HIGH VACUUM TECHNIQUE.

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The ever increasing use of high vacua in research and in the industries has given an added impetus to pump design. The Toepler mercury vacuum pump designed some fifty years ago and modified by various research workers was the most satisfactory means of producing a high vacuum until Gaede[1] in 1905 began his well known researches. These researches[2] in 1915 culminated in his mercury-vapor diffusion pump which formed (and still is) the basis of our present efficient mercury-vapor condensation pumps. Langmuir[3] in 1916 was the first to add this condensation feature by external water cooling. The speed of exhaustion and the degree of vacuum attainable were thus very much improved.

Mercury-vapor pumps require a supporting or fore-pump. The degree of exhaustion required of the fore-pump is determined by the nozzle design of the mercury-vapor pump. If a high speed of exhaustion is required then the throat or nozzle must be large. This in turn will require a fore or backing pump capable of producing a high vacuum—of the order of .01 to .001 mm. of mercury. On the other hand if the speed is secondary then a small nozzle may be employed and the pump will function on a less efficient backing pump. Mercury-vapor pumps have been designed that work satisfactorily against a backing pressure of 20 mm. of mercury.

By placing two mercury-vapor pumps in series high speeds of exhaustion may be retained even at a considerable backing pressure. When the two pumps are built as one piece and fed by the same boiler the resulting construction is spoken of as a two-stage pump. Pumps having three or even four stages are now on the market.

Following closely upon the publication of the article descriptive of the Langmuir pump, referred to above, it is interesting to note that most every laboratory possessing glass-blowing facilities undertook the construction of mercury-vapor pumps. Successful blowing was at first beset by many difficulties, how-

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[1] Phys. Zeitschr., 6, 758, 1905.
[2] Ann. d. Phys. 46, 374, 1915.
[3] Gen. Electric Rev., 19, p. 1060, 1916.

ever, with the appearance of Pyrex glass the task became comparatively easy. This activity on the part of novices in glassblowing (and veterans as well) resulted in many designs of mercury-vapor pumps—some exceedingly simple and inexpensive, others especially those having two or more stages, quite complex and costly.

Our own efforts[4] along this line began in 1917 when two designs were drawn up and their construction of common soda glass undertaken. The attempt was only partially successful. The following year Pyrex glass was employed and further glassblowing difficulties were no longer encountered. The first pump blown in this laboratory was an umbrella type having an annular nozzle. Figure 1 shows this pump as it is blown at the present time. It differs from the original as designed in 1917 only in that the branch A is now fused *through the* water-jacket (as shown in Fig. 1) instead of below it. The branch A is attached to the force-pump, and B to the vessel to be exhausted. This type of pump is exceedingly simple and quite rapid. Since the annular nozzle is large this pump requires a rather good fore-pump—one that will produce a vacuum of about .01 mm. of mercury. Its action is evident from a study of Fig. 1. The second design was an upward vertical nozzle type (no figure). This type is also still in use. It is even more simple in design and operation than the umbrella type. In it the nozzle is placed near the lower end of the water-jacket. This requires that A and B be interchanged. The condensed mercury-vapor finds its way back to the boiler by trickling down past the nozzle and on through the capillary opening which serves as a valve (shown at bottom of chimney on left side, Fig. 1). Upward vertical nozzle types of pumps are successful only when the nozzle is large and there is plenty of clearance for the return of the mercury globules.

Two other interesting and newly designed forms of pumps, that we have recently constructed, are shown in Figs. 2 and 3. These have *internal* water cooling, to distinguish them from external cooling as in Fig. 1. The nipples for making the water connections are shown. Fig. 2 is a single stage pump, while Fig. 3 is a two-stage pump.

In Fig. 2 the mercury vapor issuing from the hot mercury surface passes up along the main tube next to the outside wall

[4] Phys. Rev., II, 9, Apr. 1917; Science, Feb. 17, 1922.

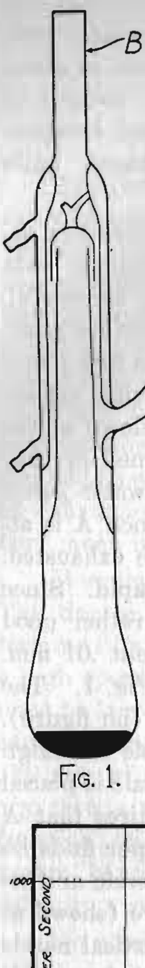

FIG. 1.

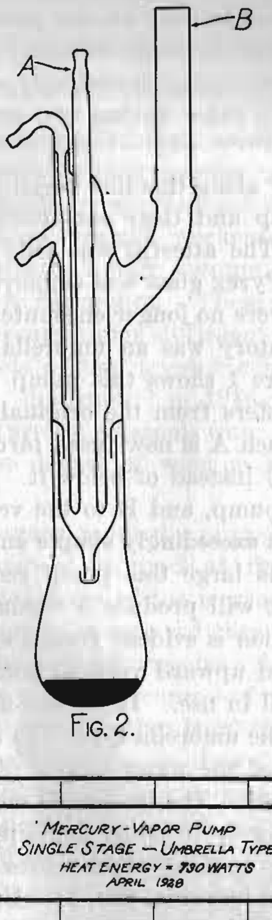

FIG. 2.

