United States Patent

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[54] **HIGH EFFICIENCY FLASHING NOZZLE**
2 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **239/601**
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[50] **Field of Search** 239/601

[56] **References Cited**

UNITED STATES PATENTS

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163,586	6/1958	Sweden	239/601

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ABSTRACT: A high-efficiency flashing nozzle having a converging inlet section and a diverging outlet section. The diverging section which extends from the throat to the exit has a sufficiently rapid enlargement at or near the point where evaporation begins to prevent an excessive drop of the wall static pressure in this region.

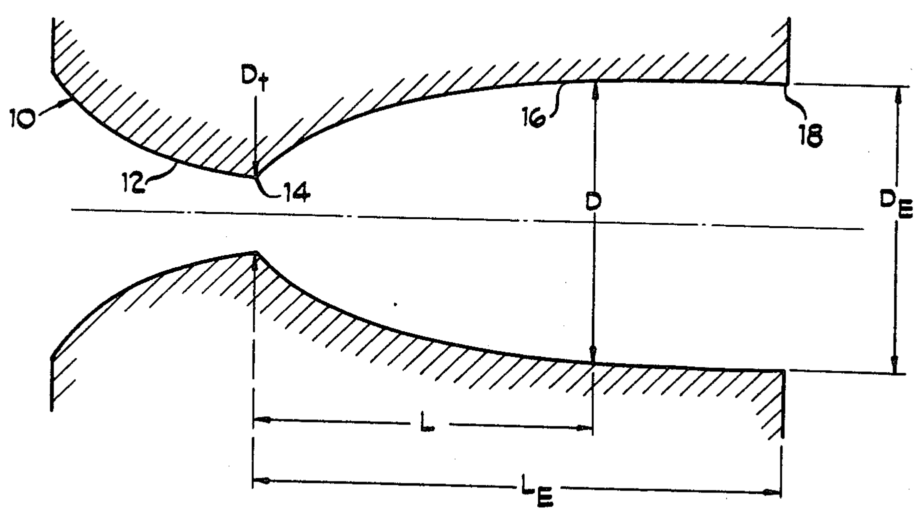

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Fig 1

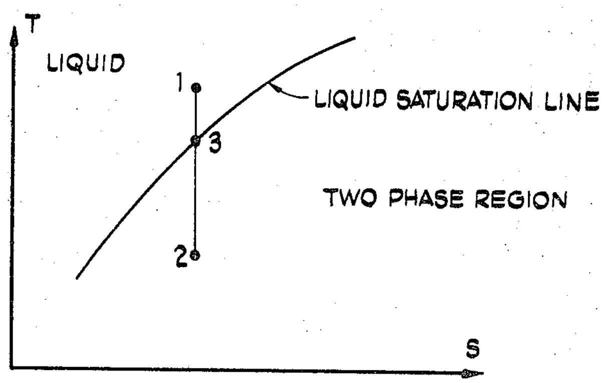


Fig 2

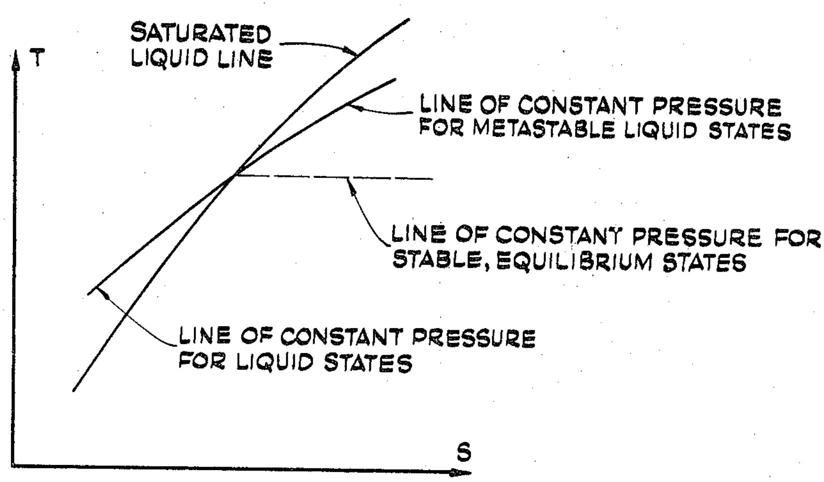
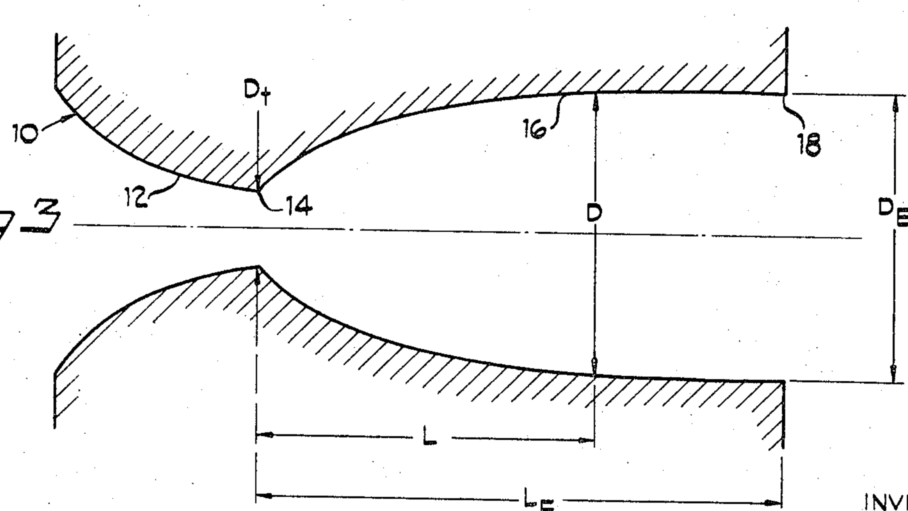


