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MODELING OF AMMONIA-WATER BASED ABSORPTION REFRIGERATION SYSTEMS – THE REFRIGERATION CIRCUIT

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ABSTACT: The absorption refrigeration is the most economical cooling method. In this article, we draw up the base of this method, and introduce mathematical model of the refrigerator system, to calculate its main parameters, leaning on our previously showed estimation of properties of refrigeration. Both work without difficultly available databases and expensive programs background.
Keywords: Absorption, refrigeration, ammonia, water

1. INTRODUTION
Several refrigeration methods are known. Among those, if the heat source is available, the most effective and energy saver procedure is the vapor absorption refrigeration. If there is any junk heat from another industrial procedure (for example a power plant), the work cost is free indeed. Moreover, this can be used as a heat pump as well. In our previous article, we introduced a calculation method, to estimate the property of the most frequently used refrigerant pair, the ammonia-water system [1], now, we introduce, how to estimate the main parameters of the entire working system leaning on that previous calculation.
These main parameters are:

- refrigeration power,
- heat request,
- arising pressures,
- power request of the pump,
- COP.

2. THE ABSORPTION REFRIGERATION
The vapor compression refrigerator is well known, because that is the so called ordinary cooling method. The difference, between that and the absorption one is that the high power refrigerant pump is substituted with a generator-absorber unit pair. (Figure 1) To avoid the confusion, this is the so called Carré-method. [2]
Working principle of absorption refrigerator is the following:
Refrigerant-solvent pair is used instead of poor refrigerant. The generator must be heated up to 80…130 C°, where the solution has for example 30% of refrigerant. The hot refrigerant leaves the generator as vapor. Than it condensates in the condenser, and passes the expansion valve, where evaporates under low pressure, and extracts 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 gets dissolved in the solution shower. Logically, the absorber gets richer and richer in refrigerant. This is the reason why a pump is needed to circulate the solution

between the absorber and the generator. This solution pump needs negligibly small power (just 0,5…2 percent of the entire process) but these two places have different temperatures, so a heat exchanger is needed as well.

The huge advantage of this method, that it needs power mostly in heat, not in electrical power. Moreover it needs low temperature (80…120 C°) heat that can get from another process as a junk heat. 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 if there is free power source, that is no matter.

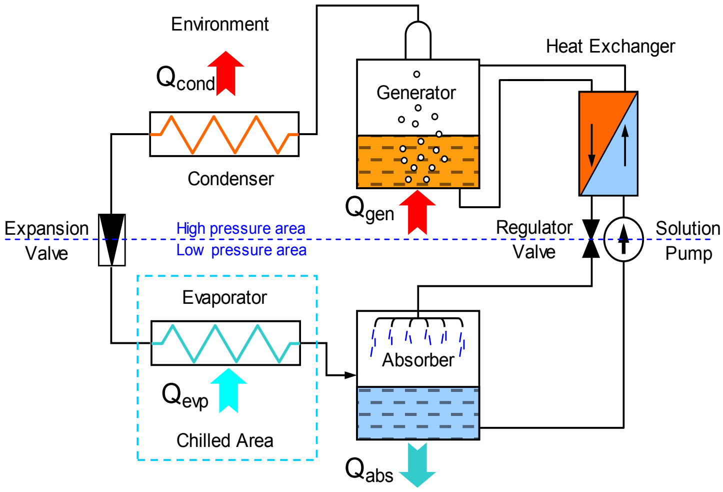

Figure 1. The layout of the absorption refrigerator

3. MODEL OF THE REFRIGERATION SYSTEM

The following properties of the refrigerant pair must be know:

- Vapor pressure curve,
- Vapor-liquid equilibrium curve,
- Enthalpy of saturated solution,
- Enthalpy of saturated vapor.

Our previous article [1] contains the estimation methods, or optionally, the methods of the quoted relevant literature can be used [3], [4], [5].

Given data are the following:

- The concentrations in generator and absorber,
- Generator temperature - given from the heat source,
- Absorber temperature – given from cooling water,
- Chilled area temperature - requested form the goal of the refrigeration.

To describe the entire procedure, these part procedures must be known:

- 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.

