ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering
Tome XIII [2015] – Fascicule 3 [August]
ISSN: 1584-2673 [CD-Rom; online]
a free-access multidisciplinary publication of the Faculty of Engineering Hunedoara

[1.] Gyula KRAMER, [2.] Zoltán SIMENFALVI, [3.] Gábor L. SZEPESI

MODELING OF AMMONIA-WATER BASED ABSORPTION REFRIGERATION SYSTEMS – PROPERTIES OF THE REFRIGERANT

[1–3.] University of Miskolc, Institute of Energy and Chemical Machinery, Department of Chemical Machinery, Miskolc, HUNGARY

Abstract: The absorption refrigeration is the cheapest cooling method. That device, with ammonia-water refrigerant pair is able to be used as a heat pump as well. In this article, we show its place among the refrigeration methods, than draw up the base of this method, finally we introduce a mathematical model of this refrigerant system, which works without difficultly available databases and expensive programs background.
Keywords: Absorption, refrigeration, ammonia, water

1. INTRODUCTION

There are many kind of refrigeration methods. Those have versatile domestic, commercial and industrial utilization, some used as a cryotechnic with scientific purpose. (Table 1)

Table 1: Applications of Refrigeration

Some Application of Refrigeration
Air contitioning (+20…+10 C°)
Food Chillers (+5…-5 C°)
Frozen food Refrigerators (-20…-35 C°)
Fast Freezers (-50…-100 C°)
Gas Liquidzation (-150…-250 C°)
Superconductive magnets (-200...-250 C°)
0 K closed resouce (-250…-273,4 C°)

Table 2: Methods of Refrigeration (the scientifically used ones in blue color)

- Methods of Refrigeration
  - Cyclic Refrigeration
    - Vapor Cycle
      - Vapor compression
      - Vapor sorption
        - Adsorption
        - Absorption
    - Gas Cycle
      - Joule-Thomson-Linde cooler
      - Stirling Cryocooler
      - Pulse tube Cryocooler
      - Cifford-McMachon cooler
  - Other Methods
    - Vortex tube
    - Thermoelectric method
    - Adiabatic demagnetisation
    - Dilution Cryocooler
    - Laser Cryocooler

These different purposes cover the temperature scale up to the absolute zero point. So those need different refrigeration methods and devices as well. (Table 2) If the heat source is available, the most effective, energy saver procedure is the vapor sorption refrigeration among those.

This method has huge importance, because when we have junk heat from another industrial procedure (for example a power plant), the work cost of a sorption refrigerator is free. Moreover, the absorption one can be used as a heat pump as well.

2. THE ABSORPTION REFRIGERATION

Everybody knows the vapor compression refrigerator, because that is the so called ordinary cooling method. The difference, between that and the absorption one is the following: There is a generator-absorber pair instead of a high power refrigerant pump. (Figure 1).

Working principle of Absorption refrigerator (Carré-method) [1]:

We use not a pure refrigerant, than a refrigerant-solvent pair. We heat up the generator up to 80…100 C°, where the solution has for example 30% of refrigerant. The hot refrigerant leaves the generator as vapor. Than that liquefies in the condenser, passes the expansion valve, and evaporates under low pressure, and extract heat from the chilled area. (like in the ordinary method). Than the cold refrigerant vapor enters into the absorber (which is at for example 30…40 C°), and dissolved in the solution shower. Logically, the absorber gets richer and richer in refrigerant. This is why we need a pump that circulates the solution between the absorber and the generator. I have to mention, that this solution pump needs very small power (just 0,5…2 percent of the entire process)

But these two places have different temperatures, so we need a heat exchanger as well. (Unfortunately, there is no perfect exchanger, so that causes a lot of heat loss).

