance for which the individual pump is specifically designed.

The conduit **28**, extends upward higher than the others and, capped with its conical cap **32**, reaches near to the top of pumping chamber **10**. Spaced apart around the upper end of conduit **28** are a plurality of vapor jet orifices **33** opening under and facing the underside of the downward and outward depending portion of cap **32** which ends in a diameter greater than that of conduit **28**, so that the jets **34** will pass clear of this conduit.

The outermost conduit **31** has at its lower end an outward extending flare **36** by the lower end of which it is supported from the top of condensate cascade **27**. The latter extends downward toward the pool of pumping liquid with its lower end as near as practicable to it but providing a sufficient gap above the surface of the pool not only to avoid being reached by the boiling liquid but also to compel a large part of the vapors escaping from it to rise and reflux around the outside surface of cascade **27**. The same applies to the distance to which cascades **127** and **227** extend downward.

Possibly slightly more than half way down its length, cascade **27** is reduced in diameter sufficiently to form the shoulder **37**. Then it continues downward again terminating at its lower end with inward extending flange **38**. Supported on flange **38** and in liquid tight engagement with the lowermost portion of cascade **27**, the frusto-conical fractionating bell **40** extends upward to an inward turned shoulder **41** at a height possibly half that of cascade **27** and ending in a short nipple **42** extending vertically above shoulder **41**. The lower end of chimney

28 fits in liquid tight engagement around nipple 42 and rests on shoulder 41.

A similar frusto-conical bell 43, having its lowermost portion in liquid tight engagement with the inner surface of cascade 27 just above shoulder 37, extends upward from it to an inward turned shoulder 45, at a height about equal with the lower end of flare 36, and ending in a short nipple 46 extending vertically above shoulder 45.

Outermost conduit 31 extends to a height somewhat less than half of the height of chamber 10. Intermediate conduit 30, with its lower end in liquid-tight engagement with nipple 46 and resting on shoulder 45, extends to a height somewhat less than half of the distance between the tops of chamber 10 and conduit 31. Spaced around the upper end of intermediate conduit 30 is a plurality of vapor jet orifices 47 opening under and facing the under side of the downward and outward depending skirt. The latter has at its lower end a greater diameter than that of conduit 30 and thereby provides the jet 49 ejecting downward from this conduit.

Similarly, spaced around the upper end of outer conduit 31 are vapor jet orifices 51 opening under and facing the under side of the flaring skirt 52.

A large portion of the vapors rising from the pool 23 of pumping liquid heated by the immersion heater 24 flows upward along bell 40 into inner conduit 28. Also a portion of the vapors rising from pool 23 passes through the apertures 59 in bell 40 and flows upward into and through intermediate conduit 30, and mingles with vapors that were fractionated out of the film of returning condensate descending along the inside of condensate flume 27. Finally, a portion of the vapors in bell 43 passes through the apertures 58 in it and flows upward into and through outer conduit 31 and similarly mingles with more volatile vapors fractionated out of the falling film of condensate.

The separate streams of vapors continuously flowing upward through each of the three vapor conduits are thus likewise regularly ejected through the jets 34, 49 and 53 into the pumping zone. There they entrain the molecules of the gas that diffused into the pumping zone from the system being evacuated.

Helical cooling coil 55 is wrapped in close contact around the outside of chamber 10. Cooling liquid from a convenient source (not shown) flowing through coil 55 at a suitable rate maintains the pumping chamber sufficiently cool to condense the pumping vapors ejected from the jets 34, 49 and 53.

The condensate return orifices 56 are made small enough in size and number for the condensed vapors to accumulate in the condensate collection area 57 to a height, below the bottom of the exhaust arm 22, great enough for the layer of accumulated condensate to serve as a liquid seal against the escape of vapors from conduit 31 through the orifices 56. The hot vapors from the boiling pool 23 of pumping liquid refluxing around the lower end 19 of chamber 10 transmit heat through it to this liquid seal layer of condensate in collection area 57. Thereby the condensate that regularly passes from the liquid seal through orifices 56 not only is pre-heated initially before entering these orifices but also in being so pre-heated has expelled from it the dissolved gases that were entrained by the vapors ejected from the jets.

Just as the thus de-gassed condensate returns through the orifices 56 to the fractionation system of the modification shown in Figure 1, it returns in the same way in the modification illustrated in Figures 2 and 3. In both of these the separate streams of vapor flowing through the conduits 28, 30 and 31 passed through the same series of operations as described in relation to Figure 1 before returning as condensate through the orifices 56.

