Dependence of optimal separative power of the ”high-speed” Iguasu centrifuge on pressure of working gas

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Abstract. The results of optimization calculations of the separative power of the ”high-speed” Iguasu gas centrifuge are presented. Iguasu gas centrifuge has the rotational speed of 1000 m/s, the rotor length of 1 m. The dependence of the optimal separative power on the pressure of the working gas on the rotor wall was obtained using the numerical simulations. It is shown, that maximum of the optimal separative power corresponds to the pressure of 1100 mmHg. Maximum value of separative power is 31.9 SWU.

1. Introduction
Isotope separation by gas centrifuges (hereafter GC) receieving increasing attention during the last years both from theoretical and practical points of view. One of the main problems arising in the design of the gas centrifuges is the problem of increasing the efficiency of GC, i.e. increasing the separative power $\delta U$ of single GC. One way is to increase the velocity of the rotor of GC [1, 2]. However, the characteristic thickness of the separative layer of gas inside the rotor GC reduces as rotor velocity increases. It can lead to a decrease of the separative power. In addition, the question arises: what are flow parameters inside GC rotor must be to achieve optimal separative power. The answers of these questions require long-term and expensive experimental studies.

In recent years the numerical methods of the GC separative power calculation based on numerical simulations are becoming an increasingly popular [3, 4, 5]. These methods allows one to calculate the separative power using the numerical solution of the hydrodynamics equations and convective diffusion inside the rotor of GC. This approach allows to significantly reduce the cost of research and to answer to two basic questions: what is the maximum separative power of GC with the specified velocity of rotor and the rotor length, and what are flow parameters must be to achive this separative power.

In this paper we present the results of numerical calculation of flow and separation in ”high-speed” Iguasu GC (rotational velocity of 1000 m/s). The main attention is focused on the calculation of the optimal separative power and its dependence on pressure of working gas.
2. Model and method

The modelling of the flow and separation in the Iguasu GC is performed in axisymmetric approximation in rotating coordinate system for Iguasu GC (diameter of rotor of GC \(d = 0.12\) cm, linear velocity of rotation \(v = 1000\) m/s and length of rotor \(L = 1\) m). The computational domain represents the cylindrical sector with a span angle \(1^\circ\). Influence of a waste scoop was modelled by the sources of mass, momentum and energy, which are uniformly distributed on small toroidal region [6]. The mass sink value was fixed according to the feed value and feed cut \(\theta = 0.5\). The product chamber of the centrifuge was absent in the computational domain. Influence of the product chamber was modelled by pressure imposed to the rotor wall near the lower baffle. The mass flux at the outlet has been specified by the conservation of mass.

A linear temperature profile has been specified at the rotor wall. The minimal temperature \(T_0\) has been specified above the temperature of sublimation of the working gas. At every step of the optimization procedure of the GC the temperature of the gas has been calculated at the pressure exceeding on 10\% the current pressure at the wall. This temperature has been taken as \(T_0\). The sublimation of the gas is avoided due to this procedure.

Internal boundary of the computational domain corresponds to the Knudsen zone where the gas pressure is of the order of 1 Pa. The feed flux has been specified at the surface of this boundary.

Optimization procedure was carried out by the direct search method without use of information about derivatives of separative capacity by the optimization parameters. The algorithm BOBYQA [7] was used in operation. This algorithm is included in a library of nonlinear optimization algorithms, NLopt [8]. In the beginning of optimization procedure we fix the length of the rotor, its radius and rotational speed, and the pressure on a rotor wall. Thus, the optimization procedure was performed in three-dimensional space of the following list of working parameters: feed flux \(F\), temperature drop \(\Delta T\) and power of the braking of the gas by the scoop \(W\). Calculations were performed for different values of the pressure \(p\) in the range of 15 mmHg to 1500 mmHg and the dependence of the optimal separative power on the pressure was obtained.

3. Results and discussion

![Dependence of the optimal separative power on the pressure at the wall of rotor.](image)
The dependence of the optimal separative power on pressure at the wall of rotor is shown on fig. 1. Optimal separative power reaches its maximum value $\delta U_{\text{max}} = 31.9$ SWU at a pressure of $p = 1100 \text{ mmHg}$. It is necessary to emphasize that the obtained value of the optimal separative power is much higher than the value predicted by the empirical formula from the work [4]:

$$\delta U_{\text{empirical}} = 12L \cdot \left( \frac{v}{700 \text{ m/s}} \right)^2 \left( \frac{d}{12 \text{ cm}} \right) = 24.4 \text{ SWU}. \quad (1)$$

This distinction is connected with the fact that dependence of optimal separative power on the speed of rotor does not satisfy the quadratic law. As shown in [9], optimal separative power of the Iguasu GC grows with the speed of a rotor as $\sim v^{2.6}$. At the same time, from a figure 1 it is clear that optimal separative power has a small "plateau" in the pressure range from 100 mmHg to 200 mmHg. In this pressure interval separative power $\delta U$ changes in the range of 4%. Separative power value in this range corresponds to the formula (1). Thus, if we introduce the top limit for the pressure, optimal separative power value would satisfy the law $\sim v^2$. It confirms the conclusions of the work [9].

4. Conclusions
The results of the optimization studies of the "high-speed" Iguasu GC with a rotor length $L = 1$ m and rotational velocity $v = 1000$ m/s are presented. The dependence of optimal separative power on a pressure of the working gas is calculated. It is shown, that optimal separative power has a maximum $\delta U_{\text{max}} = 31.9$ SWU at the pressure of $p = 1100 \text{ mmHg}$. It corresponds to dependence of the optimal separative power on velocity of the rotor $\sim v^{2.6}$. The dependence of the optimal separative power has a "plateau" the range of pressures from 100 mmHg to 200 mmHg. Optimal separative power on this "plateau" changes slightly around the value 24.4 SWU, which corresponds to the dependence $\sim v^2$.

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