MultiScience - XXX. microCAD International Multidisciplinary Scientific Conference
University of Miskolc, Hungary, 21-22 April 2016, ISBN 978-963-358-113-1

CALCULATION OF PROPERTIES OF NH_3-H_2O REFRIGERANT, AND MODELING OF ABSORPTION REFRIGERATION SYSTEMS

Gyula KRAMER[1], Zoltan SIMENFALVI[2], Gabor L. SZEPESI[2]
[1]PhD student, [2]associate professor, head of department, [3]associate professor
[1-3]University of Miskolc, Institute of Energy and Chemical Machinery, Department of Chemical Machinery, Miskolc, HUNGARY

ABSTRACT

The absorption refrigeration is the most economical cooling method. In this article, we show its place among the refrigeration methods, than draw up the base of this method, finally we introduce method to estimate the property of the refrigerant, and a mathematical model of the refrigerator system, which works without difficultly available databases and expensive programs background.

1. INTRODUTION

There are many kind of refrigeration methods. Those have versatile domestic, commercial and industrial utilization, some used in the cryotechnics with scientific purpose. (Table 1) These different purposes cover the entire temperature scale. So those need different refrigeration methods and devices as well. (Table 2)

Table 1
Applications of Refrigeration

Name	**Characteristic Temperature**
Air Conditioning	+20…+10 °C
Food Chillers	+5…-5 °C
Frozen Food Refrigerators	-20…-35 °C
Fast Freezers	-50…-100 °C
Gas Liquidisation	-150…-250 °C
Superconductive Magnets	-200…250 °C
0 K Closed Resource	-250…-273.4 °C

Table 2
Methods of Refrigeration

Methods of Refrigeration		
Cyclic Refrigeration		**Other Methods**
Vapor Cycle	**Gas Cycle**	Vortex Tube
Vapor Compression	Joule-Thomson-Linde Cooler	Thermoelectric Method
Vapor Sorption	Stirling Cryocooler	Adiabatic
Adsorption	Pulse Tube Cryocooler	Dilution Cryocooler
Absorption	Cifford-McMachon Cooler	Laser Cryocooler

DOI: 10.26649/musci.2016.100

2. THE ABSORPTION REFRIGERATION

If the heat source is available, the most effective, energy saver procedure is the vapor sorption refrigeration among those.
When we have junk heat from another industrial procedure (for example a power plant), the work cost is free indeed. Moreover, the absorption one can be used as a heat pump as well.
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)