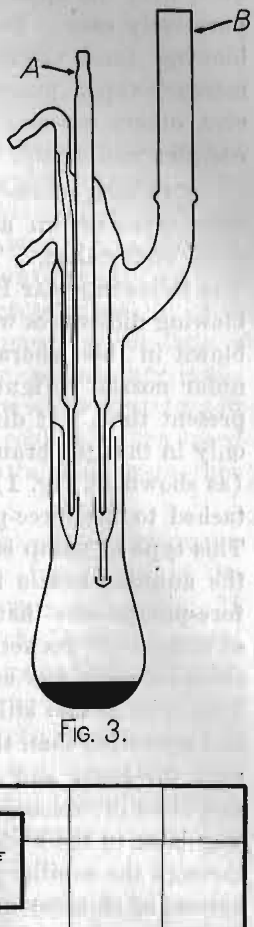

FIG. 3.

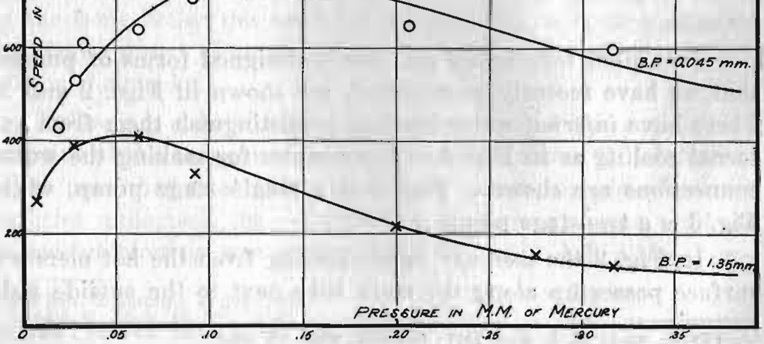

FIG. 4.

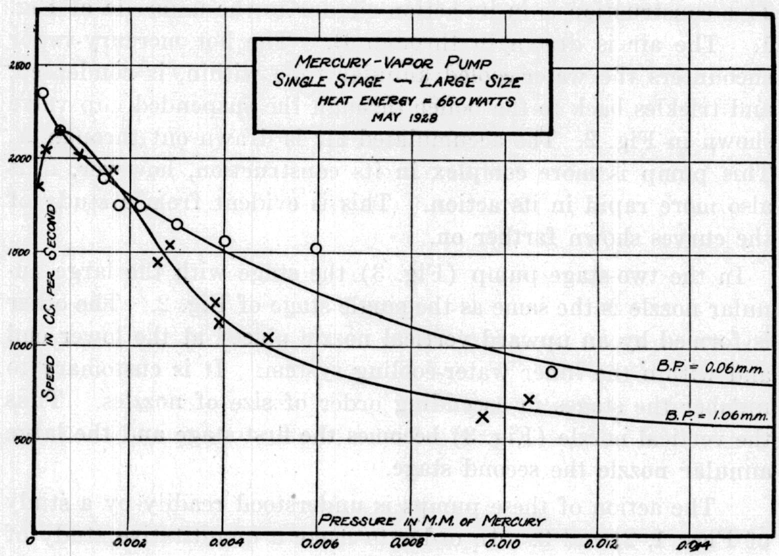
MERCURY-VAPOR PUMP
SINGLE STAGE — LARGE SIZE
HEAT ENERGY = 650 WATTS
MAY 1928
SPEED IN C.C. PER SECOND
B.P. = 0.06 m.m.
B.P. = 1.06 m.m.
PRESSURE IN M.M. OF MERCURY
2500
2000
1000
500
0
0.002
0.004
0.006
0.008
0.010
0.012
0.014

FIG. 5.

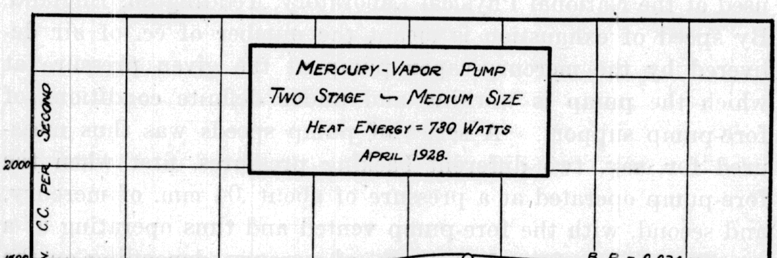
MERCURY-VAPOR PUMP
TWO STAGE — MEDIUM SIZE
HEAT ENERGY = 730 WATTS
APRIL 1928.
SPEED IN C.C. PER SECOND
B.P. = 0.034 mm.
B.P. = 3.1 mm
PRESSURE IN M.M. OF MERCURY
2000
1500
1000
500
0
.05
.1
.15
.2
.25
.3
.35

FIG. 6.

and is turned down by the collar which forms the annular nozzle. This construction is in its action similar to the umbrella of Fig. 1. The air is drawn in through B. The hot mercury-vapor encounters the water-cooled annular tube within, is condensed, and trickles back to the boiler through the suspended cup valve shown in Fig. 2. The accumulated air is drawn out through A. This pump is more complex in its construction, however, it is also more rapid in its action. This is evident from a study of the curves shown farther on.

