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Short Communication

Triple Point Behavior of Ammonia under Compression

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Abstract

Liquid ammonia has several industrial uses. Based on the end use, ammonia solutions of varying concentrations are used commercially. There are several methods to liquefy ammonia. However, the most preferred method for liquefying anhydrous ammonia is the use of a two stage, two- cylinder compressor. In this study, we designed a new ammonia compressor based on our examination of compressor designs comprising more than one stage and cylinder. Further, our investigation of the thermodynamic behavior of ammonia at high pressures also influenced our compressor design.

Key words: Liquefaction, one- stage compressor, two- stage compressor, triple point.

Introduction

Ever since ammonia was first studied, its commercial value has constantly increased with its industrial demand[1]. Ammonia is used in many industrial processes at different stages based on the end use. Depending on the nature of the final product, ammonia as raw material can be utilized in its liquid or gas phase. The storage of liquid ammonia involves extra treatment and specialized equipment that increase commercial costs. In general, the liquefaction of ammonia involves the use of multistage compressors[2] and this increases the cost of liquefaction.

Material and Methods

In order to examine the process of ammonia liquefaction using compressors with more stages, it is necessary to study the liquefaction process in each stage[3]. The work involved in compression in a stage is given by the following expression[4]:

$$W = (n/(n - 1)) \times M \times R \times T \times [(p_2/p_1)^{(n - 1)/n} - 1]$$

Where W: Compressor power (kW/h), n: Compressor stage number, M: Quantity of liquefied ammonia (kg/h), R: Liquefaction coefficient of ammonia, T: Ammonia temperature at point of entry into compressor (°C), p_2: Compressor output pressure, p_1: Compressor input pressure

Rewriting this equation for a two- stage compressor with 100% yield, we obtain the following equation:

$$W = (2/(2 - 1)) \times 2100 \times (1.802 \times 10^{-5}) \times (17.9/0.04)^{(2-1)/2} – 1$$
$$W = 366 \text{ kW/h}$$

It is noteworthy that the design performance of a compressor is affected by a variety of factors that influence compressor yield under various liquefaction pressures.

Results and Discussion

In our experiments on the physico- chemical behavior of ammonia, we obtained compressibility coefficients for different triple points under different pressures; the compressibility coefficient in each case described the maximum liquefaction tendency of ammonia at each pressure. When the pressure on gaseous ammonia was increased beyond a threshold value, ammonia showed unsteady behavior at every triple point. Our results showed that 0.05% liquid ammonia evaporates for a temperature change of 0.5°C under 20 atm pressure; however, the evaporation rate reduces to 0.01% for a temperature change of 0.5°C under 13 atm pressure[5].

On the other hand, we determined that at the triple points for three different pressure values on the temperature-volume graph for ammonia, when the slope of the curve along the gaseous side of the triple point was parallel to the y axis (figure-1), the system appeared to show an unsteady equilibrium[6]. Consequently, it was difficult to obtain a stable liquid state of ammonia under such liquefaction conditions[7]. If a compressor is designed on the basis of these values, the increase in the number of stages will increase the pressure in the system, which will lead to an unstable liquid ammonia state. Hence, increasing the number of stages beyond a certain threshold is not considered viable.

Therefore, for the practical design of an ammonia compressor, the optimal number of stages is limited to two.

The other aspect of our study focused on the number of cylinders used in the compressor stages. The initial pressure required to compress ammonia from its gas phase to its liquid phase is less than 1 atm, and this leads to a liquefaction problem that is independent of the stage number. Consequently, the optimal number of cylinders for compression should maximize the stable point of liquid ammonia at the triple point for each corresponding pressure[8].

For example, a 10 atm outlet pressure obtained at the first stage of compression corresponds to a temperature of 90°C[9]. Therefore, increasing the number of cylinders in this stage increases the temperature of compressed ammonia, and consequently, the outlet pressure also increases. If the stage number is increased areas of low pressure and high pressure are formed. Therefore, increasing the number of compressing cylinders in each stage ensures a wider compressor design range for the various triple points obtained under different pressure values.

For a compressor designed on the basis of the above discussion, the evaporation of ammonia occurs at 10°C, while condensation at 35°C. These values are valid only for a single compressing stage. For high- pressure compressors, the storage of ammonia in the liquid phase can be achieved over a wider temperature range. For example, in a multistage compressor, at the high-pressure stage, the evaporation temperature of ammonia is 10 °C, while its condensation temperature is 35°C. For the low-pressure stage, evaporation occurs at - 35°C, while condensation occurs at -10°C. Consequently, double- stage ammonia compressors can function over a wider temperature range[10]. Therefore, it is easier to maintain and transport ammonia in its liquefied phase than in its gaseous phase.