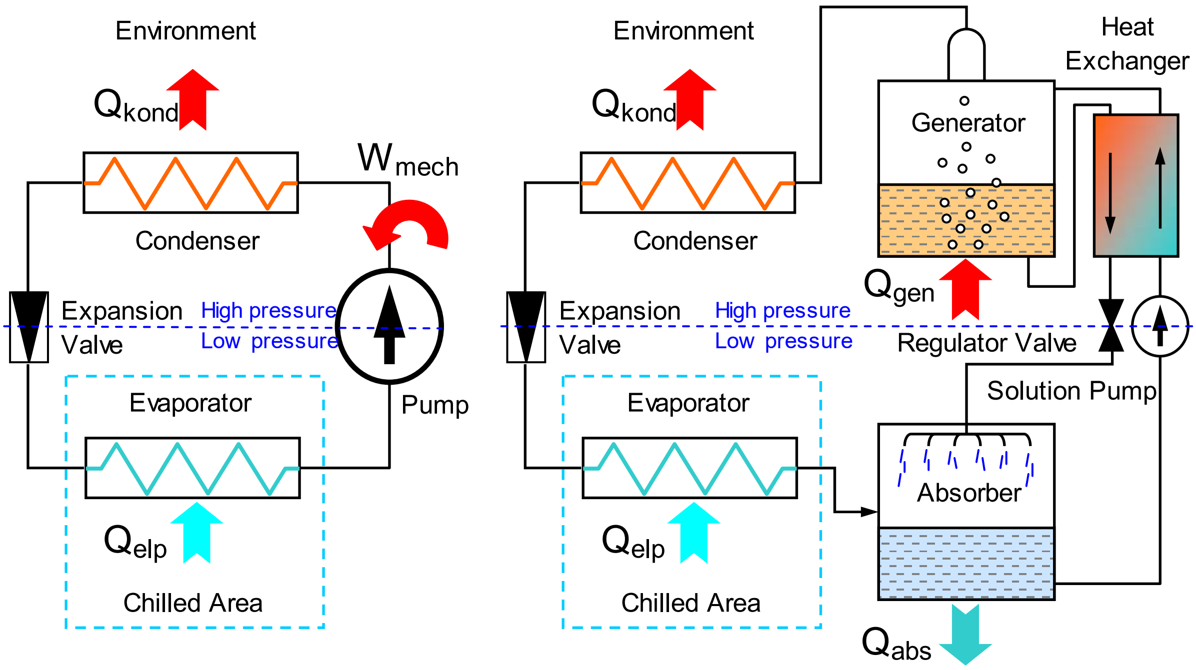

Figure 1:
Vapor compression refrigerator versa absorption refrigerator (Carré-method)

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)

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 PROPERTIES 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. 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 neither time nor place to show all of those, so we introduce the first 2 ones. The reference [2] contains the detailed calculations.

4. VAPOR PRESSURE CURVE

We have seen a few expensive software products. Those approached the properties with very complicated high degree polynomials. [3], [4] Let us make that easier! We know that theoretically the Antoine equation (1) gives that curve. Let us start from that. We know that is good for ideal matters only. 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).

$$p(t) = e^{A - \frac{B}{t+C}} \tag{1}$$

$$p(t,x) = e^{A(x) - \frac{B(x)}{t+C(x)}} \tag{2}$$

$$t(p,x) = \frac{B(x)}{A(x) - \ln(p)} - C(x) \tag{3}$$

We developed Carl G. Almén's earlier work [5] and got for *A(x)*, *B(x)*, *C(x)* the following: (4)

$$\begin{aligned} A(x) &= 11.675 \cdot \left[1 - (0.223 - 0.155 \cdot x) \cdot \sqrt{x}\right] \\ B(x) &= 3840 \cdot \left(0.216 \cdot x^{2.62} + 0.1157 \cdot x^{1.62} - 0.62 \cdot x^{0.62} + 1\right) \\ C(x) &= (229 + 47.7x - 20x^2) - 7\sin(2.8x) - 1.5\sin(8.5x) \end{aligned} \tag{4}$$

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

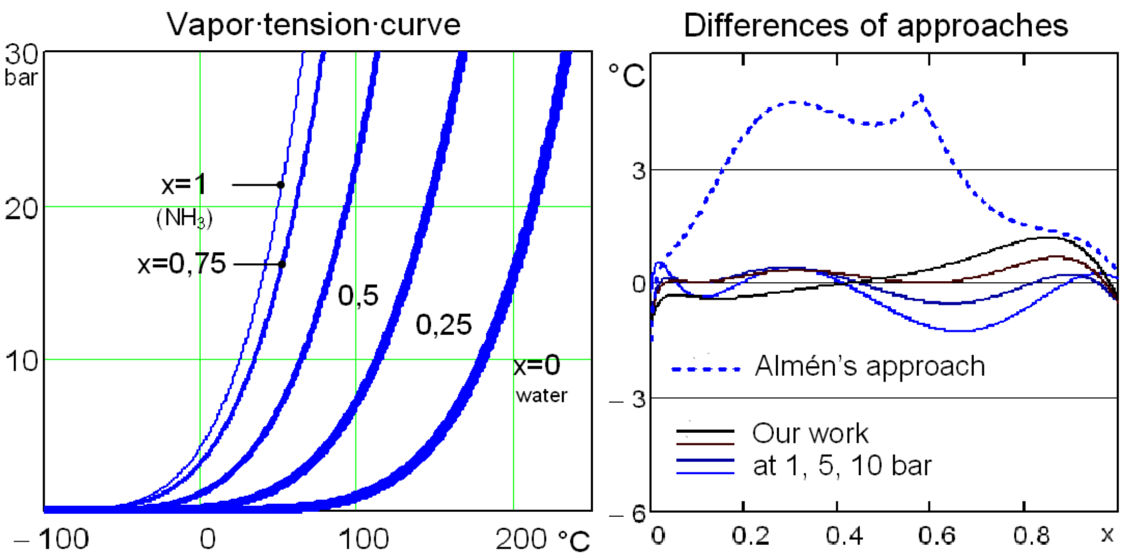

Figure 2
Vapor tension curves and the deviation of Almén's and our estimations

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):

