FEASIBILITY EVALUATION OF SOME METHODS AND INSTALLATIONS FOR CLEANING OF WORKING AIR FROM INDUSTRIAL PLANTS

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Abstract: The techno-economic evaluation of four of the most used methods for cleaning of air by industrial work areas, polluted with organic vapor compounds, is done. The operating costs and the value of the energy sources needed for these methods implementation and the value of the recovered solvents are defined. Their advantages and disadvantages are established.
Keywords: air cleaning, volatile organic compounds, ethanol, methanol, ethyl acetate

Introduction:

The air in work zones in many companies from food, biotechnological and other industries is polluted with vapors of different volatile organic solutions (VOS), used in technological process. Under the Law on protection of the environment [7], synchronized with the European legislation on environmental protection and the Regulation for the procedure of issuing complex permits for building and exploitation of existing industrial plants [8] it is required the application of best available techniques in the field of environmental protection and air protection in the working premises. Therefore, such companies need to build plants for working air purification. In addition to the realized environmental effect the economic effect can be achieved through these solvents recovery [1].

In the selection of appropriate technology for purification of air the origin, concentration and other parameters of contaminants such as corrosivity, abrasiveness, toxicity, flammability, temperature, relative humidity, pressure, flow and content of particles in the emissions, efficiency, maximum admissible concentrations (MAC), opportunities and economic efficiency for recycling or recovery of the respective pollutant, energy efficiency, costs of installation and maintenance, etc. must be taken into account. In practice, different methods and technical equipment for purification of polluted with vapors of organic substances air, which have several advantages and disadvantages [12.13] are used.

The purpose of this study is analysis and evaluation of four of most used in practice methods for purification of air from the working premises from vapors of the most used volatile organic solvents (VOS).

Materials and methods:

The possibility and the costs for separation of vapors of the most widely used in industry organic solvents ethanol, methanol and ethyl acetate from their respective mixtures with air in the working premises was examined.
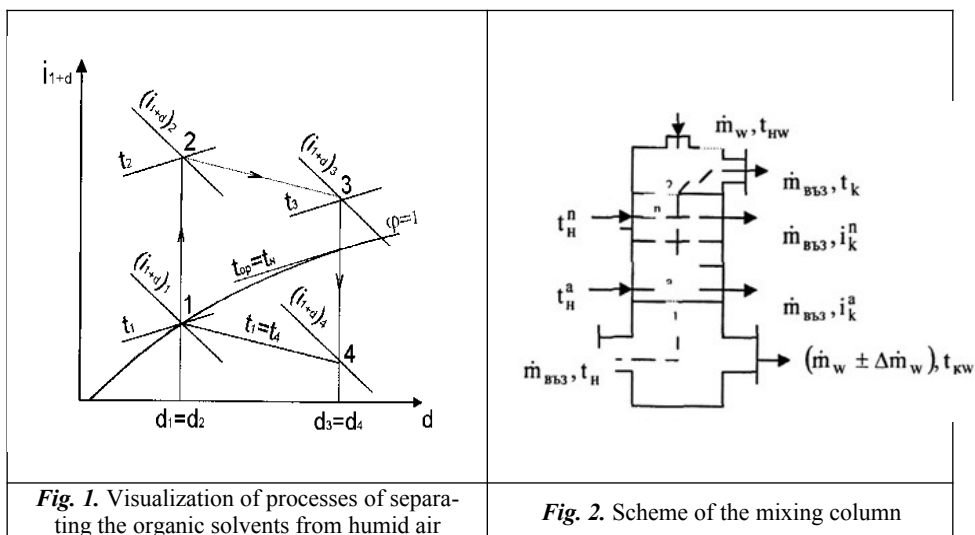
The following technical solutions were studied:

I method - Condensation. Solvent's vapors were separated from air by installation, which consists of condenser, fan and heater. The contaminated air is sucked by the fan and passes through the condenser, where is indirectly cooled by water from the environment.

Part of the organic vapors condense and then are separated as a liquid. The rest air, still containing some organic vapor is heated in the heater to its initial temperature and returns to the working area.

II method – Cryocondensation. The organic solvent vapor is separated from the air in working areas by indirect cooling to lower temperatures with refrigerant. The installation consists of fan, calorifier and refrigerating machine [4]. The air from the workplace is sucked by the fan (point 3) and submitted to the evaporator-condenser of the refrigeration machine. Here the mixture is cooled indirectly with refrigerant, the organic vapors condense (point 4), the obtained condensate is separated and the remaining air (point 1) is again heated in the heater to its initial temperature (point 2) and returned in the work area (fig. 1). This variant gives possibility for complete separation and recovery of the organic solvent.