In the modification shown in Figure 2, the condensate returning from orifices 56 flows down in form of a descending film over the inner surfaces of the bellows 128 of the condensate trickler or flume 127. Just as with the flume 27 of Figure 1, vapors from the boiling pool 23 of pumping liquid reflux about the outer side of the flume 127. Then similarly by indirect heat exchange these refluxing vapors transmit heat through the bellows to the condensate descending as a film on the other (or inner) side of them. Accordingly, the most volatile constituents of the condensate (i.e. those having the highest vapor pressure) are fractionated out in about the upper half of the bellows and rise into conduit 31. Then the fraction with the intermediate vapor pressure is fractionated out in the lower part of the bellows and ascends into conduit 30. Just as in the earlier description this fractionation using the heat absorbed by indirect heat exchanged from the refluxing vapors is assisted also by the direct interchange with the vapors rising from the boiling liquid and entering the zone embraced within the bellows. Then conduit 28, extending lower than the others receives practically only the rather pure, highest boiling fraction constituting for the most part the boiling pool of liquid.

The operation in relation to the modification of Figure 3 is essentially the same as for that of Figure 2. The only difference is that in place of a bellows as the condensate flume, the condensate annulus 227 consists of a vertical series of consecutively superimposed annular pockets each open on the inner side; i.e., toward the vertical axis of the annulus 227. With this series of pockets the essential difference over the operation described in relation to Figure 2 is that instead of merely fractionating the film of condensate descending from the orifice 56, a shallow bath of condensate remains in each pocket.

This condition provides an additional advantageous feature in that the condensate reaching these pockets is in its most contaminated state, because it then contains the various constituents having the higher vapor pressures (i.e. the more volatile ones). Accordingly, when the pump is stopped, these pockets will still contain the poorest parts of the pumping liquid so that they do not mingle with the main pool on the bottom of the boiler, which then contains the relatively highly purified highest boiling constituent part of the pumping liquid. Thus, when the pump is re-started, vapors of this highest boiling liquid can flow directly into the conduit 28 leading to the jet at the highest elevation. In addition, the period for any further purification will be considerably shorter.

In all of the modifications, vapor rises into all of the jet conduits from the same uninterrupted and undivided boiling pool of liquid at the bottom of the boiler. Thus, at worst there are only minor differences in pressure at the entrances to the several jets. Accordingly, it is impossible to build up undesirably large pressure differences between the jets.

The bottom of the condensate flume, as in Figure 1, or the bottom of the inner conduit, as in the modification of Figures 2 and 3, can extend to from one-half inch to one inch and more above the top surface of the pool of liquid on the bottom of the boiler.

While the uninterrupted and undivided pool of pumping liquid at the bottom of the boiler permits using the more rapid and very efficient immersion heater, some other form of heating now available, if desired, can be used in connection with the other advantageous features of the invention. Likewise, any of the available or applicable pumping fluids can be used with the pumps of the invention, such as the hydrocarbon oils, the halogenated hydrocarbons, the various dialkyl phthalates, or other esters, or the types of silicone oils used, or others.

There is no restriction to the specific proportions or relative positioning of any of the parts of the pumps that are variable in specific proportions or relative positioning. Also there is no restriction to only one jet on each pumping conduit as more than one can be used so long as the fractionation feature is retained. Then also any of the practicable jets can be used, as well as either a

plurality of single jets around a circle at the jet elevation or a single jet built in the circular form.

Likewise, other forms of practicable condensate tricklers or flumes can be used. For example, the one in Figure 1, can have included in either its upper or lower half, or both, one or more shoulders, quite similar to shoulder **37**, not for supporting other parts, but rather to increase the path, or slow down the rate, of descent of the descending condensate. Alternatively, there could be used such a shoulder in the form of a helix. Similarly, the bellows in Figure 2, or the pockets of Figure 3, could be made in the form of a helix. However, converting the superimposed pockets of Figure 3 to a helix form eliminates the added advantageous feature of serving to keep out of the main pool the poorest fractions of the pumping liquid, when the pump is shut down, as has been described.

Moreover, many changes can be made in the specific shape of any of the individual parts, or more than one can be combined in one, to simplify steps, for example, individual spinnings, to be used in constructing the pump. Some well recognized parts ordinarily used may not be shown in the drawings, for example, a plug in a lower part of the boiler to provide an aperture through which the pumping liquid can be withdrawn. However, one such form is shown in Figure 2 by the outlet **60** and its screw cap **61** and compressible inert plug **62**. Along this line, none of the drawings shows an aperture and closure in an upper part of the boiler to permit adding pumping liquid.

