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## DESIGN OF AMMONIA RECOVERY SYSTEM

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**Abstract:** From environmental aspect purification of ammonia containing wastewater is expected. After the desorption process, ammonia can be recovered and used in another technology. The calculation method described below give some methods to find either the minimum column height or ammonia rich solution of the effluent.

**Keywords:** absorber, desorber, packed column

### 1. INTRODUCTION

Desorption of waste water containing ammonia in high concentration can be realized with air, in packed column filled with different packing elements. The desorption rate of the ammonia depends on the air-water rate, the air-water temperature, wetted area and the type and the height of the packing.

The ammonia diffused into the air – in appropriate concentration – can be usable material for further technologies.

The aim of the calculation can be to investigate the main parameters that have influence on the running and investment costs. Otherwise the aim of the design can be to produce ammonia rich water concentration so that the ammonia can be recycled in another process.

### 2. THE PROCESS

The process wastewater – from previous water treatment – flows to the recovery system. Fig.1. shows the scheme of the recovery system. This process realizes  $\text{NH}_4\text{OH}$  aqueous solution from the waste water to be used in further technologies.

Desorption of the ammonia from the waste water occurs with air in the desorption column **1**. The rate of ammonia desorption depends on the temperature, the height of the packed column and the air flow. The air - containing ammonia – flows into the absorption column **2**.

In this column ammonia diffuses into pure, chilled water. Proper contact between gas and liquid phase and low temperature produces ammonia rich concentration. Aqueous ammonia solution from the absorber can be recycled in another technology.

Water, from column **1** needs further purification or can be drained. The concentration of the air emission from the absorption column must be under limit.

The required temperature for desorption and absorption process is assured by heat exchangers **3** and **4**.

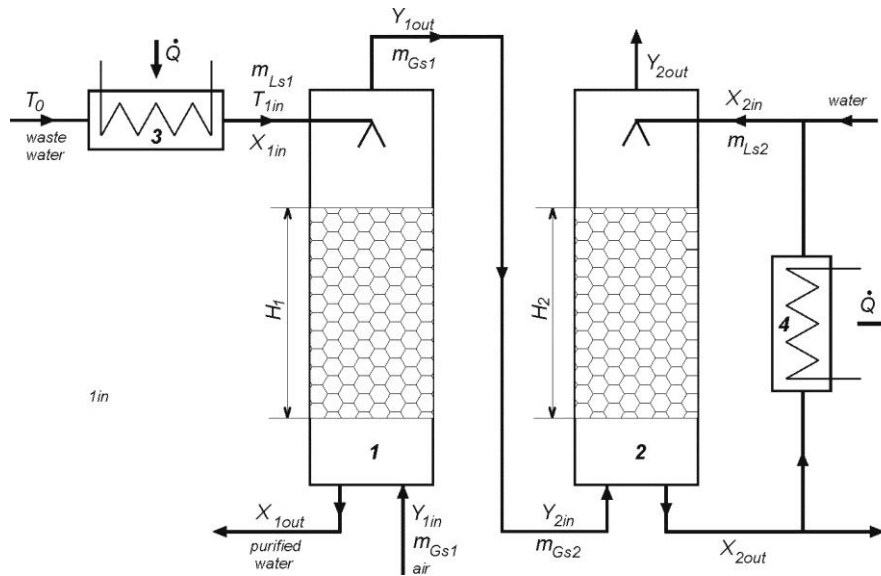


Fig 1. Scheme of the process

### 3. EQUATIONS

In a counter-current packed column mass transfer occurs on the phase-contacting area. Generally, literatures dealing with absorption and desorption discuss the phenomenon in molar flow [1,4]. The material balance of the diffusible component between the cross section **A** and **B** of Fig.2. can be written both for absorption and desorption:

$$G_S \cdot Y_{in} + L_S \cdot X_{in} = G_S \cdot Y_{out} + L_S \cdot X_{out} \quad (1)$$

As  $G_S$  and  $L_S$  are constant:

$$G_S(Y_{in} - Y_{out}) = L_S(X_{out} - X_{in}) \quad (2)$$

In the desorption column **1** the right side of Eq. (2) gives the amount of ammonia released from the water, the left side of Eq.(2) gives the molar flow of the diffusible component ( $\text{NH}_3$ ) into the air.

