Modeling of filling gas centrifuge cascade for nickel isotope separation by feed flow input to different stages

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Abstract. The article presents results of research filling gas centrifuge cascade by process gas fed into different stages. The modeling of filling cascade was done for nickel isotope separation. Analysis of the research results shows that nickel isotope concentrations of light and heavy fraction flows after filling cascade depend on feed stage number.

1 Introduction

During the operation of gas centrifuge (GC) cascade for the multicomponent isotope mixture (MCIM) separation there are nonstationary hydraulic and separation processes. It is necessary to ensure safety of the equipment and to minimize losses of cascade productivity during nonstationary processes. In this regard, actual task is full-scale research of nonstationary processes. It is advisable to study the nonstationary processes by mathematical modeling. Known mathematical models [1-4] describe nonstationary hydraulic processes for only long cascade and nonstationary separation processes in the case of stationary hydraulic parameters of cascade. For elimination of these disadvantages we had developed the mathematical model of nonstationary hydraulic and separation processes occurring in GC cascade for the MCIM separation [5-7]. Earlier we had done verification of developed mathematical model as an example silicon and germanium isotope separation. Isotope separation mode in GC cascade is preceded by its filling with process gas. So far a modeling of filling cascade was not carried out.

The results of research filling GC cascade for nickel isotope separation by feed flow input to different stages is shown in this article. Nickel isotopes are used for nuclear physics experiments and production radioactive isotopes (for example, ^{62}Ni stable isotope is used as source material to produce ^{63}Ni radioactive isotope).

2 Description of the mathematical model

The basic equations of nonstationary processes during MCIM separation is written below.

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MCIM separation takes place into a cascade (Fig. 1), consisting of S separation stages numbered by i index ($i = \overline{1, S}$). The cascade has three flows: input feed flow F, output light fraction flow P and heavy fraction flow W.
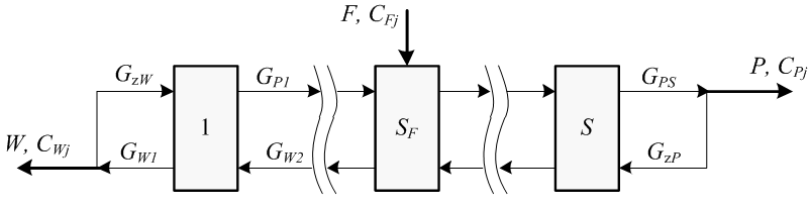

Fig. 1. Separation cascade.

During stationary hydraulic process the flows of cascade are interrelated by material balance equation:

$$F = P + W,\qquad(1)$$

$$FC_{Fj} = PC_{Pj} + WC_{Wj}.\qquad(2)$$

The stage has three flows: input feed flow G_{Fi}, output light fraction flow G_{Pi} and heavy fraction flow G_{Wi}:

$$G_{Fi} = G_{Pi} + G_{Wi},\qquad(3)$$

$$G_{Fi}C_{Fij} = G_{Pi}C_{Pij} + G_{Wi}C_{Wij}.\qquad(4)$$

The MCIM separation in stage is determined by equations:

$$\chi_{ijl} = \frac{C_{Pij}C_{Wil}}{C_{Pil}C_{Wij}},\qquad(5)$$

$$\chi_{ijl} = \chi_{0i}^{M_j - M_l},\qquad(6)$$

where χ_{ijl} is separation factor of jth и lth components; χ_{0i} is overall separation factor per unit of mass numbers difference; M_j, M_l – is mass numbers of jth и lth components.

Nonstationary processes are described by differential equation systems. The solution algorithm is written on publications [5, 6].

3 The results of calculation cascade for nickel isotope separation

We have researched filling square cascade consisted of 60 stages (S=60) with equal flow rate G_F for all the stages during stationary mode. The overall separation factor χ_0 is equal 1.1. The ratio of cascade feed flow and stage flow F/G_F is equal 0.13. The trifluorophosphinenickel (Ni(PF$_3$)$_4$, molar mass is 411 kg/kmol) was used as process gas for nickel isotope separation in GC cascade.