Conclusion

In our study, we determined that the liquefaction of gaseous ammonia can be optimally achieved by compressors that have two stages. According to our calculations and experimental observations, the compressor design for optimal condensation and evaporation values is directly related to the maximum pressure value and the physico- chemical behavior of ammonia at the triple point for this pressure. Further, the physico-chemical behavior of ammonia during liquefaction is unstable under such conditions.

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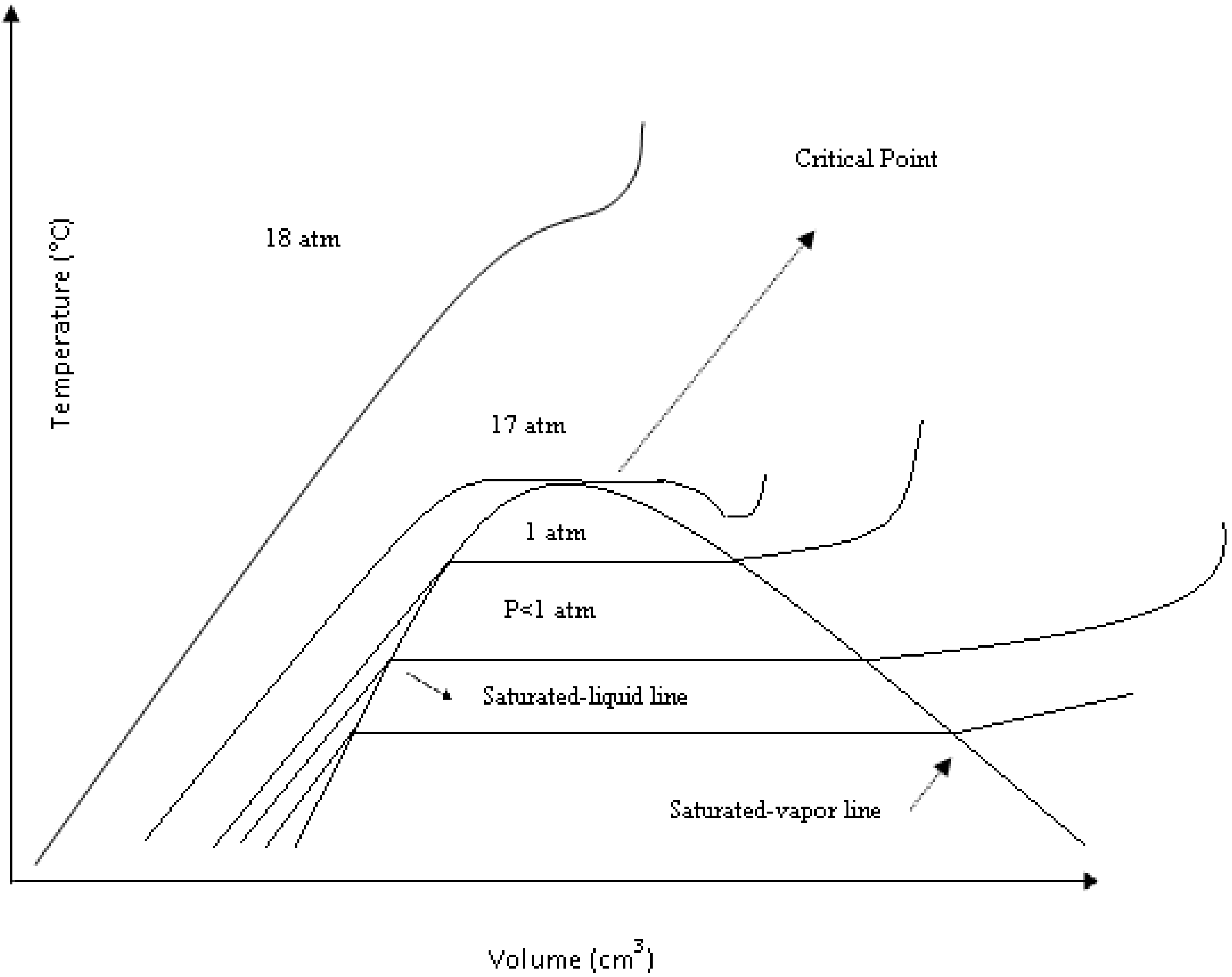

Figure-1
Physico-chemical behavior of ammonia at different pressures