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THERMODYNAMIC DIAGRAM «ENTHALPY-HEXANE VAPOR CONTENT» FOR HUMID AIR-HEXANE VAPOR MIXTURE

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В разных отраслях промышленности используются органические разтворители, которые в ходе технологического процеса выделяются ввиде пара в воздух рабочей среды, а затем выбрасывается в атмосферу. Это приводит к ухудшению параметров рабочей среды и загрязнению атмосферного воздуха. В работе проведены иследования термодинамических параметров смеси влажного воздуха и паров гексана. Также построена термодинамическая «энтальпия – содержание паров гексана» для исследуемой смеси при насыщении воздуха органическоми парами от 0 % до 100 %. Диаграмма может быть использована в практике при строительстве промышленной установки для очистки воздуха.

Organic solvents are used in different industrial branches such as food and flavor, cosmetics, pharmaceutical, biotechnological, printing and etc. During the technological process they are evaporated and saturated the humid air and than exhausted into the atmosphere. This leads to deterioration of the working environment parameters and pollution of the atmosphere. The thermodynamic properties of the mixture humid air-hexane vapor for φ = 0 to 100 % are studied in this paper. Equation of the specific enthalpy of this mixture is derived and thermodynamic diagram «enthalpy-hexane vapor content» for humid air-hexane vapor mixture is plotted.

Key words: humid air, hexane, vapor, workplace, safety, environment, pollution.

Introduction

Organic solvents are often used in different industrial branches such as food and flavor, cosmetics, pharmaceutical, biotechnological, printing, production of coatings, varnish, ink, gum and rubber, impregnation and laminating of wood and plastic, and etc. In accordance with the European requirements for limitation and prevention of environmental pollution by Regulation No. 7 from 21.10.2003 in Bulgaria are set emission limit values of volatile organic compounds emitted from the installations where organic solvents are used. On the other hand, by Regulation No. 13 from 30.12.2003 are set standards for the protection of workers from risks related to exposition to chemical agents at work [6,7].

In accordance with Directives 2009/32/EO and 2008/128/EO, and Bulgarian Regulation No. 21 from 15.10.2002, hexane is permitted for use as an extraction solvent in the production and/or fractionation of fats and oils, production of cocoa butter, formulation of defatted cereal germs, production of some flavorings and for extraction of colorants for using in foods as additives [5].

During the technological process used organic solvent is evaporated and saturates the humid air and then it is exhausted into the atmosphere. This leads to deterioration of the working environment parameters and pollution of the atmosphere and in definite concentrations of the organic vapor into the air, explosive mixtures can be formulated. Therefore it is necessary to separate the organic solvent vapor from the air and subsequently regeneration and recycling of the solvent. Thus will be realized both environmental and economic effects [1, 2].

For thermal and constructive calculations of the industrial installations for separation and recovery of the organic solvents vapors from the air it is necessary to have a thermodynamic diagram «enthalpy – organic solvent vapor content» for humid air – organic solvent vapor mixture such as [2,3,8,9].

The aim of this research is to developed a thermodynamic diagram «enthalpy – hexane vapor content» for humid air saturated with hexane vapor from 0 to 100 % in barometric pressure.

Materials and methods

Mixture of humid air and hexane vapor is examined as a two components mixture of humid air with constant moisture content d_1 and hexane vapor with changeable content d_2. According to [11] can be assumed that the humid air has constant moisture content d_1=0,01 kg water/kg dry air. Then the specific enthalpy of the humid air – hexane vapor mixture can be calculated by the following equation:

$$i(1+d_1+d_2)=i_{d.a.}+0{,}01\,.i_{w.v.}+d_2\,.i_{h.v.}\,, \qquad (1)$$

where:

$i_{d.a.}$, $i_{w.v.}$, $i_{h.v.}$ – are the specific enthalpies of dry air, water vapor and hexane vapor respectively, kJ/kg.

Specific enthalpy of dry air can be represented as a multiplication of its isobaric specific heat capacity at temperature 0 °C and its corresponding temperature – ($c_{Pd.a.}.t$). Specific enthalpies of water vapors and hexane vapor can be represented as ($r_w+c_{Pw.v.}.t$) and ($r_x+c_{Ph.v.}.t$), respectively, where: r_w and r_h are specific heat of evaporation at temperature 0 °C of water and hexane, respectively, kJ/kg; $c_{Pw.v}$ и $c_{Ph.v}$ – isobaric specific heat capacity at temperature 0 °C of water and hexane, respectively, kJ/(kg.K).

