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Modeling of Waves in the Iguasu Gas Centrifuge

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Abstract

2D axisymmetric transient flow induced by a pulsed braking force in the Iguasu gas centrifuge was simulated numerically. The computational domain consists of three cameras: top, working and bottom. The feed flow injected to the working camera, product and waste fluxes removed in the bottom and top cameras, respectively.
The transient case is compared with the stationary case where the flow is excited by the stationery braking force. The braking forces averaged over the period of the rotation are equal each other in both cases. In the transient case the gas flux through the gap in the bottom baffle 15 % exceeds the flux in the stationary case for the same pressure and temperature. We argued that the waves reduce the pressure in the GC on the same 15 %.

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Keywords: gas dynamics, fast gas rotation, gas centrifuges, isotope separation, numerical simulation;

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1. Introduction

Gas centrifuges are widely used for enrichment of the uranium in industrial scale. Millions GC are explored in enrichment cascade to produce uranium for nuclear power station. A small improvement of a single GC results into essential increase of capacity of the plant. It is important to explore any physical process to maximize separative power of the GC.

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Recently authors have shown that conventional acoustic waves are essentially modified in strong centrifugal fields [1]. The waves are generated in the GC as a result of interaction of scoops with the rotating gas. Scoops are located at the top and bottom caps of the rotor. They are used to extract enriched and depleted gas from the GC. Interaction of the fast rotating gas and the scoops result into formation of shock waves which propagate in the axial direction and are quickly transformed into linear waves. It was shown in [2] that only one type of waves which correspond to the dispersion law $\omega=kc$ survives in the GC. The waves essentially modify the circulation of the gas in the GC [2], [3]. In this work we focus on the affect of the waves on the product flux of the GC.

2. Formulation of the problem

The waves produced by the scoops are stationary in the laboratory frame system. Computer modeling of the gas flow in the GC is performed in rotating frame system [4]-[8]. 2-D axisimmetric model of source-sinks is applied [6]. In this work we use axisymmetric model of the sources and sinks in the rotating frame system as well. The waves are not stationary in this model. Special computer code has been developed in MEPhI for numerical simulation of the nonstationary gas dynamics in strong centrifugal fields . The results of verification of the code were presented in [9],[10].

A scheme of the computational domain is presented in Figure 1. The domain consists of three cameras: top, working and bottom. Product (enriched) and waste (depleted) fluxes are removed in the bottom and top cameras, respectively by the sinks shown by solid points 6 and 2. Feed flow (*F*) is injected at the middle of the working camera. Circulation flow (*C*) is induced due to two mechanisms: temperature gradient ΔT on the rotor wall and brake of the gas in the top camera. The braking force is located in the point source 2.

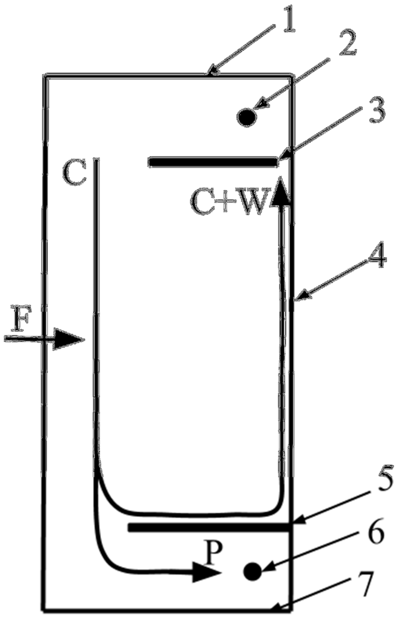


Fig. 1. Scheme of the computational domain. F,P,W – feed, product, waste fluxes, respectively, and C– circulation flow. 1 – the top cap, 2 – source of the momentum and energy, sink of the waste flux, 3 – the top baffle, 4 – the rotor wall, 5 – the bottom baffle, 6 – sink of the product flux, 7 – the bottom cap

Rotation of the gas results into high pressure gradient in radial direction about 10^5 per 1 cm. At a certain radius the pressure becomes so small that hydrodynamical approximation fails. At this radius free slip and adiabatic boundary conditions are specified according to [8]. No slip boundary condition is specified on the rotor wall. The wall rotates with angular velocity ω.

Stationary problem with steady state braking force and transient problem with periodically pulsating braking force have been solved to determine the impact of the waves on the product flux. The dependence on time of the pulsating braking force is shown in Figure 2. In the transient case the duration of the braking force is about 1/10 period of the rotation. This reproduces the affect of the rotating scoop on the gas. The pulsed braking force averaged over the period of the rotation equals to the force in the stationary case.

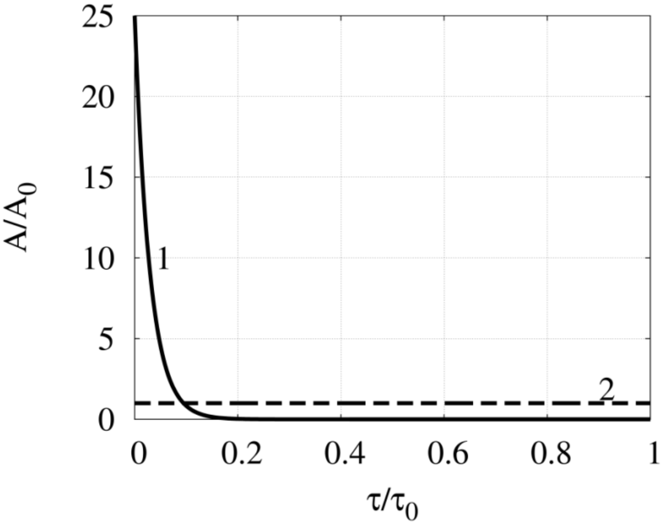


Fig. 2. The dimensionless braking force in the top source versus dimensionless period of the rotation. 1 – non-stationary case, 2 – stationary case.

