An Experimental Investigation on Expansion Devices in Refrigeration System

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AN EXPERIMENTAL INVESTIGATION ON EXPANSION DEVISES IN REFRIGERATION SYSTEM

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1. INTRODUCTION

It is well known that the expansion device is one of the four essential elements in refrigeratinn system. The device controls the flow rate of the refrigerant and the pressure difference between condenser and evaporator. By adjusting the expansion device, the working condition of the refrigeration system can be determined, therefore, different low temperature and capacity can be obtained. In modern automatic refrigeration system, expansion device plays an important role on executing part controlled by computer. In order to understand the effect of expansion device on the refrigeration system, the performance of expansion device, such as correlation of flow rate with opening, pressure difference, refrigerant quality x downstream of the device, and the inner construction of the device have to be investigated.

From fluid mechanics, the expansion devices, such as manual throttle valve and thermostatic expansion valve are variable-drag throttle elements. Under certain opening, the flow rate through the device is proportional to the square of the pressure drop, as same as in the case of orifice. When the opening changes, the flow area and drag coefficient change too, therefore the valves can be considered as a series of orifice, each of which has different diameter.

2. THEORETICAL STUDIES

At inlet of the expansion device, refrigerant is supercooled or saturated liquid, but at outlet, it becomes mixture of liquid with a little vapor, standing in the two-phase region. Previous studies have made it clear that the refrigerant going through the expansion device is a quasi-static process /2/, and the flash vapor occurs only downstream of the device, even though pressure of the refrigerant may have decreased to the saturated pressure corresponded with its temperature earlier. As a result, it is not easy to calculate the performance of expansion device in refrigeration system. It is different not only from the case of pure liquid, but also from the case of normal two-phase flow.

To simplify the analyses, orifice has been used as a model to simulate a certain working condition of expansion device. Fig. 1 is a scheme of fluid going through the orifice, c-c is the minimum section of the flux. It can be divided into two portions: In first portion, the flux section becomes smaller gradually, from 1-1 to c-c; in second, the section becomes larger gradually, from c-c to 2-2.

Two kinds of flow going through the orifice are discussed to bring to light the characteristics of refrigerant expansion devices. One is NO FLASH vapor case --- always liquid, another, FLASH vapor case --- becoming two-phase after expansion, which will be studied here in detail.

(1) No Flash Vapor

In the flowing process from 1-1 to c-c in Fig. 1, almost all pressure energy is converted into kinetic energy, with very small vortex dissipation. During this process, pressure of the fluid decreases, but speed increases. At c-c, pressure reaches minimum, but the pressure is still higher than the saturated pressure corresponding with its temperature, that is, the liquid is in supercooling state, After passing c-c, the speed of the liquid decreases gradually and pressure recovers. But the enlargement of the flux section along the flowing channal results in many vortex, which causes some velocity energy to change into heat. In the whole process from 1-1 to 2-2, the temperature of the liquid almost unchanges since the isenthalpic decompression process of liquid is approximately isothermal process. Only if when it entering two-phase region, the temperature of refrigerant will decrease greatly by isenthalpic decompression.

(2) Flash Vapor Occurs

The flowing pattern of the liquid from 1-1 to c-c is similar to that in (1). But, at c-c, the liquid pressure is below the saturated pressure corresponded with its temperature, i.e. , the liquid is in superheat state. This state is quasi-static, because of disturbing of vortex, flash vapor occurs immediately and the liquid enters two-phase region. Actually, the process is an irreversible heat transfer process under certain temperature difference. Therfore, entropy of refrigerant increases. Evaporation of some liquid causes temperature of the mixture to decrease. In this case, the pressure recovery from c-c to 2-2 is less than that in (1).