In the two-stage pump (Fig. 3) the stage with the large annular nozzle is the same as the single stage of Fig. 2. The other is formed by an upward vertical nozzle placed at the lower end and within the inner water-cooling system. It is customary to number the stages in ascending order of size of nozzles. Thus the vertical nozzle (Fig. 3) becomes the first stage and the large annular nozzle the second stage.

The action of these pumps is understood readily by a study of Figs. 1, 2, and 3. In order to make a quantitative study of any given pump it is necessary to determine its speed of exhaustion under varying conditions of pressure and fore-pump or backing support. This was done by the mercury-pellet method[5] used at the National Physical Laboratory, Teddington, England. By speed of exhaustion is meant the number of cc. of air delivered by the mercury-vapor pump at the given pressure at which the pump is working and under definite conditions of fore-pump support. A series of pump speeds was thus measured for, say, two different backing pressures, first when the fore-pump operated at a pressure of about .04 mm. of mercury, and second, with the fore-pump vented and thus operating at a pressure of, say, from 1 to 4 mm. of mercury, depending on the nozzle construction of the particular mercury vapor pump under test. Thus for a given backing pressure of the fore-pump the needle valve is adjusted to give a minute constant leak. The mercury-vapor pump is allowed to evacuate the vessel against this leak. An observation is now made on pump speed (by the mercury-pellet method referred to above), the rate of leak is then adjusted to a new value and the speed determined again, and so on over the entire range.

Figs. 4, 5, and 6 are graphical representations of pump speeds of the pumps shown in Figs. 1, 2 and 3 respectively.

[5] High Vacua, Kaye, Longmans Green & Co., Ltd., 1927.

Measurements of speeds for a given pump were made as outlined above over a considerable range for two different backing pressures (marked BP on the graphs.) The heat energy supplied to the boiler of the pump under test was kept constant. The speeds in cc. per second are shown plotted against the corresponding pressures in mm. of mercury.

The data for the umbrella type of pump shown in Fig. 1, when graphed, are shown in Fig. 4. The upper curve is for a backing pressure (B.P.) of .045 mm. of mercury. The speed of exhaustion rose rapidly from a value of about 400 cc. per second when pumping at a constant exhaustion pressure of .005 mm. of mercury, to a maximum of nearly 800 cc. per second when pumping at a constant pressure of about .13 mm. of mercury. The lower curve shows the corresponding speeds when the backing pressure was raised to 1.3 mm. of mercury. In this case the maximum speed was 400 cc. per second, and was reached when the pump was working at a lower degree of exhaustion, i. e., at about .05 mm. of mercury.

The curves shown in Fig. 5 are for the pump sketched in Fig. 2. This is a new design evolved in the physics department, University of Illinois, and has surprising characteristics. It has internal water cooling, as previously stated. This particular pump is one of the largest that we have thus far blown. The outside diameter at the nozzle is 60 mm., the nozzle diameter 40 mm., and the area of the annular jet is 2.5 sq. cm. To reduce the air friction to a minimum the diameter of B was made 40 mm. By reference to the graphs (Fig. 5) it is evident that this pump works, at high degrees of exhaustion, at approximately equal speeds whether the backing pressure is .06 mm. or 1.06 mm. of mercury. This large range is a desirable feature, for it is no longer necessary that the fore-pump be one of high efficiency. This pump is also characterized by a high speed of exhaustion.

Finally, in Fig. 6 are shown the characteristics of the two-stage pump sketched in Fig. 3. The step in design in going from that in Fig. 2 to that in Fig. 3 is exceedingly simple. The extra stage is on the *inside* lower end of the internal water cooling system. This pump is also a new creation designed and blown in our laboratory. Two-stage pumps are primarily designed to operate on higher backing pressures. By reason of the two stages they are inherently slower in exhaustion than are single stage pumps. The two curves in Fig. 6 are self-explanatory, suffice to remark that this pump works satisfactorily on a B.P. of 3.1 mm. of mercury.

From the foregoing data it appears that for high speeds of exhaustion the design shown in Fig. 2 has promising possibilities. By increasing the size of the annular nozzle, and the other parts in proportion, a pump of exceedingly high speed should result, without exceeding the limit of any usually available fore-pumps. Pumps of extreme speed are of the utmost importance in certain researches. The two-stage pump described has possibilities of working satisfactorily on high backing pressure, approaching that of an ordinary aspirator commonly used for rough vacuum work.

The writer takes this opportunity to express his appreciation to P. C. Ludolph, graduate student in General Engineering Physics, for his skill in making the observations.