In the case of absorption column **2**, the left side of Eq. (2) shows the molar flow of ammonia released from the air, the right side shows the amount of ammonia absorbed in pure water.

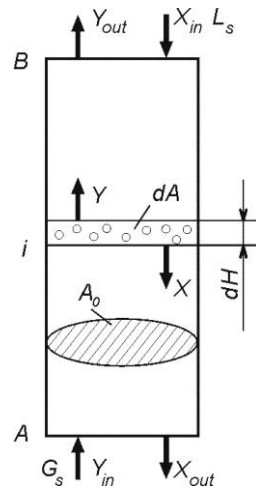
Molar flow of the gas phase:  $G = G_D + G_S$

Molar flow of the liquid phase:  $L = L_D + L_S$

Concentration of the gas (Y) and liquid (X) phase:

$$Y = \frac{G_D}{G_S} \quad G_D = \frac{m_{GD}}{M_D} \quad G_S = \frac{m_{GS}}{M_{GS}}$$

$$X = \frac{L_D}{L_S} \quad L_D = \frac{m_{LD}}{M_D} \quad L_S = \frac{m_{LS}}{M_{LS}}$$



**Fig. 2.** Scheme of the absorber and desorber column

Material balance for the diffusible component ( $\text{NH}_3$ ) between cross section **A** and **i** of Fig. 2. gives the operating line. For absorption and desorption the operating line of the process:

$$Y = Y_{in} + \frac{L_S}{G_S} (X - X_{out}) \quad (3)$$

The slope of operating line from Eq.(3) and in Fig. 3. expresses liquid and gas ratio:

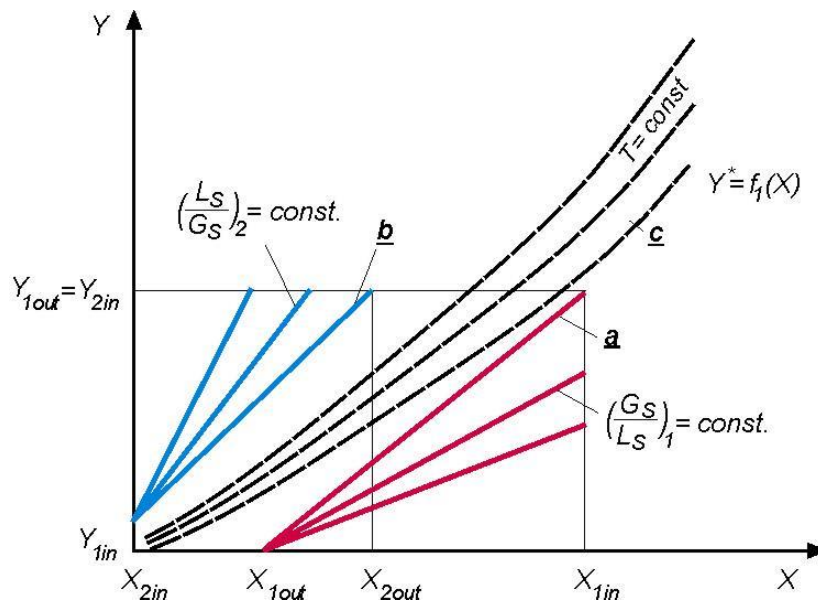
$$\frac{L_S}{G_S} = g \left( \frac{m_{LS}}{m_{GS}} \right)_{1,2}$$

Fig. 3. shows the practicable site of the operating line, **a** – lines in the desorption column and **b** - lines in the absorption column.

The position of the equilibrium curve  $Y^* = f_1(X)$  show curves **c.**, at constant temperature.

Meanwhile, the slope of equilibrium curve will be straight if the system obeys Henry's law.

The difference between the operating line and the equilibrium curve expresses the driving force.