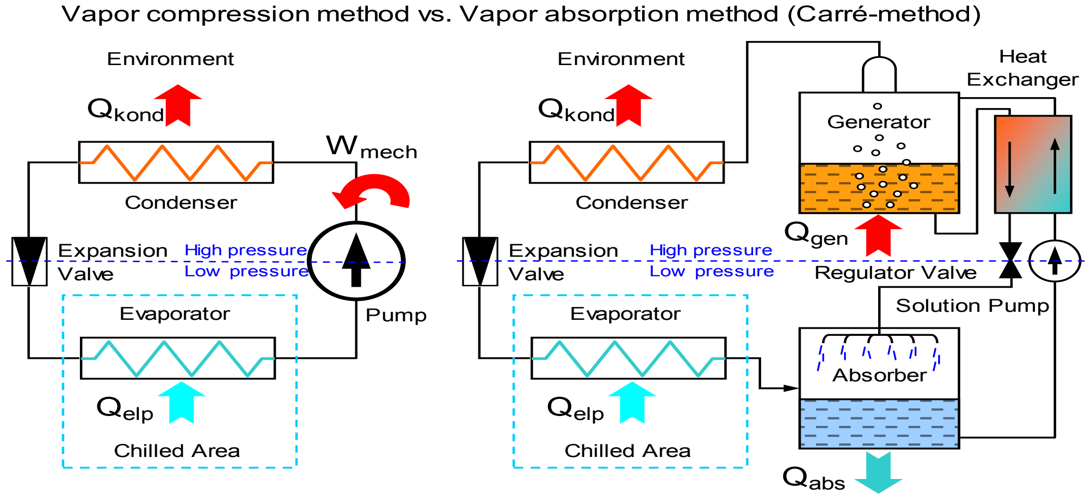

Figure 1: Vapor compression refrigerator versa absorption refrigerator

The huge advantage of that method, that it needs power mostly (about 99%) in heat, not in electrical power. Moreover it needs low temperature (80…120 C°) heat that we can get from another process as a junk heat. It is true, that the COP of this procedure is much lower (0,5…0,7, in two stage up to 1,5) that the compressor ones (2…3…even 4,5), but when we have free (junk) power source, that is no matter.

A few words about the other absorption system, the so called Platen-Munters procedure, to avoid the confusion: This has no pressure difference inside, and has no pump at all, however it has a third working component, the hydrogen, as inner atmosphere. This process has very weak COP (0,15…0,3) so that has just domestic use (where electricity is not available, for example in caravans).

3. PHISICAL FEATURES OF THE AMMONIA WATER SYSTEM

The most frequently used refrigerant-solvent pair is the ammonia and the water. (Table 3) It is true, that material is slightly harmful and corrosive, but that is the most useable one, that able to achieve all our goals, such us heat pump function, or low temperature refrigeration.

Table 3: A few refrigerant solvent pairs

Refrigerant	Solvent	Remark	Use
ammonia	water	Able for heat pump, low temperature available, harmful	yes
water	LiBr	Gives a bit better COP, but just for air conditioning	yes
ammonia	$LiNO_3$	Gives a bit better COP, low temperature available, harmful	experimental
methanol	$LiBr_3$	Gives a bit better COP, low temperature available	experimental
acetone	$ZnBr_2$	Gives a bit better COP, low temperature available	experimental
H_2SO_4	water	Theoretically good, but very harmful and very corrosive	not in use
HCl	water	Theoretically good, but very harmful and very corrosive	not in use

If we would like to create a mathematical model, we desperately need the character of the ammonia-water system.

We created easy, well useable, and satisfactorily accurate methods to estimate the wanted physical features. [2] Those are 3D surfaces, depending on the ammonia concentration and on the temperature or pressure.

Which features do we need?

- Vapor pressure curve
- Vapor-liquid equilibrium curve
- Enthalpy of saturated solution,
- Enthalpy of saturated vapor
- Other features (special heat, density, viscosity)

Unfortunately there is no time and place to show all of those, but we introduce the first 2 ones.

4. VAPOR PRESSURE CURVE

We have seen a few expensive software products. Those approached the properties with very complicated high degree polynomials. Let us make that easier!

$$p(t)=e^{A-\frac{B}{t+C}} \quad (1) \qquad p(t)=e^{A-\frac{B}{t+C}} \quad (2) \qquad p(t)=e^{A-\frac{B}{t+C}} \quad (3)$$

We know that theoretically the Antoine equation (1) gives that curve. Let us start from that! We know that is good just for ideal matters. Also our material is a mixture, so we need one more variable, (concentration, x) in the function. We have to modify that equation (2). So, this way we can express the temperature with the pressure (3).

