Research of design parameters influence on the operation characteristics of solution concentrator

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Abstract

The gas flow in the cylindrical and conical test-tubes was studied by specially developed mathematical model. The geometrical parameters of the liquid concentrator were determined which significantly affect on the evaporation of the certain volume of liquid from the test-tube. The influence of impurities in liquid on the evaporation rate was fixed. The selection guideline for the device design parameters is given to provide maximum performance.

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1. Introduction

The pneumatic liquid concentrators based on distillation (the concentration by the solvent evaporation) [1] are increasingly used for the concentration of chemical solutions and high molecular weight species solutions.

These devices are compact, have a simple design and long lifetime. However, the influence of various geometrical concentrator parameters and physical parameters of the gas flow used in the concentrator is still underexplored. This factor does not allow determining unit characteristics and obtaining high technical and economical parameters for the different types of the test-tubes and liquids placed in them.

The aim of this work is to study the influence of device working chamber geometry on the steam mass flow rate and the concentration time of certain sample volume.

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2. Calculation and theoretical research

The main parameter of liquid concentrator that is of interest to the user is the expulsion time \( t \) of certain volume of liquid \( V \) out of test-tube with the solution. In case of evaporation, this parameter can be defined by the formula (1) [2]:

\[
    t = \int_{V_2}^{V_1} \frac{\rho}{J \cdot S} dV,
\]

\[
    V = V_1 - V_2,
\]

where \( \rho \) is the evaporating liquid density, \( J \) is the steam mass flow, \( S \) is the evaporation surface area, \( V_1, V_2 \) are the initial and final value of the liquid volume in the test-tube.

The reduction of concentration time might be achieved by increasing of the free surface area or increasing of the gas mass flow without changing of liquid type. To achieve the growth of free area for the fixed test-tube geometry is possible only by deflecting of test-tube axis from the vertical position for an angle \( \alpha \):

\[
    S_1 = S / \cos(\alpha)
\]

The evaporation of liquid with the higher molecular weight compared to the working gas was investigated (as opposed to [3, 4]). The steam mass flow is defined by Stephen formula and depends on many factors, but only the influence of concentration gradient zone thickness \( (h') \) [5] is taken in to account in present analysis:

\[
    J = \frac{f(D, p_{ls}, p_l, T_l)}{h'},
\]

where \( D \) is the diffusion coefficient, \( p_{ls} \) is the pressure of the saturated steam in the liquid, \( p_l, T_l \) is the steam pressure and liquid temperature.

Parameter \( (h') \) can be determined by formula (4):

\[
    h' = h - \bar{h}_0 = h - \frac{\iint h_0(x, y)dx dy}{S},
\]

where \( h \) is the distance from the mesh input boundary to the phase boundary, \( h_0(x, y) \) is the distance from the mesh input boundary to the conventional surface where the gas velocity projection on the test-tube axis is equal to 0 (Fig. 1.a.).

For the inclined position of test-tube the value of \( h \) is measured between the mesh input boundary and the intersection of the phase boundary with the center line (Fig. 1.b).
The mathematical model of processes in the pneumatic-and-vacuum liquid concentrator, described in [6]. It allows determining of gas flow velocity field in the computational domain. The approximate iteration method is used (control volume method) to solve the differential equations. This method is based on computational domain sampling and substituting differential equation system by linear equations.

The effect of input/output area \((s)\) ratio and the guide tube immersion depth up on position of surface \((h_g)\) were studied. Figure 2-4 show the gas flow velocity field in the computational domain and the dependence of gas flow velocity from parameter \(s\). Velocities exceeding 0.1 m/s are marked by red color, and velocities equal to 0 are marked with the blue color.

![Fig. 1. Computational mesh diagram for determining of concentration gradient zone thickness.: (a) test-tube placed vertically; (b) inclined test-tube.](image)

![Fig. 2. The gas flow velocity fields in the computational domain at different values of parameter \((s)\) and a constant pressure drop.](image)
It is clearly seen that the function has a cute maximum when input/output area ratio is equal to 1, therefore the deviation of the area ratio from the optimum leads to significant increasing of the concentration gradient zone thickness. The phase boundary position does not influence on the position of surface $h_0$, which depends only on gas flow velocity.

The effect of free surface area deformation and test-tube deflection angle on the $h_0$ surface position was studied in the conical test-tube. Figure 5 shows the gas velocity fields in the conical computational domain with the pressure drop 1kPa.
The increasing of concentration gradient zone thickness takes a place as the test-tube is inclined. However, the value of the parameter at inclined position varies slightly.

The calculated values were confirmed in the experimental studies of pure liquid evaporation but the contamination in the liquid leads to the reduction of the free surface area and the evaporation rate is decreasing with the increasing of contamination concentration. This effect has to be studied and taken into account by introduction of a correction factor in the mathematical model.

3. Conclusion

While choosing the geometrical parameters of the liquid concentrator, the guide tube diameter and thickness has to be selected taking into the account the test-tube inner diameter in order to achieve equality of input and output section of the evaporation mesh. The guide tube immersion in to the test-tube has no significant influence on the evaporation rate and adversely affects on the maximal possible volume of liquid which may be placed in to the test-tube. The test-tube deviation from vertical position increases the free liquid surface area from one side, and from the other side increases the concentration gradient zone thickness. Therefore, the evaporation time of certain liquid volume can either increase or decrease.

References