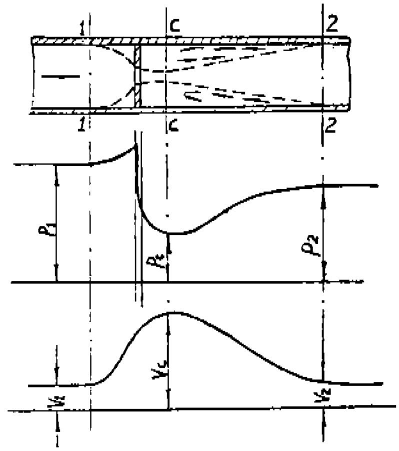


Fig. 1 Flowing through orifice

As metioned above, it can be seen that whether or not the flash vapor exists downstream of the orifice, $\Delta P_{1-c} = P_1 - P_c$ does not change so long as the mass flow does not change. So, if post-expansion pressure could be measured at c-c, the flash vapor would not have any influence on the measurement, but the location of the c-c section changes with different flow rate, while in real experiment, the measuring point is exactly stationary and always located after c-c section. Since the pressure recovery, the measured pressure P_2 in the flash case is lower than that in the no flash case $P_{2'}$, that is, if the measured pressure differences are same in the two cases, the mass flow in the former is smaller than in the latter. Here, a expansion coefficient ε is introduced into conventional mass flow equation, so that the mass flow passing the expansion device can be exactly calculated. For no flash case, the mass flow equation is:

$$M = \alpha A_o \sqrt{2g\rho\,[P_1 - P_c - (P_{2'} - P_c)]} \qquad (1)$$

where, ρ is refrigerant density before expansion and g, the gravity factor.

After introducing expansion coefficient ε , the mass flow equation in the flash case would be expressed as follows:

$$M = \alpha A_o \varepsilon \sqrt{2g\rho\,[P_1 - P_c - (P_2 - P_c)]} \qquad (2)$$

Suppose the mass flow are same in the two cases, correlating eq.(1) with eq.(2), then

$$\varepsilon = \frac{\sqrt{P_1 - P_c - (P_{2'} - P_c)}}{\sqrt{P_1 - P_c - (P_2 - P_c)}} \qquad (3)$$

Since it is difficult to analyse the pressure recovery in flash case by theoretical method, here, an experimental measure has been accepted to get the value of ε in indirect way.

3. EXPERIMENTS

Testing samples are three orifices (D=1.215, 1.156, and 0.849 mm) and two manual needle throttle valves (D = 5, 9 mm). Experiments were conducted on a refrigeration system testing installation (Fig. 2), in which the mass flow of the refrigerant was measured by calorimeter method, with condenser side confirming. Refrigerant R12 was circulated by a variable-speed compressor. In the experiments, the range of parameters were: $x = 0.037-0.185$, $m = 0.0044-0.36$, $m \cdot \alpha = 0.003-0.013$, $\Delta P/P_1 = (P_1 - P_2)/P_1 = 0.33-0.74$.

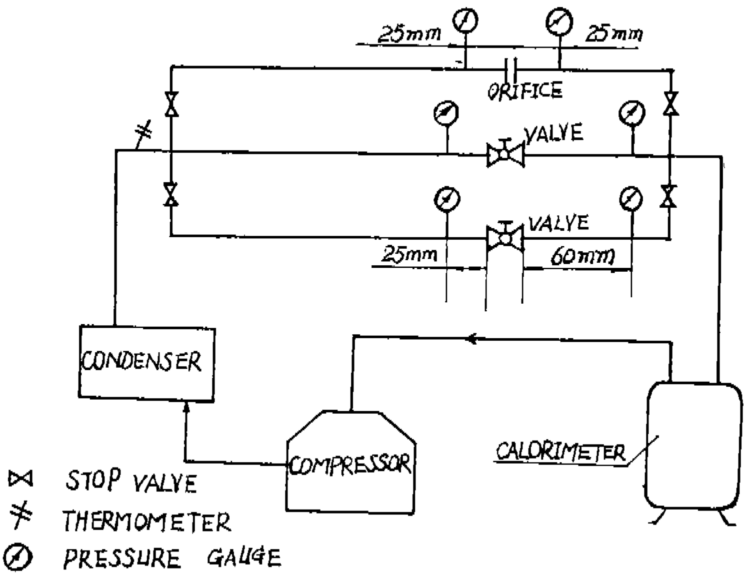


Fig. 2 Testing installation

From eq. (2)

$$\xi = \frac{M}{A_o \alpha \sqrt{2g\rho \Delta P}} \qquad (4)$$

M in eq.(4), mass flow of refrigerant, is calculated by measured data in the experiments and the discharge coefficient α of each sample was determined by hydraulic tests before the experiments. For orifices, the throttle area $A_o = \pi D^2/4$. For the valves, the throttle area

$$A_o = \frac{\pi}{4}\left[D^2 - 4\tan^2\beta(b-h)^2\right]$$

where,

$b = D/(2\tan\beta)$; D is the diameter of flow area; h, the needle lift of valves; and β, the semi-conical angle of the needle.