We developed Carl G. Almén's earlier work [3] and got for A(x), B(x), C(x) the following:

$$A(x)=11{,}675\cdot\left[1-(0.223-0.155\cdot x)\cdot\sqrt{x}\right]$$
$$B(x)=3840\cdot\left(0.216\cdot x^{2{,}62}+0.1157\cdot x^{1{,}62}-0.62\cdot x^{0{,}62}+1\right)$$
$$C(x)=\left(229+47.7x-20x^{2}\right)-7\sin(2.8x)-1.5\sin(8.5x) \quad (4)$$

Our diagrams look this way. (Figure 2) Also, as you can see, we could create a really accurate approach.

If we have that we can draw up the so called Dühring diagram (Figure 3), also we can draw up the refrigeration cycle on it as well.

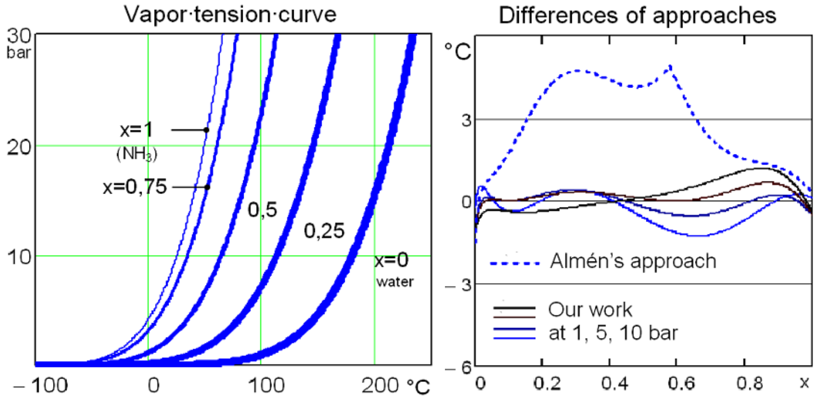

Figure 2: Vapor tension curves, and the difference of approach and measured value.

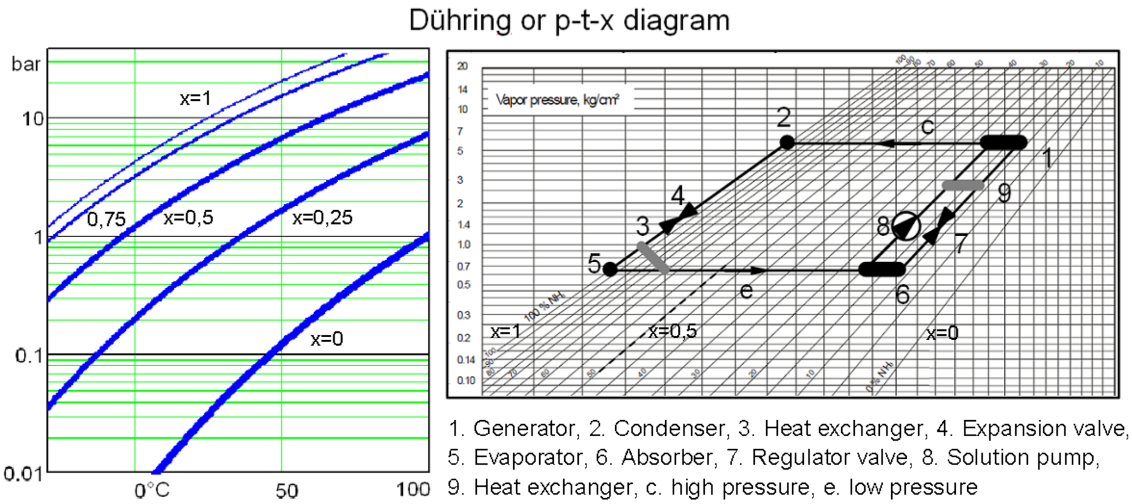

Figure 3: Dühring, or p-t-x diagrams, and the refrigeration cycle [4] on it.

5. VAPOR-LIQUID EQUILIBRIUM CURVE

This curve (in our case this 2D surface) gives that and the liquid phase, with x concentration and what y concentration vapor can hold balance at a given p pressure (or given t temperature). We got the following equation, as acceptable approach (5):

$$y(p,x)=B_y(x)-e^{A_y(p)\cdot x} \qquad \text{Where } A_y(p) \text{ and } B_y(x):$$
$$A_y(p)=1{,}5413\cdot e^{-p}+2{,}5151\cdot\ln(p)-14.2715$$
$$B_y(x)=1-0{,}0353\sin\left(\pi\cdot e^{-8x}\right) \quad (5)$$

Our diagrams look this way. (Figure 4) Also, as you can see, we could create an acceptable approach. Better that the old one anyway. Moreover, that is significantly better at the important concentrations. (between 20-40%, and above 80%)

If we have that we can draw up the bubble point and dew point diagram (Figure 5), at constant pressure and temperature as well.