The content of hexane vapor in investigated mixture can be represented by the equation:

$$d_2 = \frac{m_{h.nv}}{m_{h.a.}} = \frac{R_{h.a.}}{R_{h.v.}} \cdot \frac{\varphi . p_v}{p - \varphi . p_v}, \qquad (2)$$

where:

$m_{h.a.}$, $m_{h.v.}$ – mass of the humid air and hexane vapor respectively, kg;

$R_{h.a.}$, $R_{h.v.}$ – specific gas constant of humid air and hexane vapor respectively, kJ/(kg.K);

p и p_v – total pressure of the mixture and partial vapor pressure of hexane, кPa;

φ – degree of air saturation with hexane vapor, %.

The specific gas constant of the humid air is determined from the equation:

$$R_{h.a.} = \zeta_{d.a.} . R_{d.a.} + \zeta_{w.v.} . R_{w.v.}, \qquad (3)$$

where: $\zeta_{d.a.}$ и $\zeta_{w.v.}$ – mass concentration of dry air and water vapor respectively;

$R_{d.a.}$ – specific gas constant of dry air, kJ/(kg.K).

Similar to diagram «enthalpy – moisture content» for humid air, based on the above equations was constructed diagram «enthalpy – hexane vapor content» for the mixture of humid air saturated with hexane vapor. To construct the line of the humid air, saturated with hexane vapor, is used equation (2), where a partial pressure p_v is replaced by the saturation pressure of hexane at the appropriate temperature – p_s, кPa.

Results and discussion

All parameters of the humid air – hexane vapor mixture were determined in constant (barometric) pressure p=100 кPa. The specific heat capacities of dry air and water vapor were reported by tables of thermo physical properties of these substances [4], and those for hexane vapor by [12]. Their values are respectively: $c_{Pd.a.}$ =1 kJ/(kg.K), $c_{Pw.v.}$ =1,86 kJ/(kg.K) and $c_{Ph.v.}$ =2,272 kJ/(kg.K). Specific heat of evaporation of the water was reported by [10], and for hexane by [12]. The values are respectively r_w=2500 kJ/kg and r_h=366,62 kJ/kg. Specific gas constant of the humid air was calculated by equation (3) and the value is $R_{h.d.}$ =288,9 kJ/(kg.K). The value of specific gas constant of the hexane is $R_{h.v.}$ =96,5 kJ/(kg.K).

Under these conditions, the equation (2) can be written as:

$$d_{2s} = 2{,}994 . \frac{\varphi . p_s}{100 - \varphi . p_s}, \qquad (4)$$

The content of saturated hexane vapor into investigated mixture was calculated by substituting the values of saturation of hexane vapor, reported by [12], in equation (4). Substituting of these calculated values in equation (1) leads to determination of the specific enthalpy of the saturated air.

Based on the calculations carried out, diagram "enthalpy – hexane vapour content" was developed, similar to the diagram «enthalpy – moisture content» of humid air at barometric pressure and was plotted in coordinate system with an angle between the axes 135°, which is presented on fig. 1. On the abscissa are plotted the values of the hexane vapour content and on the ordinate are plotted the specific enthalpy of the mixture. The lines of humid air saturated with hexane vapour at φ = 0 to 100 % are plotted into the diagram. On completion of the isotherms were defined angle of its slope and its intercept from the ordinate using the mathematical model of the equation of a straight line. The line of the partial pressure of hexane vapour is plotted also. The respective values of the pressure at different hexane content into the investigated mixture were calculated using equation (4)

The relative error of the saturated hexane vapour content into the mixture of humid air – hexane vapour was determined in case that the moisture content d_1 is different from this in the investigated mixture. For this purpose the content of the saturated hexane vapour into the mixture of dry air (d_1 = 0) – hexane vapor was determined as well as the content into the mixture of humid air (d_1 = 0,08) – hexane vapor under the same other conditions. The relative error for the content of the saturated hexane vapor in the first case is 0,6 % and in the second is 3,6 %. This error related to the dew point is 0,08 °C for the first case and 0,47 °C for the second. This shows that in calculation of the dew point of hexane at moisture content of humid air different from the assumed d_1 =0,01 kg/kg, the error will be insignificant.

