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Enrichment of ^{111}Cd Isotope from natural Cadmium composition by 3-Section Squared-off

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Abstract

In this paper, the simulation and optimization of a 3-section squared-off cascade is investigated for enrichment of ^{111}Cd isotope to 80% enrichment level by PSO algorithm. The optimized parameters of the squared-off cascade based on the simultaneously maximize the cascade capacity, recovery factor and the D-function and 140 centrifuges are included the cascade feed flow rate, the feed stage, the sections feed flow rate, the number of stages of each section, the cascade cut, the first-stage cut and the return flow fractions between sections. The results show that the steps separation recovery of ^{111}Cd isotope by using a single structure are 96% and 97% respectively and this cascade is the best option for industrialization and reducing installation and commissioning costs.

Keywords: PSO algorithm, The cadmium middle isotope (^{111}Cd), 3-section squared-off cascade

Introduction

Isotopes are widely used in many fields such as medical, industrial and research applications and etc. For example Cd stable isotopes were initially used to study mass-dependent fractionation in ordinary chondrites and lunar samples, generated by partial evaporation and condensation. In addition, Cd stable isotopes could be used as tracers for anthropogenic Cd pollution of the environment [1]. With the growing use of enriched stable isotopes in several fields, it is necessary to find better methods for separating from multicomponent mixtures to the desired levels. For the separation of heavy and semi-heavy isotopes, there are several advantages to use the technique known as centrifugal separation in the setups called enrichment cascades. However, the structure of the cascade and a good strategy also plays an important role in this area. Because of the isotopes of a multicomponent mixtures can't be enriched in one time using the cascade, selected a flexible cascade with high recovery for separation all isotopes of an element are very important. Separation of middle, the heaviest and lightest isotopes can be affected on the separation strategy. The attempts to combine the advantages of tapered (high recovery factor) and square cascades (flexible) have led to the development of a group of cascades called squared-off cascades. Like tapered cascades, square and squared-off cascades can significantly benefit from process optimization that it leads to reduce the cost of plant or increase the profit margin of the product [2]. In recent years, researchers have shown great interest in analyzing optimization problems such as the ones discussed in this paper with the help of nature-inspired algorithms [3-5]. In this field, one needs to not only find an efficient cascade for isotope separation but also adopt an appropriate strategy for arranging the cascades such that the target isotopes can be efficiently separated. This can be done with the help of flexible cascades, that is, by defining a suitable objective function and then using one of the aforementioned or new methods to optimize the setup configuration for separating the target isotopes of an element. In this way, in the present study is investigated the performance of the 3-section squared-off cascades for the ^{111}Cd separation after a series of optimizations. First, we determine the optimal number of stages of each section in separation step 1 and then fix it for other separation steps by using the particle swarm optimization algorithm. Other optimized parameters include cascade feed flow rate, feed stage, the fraction of the flow that is returned from one section to the others, the input feed flow rate of the stages, the first stage cut, and the cascade cut. The objective function of the optimization consists of multiple terms dedicated to maximizing the separation recovery and maximizing the Division factor, D. The constraint of the optimization is devoted to reaching a concentration of 80% in the final product.

Theory

The squared-off cascade actually consists of the connection of several square cascades in series, thus it has performance between the tapered and square cascades. The squared-off cascade with 3-sections can be used in three different structures and the feed stage of the cascade is in the section with the highest stages feed flow rate or the number of centrifuges in each stage.

The unknowns of this cascade include are $3NN_c+3N+7$ in total, and the number of equations are $3NN_c+3N+3$. It is clear that for simulation of this cascade, four unknown must be considered as input. In this research cascade cut, first stage cut and the fraction returned flow rates are unknowns which are selected as input. The concentration equations are nonlinear type, in order to solve them the q-iteration technique can be used which was first proposed by Zang et al. [6]. In this research,

This algorithm, introduced by James Kennedy and Russell C. Eberhart in 1995, is based on modeling and simulating the behavior of flocking birds or the movement of fish schooling [7]. The objective function of the optimization consists of multiple terms dedicated to maximizing the separation recovery and maximizing D with the achievement of 80% enrichment.