$$
\begin{aligned}
& y(p,x) = B_y(x) - e^{A_y(p)\cdot x}\text{, where:} \\
& A_y(p) = 1.5413\cdot e^{-p} + 2.5151\cdot \ln(p) - 14.2715 \\
& B_y(x) = 1 - 0.0353\cdot \sin\left(\pi\cdot e^{-8x}\right)
\end{aligned}
\qquad (5)
$$

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%)

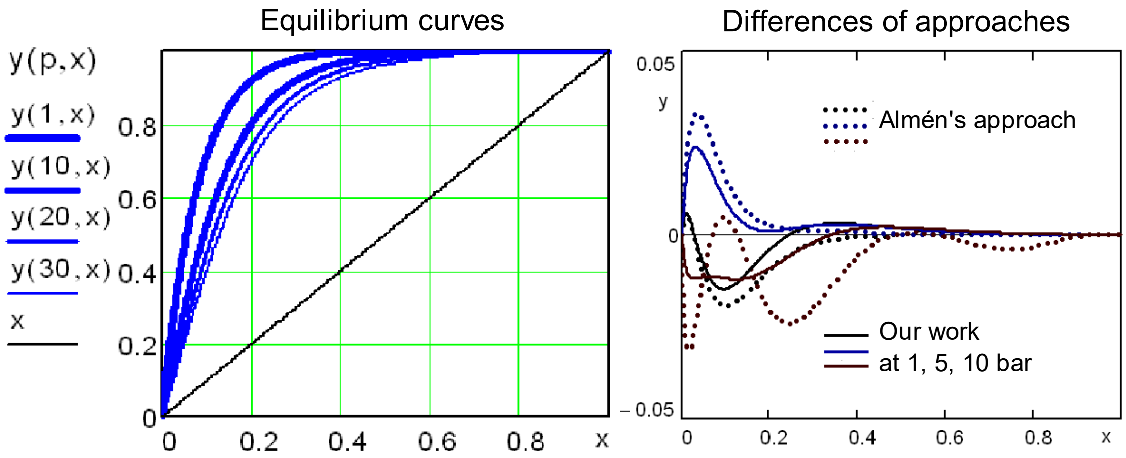

Figure 4
Vapor-liquid equilibrium curves and the deviation of estimations

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

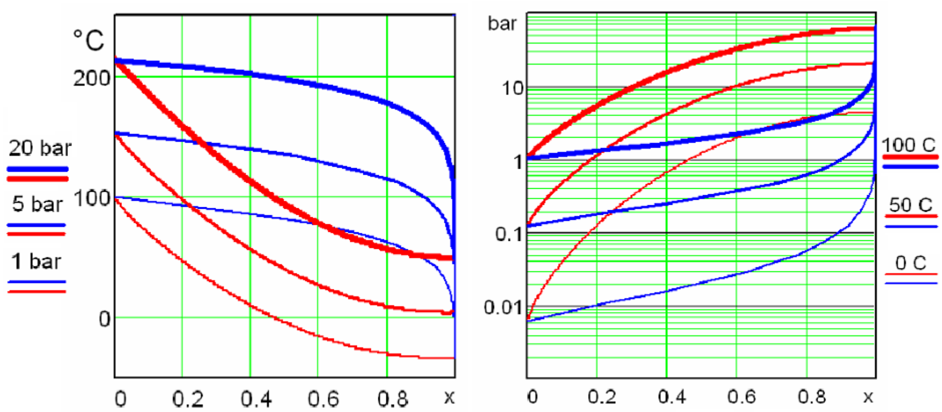

Figure 5
Bubble point (red) and dew point (blue) diagrams at constant pressures (at left) and constant temperatures (at right)

6. MODEL OF THE REFRIGERATION SYSTEM

We just know a few estimation formulas, and we could get know so much information about the system.
If we want to describe the entire procedure, we have to describe its part procedures, such as:

- Generator – ammonia, the refrigerant boils out of the solution,
- Condenser – condensation of the refrigerant,
- Expansion valve – isenthalpic expansion,
- Evaporator – heat extraction of the environment,
- Absorber – dissolving of refrigerant,
- Heat exchanger – heat transfer between the poor and rich solutions.