Parameters used for the computer simulation of the Iguasu centrifuge are presented in the Table 1 [11].

Table 1. Basic parameters of the GC Iguasu

Parameter	Value
M	0.352 kg/mol
a	0.065 m
T_0	300 K
p_w	80 mm Hg
c_p	385 J/kg·K
ω	1700 ·2π s^{-1}
μ	$1.83 \cdot 10^{-5}$Pa·s
λ	0.0061 W/m·K
ΔT	10 K
L	0.526 m
r_{in}	0.052 m

3. Results and discussion

3.1. Steady state case

The waste flux has been specified in the point 2 equal to 0.55 of the feed flux. The pressure in the working camera is obtained in the process of the solution. It equals to 79 mm Hg. This pressure provides the product flux satisfying the mass conservation. It equals to 7.2 mg/s. The stream lines of the stationary flow are shown in Figure 3.

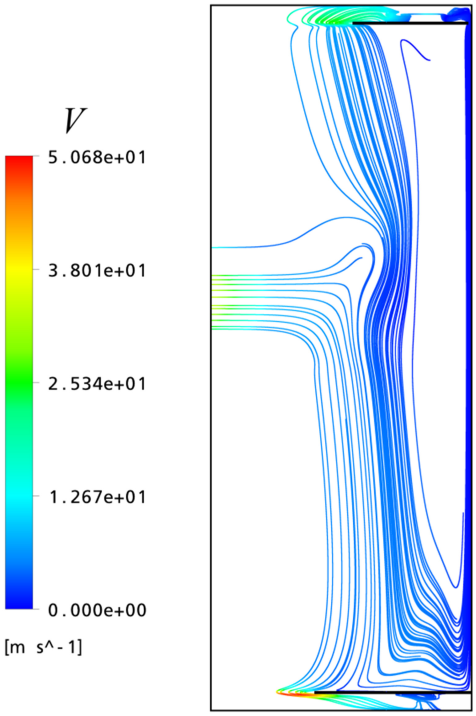


Fig. 3. The stream lines in the case of stationary braking force. Scale in radial direction multiplied 15 times.

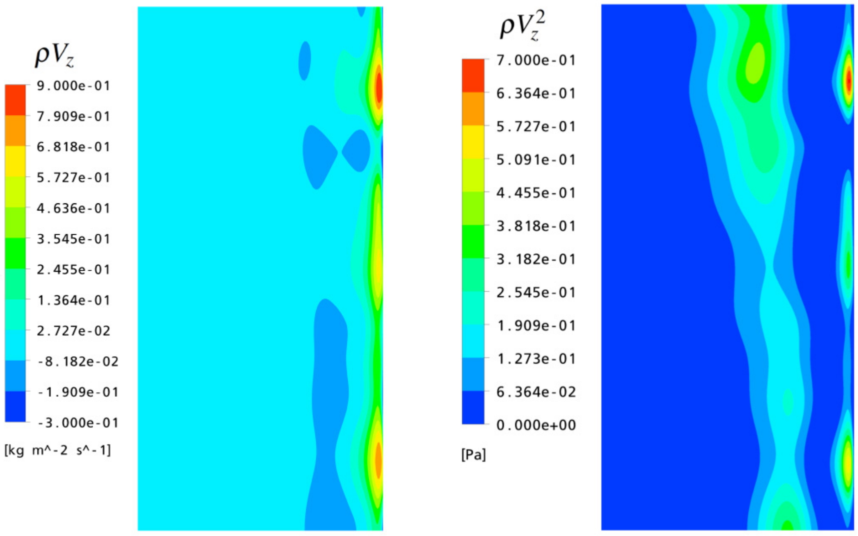
3.2. Transient case

Initially the sink fluxes and pressure were taken as in the stationary one. Simulation shows that in the transient flow the flux through the gap in the bottom baffle appears 15% higher than the product flux. This means that the mass is not conserved in the transient case. The mass conservation will take place when pressure in the working camera falls down to reduce the mass flux through the gap in the bottom baffle to the value equal to the product flux. But this takes a lot of time. Duration of such simulation exceeds any reasonable value. Nevertheless, we can conclude from this simulation that the waves can essentially change the working pressure in the GC.

Figure 4 shows distribution of the product ρV_z in the working camera. The waves are well seen in the figure. The wavelength of the waves is close to 5 cm which well agree with the dispersion low $\omega=kc$. The energy of the waves is concentrated at the rotor wall as predicted in [1].

4. Conclusion

In this work we compared two cases of the flow in the GC. The flow induced by the stationary braking force and the transient flow induced by the pulsed force. The waves in the transient case are damped weakly on distance ~1 meter which is twice length of the working camera of the GC.



(a) *(b)*

Fig.4. Waves in the working camera of the GC. (a) – axial mass flux density, (b) – axial energy flux density.

The product flux in the transient case 15 % exceeds the product flux of the stationary case for the same pressure and temperature in the working camera. This means that in the steady-state regime the pressure in the working camera of the transient case is expected to be lower than the pressure in the stationary case approximately on the same 15%.

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