4. THE GENERATOR

The generator is the most complicated part of the system. This complex unit has a heated and a cooled part. (Figure 2) The 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}. This temperature gives us the pressure, the p_{gen} as well. From these, the ammonia concentration of the arisen steam y_{gen} can be estimated. This steam gets into the deflegmator, where it cooled back, so its water condensates. Practically pure ammonia leaves the unit so $x_{ref} = y_{ref} = 0$, and pure water goes back to the boiler, so $x_{def} = y_{def} = 1$. This unit loses ammonia constantly, so this is recovered. This is why the solution must be circulated. From generator pure, (x_{gen}), from absorber rich, (x_{abs}) solution flows, where $m_{abs} = m_{gen} + m_{ref}$ logically.

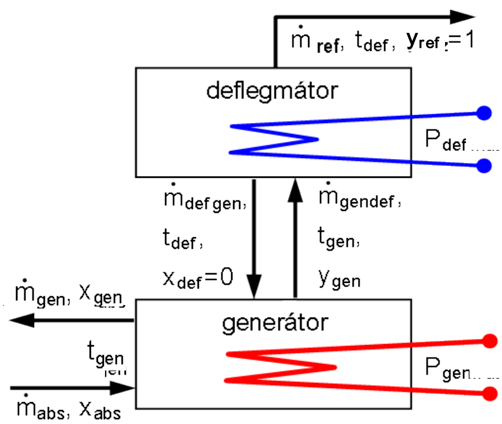

Figure 2. Layout of Generator

From the ammonia-water properties, the pressure and the concentration of arising steam can be estimated, from these the enthalpies of existing and arising phases can estimated as introduced before. To compose the energy equation of this part system, and express the heat request of this procedure from it. (1)

$$P_{gen}=\frac{dm_{gen}}{d\tau}\cdot h_{gen}+\frac{dm_{gendef}}{d\tau}\cdot h_{gendef}-\frac{dm_{abs}}{d\tau}\cdot h_{abs}-\frac{dm_{defgen}}{d\tau}\cdot h_{defgen} \quad (1)$$

The mass-streams are expressed from the mass-balance equation (2).

$$\frac{dm_{gen}}{d\tau}=\frac{y_{ref}-x_{abs}}{x_{abs}-x_{gen}}\cdot\frac{dm_{ref}}{d\tau} \quad (2)$$

Let us define the so called flow ratio as a yield of mass of solution that goes from absorber to generator and the mass of circulating refrigerant. (3) To simplify the calculation it is continued with a given mass unit of refrigerant.

$$FR=\frac{m_{abs}}{m_{ref}} \quad (3)$$

5. HEAT EXCHANGER

The rich and cold solution must be heated up to regenerator temperature. That needs the following heat. (4)

$$Q_{FR}=\cdot m_{ref}\cdot FR\cdot\int_{t_{abs}}^{t_{gen}}c_p\left(t,x_{abs}\right)\cdot dt \quad (4)$$

That job is helped by the heat exchanger. However this and the heat source have certain effectiveness. So the heat request of the entire system can be expressed. (5)

$$Q_{heat}=\frac{Q_{gen}+(1-\eta_{heatexcanger})\cdot Q_{FR}}{\eta_{heatsource}} \quad (5)$$

6. THE EXPANSION VALVE

In the expansion valve the liquid refrigerant gets partially evaporated. The pressure before the valve is known, and we can calculate the generator pressure. From those after the process arising the temperature can be calculated. (6)

$$p_{abs}=p(t_{abs},x_{abs}) \quad \text{and} \quad t_{exp}=t(p_{abs},x_{ref}) \quad (6)$$

The process is adiabatic, so when temperature falls, heat arises, it makes evaporate a part of refrigerant. The enthalpies can be calculated, so their difference as well (7), and the enthalpy of vaporization (8) from the property estimations, so the masses of vapor and liquid phases are the fallowing: (9)

$$\Delta h_{exp}=h_{liquid}\left(t_{cond},x_{ref}\right)-h_{liquid}\left(t_{exp},x_{ref}\right) \quad (7)$$

$$r_{ref}=h_{vapor}\left(p_{evap},x_{ref}\right)-h_{liquid}\left(t_{exp},x_{ref}\right) \quad (8)$$

$$m_{ref.vapor}=m_{ref}\cdot\frac{\Delta h_{exp}}{r_{ref}};\quad m_{ref.liqid}=m_{ewf}-m_{ref.vapor} \quad (9)$$