**Fig. 3.** Position of the operating line and equilibrium curve

Mass transfer rate at steady state on  $dA$  surface in Fig 2. can be expressed by the transfer coefficient, the driving force and the contacting area:

$$N_{NH_3}dA = d(G_S \cdot Y) = K_Y(Y - Y^*)dA \quad (4)$$

The differential contacting area with the wetted area of the packing  $a$ , tower cross section  $A_0$  and differential height  $dH$ :

$$dA = a \cdot A_0 \cdot dH \quad (5)$$

With Eq. (4) and (5):

$$dH = \frac{G_S}{K_Y a A_0} \cdot \frac{dY}{Y - Y^*} \quad (6)$$

Assuming:  $G_S = const.$ ,  $K_Y \approx const.$ ,  $a = const.$ ,  $A_0 = const.$ , integrating Eq. (6) from the bottom to the top of the column:

$$H = \int_{H=0}^{H=H} dH = \frac{G_S}{K_Y a A_0} \int_{Y_{ki}}^{Y_{be}} \frac{dY}{Y - Y^*} = H_{OG} \cdot N_{OG} \quad (7)$$

The definitions of  $H_{OG}$  and  $N_{OG}$  are given as follows:

Height of overall transfer unit:

$$H_{OG} = \frac{G_S}{K_Y a A_0}$$

Number of overall transfer unit:

$$N_{OG} = \int_{Y_{ki}}^{Y_{be}} \frac{dY}{Y - Y^*}$$

## 4. RESULTS

### 4.1 Desorption column

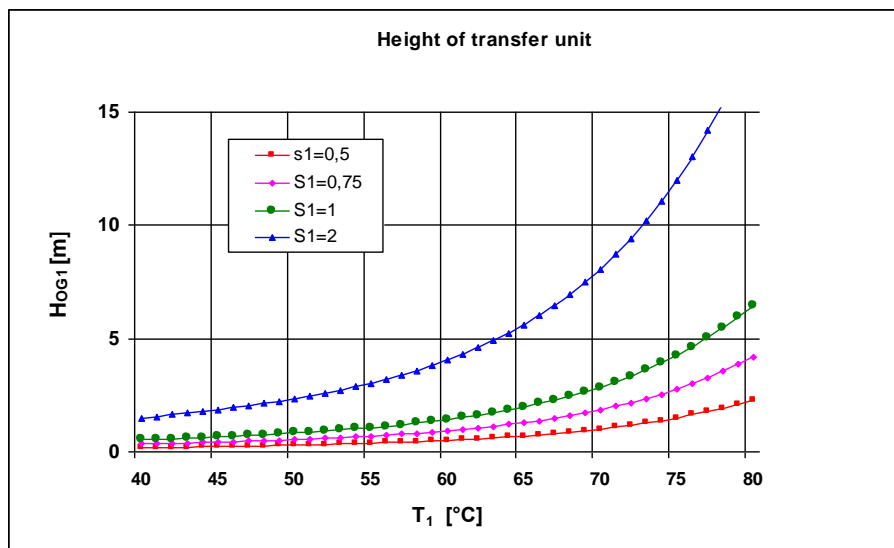
In the desorption process of ammonia-air-water, the temperature and the gas-liquid rate is essential. The height of overall mass transfer unit [3] :

$$H_{OG1} = C_1 \left( \frac{m_{GS}}{m_{LS}} \right)_1 b_1$$

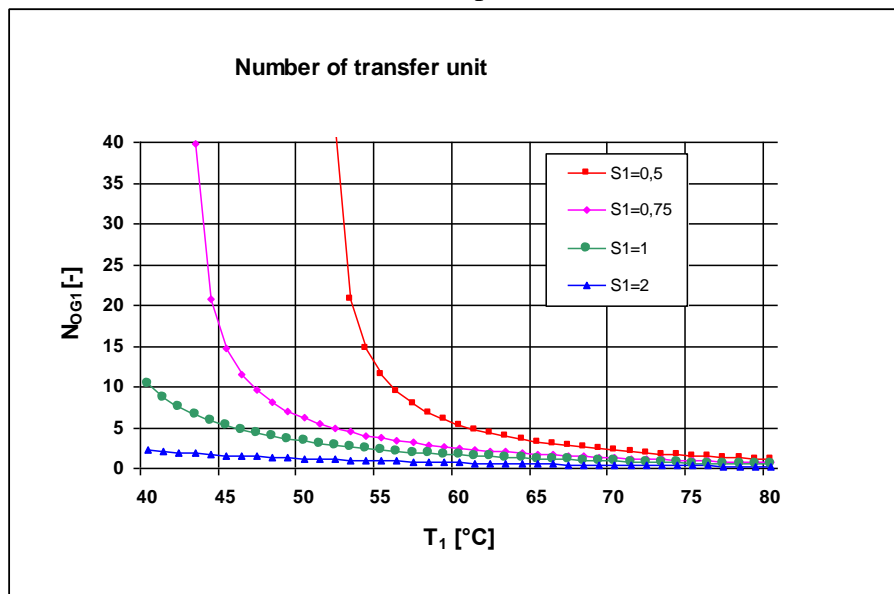
The gas-liquid rate in the desorption column is:

$$s_1 = \left( \frac{m_{GS}}{m_{LS}} \right)_1$$

Fig. 4. shows the influence of the temperature and the gas-liquid rate on the height of overall mass transfer unit. The driving force of the desorption process is proportional to the number of transfer units, that depend on the temperature and the gas-liquid rate, Fig. 5.



**Fig. 4.** Height of transfer unit in function of temperature and gas-liquid rate at desorption



**Fig.5.** Number of transfer unit in function of temperature and gas-liquid rate at desorption

The height of the packed column according to Eq. (7) can be seen in Fig.6. The gas-liquid temperature has great influence on the height of the column in the lower temperature interval. Desorption of the given ammonia amount in certain low temperature and low gas-liquid rate is unrealizable.

According to the calculation, the lowest packed height can be expected between 60-70 °C, at gas-liquid rate  $s_1=1$ , in the observed case. Fig.6. shows vary of the heat exchanger surface in function of the process temperature.

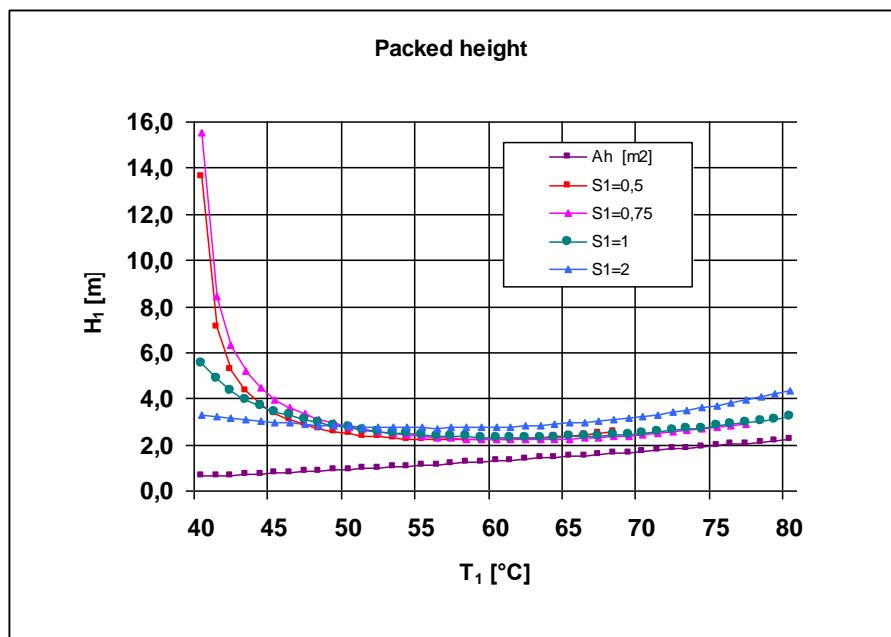


Fig. 6. Packed height of the desorber column in function of temperature

#### 4.2 Absorption column

The recycling of the ammonia takes place in the absorption column 2. In this column gas diffuses into pure and chilled water. The gas flows into the absorption column with the amount of  $m_{GS1}$ , that equal up to the rate  $s_1=1$ .

The liquid-gas rate in the absorption column is: 
$$s_2 = \left( \frac{m_{LS}}{m_{GS}} \right)_2$$

The height of overall mass transfer unit at absorption depends on the liquid-gas rate and the wetted surface of the packing [3]:

$$H_{OG2} = C_2 \frac{(m_{GS2})^{a_2}}{(m_{LS2})^{b_2}}$$

Fig.7. and 8. show the height and number of transfer units in function of temperature and liquid-gas rate, Fig. 9. illustrates the packed height, with SO-Spirax type packing.