III method - Absorption. The contaminated air is submitted to the bottom of the mixing packed column (scrubber), and the top of the filling is irrigated with water (Fig. 2). Here the gas mixture is cooled and the solvent vapors condense and then are discharged along with the water at the bottom of the scrubber and then are regenerated. The cleaned air is removed from the top of the column.

Fig. 1. Visualization of processes of separating the organic solvents from humid air	*Fig. 2.* Scheme of the mixing column

IV method - Adsorption. The air from the working area containing organic vapors is pressed into an installation for adsorption of these organic vapors. Activated carbon, which has a large specific surface is used as an adsorbent. After saturation of the activated carbon it is regenerated with steam, as absorbed organic vapors are mixed with water vapor and, after cooling, are separated from it.

The thermodynamic diagrams "enthalpy - vapor content of the organic solvents" in which the gas mixture "air-organic vapor" is regarded as a binary mixture (moist air with constant moisture content of 0.01 kg/kg and vapor of organic solvent) [3, 9, 10] are used for graphical presentation of the studied processes For comparison the discussed four methods for purification of air is considered the same solvent flow rate of regenerated solvent in all

methods - 1 kg/h. The actual prices with VAT for industrial consumers in force at 1.1.2012 (electricity - 0.179 BGN/kWh, water - 1.98B GN/m^3, heat energy - 110 BGN/MWh) were used for determination of the economic efficiency of the proposed methods and installations. The prices of the investigated organic solvents including VAT are: ethanol - 19.50 BGN/l, methanol - 1.60 BGN/l, the ethyl acetate - 4.70 BGN/l, according to [14].

Results and discussion:

At the first method part of the solvent vapors from the polluted air condense by cooling with water. The disadvantage of this method is that the used cooling water is has an initial temperature of about 14 ^{0}C, thus the mixture "humid air - organic vapors" can not be cooled below 17 ^{0}C. This does not allow the concentration of organic vapors in air to be reduced to a minimum limit from the point of view of admissible limits of ignition. If it is assumed that the content of organic vapors in air before cooling is d_3 (Fig. 1, Table 1), from the i, d - diagram [3, 9, 10] is read that at 17 ^{0}C the ethanol vapor content in the gas mixture is $d_4 = 0.08$, the methanol vapor content - $d_4 = 0.13$, and in the case of ethyl acetate the temperature at all did not reaches the dew point and it is impossible to separate its vapor from the gas mixture. Therefore, this method can't be used for cleaning of the air polluted with ethyl acetate vapors. The operating costs of this method are: cost of cooling water and steam consumption for heating of the purified air into the heater.

At the second method the cooling of the mixture "air - vapor of organic solvent" is carried out with refrigerating machine. Depending on the considered organic solvent it is assumed that for the ethanol $t_4 = 7.2$ ^{0}C; for the methanol - $t_4 = 8.5$ ^{0}C and for the ethyl acetate - $t_4 = - 7.1$ ^{0}C. These temperatures are the dew point temperatures at the minimal limit of ignition of the corresponding organic vapors in air, according to [2]. Operating costs for this variant are: electricity for the fan, compressor and pump for cooling water, as well as the consumption of cooling water and steam for heating of the purified air into the heater.

At the first and second methods the specific enthalpy of conditions 1 and 2 are read by the respective i, d-diagrams. The enthalpy of state 3 is calculated from the energy balance of the corresponding apparatus, and the enthalpy of the state 4 - analytical (the point is located in the area of the fog). The heat flux $\dot{Q}_{34}$ which must be discharged from the condenser - evaporator for cooling of the gas mixture is determined.

$$\dot{Q}_{34} = \dot{m}_B.(i_4 - i_3), \tag{1}$$

where: i_3 and i_4 are the specific enthalpies of the gas mixture before and after the condenser-evaporator [J/kg];
- mass flow rate of the humid air, [kg/s].

From the energy balance of the heater is defined the heat flux $\dot{Q}_{12}$ for heating the humid air from state 1 to state 2.

$$\dot{Q}_{12} = \dot{m}_B.(i_2 - i_1), \tag{2}$$

where: and i_2 are the specific enthalpy of moist air before and after the heater [J/kg].

For the second method - the output of the compressor and the efficiency ratio of the refrigeration machine are calculated. The consumption of electricity, steam and cooling water, required for separation of the organic vapors from humid air are defined [5]. The

economic effect of the work of these installations in industrial environments to purify contaminated with organic vapor moist air is estimated. The recovered organic solvents are returned to the main production process.

