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An Application of MVO algorithm for the optimization of squared-off cascade in the separation of ^{124}Xe

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Abstract

In this research, the optimization of squared-off cascade for the separation of end component ^{124}Xe to 90% by two nature-inspired optimization algorithms of Particle swarm optimization and Multi-verse optimization is evaluated. The total number of single elements is considered to be 150. The objective function items are the maximization of the division factor, D, the total recovery factor, R, and the quantity of total product to be produced. The results showed that the PSO algorithm is more functional than the MVO.

Keywords: MVO algorithm, Squared-off cascade, PSO algorithm, Division factor

Introduction

Xenon-124 is the most important component of the nine stable isotopes of xenon element, which is used in medical sciences and nuclear physics research. ^{124}Xe with a concentration of higher than 99.9% can be converted to ^{123}I for using in the single photon emission computed tomography, SPECT and to ^{125}I for using in the SPECT and brachytherapy of several types of cancers. For the separation of heavy and semi-heavy stable isotopes, there are several advantages to use the centrifugal separation technique in the setups called enrichment cascades. many researchers have been focused on advancing this field in recent years. There are several steady state and transient cascades for extracting end and middle components of a multicomponent mixtures. These cascades can be applied in the several forms. Some examples can be addressed as representative such as tapered, square and squared-off cascades. In order to achieve the optimum operating conditions, the cascade feed should enter the stage with the most number of machines. Moreover, because of the limited separation factor of a single centrifuge, it is not possible to completely separate the isotopes with low natural concentration, by one separation step and it is necessary to use the separation cascade more than once to obtain the desired concentration of the target isotope. Because of variety of the design and operational parameters in the separation steps, the feed stage number will be different in each step. Therefore, if tapered cascades are used, the cascade configuration must change in each step requiring the construction of a different piping system. To solve this problem and using a single cascade for different separation steps, square and squared-off cascades have been recommended. Square cascades are very flexible but they have lower efficiency than tapered cascade. the purpose of using a squared-off cascade is to benefit from the advantages of square and tapered cascades simultaneously. In recent years, meta-heuristic optimization algorithms have attracted great attention from scientists in the optimization problems and have also found increasing use in the design of separation processes for multi-component mixtures [1, 2, 3, 4]. In this article, Multi verse optimization algorithm, MVO that is a powerful method, has been applied for the separation of ^{124}Xe to 90% enrichment level in the squared-off cascade ant its results has been compared with the results of Particle swarm optimization algorithm.

Theory

Figure 1 shows the schematic of different types of cascades.

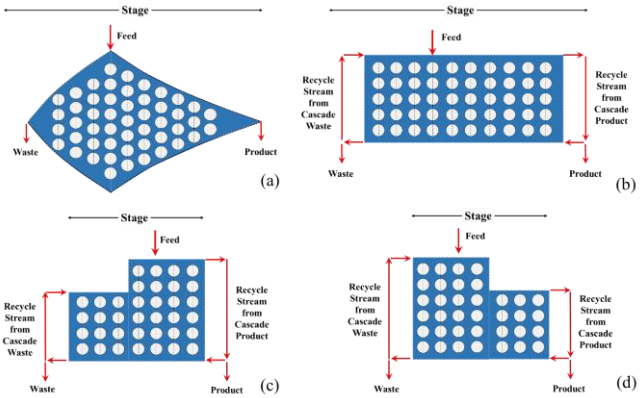

Figure 1. Types of gas centrifuge cascades: (a) Tapered, (b) Square & (c-d) Typical 2-section squared-off.

