THEORETICAL STUDY OF FLASH GAS FORMATION IN VAPOR COMPRESSION REFRIGERATION SYSTEM UNDER SUB-COOLING

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ABSTRACT

The presence of flash gas in various amounts in vapor refrigeration system gives different capacities and efficiencies in like systems. Vapor refrigeration systems need a restriction between the condenser and the evaporator or else the system would not work. This restriction gives rise to flash gas which eventually influenced the amount of liquid refrigerant into the evaporator. The more of this gas into the evaporator, the more the amount by which the capacity and efficiency of the system reduced. The effect of flash gas can be controlled under the classification of either sub-cooling or by-pass process in which the system capacity is improved.

For better refrigerants in terms of low flash gas formation and high refrigerating capacity for vapor refrigeration systems, comparison was conducted between organic refrigerants of single and blend types, and inorganic refrigerant available. This was computed and determined using a refrigeration cycle of standard working conditions of 37°c condensation temperature and -5°c evaporation temperature and at 7K and 17K different degree of sub-cooling. It is being shown that under sub-cooling condition, the blend refrigerants have highest refrigerating effect and relatively low tendency of gas formation compared to the single form and the inorganic form of refrigerants.

Key-words: *Refrigeration, Refrigerants, Sub-cooling, vapor compression system, and refrigerating effect.*

1.0 INTRODUCTION

Refrigeration is a continuous cycle process of maintaining or removing heat from an enclosed space or from a substance at low temperature and depositing it to a place where it is unobjectionable at high temperature (Dossat, 2004, Osore, 2000, Rajput, 2003).

In vapor refrigeration systems, high temperature liquid refrigerant enters the expansion device (throttling valve or refrigerant control); while homogeneous mixture of liquid and vapor infiltrated into the evaporator from expansion device. The more of the vapor introduced into the evaporator, the less the refrigerating effect and the less the efficiency of the refrigeration system. The formation of flash gas happens inside the expansion device, in order to achieve the low temperature/pressure operating liquid refrigerant at the evaporator. Haresh, 2008, defined expansion device as a small orifice through which liquid refrigerant passes to reduce its pressure suddenly due to friction. This device meters liquid refrigerant from liquid line into the evaporator at evaporating temperature, and also maintains a pressure differential between the high and the low pressure sides of the system for refrigerant to vaporize at desired low pressure in the evaporator. It then condenses at high pressure inside the condenser simultaneously (Dossat, 2004, Osore, 2000). The rate of refrigerant flows through the expansion device depends on the size and opening of the orifice and also on the pressure difference between the evaporator and the condenser.

There are different types of expansion devices with each incorporating throttling valve except the fixed bore. The common types of throttle valve expansion device are: Thermostatic Expansion Valve which monitors the superheat in the evaporator using a thermal sensing element; Automatic Expansion Valve which maintains a constant pressure (but not superheat) in the evaporator using a pressure sensing element; Fixed Bore (Capillary tube) which has no moving parts and is not controlled by either superheat or pressure in the system but performs expansion due to internal work.

Expansion process takes place in the expansion device and it is the fourth process necessary for the compression refrigeration cycle to function. The process is is enthalpic, ($h_{IN} = h_{OUT}$).

The aim of this work is to study and to state the effects of flash gas in vapor compression refrigeration system; and to differentiate it from other forms of gas form in the system. The objective of this work is to analyze the means by which the flash gas can be controlled in order to improve the refrigerating effect and efficiency of vapor compression refrigeration systems as well as to identify the kind of refrigerant with low tendency of flash gas formation when subjected to sub-cooling.

2.0 LITERATURE REVIEW

2.1 Effects of Flash Gas in Refrigeration System

Refrigerant control device supplies the

evaporator with homogeneously mixed liquid refrigerant and flash gas. Flash gas is a refrigerant already in vapor form and which is unable to absorb heat compared to liquid which is of high tendency of heat absorption. The presence of flash gas in refrigeration system influences the system in the following ways: it reduces the amount of liquid refrigerant supplied into the evaporator by the refrigerant control, since the gas already occupies certain volume of total liquid supplied into the evaporator. The gas does not perform any tangible cooling at the evaporator because it is already in vapor form. As a result of this, it is often referred to as useless gas in the system. The gas increases the work of compression, since it is compressed together with the vaporized refrigerant. Therefore, the coefficient of performance of system is reduced drastically by the presence of flash gas.