In case of ammonia absorption with decreasing temperature, the packed height decreases as well. The lowest air-water temperature depends on the applied technology. The contacting, wetted surface of the different packings also have influence on the height of the column. Fig.10. shows the influence of the contacting, wetted surface of the different packings (M-Spirax  $a=127 \text{ m}^2/\text{m}^3$ ; L-Spirax  $a=94 \text{ m}^2/\text{m}^3$ ; SO-Spirax  $a=185 \text{ m}^2/\text{m}^3$ ; Metalett40  $a=144 \text{ m}^2/\text{m}^3$ ).

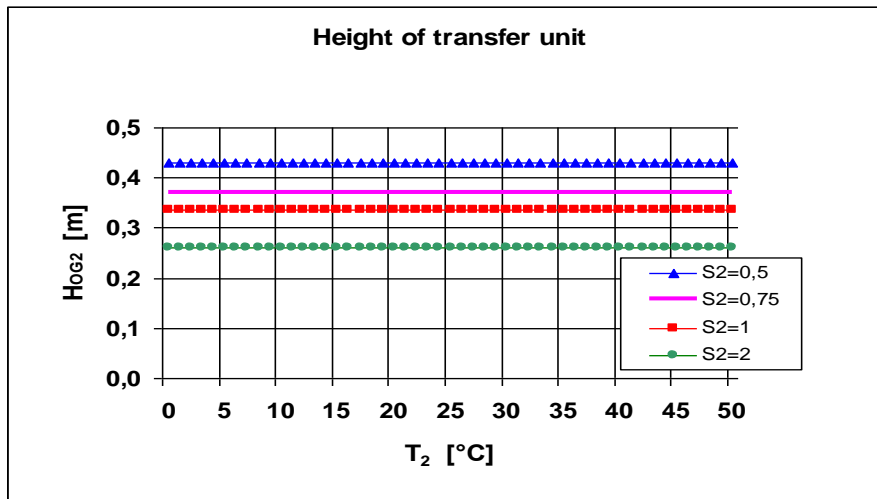


Fig.7. Height of transfer unit in function of temperature

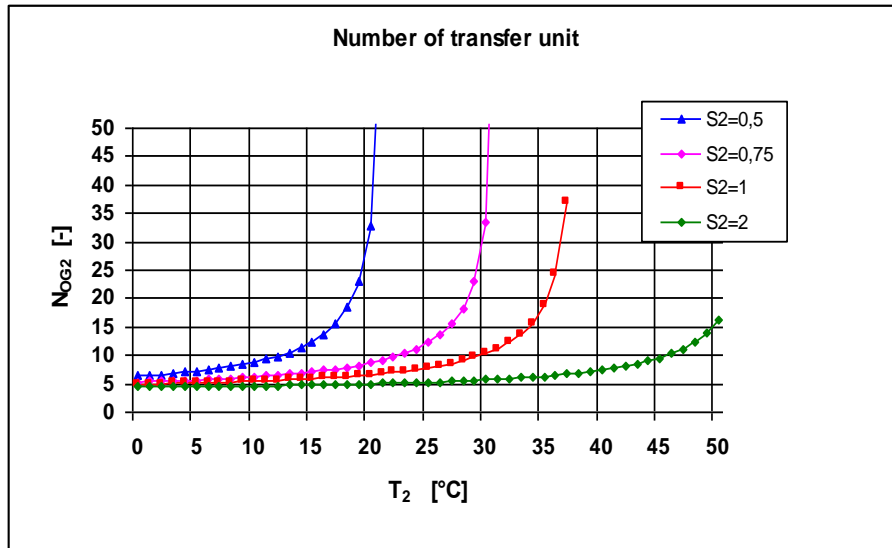