4. RESULTS ANALYSES

From experimental results, it can be found out that for a certain throttle area, ξ is only related to x, but if m, the ratio of throttle area to the inlet pipe section area, is changed, ξ is changed too. Changes of ξ with m and x are expressed in Fig. 3 and Fig. 4. The figures show that:

(1) For a certain expansion device, ξ decreases with the increase of x when m equals constant. The reason is that the bigger the x, the bigger the difference of pressure recovery between flash and no flash cases, causing ξ

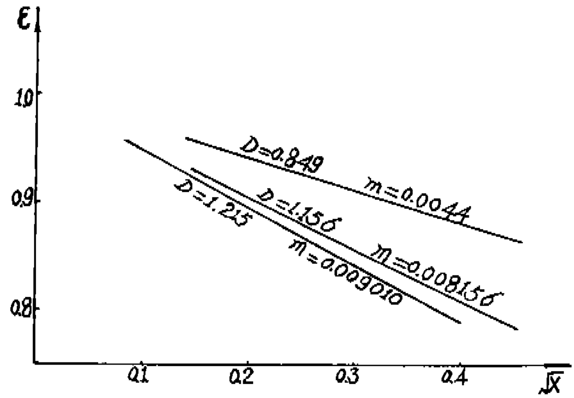


Fig. 3 ε-x for orifice

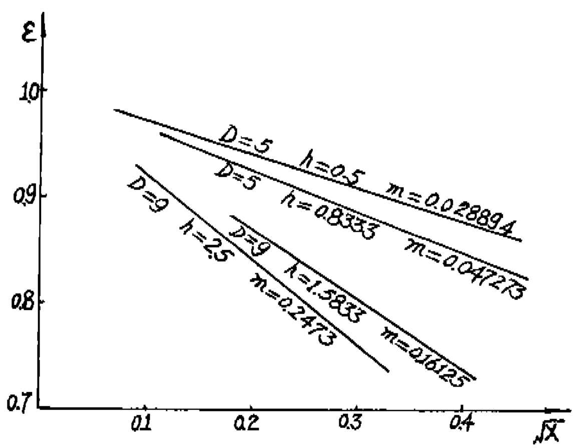


Fig. 4 ε-x for valves

to decrease.

(2) When x constant, ε decreases with the increase of m. This is because when m increases, if M unchanging, then the pressure difference P_{1-c} decreases, so that the proportion of pressure recovery in the total pressure difference increases, thereof ε decreases. If P_{1-c} unchanging, the increase of M would bring about more irreversible flash and therefore more available energy loss, which results in the decrease of ε.

(3) The changing rate of ε with x increases when m increases.

After the 244 experiment points have been processed by computer with multivariate linear regression method, the correlation formulas can be developed as follows:

$$\varepsilon = 1 - 20.65\, x^{0.5}\, m^{0.78} \qquad (5)$$

$$\varepsilon = 1 - 1.47\, x^{0.5}\, m^{0.44} \qquad (6)$$

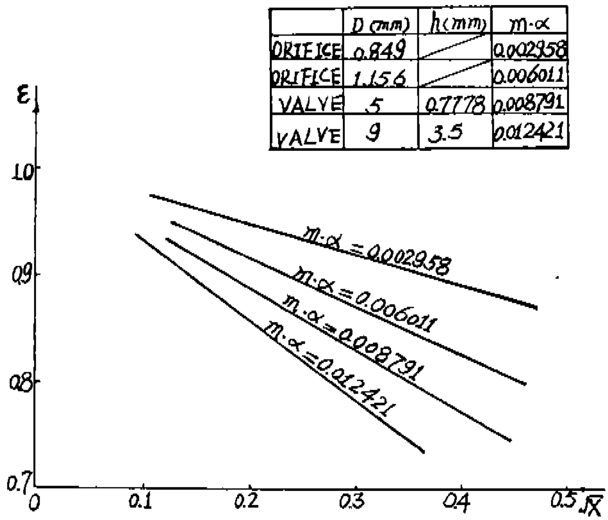
eq.(5) and eq.(6) are available to orifices and needle valves respectively.