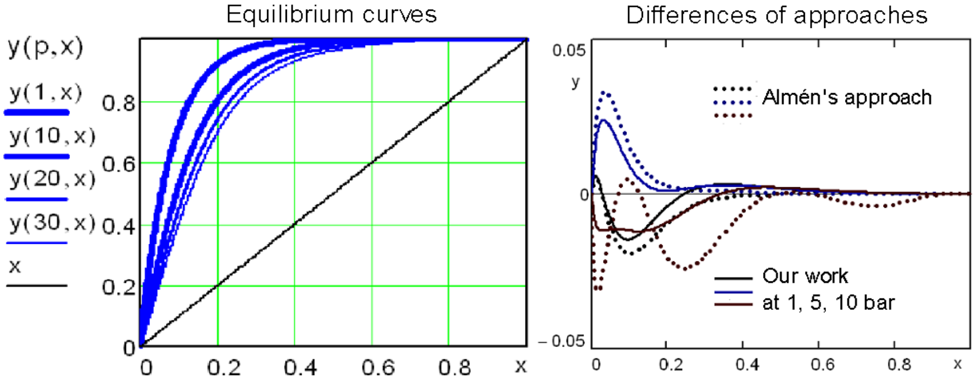

Figure 4: Vapor-liquid equilibrium curves, and the difference of approach and measured value.

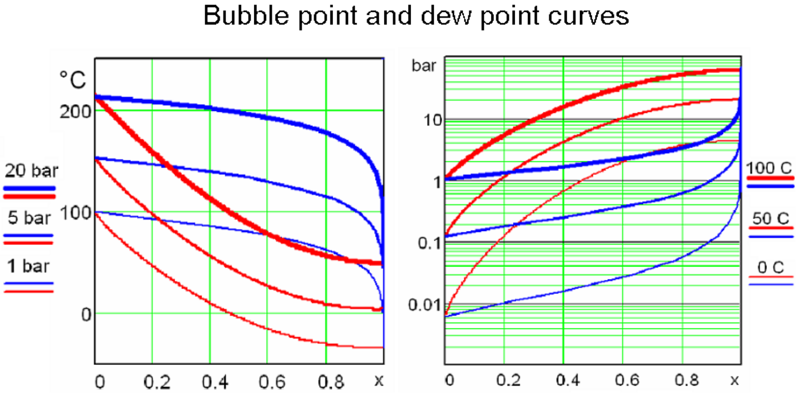

Figure 5: Bubble point (red) and dew point (blue) diagrams at constant pressures (at left) and constant temperatures (at right)

We just know a few estimation formulas, and we could get know so much information about the system.

6. CONCLUSIONS

In this article, we introduced the base of the absorption refrigeration, also introduced two methods that we developed, which are easier and more accurate than the previous ones. One for estimation the vapor pressure and one for the vapor-liquid equilibrium curves in ammonia-water system. Based on this work, in our next article, we introduce how to design an entire refrigeration system how to define its main values and estimate its COP.

ACKNOLEDGEMENT

This research was carried out as part of the TAMOP– 4.2.1.B– 10/2/KONV– 2010– 0001 project with support by the European Union, co–financed by the European Social Fund.

NOMENCLATURE

COP	Coefficient of Performance	[-]
x	NH_3 concentration in liquid phase,	[m/m]
y	NH_3 concentration in vapor phase,	[m/m]
p	pressure	[bar]
t	temperature	[C°]

REFERENCES

[1.] G. Kramer, Dr. Z. Siménfalvi, Dr. G. Szepesi: A Rewiev And Comparison Of Ab- And Adsoption Cooling Methods, 2014

[2.] G. Kramer, Dr. Z. Siménfalvi, Dr. G. Szepesi: Calculation Of Data Of Ammonia-Water System To Absoption Cooling Methods, 2015

[3.] Carl G. Almén: Gas Absorption Refrigeration, 1985

[4.] M. R. Conde, Conde Engineering Zürich, Thermophysical Properties Of Nh_3-H_2o Solutions For Industrial Design Of Absorption Refrigeration Equipment, 2004