5- *Results and discussion*

The aim of this study is to optimize a 3-section squared-off cascade for enrichment the middle isotope of cadmium to 80%. First, in order to design and optimize the cascade, the known inputs for the 3-section squared-off cascade and variable parameters of the squared-off cascade must be specified. Then the 3-section squared-off cascade should be simulated and optimized and at the end the results must be investigated.

The separation of ^{111}Cd from natural cadmium concentration (0.128) as $Cd(CH_3)_2$ is done by 200 centrifuges. The minimum and maximum amount of feed flow rates to the gas centrifuge and the unit separation factor is a supposition factor as follow: $1.4*f^{-0.051}$. The variable parameters include cascade feed flow rate, feed stage, the fraction of the flow that is returned from one section to the others, the input feed flow rate of the stages, the first stage cut, and the cascade cut and the unit separation factor, the number of gas centrifuges, mass molar and the concentration of the isotopes in feed flow and the unit separation factor are the constant parameters. The cascade is simulated and optimized by PSO algorithm. The best arrangements for ^{111}Cd enrichment are obtained after optimization the 3-section squared-off cascade by PSO are shown in Figure 1.

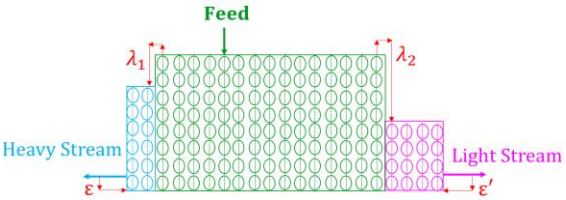

Figure 1. the optimized arrangement of the squared-off cascades based on ^{111}Cd step1 separation

The other optimized parameters and the results of ^{111}Cd enrichment by using the are presented in Table 1.

Table 1. The optimized parameters of the squared-off cascade for separation steps of ^{111}Cd by PSO

No.	Parameters	Step 1	Step 2
1	Feed (mg/s)	2.03	0.50
2	N_F	11	9
3	θ	0.290	0.482
4	θ_1	0.32	0.35
5	λ_1	0.00	0.00
6	λ_2	0.55	0.50
7	D	0.97	0.94
8	Recovery (%)	0.96	0.97
9	Cp (Target)	0.425	0.800
10	Operation days	168	197
11	Total Feed (Kg/y)	29.40	8.53
12	Total Product (Kg/y)	8.53	4.42
13	Total Recovery (%)	94	

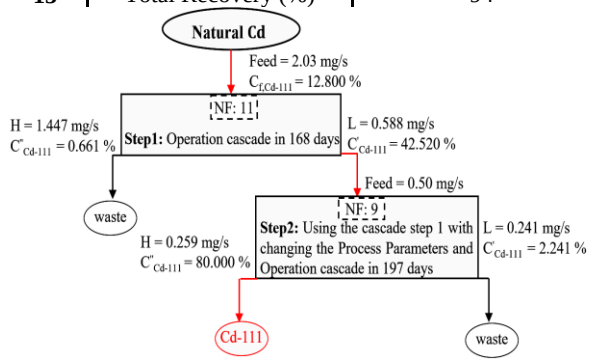

Figure 2. The separation steps sequence of ^{111}Cd

Conclusions

In this study, the enrichment of the middle isotope of molybdenum element (^{111}Cd) to 80% level has been investigated by an optimized 3-section squared-off cascade gas centrifuge. The optimization of the cascade has been done by using the PSO. As observed, ^{111}Cd reached 80% in two step with the feed consumption, product capacity and the recovery factor equal to 29.4 kg/y, 4.42 kg/y and 94% respectively. The results show that the 3-section squared-off cascade is appropriate options to separation stable isotopes to .

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