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Crystallization Equation for determining working zone of LiBr in Vapour Absorption Refrigeration Systems

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Abstract: Lithium bromide–water (LiBr–H_2O) absorption refrigeration systems (VARS) are widely used for cooling applications due to their ability to operate on low-grade energy sources. However, a major operational limitation is *crystallization*, which occurs when the solution becomes supersaturated with LiBr. Crystallization can block system components, reduce efficiency, and lead to system failure. This paper presents a thermodynamic analysis of the crystallization phenomenon, supported by simulation results using Engineering Equation Solver (EES). A crystallization condition equation is derived, and a crystallization curve relating generator and absorber temperatures is formulated to define the safe working zone of the system.

Keywords: Crystallization Boundary, Lithium Bromide (LiBr), Working Concentration Zone, Vapour Absorption Refrigeration System (VARS).

I. INTRODUCTION

Refrigeration is the process of removing heat from a substance and maintaining its temperature below the surroundings under controlled conditions. It plays a vital role in food preservation, air conditioning, medical storage, industrial processes, and transportation of perishable goods.

Modern refrigeration mainly operates through two systems: Vapor Compression Refrigeration System (VCRS) and Vapor Absorption Refrigeration System (VARS). VCRS, driven by mechanical compression, is widely used in domestic and commercial applications, while VARS utilizes heat energy from sources such as solar, geothermal, or waste heat. This makes VARS an eco-friendly alternative with potential to reduce environmental impact.[1]

Refrigeration and air conditioning share common thermodynamic principles and components, with performance measured by their coefficient of performance (COP). However, a critical challenge in VARS, particularly in lithium bromide–water (LiBr–H_2O) systems, is crystallization of the absorbent, which can obstruct flow and compromise system performance. Addressing this issue is essential for ensuring efficient and reliable operation of absorption systems.[2]

II. METHODOLOGY

The energy and mass balance equation of the various components are applied on EES(Engineering Equation Solver). The crystallization analysis was carried out in two stages. First, the classical crystallization condition was used to determine the onset of salt precipitation in the LiBr–H_2O solution. The condition is expressed as:

$$[X_{rich} \geq X_c(T)]$$

where $X_{rich}$is the rich solution concentration and $X_c(T)$ is the critical crystallization concentration, calculated using the established empirical relation:

$$X_c = [9.8459 \times E^{-2} \times T] + 59.7995$$

with (T) representing the operating temperature (°C). For each absorber temperature, generator operating points were examined, and the onset of crystallization was identified when the above condition was satisfied as shown in fig.1.

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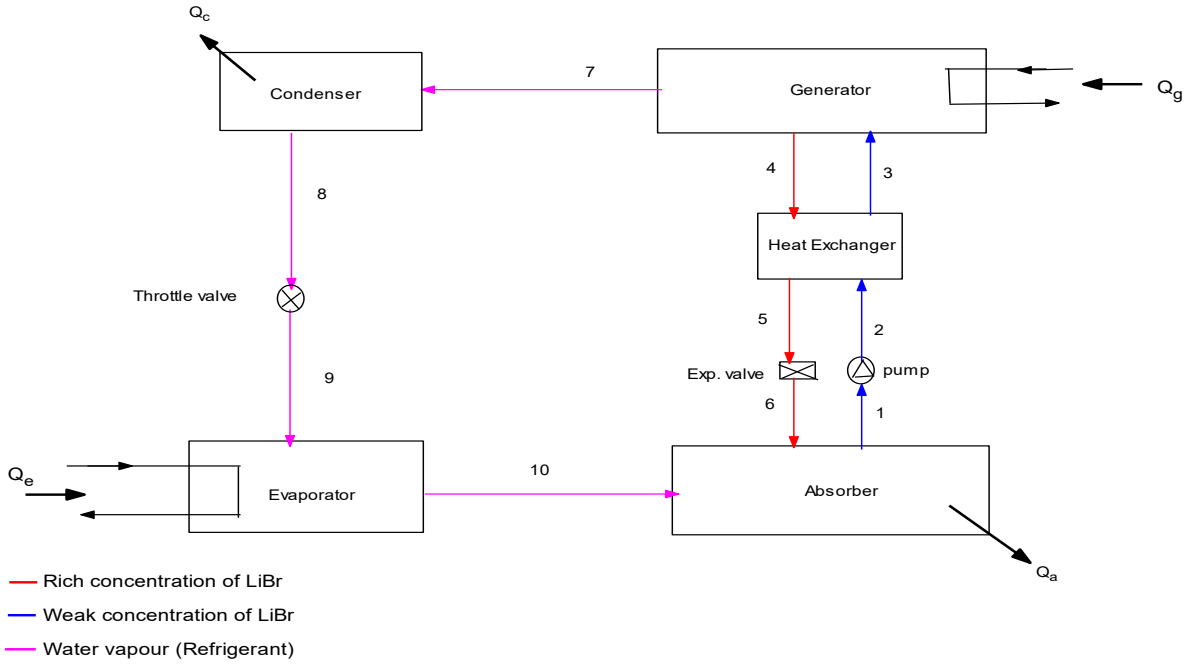

Figure 1. Single Effect LiBr-Water VAS.

In the second stage, the corresponding generator–absorber temperature pairs at crystallization were analyzed. A *linear regression model* of the form

$$[T\_g = a + bT\_a]$$

was applied, where (T_g) is the generator temperature and (T_a) is the absorber temperature. This regression provided a simplified crystallization boundary equation, eliminating the need for direct concentration evaluation while preserving high accuracy.