For the III-td method it is accepted that the mass flow rate of gas mixture is 51 kg/h (mass flow rate of air - 50 kg/h and mass flow rate of organic vapors - 1 kg/h). For the mixture "air - vapors of ethanol" the required mass flow rate of cooling water is 104.5 kg/h, and its cost is 0.21 BGN/h. For the mixture "air – methanol's vapors" the required mass flow rate of water is 196.3 kg/h, and its cost is 0.39 BGN/h. Calculations for the change in temperatures of the mixture "air-organic solvent vapors" and of the cooling water for each stage of the scrubber's height are done [6]. The results are presented in Fig. 3 and 4. A pump with output of 0.37 kW and a fan with output 0.245 kW are chosen.
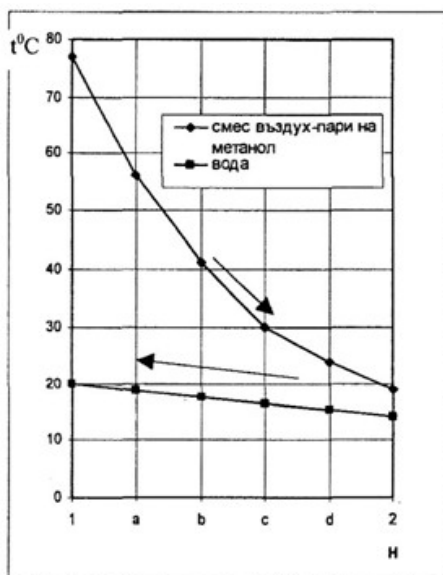

Fig. 3. Change in temperatures of the mixture "air-methanol's vapors" and of the cooling water for each stage of the scrubber's height, if the outgoing water temperature is 20 ^{0}C
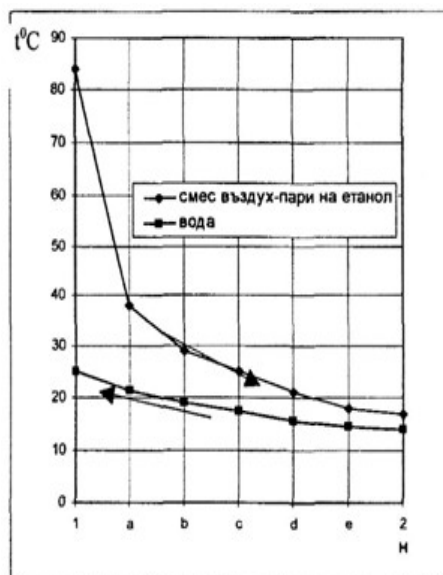
Fig. 4. Change in temperatures of the mixture "air-ethanol's vapors" and of the cooling water for each stage of the scrubber's height, if the temperature of the outgoing water is 25 ^{0}C

For the IV-th method - the organic vapors from the air are adsorbed of activated carbon and then the organic solvents are recovered by desorption. This method is used at low concentrations of organic vapor in air (50 g/m3). It uses electricity for fans, steam, hot and cold air for desorption process and additional energy for distillation of solvents. The average energy consumption for 1 t recovered solvent is: water vapor - 3 ÷ 5 t, cooling water - 30 ÷ 100 m^3, electricity - 50 ÷ 600 kWh and activated carbon – 0.5 ÷ 1 kg [11]. The results of the data processing for the four studied methods are presented in Table 1.

Table 1. Parameters of the process cleaning of polluted with volatile organic components air