Fig 3



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HIGH EFFICIENCY FLASHING NOZZLE

BACKGROUND AND SUMMARY OF THE INVENTION

In certain flow processes, compressed liquid at a particular stagnation temperature and pressure is accelerated in a nozzle to a high velocity at a lower pressure; the pressure of the flow exiting from the nozzle is sufficiently low that the flow is a two-phase mixture of liquid and vapor.

As used herein, the term "compressed liquid" refers to a liquid, the pressure of which is in excess of the equilibrium saturation pressure corresponding to its temperature.

If such a nozzle is designed according to the best current practice and technology, the efficiency of this nozzle would be quite low, e.g. on the order of 50 percent. The subject of this invention is a novel design of a flashing nozzle which yields efficiencies up to about 85 percent.

Accordingly, it is a principal object of the invention to provide an improved nozzle, suitable for use in a multiphase ejector such as disclosed, for example, in U.S. Pat. No. 3,277,660 to Clarence A. Kemper et al. issued on Oct. 11, 1966.

Another object of the invention is to provide an improved nozzle configuration with improved efficiencies during operation with a two-phase mixture of liquid and vapor.

Additional objects and advantages will be apparent from reading the detailed description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a portion of a temperature-entropy diagram for a suitable refrigerant;

FIG. 2 shows a portion of a temperature-entropy diagram illustrating certain effects in a flow in a real nozzle; and

FIG. 3 illustrates the internal surface contour of an improved nozzle constructed in accordance with the principles of the present invention.

DESCRIPTION OF THE INVENTION

In order to appreciate fully the nature of the invention, one must understand the concept of liquid superheat. First, it is necessary to analyze the idealized process of a liquid flowing from state 1 to state 2 on the temperature-entropy diagram in FIG. 1.

The process is assumed to consist of stable, equilibrium states along an isentrope. State 1 is a stagnation state; as the flow accelerates and the pressure decreases through the nozzle, the states encountered fall on the line between state 1 and state 2. Between state 1 and state 3, the fluid is all liquid, and between state 3 and state 2 the flow has an increasing percentage of vapor by mass (increasing quality), with evaporation beginning at state 3. For this flow, it is possible to calculate the fluid properties at each pressure, and from this, one can calculate the cross-sectional area required for the nozzle at each pressure. If one specifies a desired profile of pressure versus length down the nozzle, the nozzle shape is determined for this assumed isentropic, equilibrium-flow nozzle.

In a real nozzle, the flow events occur over finite time intervals and it is not possible to have a succession of equilibrium states within the flow. During the expansion process to lower pressures, vapor is generated, heat is transferred within each phase and between the phases, and in general the flow at any one cross section is not at uniform velocity or temperature as required by the isentropic, equilibrium flow assumed above. Thus, a real nozzle will have a different profile of area versus pressure, and hence a well designed nozzle will have a different profile of area versus length.

Flow in a real nozzle differs from the assumed "ideal" isentropic equilibrium flow in a second way. When the flow occurs at finite velocities, it has been discovered that the flow does not begin to generate vapor at the saturated-liquid line depicted in FIG. 1, but rather the flow tends to persist as substantially all liquid at pressures which are below the pressure for which equilibrium evaporation occurs for that temperature. This effect is well known, and such a fluid is said to be in a metastable state. It is possible to represent approximately such a metastable state on a temperature-entropy diagram as shown in FIG. 2 by extrapolating the liquid properties into the region under the saturation dome.

The proper design of an efficient nozzle must take into account both of the effects discussed above—the existence of metastable liquid states, and the existence of nonequilibrium states in the evaporating flow with rate processes tending to drive the flow toward equilibrium states. The principal effect of the rate processes is to require relatively long nozzles so that the heat transfer and other rate processes have sufficient time for the desired interactions to occur. The principal effect of the existence of metastable states prior to flashing is that once some evaporation has occurred, there is a large temperature difference between the bulk of the liquid and the bulk of the vapor so that the initial heat-transfer rates and the initial evaporation rates are unusually large. If the nozzle area does not increase rapidly at this point also, the flow must accelerate because of the increased volumetric flow. Since the vapor has a smaller mass density than the liquid, the vapor will tend to accelerate more rapidly than the liquid. The resulting difference in velocities will cause viscous dissipation of a portion of the kinetic energy of the flow, thus lowering the efficiency of the nozzle. The presence of this undesirable difference in acceleration can be detected as a sudden drop in the static pressure of the flow (as measured at the wall) as it proceeds downstream in the nozzle.