After those we can calculate the cooling power, the heat request, and the COP.

7. MODELING OF THE GENERATOR

We show one sample, the generator. This is the most complicated part of the system. (Figure 6) This is a complex unit. Its heated part, where the ammonia boils out of the solution, is the generator indeed. Where the power request is P_{gen}, the temperature is t_{gen}, which gives us the pressure as well. From these, we can estimate the ammonia concentration of the arisen steam, y_{gen}. This steam gets to the deflegmator, where we cool it back, to condensate the water. So practically pure ammonia leaves the unit, and pure water goes back to the boiler, so $x_{def}=0$, $y_{ref}=1$.
That unit looses ammonia constantly, so we have to cover it. This is why we have to circulate the solution between generator (pure, x_{gen}, t_{gen}) and absorber (rich, x_{abs}, t_{abs}), where $m_{abs} = m_{gen}$ logically.

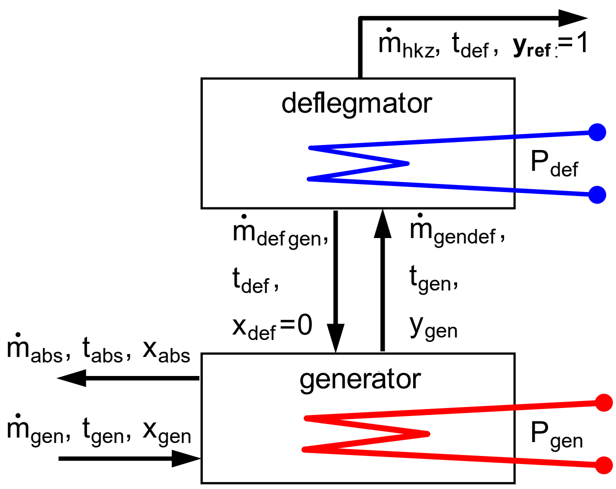

Figure 6
Layout of Generator

The temperatures, the concentration in the absorber and generator are given, also we know the properties of the ammonia-water system, so we can estimate the pressure and the concentration of arising steam, also we can estimate the enthalpies of existing and arising phases as we introduced above. We just have to compose the energy equation of this partial system, and we can express the heat request of this procedure. (6)

$$P_{gen} = \frac{dm_{gen}}{d\tau} \cdot h_{gen} + \frac{dm_{gendef}}{d\tau} \cdot h_{gendef} - \frac{dm_{abs}}{d\tau} \cdot h_{abs} - \frac{dm_{defgen}}{d\tau} \cdot h_{defgen} \qquad (6)$$

We can describe the procedures in the other part of refrigerator circuit, such as condenser, valve, evaporator and absorber. From the energy equation of evaporator, we got the refrigeration power. With the effectiveness of heat exchanger, we can calculate the heat request of the solution stream. That we added to the heat request of boiling, we got the heat request of the entire refrigeration system.
There is no space to talk about every thing, but the [6] reference contains the detailed calculation

7. BEHAVIOR OF THE MODEL

Now we are able to calculate the energy balance of the entire refrigeration system. Let's express its coefficient of performance, the so called COP. (7)

$$COP = \frac{P_{ref}}{P_{gen} + P_{pump}} \cong \frac{P_{ref}}{P_{heat}} \qquad (7)$$

Let's express how the temperatures of parts affect the COP. (Figure 7) We can see that our results match the measured values and the behavior of more complicated mathematical models. [7]