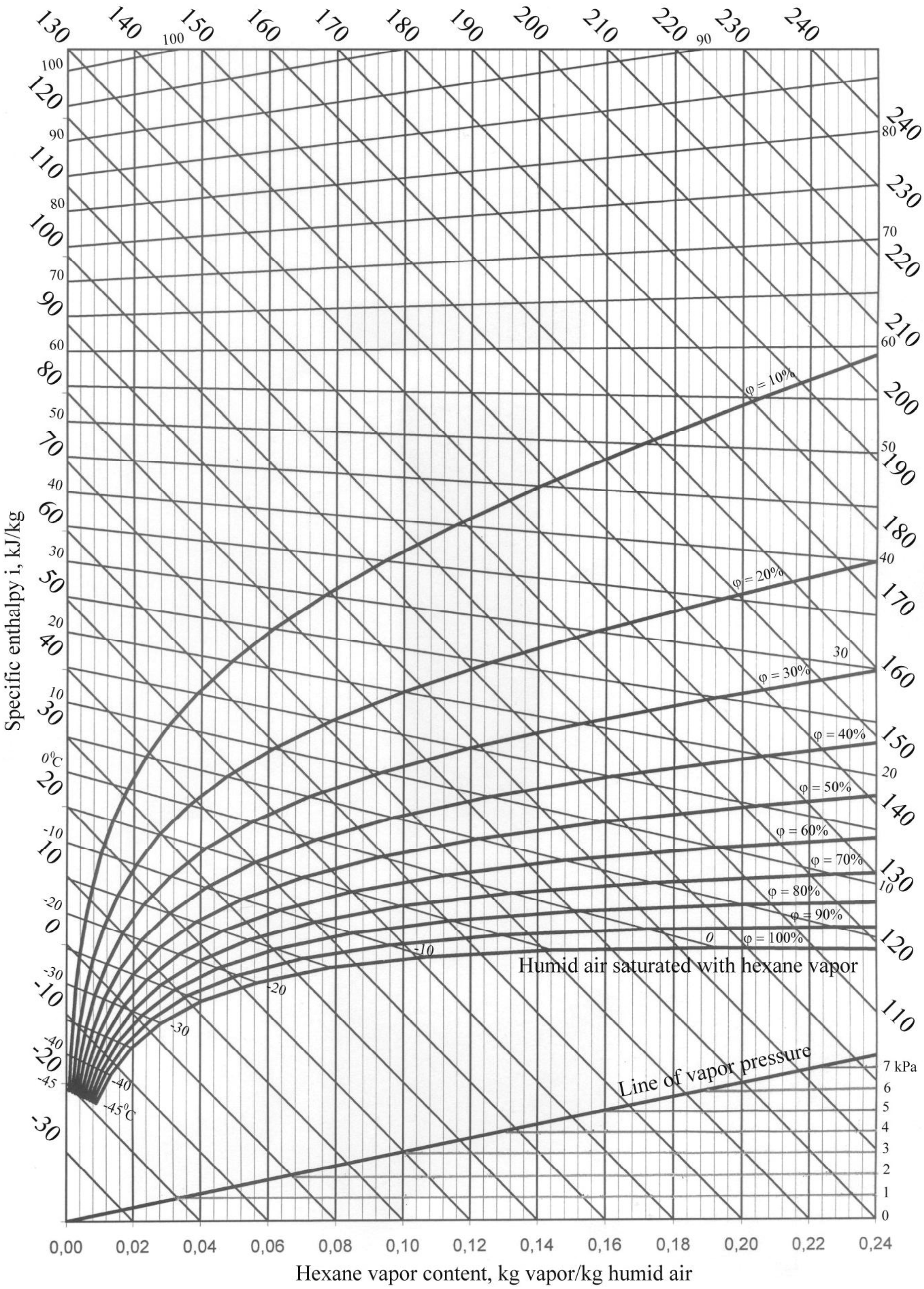

Fig. 1 – Diagram «enthalpy – hexane vapour content» for humid air – hexane vapour mixture, at φ = 0 to 100%

Conclusions

1. Thermodynamic diagram "enthalpy – hexane vapor content" for the mixture of humid air – hexane vapor was developed at different air saturation with hexane vapor from 0 to 100 %.
2. The relative errors for the content of hexane vapor and the dew point are determined at two different points of the investigated air moisture content value. The results obtained show insignificant error that allows the developed diagram to be used in different water vapor content into the air.
3. The diagram can be used in the practice for thermal and constructive calculations of the installations for separation and recovery of the hexane vapor from the air.

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МІКРОХВИЛЬОВЕ КОНЦЕНТРУВАННЯ ТА СУШІННЯ СУМІШІ ЗЕЛЕНІ ПРЯНИХ ОВОЧІВ

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Стаття присвячена визначенню впливу потужності джерела НВЧ-енергії й глибини вакуумування на тривалість нагріву, НВЧ-концентрування та НВЧ-сушіння суміші зелені пряних овочів.

The article is devoted to defining the impact power of the microwave energy and depth vacuuming the duration of heating, microwave concentration and microwave drying a mixture of spicy green vegetables.

Ключові слова: пряні овочі, НВЧ-концентрування, НВЧ-сушіння, глибина вакуумування, кінетика, маса, вологовміст.