The difference in rates can be reduced by increasing the cross-sectional area of the nozzle at the point where the pressure experiences this sudden drop in order to maintain a smooth change of pressure with length down the nozzle. For the degree of mestastability usually encountered in a flashing flow, this area increase may require an abrupt change of slope, or of radius, of the nozzle wall near the point at which evaporation begins.

Referring now to FIG. 3, there is shown a preferred nozzle design which is constructed in accordance with the principles of the present invention. Essentially, the flow passage for the nozzle is provided by any suitable means designated generally at **10** which is a flow passage constructed with a specific contour. The entrance end **11** is supplied with some fluid, which in the case of a refrigeration system is a low-boiling refrigerant such as R-12. The nozzle is divided into a first section **12** having a surface converging toward a throat **14**. The shape of the converging section may be of any conventional design and in the example illustrated is generally parabolic. A second diverging section **16** extends from the throat **14** to an exit opening **18**.

It has been found that the following criteria are essential for maximum efficiency operation of a nozzle which is used to accelerate a flow of compressed liquid into the two-phase, liquid-vapor region:

1. The nozzle is essentially axisymmetric and its axis is essentially a straight line.
2. The converging section may be any standard converging nozzle designed for single-phase flows —for example, the profile may be a circular arc, or it may have the shape of an ASME elliptical flow-nozzle.
3. The diameter of the diverging section may be specified by an equation such as the following (see FIG. 3):

$$L=L_E\frac{D^n-D_t^n}{D_E^n-D_t^n}$$

where D is the diameter at any length L downstream from the throat; where D_t is the diameter at the throat; where D_E and L_E are the diameter of, and the length to, the exit section; and where n has a value greater than unity, and is typically of the order of four or more. (The case of n infinitely large is not excluded.)

The throat and exit areas are specified in order to achieve the desired flow rate and exit pressure. It is important to note that the intersection of the converging section **12** and the diverging section **16** need not have a sharp edge at the throat

14 as shown. Ease of fabrication may require some rounding of this edge, and it has been found that some rounding of this corner is possible without affecting the flow or the nozzle efficiency. Such rounding should be kept to a minimum; however, the radius of the round may be 1/4 of the radius of the throat without affecting nozzle performance, but in no circumstance should it exceed the radius of the flow passage at the throat.

Other shapes similar to that specified by 1, 2, and 3 above will be equally satisfactory. The important aspects of this profile are:

A. Careful treatment of the liquid flow in the converging section to prevent boundary layer separation or excessive viscous losses;

B. A sufficiently rapid enlargement of the nozzle at or near the point where evaporation begins so that the wall static pressure does not fall excessively in that region;

C. A downstream section which is long enough to permit the flow to drive to states near equilibrium states, yet not so long that excessive viscous losses are incurred.

With reference to aspect B above, it is important that all points on the diverging section of the nozzle which lie within a distance downstream of the throat equal to at least five times the diameter of the throat, lie outside of a surface of revolution generated by rotating about the nozzle axis a straight line which is tangent to the nozzle surface in the region of the throat; which intersects the nozzle axis; and which intersects the nozzle surface at the exit of the nozzle. Another way of looking at this same statement is that these points lie outside of an imaginary cone which is tangent to the nozzle surface in the region of the throat and intersects the nozzle surface at the exit of the nozzle.

It should be pointed out that it is customary in the design of supersonic gas nozzles, when high efficiency is a principal aim, that nozzles are used which employ a contour similar to the one described herein. However, in the case of gas nozzles, this contouring is done to avoid oblique shock losses; whereas, in the present invention (where a liquid is supplied to the nozzle inlet), this type of contouring is used to suppress metastability losses. In using the term "liquid," this is meant to include streams which are substantially liquid, normally not exceeding 20 percent vapor, and in any event, not exceeding 50 percent vapor.

While this invention has been described in connection with a certain specific embodiment thereof, it is to be understood that this is by way of illustration and not by way of limitation.

I claim:

1. A nozzle adapted for use in an ejector comprising means defining an elongated, axisymmetric fluid passage, said fluid passage having an inlet section adapted to receive a substantially liquid stream, said section converging in the direction of fluid flow and terminating at a throat of diameter, D_T, said fluid passage having second section of length L_E diverging in the direction of fluid flow and extending from throat to an exit of diameter D_E, the contour of said second section, as established by any distance L in a direction downstream from said throat and a corresponding diameter D at length L, defined substantially by the following equation:

$$L=L_E\frac{D^n-D_t^n}{D_E^n-D_t^n}$$

where n has a value greater than unity.

2. A nozzle as defined in claim 1 wherein n is in the range of 4 to 7.