III. DATA ANALYSIS AND REGRESSION

Generator–absorber temperature pairs at which crystallization occurred were determined from thermodynamic analysis. These data points were used to develop a linear regression model of the form:

$$[T\_g = a + bT\_a]$$

where (T_g) is generator temperature and (T_a) is absorber temperature.

IV. DATA ANALYSIS AND REGRESSION

Application of the old crystallization relation confirmed its effectiveness in predicting crystallization through concentration–temperature analysis. However, this method requires detailed thermodynamic property evaluation, which may be computationally intensive.

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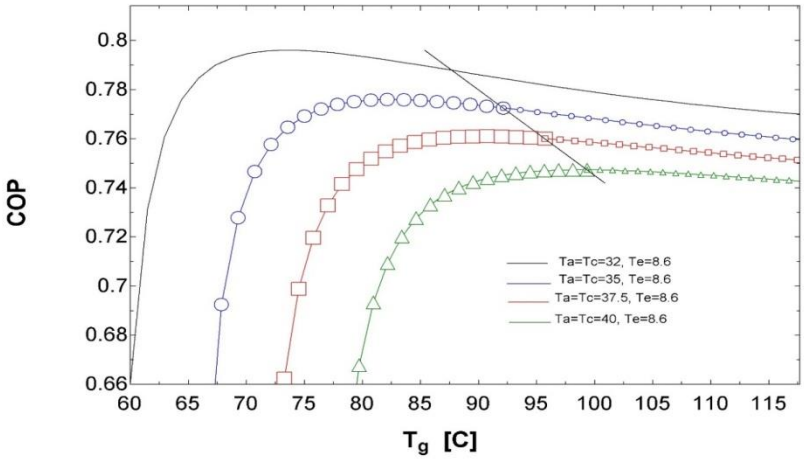

Figure 2. Graph between Generator Temperature and COP

As fig 2 shows when graph between generator temp and COP is plotted then crystallization is occurs at different generator temperature so this crystallization is calculated at different generator and absorber temperature and the value is given in table given below:

Table 1. Absorber and Generator Temperature at Crystallization

Absorber Temp	Generator Temp
30	84.9
31	86.41
32	87.84
33	89.26
34	90.7
35	92.15
36	93.57
37	95
38	96.45
39	97.89
40	99.35
41	100.8
42	102.2
43	103.6
44	105.1
45	106.5

The graph plotted between these two temperature where crystallization occurs in single effect LiBr- water vapour absorption system.

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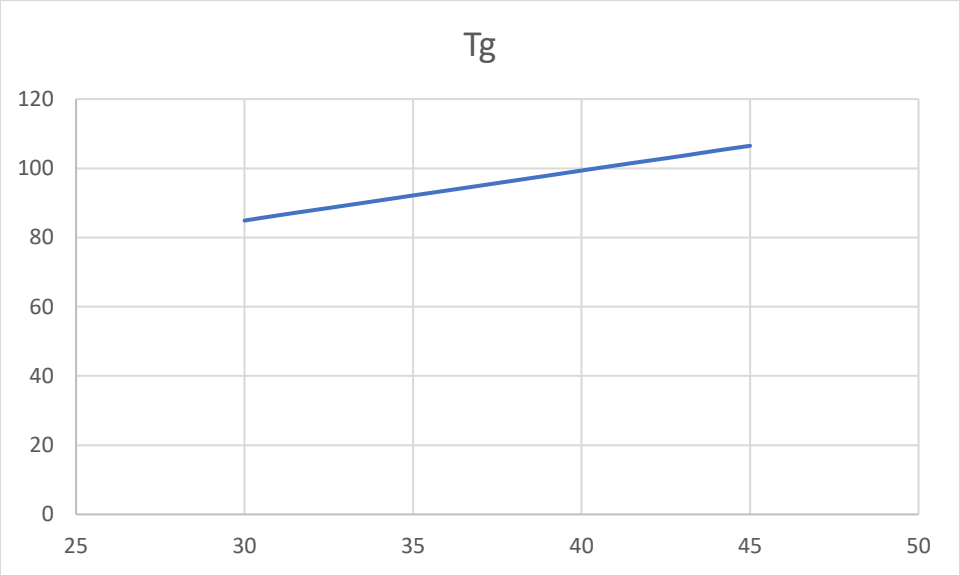

Figure 3. Graph between Absorber and Generator Temperature

The regression analysis produced a new crystallization boundary equation:

$$[T\_g = 41.804 + 1.438T\_a]$$

This linear relation directly links generator and absorber temperatures, offering a quick and practical tool for system operation.

The error analysis showed extremely low RMSE and percent error, with (R^2) close to unity, indicating excellent agreement with the thermodynamic data. The results demonstrate that the new regression equation can effectively replace detailed concentration checks for real-time monitoring, while the old equation remains useful for conservative verification.

V. CONCLUSION

This study analyzed crystallization in LiBr–H_2O VARS using both the conventional concentration–temperature approach and a newly derived linear regression equation. The old equation provides detailed and reliable predictions but requires concentration calculations. The new regression equation:

$$[T\_g = 41.804 + 1.438T\_a]$$

offers a simple yet accurate crystallization boundary for absorber temperatures in the studied range. Together, these methods provide a robust framework for safe design and operation of absorption refrigeration systems, minimizing the risk of crystallization.

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