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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]:

$$t = \int_{V_2}^{V_1} \frac{\rho}{J \cdot S} dV,$$
$$V = V_1 - V_2, \tag{1}$$

where ρ 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 α :

$$S_1 = S / \cos(\alpha) \tag{2}$$

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:

$$J = \frac{f(D, p_{ls}, p_l, T_l)}{h'}, \tag{3}$$

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):

$$h' = h - \overline{h}_0 = h - \frac{\iint_S h_0(x, y) dxdy}{\iint_S dxdy}, \tag{4}$$

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).