In the 3-section squared-off cascade there are 3NNc+3N+3 equations. But, considering the number of unknowns, 3NNc+3N+7, there are 4 more unknowns. Thus, to solve the system of equations of this cascade, in addition to the existing knowns, we need to determine the value of 4 other parameters. In this paper, cut of first stage, cascade cut and the recycled fraction between sections are used to solve the system of equations. The q-iteration method can be used for the simulation of the separation profile of the cascade [5]. In this study, the Multi verse optimization algorithm, MVO and Particle

swarm optimization algorithm have been used to optimize the parameters of a 3-section squared-off cascade in the separation of ^{134}Xe stable isotope. The main inspirations of MVO algorithm are based on three concepts in cosmology: white hole, black hole, and wormhole. The mathematical models of these three concepts are developed to perform exploration, exploitation, and local search, respectively [6]. The particle swarm optimization (PSO) algorithm, proposed by Kennedy and Eberhart in 1995 and mimics the social and individual behavior of herd of animals, schools of fishes or flocks of birds in foraging [7]. Terms of defined objective function represent the balance between production output and waste generation for normal feed consumption. Also, it follows the increasing in the total recovery factor, R, and the parameter D as much as possible.

Results and discussion

In this study, the goal is to separate ^{124}Xe from natural Xenon to 90% concentration in the final product using 150 centrifuges. The minimum and maximum amount of feed flow rates to the machines are the values of 9 mg/s and 20 mg/s, respectively, and the unit separation factor relation is $1.32*f^{-0.045}$. f is the single machine feed flow rate. The optimization process is done based on a 33 stages cascade. After optimizing the 3-section squared-off cascade, the optimized arrangement of the cascade has been shown in figure 2. Because of low enrichment of ^{124}Xe, it cannot be separated to high enrichment of 90% in one separation step and three steps are needed for this purpose. The optimized parameters and the results of ^{124}Xe separation are presented in Tables 1 and 2.

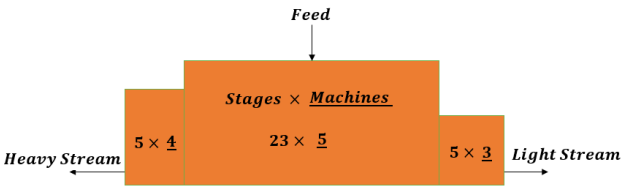

Figure 2. the optimized arrangement of the 3-section squared-off cascade

Table 1. The optimized parameters and the results of ^{124}Xe separation by PSO

Item	Parameters	Step 1	Step2	Step3
1	Feed (mg/s)	20.2728	12.8345	11.36
2	N_F	18	22	13
3	$\theta_{Cascade}$	0.05	0.07	0.293
4	θ_1	0.2596	0.4872	0.4315
5	$\lambda_{1,2}$	0.1357	0.5395	0.3738
6	$\lambda_{2,3}$	0.4780	0.0583	0.3228
7	D (mg/s)	0.9509	0.9490	0.9638
8	Recovery (%)	0.9993	0.9994	0.9736
9	Total Recovery (%)	0.9723		
10	Total Feed (kg/y)	589.12		
11	Total Product (kg/y)	0.6041		

Table 2. The optimized parameters and the results of ^{124}Xe separation by MVO

Item	Parameters	Step 1	Step2	Step3
1	Feed (mg/s)	20.1265	18.3099	11.00
2	N_F	17	13	19
3	$\theta_{Cascade}$	0.05	0.0626	0.3190
4	θ_1	0.3005	0.3619	0.3119
5	$\lambda_{1,2}$	0.3314	0.1897	0.5973
6	$\lambda_{2,3}$	0.3600	0.2352	0.2654
7	D (mg/s)	0.9509	0.9547	0.9655
8	Recovery (%)	0.9993	0.9547	0.9910
9	Total Recovery (%)	0.9454		
10	Total Feed (kg/y)	598.40		
11	Total Product (kg/y)	0.5971		

As can bee seen, PSO leads to a higher total recovery factor, 0.9723 than MVO with the value of 0.9454. Moreover, the value of the total final product obtained by the two algorithms are comparable and PSO is more successful in this field.

Conclusions

in this study, performance of 3-section squared-off cascade with the constraint of 150 machines in the the enrichment of ^{124}Xe based on PSO and MVO algorithms is investigated. The obtained results show the promising capabilities of the PSO algorithm and it outperforms the MVO in terms of some parameters such as Recovery, D and the amount of total final product.

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