Coefficient of performance is defined as the ratio of the refrigerating effect to the work of compression C.O.P =

(Dossat, 2004, Osore, 2000, Rajput, 2003) which is affected by flash gas due to the reasons given above. (Dossat, 2004 etc)

2.2 Control of Flash Gas

There are different sources of gas in refrigeration systems, any gas formation in refrigeration systems apart from the one at expansion device are classified as abnormal refrigeration gas, and examples are gas formed at liquid line, Bubbles in a sight glass, partially blocked drier, excessive long and small diameter pipe runs. The efficiency of refrigeration system can be 100 percent improved if the flash gas can be removed totally. The flash gas cannot be eliminated completely but can only be reduced in amount since throttling process, which is the fourth process in refrigeration system, is achieved by friction. In order to reduce the net loss of refrigeration capacity of a system due to flash gas, the flash gas effect is controlled either by sub-coolingor by by-pass process (Brijesh and Lalit, 2013, Bhoge and Patil, 2014). Sub-cooling process reduces the gas formation at expansion device by lowering the saturation condensation temperature of liquid before expansion process; and this can be achieved by devices such as Sub-cooler and Heat exchanger. By-pass process is to boycott the passage of flash gas through the evaporator; this separates the gas/vapor form from liquid refrigerant from entering the evaporator, since it will only increase superheating. This type of control can be achieved using devices such as Cascade condenser, Flooded (type) evaporator and Flash tank (Clito, 2017. Svenning, 2011). Therefore, to increase liquid refrigerant at the evaporator which leads to increase in refrigerating effect and efficiency of the system, any or combination of these devices can be employed

2.3 Refrigerants and Flash Gas Formation

The flash gas formation varies with type of refrigerants. Each refrigerant has different properties and any refrigerant chosen for a particular purpose must possess properties that must satisfy the conditions and requirements of that purpose. According to Rajput, 2003, refrigerants possess certain properties under the following categories: chemical, physical, thermodynamic and general properties. The boiling and condensation temperatures together with viscosity, cohesion and momentum transfer among the refrigerant molecules influence its flash gas formation (Hanfel and Pega, 2012). The table below shows samples of common refrigerants with possibility of refrigerating effect and vapor quantities obtained from each refrigerant when used in a refrigeration cycle of standard working conditions of 37^{o}c condensation temperature and -5^{o}c evaporation temperature (Gutkowski, 1976); and at 7^{o}c and 17^{o}c different degree of sub-cooling. The computations of values were made using entropy and enthalpy formulae.

3.0 METHODOLOGY

Five refrigerants including organic and inorganic refrigerants are used for the experimental purpose to know which refrigerant absorbs more heat energy at the evaporator and produces less gas at the expansion device per kilogram of refrigerant. The organic refrigerants include single and the blend forms refrigerants. The single form refrigerants used are the R134a (Tetrafluoroethane with Boiling point (BP) of -26.3^{o}c) and R290 (propane, boiling point of -42^{o}c). The blend forms of refrigerant used are the R410 (50% Difluoromethane; R32, 50% Pentafluoroethane R125. BP = -48.5^{o}c); and R407c (Difluoromethane R32; Pentafluoroethane R125 and Tetrafluoroethane R134a. BP = -43.6^{o}c). The inorganic refrigerant for the experiment is ammonia with boiling point of -33.34^{o}c.

The refrigerants are used separately in standard working conditions refrigeration system with Compressor capacity of 125W and operating design between 37^{o}c Condensation temperature and -5^{o}c Evaporation temperature and also provided with up to 17^{o}c degree of sub-cooling by Sub-cooler. From T-s and P-h cycle diagrams in figures 1 and 2, the analysis of refrigeration cycles for refrigerants was carried out based on available information.

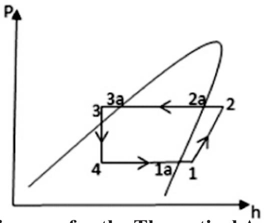

Fig. 1. T-s Diagram for the Theoretical Analysis

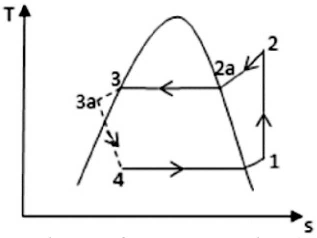

Fig. 2. P-h Diagram for the Theoretical Analysis

The computation results of gas formation at expansion device were obtained from the refrigerants using entropy and enthalpy formula, that is

$$S = Sf + XgSfg........1$$

$$h = hf = Xghfg........2$$

The refrigerating effect at the evaporator is determined for isothermal (isobaric) evaporation process, using the steady flow energy equation (SFEE). From figure 2, that is

$ql = h1 - h4$

(Heat absorbed in the evaporation or refrigerating effect).

4.0 RESULT AND DISCUSSION

Table 1, Refrigeration Effect and Quantity of Flash Gas at different temperatures

REFRIGERANTS & TYPES	Refrigerating effect (ql) in KJ/Kg and Quantity of Flash Gas (Fg) in % @ Condensation temp. and at different degree of sub-cooling in ^oC							
	Theoretical Condensation Temp.		Degree of Sub-Cooling in ^oC				Percentage	
	@ 37^oC		7^oC		17^oC		%	
	ql	Fg	ql	Fg	ql	Fg	ql	Fg
R134a Single	170	27.5	177.5	23.7	192.5	17.0	11.7	38.2
R410a Blend	167	30.0	180.0	24.3	199.8	17.0	16.4	43.3
R407c Blend	144	34.0	161.0	28.0	178.0	19.5	19.1	42.7
R290 Single	250	29.0	271.0	24.0	296.0	16.0	15.5	44.8
R717 inorganic	1061	16.3	1107.5	12.5	1153.7	8.7	8.0	46.4