Fig. 8. Number of transfer unit in function of temperature

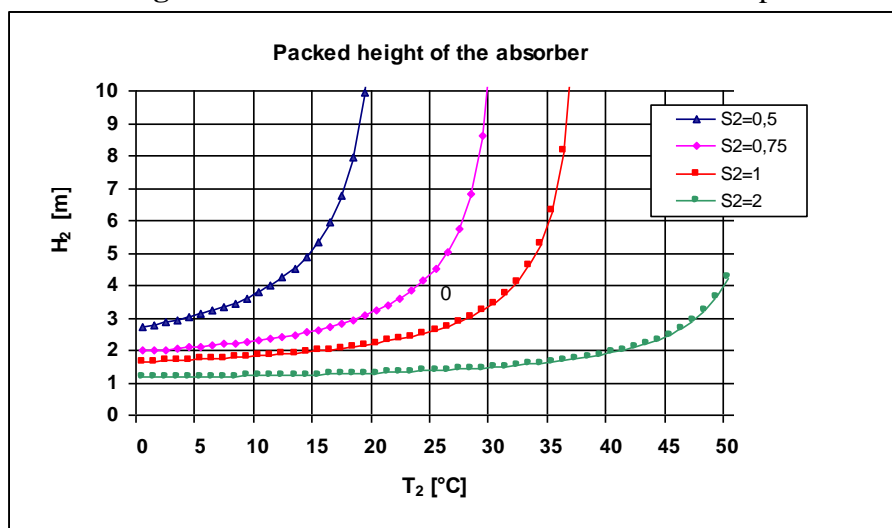
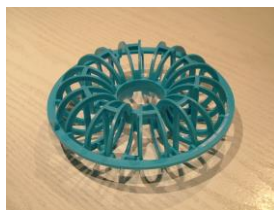
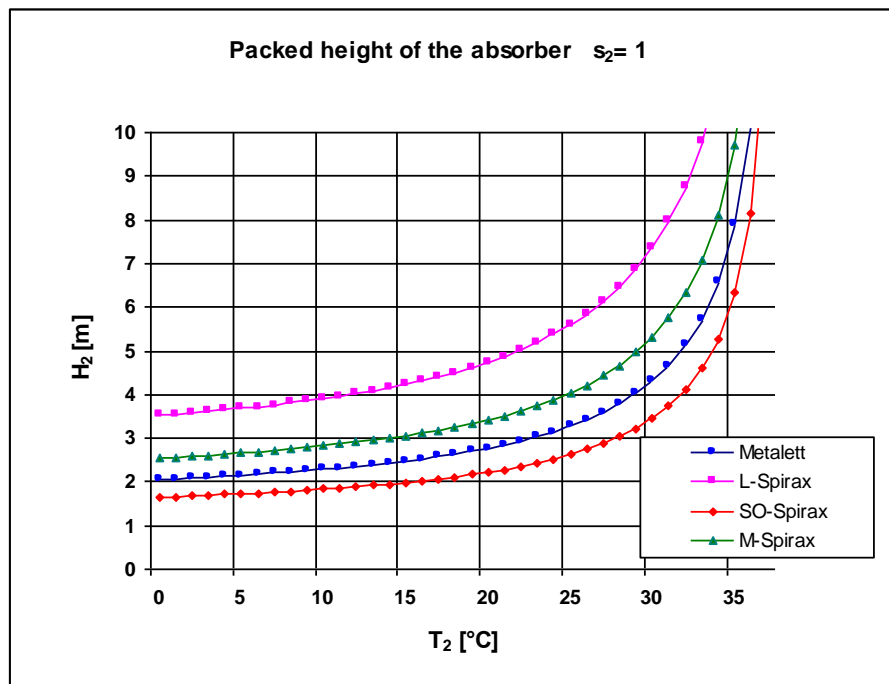


Fig. 9. Packed height of the absorber column in function of temperature



M-Spirax



L-Spirax



SO-Spirax



Metalett40

**Fig. 10.** Packed height of the absorber in function of temperature and different packing elements

The aim of the design can be to get the lowest packed height, or apply equal column height in both columns. Another aim of the design can be to get ammonia rich effluent of the absorption column 2 as much as possible  $X_{2out} > X_{1in}$ .