7. THE EVAPORATOR

Here, the remaining refrigerant evaporates (10), and gets heat up to the known t_{evap}. (11) This is the refrigeration power of the system (12). The evaporation is the significant part of the heat extraction.

$$Q_{ref.evap}=m_{ref.liquid}\left(h_{vapor}\left(p_{elp},x_{ref}\right)-h_{liquid}\left(t_{exp},x_{ref}\right)\right) \quad (10)$$

$$Q_{ref.over}=m_{ref}\cdot c_{p.vapor}\cdot\left(t_{evap}-t_{exp}\right) \quad (11)$$

$$Q_{ref}=Q_{ref.evap}+Q_{ref.over} \quad (12)$$

8. THE SOLUTION PUMP

The volume of the solution that flows from the absorber back to the generator is known also known the pressure difference between those. Only thing, the dynamical pressure loss of the pipe system, is not given by this model (13), (14).

$$W_{pump}=\frac{1}{\eta_{hidr}}\cdot FR\cdot\frac{m_{ref}}{\rho_{abs}}\cdot\Delta p \quad (13)$$

$$\Delta p=\left(p_{gen}-p_{abs}\right)+\Delta p_{other} \quad (14)$$

9. COP CALCULATION

Although the condenser and the absorber are missed out, for now, all data are available to calculate the COP (15). In these parts, no heat investment to the system, just we extract heat at ambient temperature. It could be calculated, but that does not affect the COP.

$$COP = \frac{Q_{ref}}{Q_{gen} + Q_{FR} + W_{pump}} = \frac{Q_{ref}}{Q_{heat} + W_{pump}} \cong \frac{Q_{ref}}{Q_{heat}} \quad (15)$$

According to this model (and according to the experiences), the pump means just a few percent of the entire energy request.

11. BEHAVIOR OF THE MODEL

This section shows how the temperatures of part units affect the COP. (Figure 3) The results of our model match the measured values and the behavior of more complicated mathematical models. [6]

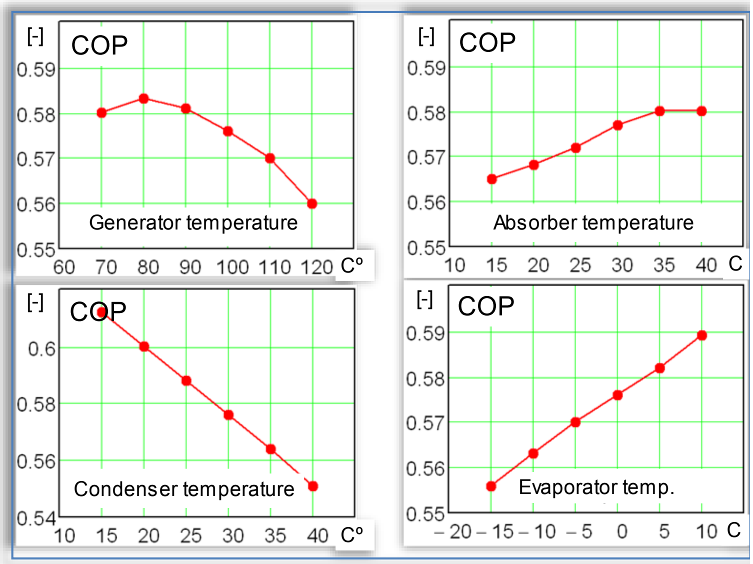

Figure 3. COP depending on the temperature of the different parts of the refrigeration circuit

12. CONCLUSIONS

In this article, we introduced the base of the absorption refrigeration, also introduced a mathematical model we developed to estimate the main parameters of that refrigeration method which works with the most frequently used ammonia-water refrigerant pair. This model is easier and more accurate than the previous ones. These main parameters are the refrigeration power, and heat request, the power request of the solution pump. Hereby we can calculate the COP of the entire system. Finally we showed its behavior of our mathematical model.

NOMENCLATURE

COP	Coefficient of Performance	[-]
c_p	special heat	[J/kg]
FR	flow ratio	[kg/kg]
H	enthalpy	[J/kg]
m	mass	[kg]
p	pressure	[bar]
P	power of heat	[W]
r	enthalpy of vaporization	[J/kg]
t	temperature	[°C]
Q	heat	[Joule]
x	NH_3 concentration in liquid phase,	[kg/kg]
y	NH_3 concentration in vapor phase,	[kg/kg]
W	work	[Joule]
τ	time	[s]

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