- Theoretical condensation temperature is the assumed condensation temperature for all the experimental refrigerants and it is taken at 37^oC

Five refrigerants involving organic refrigerants in form of single and blend refrigerants and inorganic refrigerant were considered for computation to know the level of flash gas formation during the condensation process. From the result on Table 1, it shows that the total heat absorbed and the amount of gas form by one kilogram of refrigerant at the giving working condition, from condensation temperature to the second degree of sub-cooling are increasing and decreasing. At the theoretical condensation temperature and at each other given condition, ammonia has the greatest refrigerating effect with least gas formation, followed by single and blend forms of organic refrigerants. This shows that for any given condition of refrigerant, ammonia inorganic refrigerants will displace more heat at less gas formation than others. The rate of energy absorbed and the gas formed varied from each refrigerant as shown in Table 1 despite the gas formation and system performances depending on the orifice diameter of the expansion device. The rate of gas form depends on the condensation temperature and pressure and on the refrigerant viscosity and cohesion. Refrigerant 134a used in refrigeration system and sub-cooled by 17^oC has refrigerating effect increased approximately by 12% and the gas formation decreased approximately by 38% than when operating at 37^oc condensation temperature.

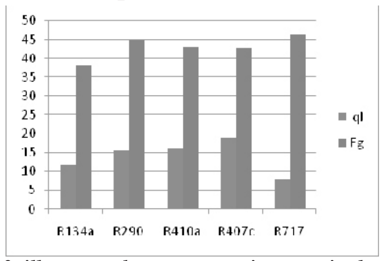

Fig. 3, illustrates the percentage increase inql and decrease inFg of given refrigerants.

From Figure 3,the percentage increase in refrigerating effect (ql) and decrease in flash gas formation (Fg) indicates the amount by which each refrigerant increases in absorbing heat per kilogram of refrigerant and decreases in vaporization of liquid to gas between the condensation temperature of 37°c and the degree of sub-cooling of 17°C below condensation temperature. From the chart, it shows that between the condensation and sub-cooling conditions, inorganic ammonia refrigerant is 8% increase in ql and 46% decrease in Fg while organic R134 single refrigerant is approximately 12% increase in ql and 38% decrease in Fg and organic (R410) blend refrigerant is 16% increase in ql and 43% decrease in Fg. It can be extracted that when refrigerants are subjected to sub-cooling, blend forms of organic refrigerants responded better by giving high refrigerating effect and high decrease in gas formation within the giving range of sub-cooling. This result supports the purpose of developing blend type of refrigerants in order to take care of conditions that cannot be managed by single organic refrigerants. The blend refrigerants are combination of more than one single organic refrigerant in different proportions, and they maintained as single refrigerants which cannot be separated again.

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Vapor compression and absorption refrigeration systems operate with restriction between the condenser and the evaporator which resulted in flash gas formation in the system. The effect of flash gas in refrigeration systems can be checked either by pre-cooling or by by-pass method which increases the system capacity.

Flash gas being the vapor forms at the expansion device when compared among different refrigerants of inorganic and organic of single and blend forms under certain conditions such as sub-cooling in order to know which form of refrigerant obtain higher refrigerating capacity and lower flash gas formation. The blend form of refrigerants gives better result than single and inorganic forms of refrigerants. The experiment shows that sub-cooling of refrigerants is more effective in blend refrigerants for having maximum value of percentage increase in refrigerating effect but being accompanied with high percentage decrease in gas formation (but less than ammonia). Inorganic refrigerants (e.g. R717) give low rate of heat energy absorption when subjected to sub-cooling(not good enough) with high percentage decrease in gas formation (very good) than both the single and blend forms of refrigerants operating at the same working conditions. The not good enough condition with other conditions such as high installation cost, some with toxicity and complexity attached to inorganic refrigerants, limited them only to large refrigeration applications.

5.2 RECOMMENDATION

The influence of Flash gas in Vapor Compression and in Vapor Absorption Refrigeration systems is enormous. The amount of gas formation at the throttle valve, apart from subcooling of temperature is also due to some factors such as viscosity, density, pressure etc. of liquid refrigerants used. From this project, it is that subcooling of liquid refrigerant to certain temperature after condensation will provide all refrigerants including organic and inorganic refrigerants with more liquid refrigerants into the evaporator; thereby increasing the refrigerating effect of the system.

For the better conclusion of this research work to be achieved, the least degree of sub-cooling, a refrigerant can attain for subcooling not to be effective or noticed need to be deduced, that is for subcooling not to give any additional improvement on the refrigerating effect of the system. This least degree of subcooling should be determined for selected refrigerants including both organic and inorganic refrigerants for comparism and evaluation.

The effect of viscosity in different liquid refrigerants can also be verified in order to know the influence of viscosity on flash gas formation at the throttle valve. Viscosity is the fluid property that determine the amount of resistance of fluid to shear stress or deformation, and measure of internal fluid friction which causes resistance to flow.

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