Method	Parameter	Ethanol	Methanol	Ethyl acetate
Meth od	d_4, kg/kg	0,10	0,15	0,185
	Mass flow of recovered solvent, kg/h	**1**	**1**	**1**
	Value of recovered solvent, BGN/h.	**15,31**	**1,26**	**4,20**
I	t_1, ^{0}C	17	17	-
	d_1, kg/kg	0,08	0,13	-
	t_3, ^{0}C	84	77	-
	t_4, ^{0}C	17	17	-
	$\dot{Q}_{12}$, W	1306	1360	-
	$\dot{Q}_{34}$, W	1328	1369	-
	Steam consumption, kg/h	2,13	2,22	-
	Cooling water consumption, kg/h	19,0	23,4	-
	Operating costs, BGN/h	**0,18**	**0,194**	**-**
II	t_1, ^{0}C	7,2	8,5	-7,1
	d_1, kg/kg	0,042	0,08	0,068
	t_3, ^{0}C	51	27	57
	t_4, ^{0}C	7,2	8,5	-7,1
	$\dot{Q}_{12}$, W	479	400	285
	$\dot{Q}_{34}$, W	499	410	316
	Refrigerating ratio - ε	3,1	3,2	3,16
	Compressor consumption, kW	0,16	0,13	0,1
	Steam consumption, kg/h	0,78	0,65	0,47
	Cooling water consumption, kg/h	18,7	15,48	12,24
	Operating costs, BGN/h	**0,12**	**0,10**	**0,0734**
III	Cooling water consumption, kg/h	104,5	196,3	-
	Pump and fan consumption, kW	0,615	0,615	-
	Operating costs, BGN/h	**0,32**	**0,50**	
IV	Steam consumption, kg/h	4	4	4
	Water consumption, kg/h	0,065	0,065	0,065
	Electricity consumption, kWh/h	0,3	0,3	0,3
	Activated carbon consumption, kg/h	0,00075	0,00075	0,00075
	Operating costs, BGN/h	**0,46**	**0,46**	**0,46**

Conclusion:

1. Analysis and evaluation for four of most used in practice methods for cleaning of polluted air with VOS vapors (condensation, cryocondensation, absorption and adsorption) have been done.

2.Operating costs for the I, II and III method are calculated, and these for the IV method are taken according to the literature. The obtained results show that the economic effect (profitability) from regeneration of 1 kg VOS from the polluted air in installation according to the II method is considerably higher in comparison with the rest three methods.

3.The I and III methods couldn't be applied to cleaning of polluted with ethyl acetate vapors air. The IV method could be used only when the organic vapors content in air is up to 0, 05 кг/m³, and except of that these installations are too large and complicated [11].

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References:

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1. Белевецкий АМ. Проектирование газо-очистительных сооружений. *Л., Химия, 1990.*

2. Вълчев Г. Рашева В. Танева Д. Термодинамични параметри на смес от влажен въздух и пари на етанол, метанол и етилацетат. *"Механика на машините", бр. 54, ТУ - Варна, 2004.*

3. Вълчев Г. Рашева В. Ташева Ст. Термодинамична диаграма "енталпия– съдържание на пари на етанол" за смес от влажен въздух и пари на етилов алкохол. *Научни трудове на УХТ - Пловдив, Том XLIX, 2003.*

4. Вълчев Г. Рашева В. Ташева Ст. Танева Д. Инсталация за отделяне на органични разтворители от влажен въздух. *Научни трудове на УХТ - Пловдив, Том L, 2003.*

5. Вълчев Г. Танева Д. Рашева В. Сравнителен анализ на някои технологични схеми и методи за очистване на влажен въздух от пари на органични разтворители. *Научна конференция с международно участие "Хранителна наука, техника и технологии 2006", Сборник доклади, Свитък 2, том LIII, 27-28 октомври 2006, с. 183-188.*

6. Вълчев Г. Танева Д. Рашева В. Ташева Ст. Възможности за очистване на влажен въздух от пари на органични разтворители. ТУ - Сливен, *Сп. "Механика на машините" № 88, Издателство на ТУ – Варна, година XVIII, кн. 4, 2010, с. 73 - 76.*

7. Закон за опазване на околната среда *(ДВ, бр. 91/2002 и бр. 77/2005).*

8. Наредба за реда за издаване на комплексни разрешителни за изграждане и експлоатация на действащи промишлени инсталации *(ПМС 62/12.03.2003, ДВ, бр. 26/2003).*

9. Рашева В. Вълчев Г. Костов А. Термодинамична диаграма "енталпия- съдържание на пари на етилацетат" за смес от влажен въздух и пари на етилацетат. *Научна конференция "Ст. Загора 2003", Сборник доклади, Том II, 2003.*

10. Рашева В. Вълчев Г. Ташева Ст. Термодинамична диаграма "енталпия- съдържание на пари на метанол" за смес от влажен въздух и пари на метилов алкохол. *"Механика на машините", бр. 48, ТУ - Варна, 2003.*

11. Henning K.D. Degel J. Purification of air, water and off gas – solvent recovery. *Meeting of the European Rotogravure Association Engineering Group, Mulhouse, France, 1990.*

12. Schifftner KC. Hesketh HE. Wet Scrubbers. *Press CRC, 1996.*

13. Faisal I. Khan and А1окс Кг. Ghoshal. Removal of Volatile Organic Compounds from polluted air. *Journal of Loss Prevention in the Process Industries, Volume 13, Issue 6, 2000, pp. 527-545.*

14. www.teocom.eu