In general, the construction of the pump is convenient for assembly and for cleaning. Thus, as seen in the modification of Figure 1, the entire chimney and the accompanying fractionation structure can be lifted through the top as a single completely assembled unit.

Thus, while the various features of the invention have been described in detail in relation to certain specific embodiments of it, it is understood that various modifications and substitutions can be made within the bounds of the appended claims which are intended also to cover equivalents of the specific embodiments.

What is claimed is:

1. A vacuum pump of the diffusion type comprising in combination, a pumping chamber having an inlet connection and a connection for a fore-pump, and including a condensing surface along which forming condensate tends to flow by gravity; a boiler beneath said pumping chamber and partially filled with volatile liquid, so that the boiler encloses a liquid-filled space, and above the level of said liquid also a vapor-space; means for heating said liquid; flow restrictor structure affording limited direct communication between said vapor-space and said pumping chamber in which restrictor structure condensate leaving said condenser surface collects and substantially inhibits direct flow of vapor from said vapor-space to the pumping chamber, while permitting return flow of condensate; a plurality of jet units in the pumping chamber arranged to direct vapor toward the fore-pump connection and in proximity to said condensing surface, said jet units being located at different respective heights; segregated vapor-flow connections from respective intakes located in the vapor-space at different respective elevations, to corresponding jet units, in which intakes of successively greater elevation lead to jet units of successively lower heights; and a trickler structure within said vapor-space and in the path of condensate leaving said restrictor structure, for effecting active heat exchange between said condensate and vapor flowing to said intakes.

2. The combination defined in claim 1 in which the trickler structure is an annularly corrugated open ended tubular sleeve in which the annular corrugations are spaced in successive substantially horizontal planes and serve to lengthen the flow path for liquid and reduce the gradient which induces liquid flow.

3. The combination defined in claim 1 in which the trickler is an annularly corrugated open ended substantially vertical tubular sleeve, in which the corrugations have liquid retaining overflow rims.

4. In a diffusion pump, the combination of means enclosing a tubular pumping chamber having a condensing surface defined by the walls thereof, an inlet connection leading to an end of said chamber and means for connecting a fore-pump near the other end of said chamber; a vapor-pressure generating boiler containing a volatile liquid which partially fills the boiler and whose surface separates a vapor space from a liquid-filled space, the boiler being at a lower level than said pumping chamber; a chimney comprising tubes of graduated diameter, all substantially coaxial with one another and with said pumping chamber, the outermost tube being sealed at its lower end to the enclosing wall of the tubular pumping chamber, but formed with at least one liquid-flow-restrictive aperture which affords a condensate drain into said boiler, the lower ends of all said tubes being within and open to the vapor space of the boiler, the innermost tube and the intervals between successive tubes each leading to a corresponding jet unit directed into said pumping chamber toward said fore-pump connection and in proximity to said condensing surface, the innermost tube having the lowest entrance from the boiler and the highest jet unit, the outermost intertube interval having the highest entrance from the boiler and the lowest jet unit, intervening intertube intervals having respective heights spaced in progressive sequence between the heights just stated; an annular trickler structure within said vapor space, encircling the entrances to said chimney tubes and located in the path of condensate discharging from said flow restrictive drain, said trickler serving to intensify heat exchange between said condensate and vapor generated in the boiler; and means for heating liquid in the boiler.

5. A multi-stage vacuum pump comprising in combination, a pumping chamber having an inlet near one end for effecting connection to a space to be evacuated, an outlet near its other end and a condensing surface between said inlet and outlet; means for sustaining a bath of pumping liquid and enclosing a vapor space above the surface of said bath; heating means for vaporizing said bath; a chimney structure for receiving vapor driven off from said bath and delivering it into said pumping chamber in jets directed against said condensing surface, said chimney being sub-divided into a plurality of passages, which, respectively lead from a series of increasing heights above the liquid bath and respectively terminate in the jets aforesaid at a series of diminishing heights within the pumping chamber; and trickler means within said vapor space and in the path of condensate flowing from said condensing surface for receiving said condensate and passing it in heat exchange relation with vapor flowing to the inlets of the chamney passages, whereby heat exchange favors fractionation and the delivery as vapor of the least volatile fraction to the jet closest to the inlet of said pumping chamber and so on through the series.

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