For this case an illustration can be seen in Fig. 11. with the operating parameters listed below:

$$m_L = 1200 \text{ kg/h}$$

$$X_{1in} = 1,6 \cdot 10^{-2} \text{ mol NH}_3/\text{mol H}_2\text{O}$$

$$X_{1out} = 5,4 \cdot 10^{-4} \text{ mol NH}_3/\text{mol H}_2\text{O}$$

$$Y_{1out} = Y_{2in} = 4,95 \cdot 10^{-2} \text{ mol NH}_3/\text{mol air}$$

$$X_{2out} = 6 \cdot 10^{-2} \text{ mol NH}_3/\text{mol H}_2\text{O}$$

$$Y_{2out} = 9 \cdot 10^{-4} \text{ mol NH}_3/\text{mol air}$$

## 5. CONCLUSION

Observing the system for purifying waste water and recycling the ammonia into a process, one can declare, that the best operating conditions can be achieved by proper temperature and gas-liquid rate. The packed height – main size of the column – depends on the type of packing as well. With this method we are able to calculate the desired or optimal operating parameters.



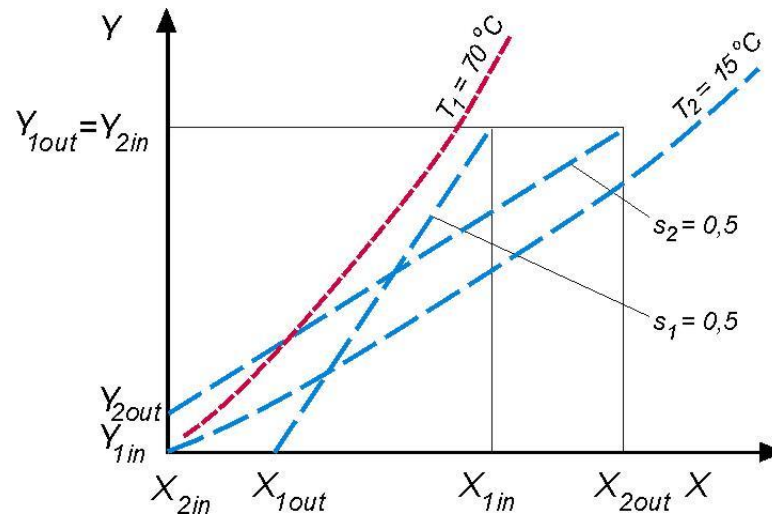


Fig. 11. Position of the operating line and equilibrium curve

### NOMENCLATURE

a	- wetted area of the packing	[m <sup>2</sup> /m <sup>3</sup> ]
A	- gas-liquid contact area	[m <sup>2</sup> ]
A <sub>0</sub>	- cross section	[m <sup>2</sup> ]
A <sub>h</sub>	- heat exchanger surface	[m <sup>2</sup> ]
C <sub>1</sub>	- constant	
C <sub>2</sub>	- constant	
G	- mol flow of the gas phase	[mol/s]
G <sub>D</sub>	- mol flow of the ammonia in the gas phase	[mol NH <sub>3</sub> /s]
G <sub>S</sub>	- mol flow of the inert (air)	[mol air/s]
H	- height	[m]
HOG	- height of overall transfer unit	[m]
K <sub>Y</sub>	- overall mass transfer coefficient	[mol/m <sup>2</sup> /s/P]
L	- mol flow of the liquid phase	[mol/s]
L <sub>D</sub>	- mol flow of the ammonia in the liquid phase	[mol NH <sub>3</sub> /s]
L <sub>S</sub>	- mol flow of the inert (water)	[mol waters/s]
m <sub>GS</sub>	- mass flow of the inert (air) in the gas phase	[kg air/s]
m <sub>GD</sub>	- mass flow of the ammonia in the gas phase	[kg NH <sub>3</sub> /s]
m <sub>LS</sub>	- mass flow of the inert (water)	[kg water/s]
m <sub>LD</sub>	- mass flow of the ammonia in the liquid phase	[kg NH <sub>3</sub> /s]
M <sub>D</sub>	- molecular mass of the diffusible (NH <sub>3</sub> ) component	[g/mol]
M <sub>GS</sub>	- molecular mass of the inert gas	[g/mol]
M <sub>LS</sub>	- molecular mass of the inert liquid	[g/mol]
N <sub>NH3</sub>	- transfer rate of ammonia	[kmol/m <sup>2</sup> /s]
N <sub>OG</sub>	- number of overall transfer unit	[-]
s <sub>1</sub>	- gas-liquid rate in the absorber	[-]
s <sub>2</sub>	- liquid-gas rate in the desorber	[-]
T	- temperature	[°C]

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