Calculated ε according to eq.(5) and eq.(6) are plotted on Fig. 3 and Fig. 4. The difference between the analyses and experiments is within 10%.

In addition, Fig. 3 and Fig. 4 demonstrate that although there is great difference between orifices' m and valves' m, the values of measured ε have little difference. By means of mathematical analysis, a new parameter, $m{\cdot}\alpha$, the ratio of effective flow area of expansion device to the inlet pipe section area, can be drawn out, with which the expansion coefficient of orifices and valves can be expressed by same formula as follows:

$$\varepsilon = 1 - 14.4\, x^{0.5}\, (m{\cdot}\alpha)^{0.68} \tag{7}$$

Fig. 5 shows the calculated ε-x curves by eq.(7), with $m{\cdot}\alpha$ as a parameter. The consistency of analyses and experiments is satisfactory. The formula is expected to predict the performance of expansion devices.



	D (mm)	h (mm)	m·α
ORIFICE	0.849		0.002958
ORIFICE	1.156		0.006011
VALVE	5	0.7778	0.008791
VALVE	9	3.5	0.012421

Fig. 5 $m{\cdot}\alpha$ as a parameter

5. CONCLUSIONS

The main characteristics of expansion device in refrigeration system is that the device makes some of refrigerant flash into vapor after decrease of its pressure. With a lot of experiments and theoretical analyses, a new concept, expansion coefficient ε, has been introduced into the mass flow equation of pure liquid, and some semi-emperical relationship of ε with x and m have been developed, so that the mass flow through expansion device in refrigeration system can be calculated exactly. Furthermore, by using parameter $m{\cdot}\alpha$, the correlationship among various expansion devices have been built and expressed by a single formula.

It is hoped that this preliminary investigation be helpful to studies of expansion devices and refrigeration system.

REFERENCES

1. Benjamin, M.W. and Miller, J.G. : The flow of saturated water through throttling orifices. ASME Trans. 1941, 63(5) pp419-429.

2. Pasqua, P.F. : Metastable flow of freon 12. Refrigerating Eng. Oct. 1953 pp1084-1088, 1131.

SUMMARY

AN EXPERIMENTAL INVESTIGATION ON EXPANSION DEVICES IN REFRIGERATION SYSTEM

A preliminary investigation on performance of expansion devices in refrigeration system has been made both theoretically and experimentally. By introducing a new parameter, expansion coefficient ε, into the conventional equation for pure liquid, the mass flow of expansion devices can be calculated exactly, meanwhile, the correlation of mass flow with pressures, opening, quality and the construction of the expansion devices has been analysed. Through a lot of experiments and further studies on orifices and valves, $m \cdot \alpha$ has been used as a parameter, with which the calculation on various expansion devices, such as orifices and throttle valves can be conducted in a same formula. The consistency of studies with experiments proves satisfactory. It is expected that the results be helpful to studies on expansion devices and refrigeration system.

ENQUÊTE EXPÉRIMENTALE SUR LES DISPOSITIFS DE DILATATION DANS LE SYSTÈME DE RÉFRIGÉRATION

Une enquête préliminaire sur les dispositifs de dilatation dans le système de réfrigération a été faite à la fois de façon théorique et expérimentale. En introduisant un nouveau paramètre, le coefficient de dilatation Σ dans l' équation classique du liquide pur, le volume des dispositifs de dilatation peut être calculé avec précision; dans un même temps, la relation du volume avec les pressions, l' ouverture, la qualité et la construction des dispositifs de dilatation a été analysée. Par le biais de nombreuses expériences et d'études ultérieures sur les orifices et les valves, $m.\alpha$ a été utilisé comme paramètre; paramètre avec lequel le calcul peut être mené de la même manière sur divers dispositifs de dilatation tels que les orifices et les soupapes d' étranglement. Le bien-fondé des études appuyées sur des expériences se révèle satisfaisant. on s'attend à ce que les résultats contribuent aux études sur les dispositifs de dilatation et les systèmes de réfrigération.