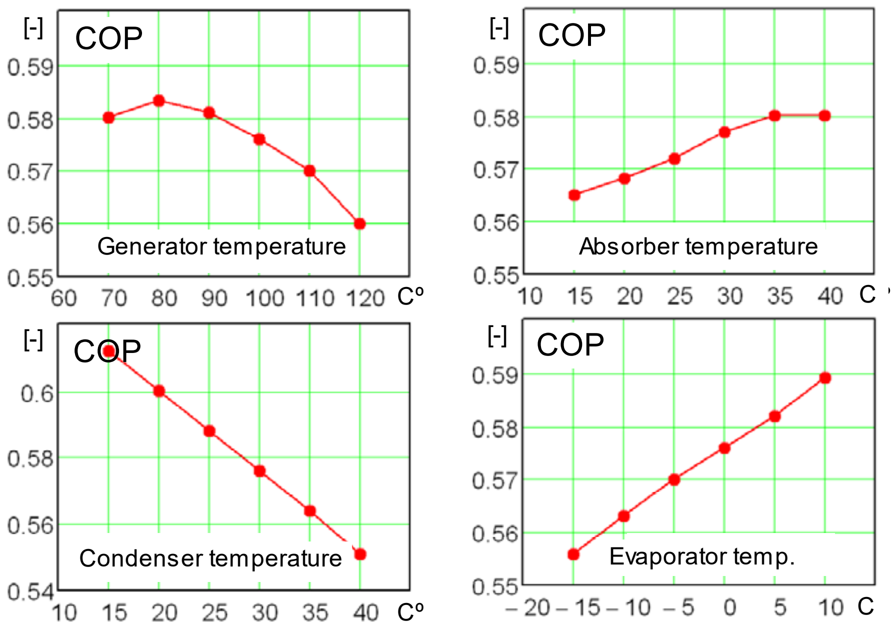

Figure 7
COP depending on the temperature of the different parts of the refrigeration circuit.

8. CONCLUSIONS

In this article, we introduced the base of the absorption refrigeration, also introduced two methods that we developed to estimate the features of the most frequently used ammonia-water refrigerant pair, which are easier and more accurate than the previous ones. Based on that, we introduced a mathematical model of the entire refrigeration circuit which calculates the refrigeration power and heat request, and gives the COP. Finally we showed its behavior.

NOMENCLATURE

m	mass	[kg]
x	NH_3 concentration in liquid phase,	[m/m]
y	NH_3 concentration in vapor phase,	[m/m]
p	pressure	[bar]
t	temperature	[C°]
τ	time	[s]
P	power of heat	[W]
COP	Coefficient of Performance	[-]

ACKNOLEDGEMENT

The research was supported by the Hungarian Scientific Research Fund OTKA T 109860 project and was partially carried out in the framework of the Center of Excellence of Innovative Engineering Design and Technologies at the University of Miskolc.

REFERENCES

[1] KRAMER G., Dr. SIMENFALVI Z., Dr. SZEPESI G.: **Review and comparison of ab- and adsorption cooling methods**, GÉP 2014/6-7, 66 p.
[2] KRAMER G., Dr. SIMENFALVI Z., Dr. SZEPESI G.: **Calculation of data ammonia-water system to absorption cooling methods,** GÉP, 2014/8, 30 p.
[3] PATEK J., KLOMFAR J.: **Simple functions for fast calculations of selected thermodynamic properties of the ammonia-water system**, International Journal of Refrigeration, Vol. 31, No. 4, 1995, 228-234.
[4] CONDE M. R.: **Thermophysical properties of NH_3-H_2O solutions for industrial design of absorption refrigeration equipment**, Conde Engineering Company, Zürich, 2004,
[5] ALMÉN G. C.: **Gas absorption refrigeration**, 1985,
[6] KRAMER G., Dr. SIMENFALVI Z., Dr. SZEPESI G.: **Method for calculation effectiveness and heat request of ammonia-water based absorption cooling system**, GÉP, 2015,
[7] SINGH R., Dr. KUMAR R.: **Theoretical Analysis of NH_3-H_2O Refrigeration System**, International Organization of Scientific Research Journal, 2011.