At the initial time the cascade holdup (quantity of process gas into GC and pipelines) is equal 0. Constant feed flow is input to cascade, values of light and heavy fraction flows of cascade are equal 0 during filling cascade. At the same time the values of pressures, holdups and flows of process gas into GC and pipelines is being increased to steady values.

We have done modeling of filling cascade with process gas by feed flow input to different stages. The nickel isotope concentrations in light and heavy fraction flows of cascade are shown on fig. 2 and 3.
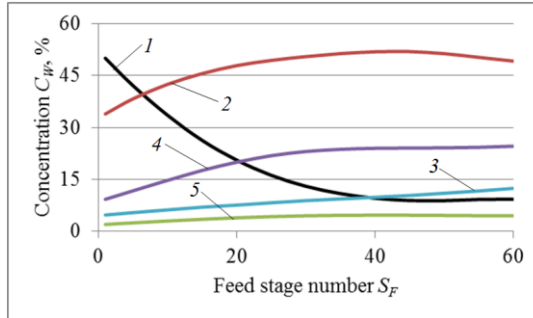

Fig. 2. Nickel isotope concentrations in heavy fraction flow of cascade after its filling depending on feed stage number: $1 - {}^{58}$Ni, $2 - {}^{60}$Ni, $3 - {}^{61}$Ni, $4 - {}^{62}$Ni, $5 - {}^{64}$Ni.
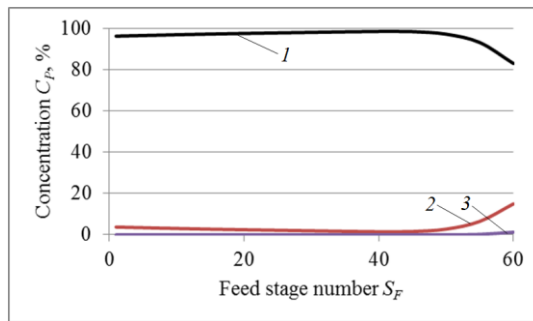

Fig. 3. Nickel isotope concentrations in light fraction flow of cascade after its filling depending on feed stage number: $1 - {}^{58}$Ni, $2 - {}^{60}$Ni, $3 - {}^{61}$Ni.

As it's seen on Fig. 2 and 3, there is optimal feed stage number for each nickel isotope when isotope concentration in light or heavy fraction flows of cascade takes on maximal value after filling cascade (see Table 1).

Table 1. Optimal feed stage numbers.

Nickel isotope	Output cascade flow	Optimal feed stage number S_{Fopt}	Maximal concentration value, %
^{58}Ni	light fraction	43	98.5
^{60}Ni	heavy fraction	43	51.8
^{61}Ni	heavy fraction	41	4.7
^{62}Ni	heavy fraction	60	24.6
^{64}Ni	heavy fraction	60	12.4

For example, ^{58}Ni isotope concentration in light fraction flow takes on maximal value (98.5 %) when feed flow is entered to stage with number S_{Fopt}=43. Optimization of feed stage number might make it possible to increase concentration of target isotope in light or heavy fraction flow after filling cascade. It will decrease duration of further nonstationary process of cascade start-up (establishment of steady-state isotope concentrations).

4 Conclusion

We have done research filling GC cascade for nickel isotope separation by feed flow input to different stages.

According to analysis of research results nickel isotope concentrations on light and heavy fraction flows after filling cascade depend on feed stage number.

The research have indicated that there is optimal feed stage number for each nickel isotope when isotope concentration in light or heavy fraction flows of cascade takes on maximal value after filling cascade with process gas.

Feed stage number optimization lets to decrease duration of further nonstationary process of cascade start-up (establishment of stationary isotope concentrations).

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