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Comparison of the ALO and PSOGSA Algorithms for Separation of ^{136}Xe Using Squared-off Cascade

Ezazi F*, Mirmohammadi S.L, Mallah M.H, Safdari S.J

Nuclear Fuel Cycle Research School, Nuclear Science and Technology Research Institute, Atomic Energy Organization, P.O. Box: 11365-8486,Tehran, Iran

* *Email: Farzaneheazazi1@gmail.com*

Abstract

In this paper, performance evaluation of two meta heuristic optimization algorithms of PSOGSA and ALO, in the optimization of 3-section squared off cascade for the separation of ^{136}Xe to the 90 concentration level is investigated. The objective function concentrated on maximizing the division factor, D, the total recovery factor, R, and the quantity of total product to be produced. The results obtained for cascade with 150 centrifuges showed that PSOGSA algorithm is superior to ALO and can guarantee a better answer to the problem.

Keywords: ALO algorithm, PSOGSA algorithm, Squared-off cascade, Objective Function

Introduction

With the growing use of stable isotopes in several fields, including the production of radioisotopes for medical applications and research in physics and other related sciences, there is an urgent need to enrich these isotopes to the desired levels. In this way, the practical applications of centrifugation in the field of multicomponent mixture separation is in progress. There are several types of cascades such as tapered, square and squared-off cascades. The tapered cascade is the most conventional and oldest isotope separation cascade, which has a higher efficiency than square and squared-off cascades. In tapered cascades, due to a different number of gas centrifuges in the stages, the feed stage entry is limited. Moreover, in the square cascades feed flow rate of all stages is equal. Therefore, cascade feed can be entered into any stages without changing the arrangement of the separating elements. But, because of violation of the ideal conditions in this type of cascade, their efficiency is lower than the tapered cascades [1, 2]. The attempts to combine the advantages of tapered and square cascades have led to the development of a group of cascades called squared-off cascades. A squared-off cascade can be viewed as a tapered cascade is divided into multiple sections, each with the same input flow rate in every stage. Separation cascades can significantly benefit from process optimization that it leads to reducing the cost of the plant or increasing the profit margin of the product. Researchers, recently, have shown great interest in analyzing optimization problems with the help of nature-inspired algorithms. These meta-heuristic algorithms have also found increasing use in the design of separation processes for multi-component mixtures [3, 4, 5 ,6]. The study of different methods of population-based meta-heuristic optimization paradigms for the separation of different materials can be of great help in advancing this field among scientists and based on no free launch theory, the best optimization methods in the field of stable isotope separation in the enrichment cascade problems can be selected and thus be used more to separate isotopes of other elements. In this way, the present study is focused on the comparison study of Antlion optimization algorithm, ALO and Particle swarm optimization-Gravitational search algorithm, PSOGSA in the separation of ^{136}Xe using a squared-off cascade. ^{136}Xe is the heaviest stable isotope of Xenon element that is very applicable in the nuclear physic researches and low temperature plasma surveys.

Theory

The practical configurations of the k-section squared-off cascade are shown in Figure 1. As shown in the figure, the feed flow rate of the sections can be quasi-tapered (a), decreasing (b), or increasing (c).

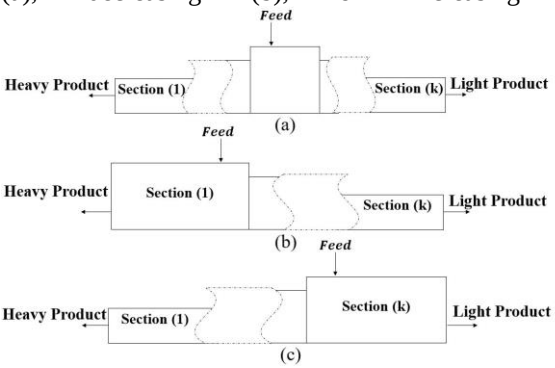

Figure 1. Schematic of the operational k-Section squared-off cascade

The k-section squared-off cascade has 3NNc+3N+3 governing equations. But, considering the number of unknowns, 3NNc+3N+4+k, there are k+1 more unknowns for this cascade than there are equations.

The difference between the number of unknowns and the number of equations for the 3-section squared-off cascade is 4. 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. For easier simulation, it is recommended to use flow parameters for this purpose, as their range is limited to the interval [0, 1]. In this study, the parameters cut of first stage, cascade cut and the recycled fraction between sections k-1 and k are used to solve the system. The

concentration equations are nonlinear type. in order to solve, the q-iteration technique can be used which was first proposed by Zeng et al. [7]. In this research, the Antlion optimization algorithm, ALO and Particle swarm optimization-Gravitational search algorithm, PSOGSA have been used to optimize the parameters of a 3-section squared-off cascade in the separation of ^{136}Xe stable isotope. The ALO mimics the hunting mechanism of antlions in nature and was introduced by Mirjalili in 2015 [8]. Various optimization problems have used this algorithm, including sizing of renewable energy resources, parallel machine scheduling, energy management, reactive power dispatch problem and so on. Also, PSOGSA is a novel hybrid optimization algorithm that it benefits the strengths of both particle swarm optimization and gravitational search algorithms [9]. Defined objective function consists of a set of different terms. The first two terms represent the balance between production output and waste generation for normal feed consumption. The third term increases the isotope recovery value, R, in the product, and the fourth term increases the parameter D as much as possible. Using this objective function means striving to obtain more of the product from a given amount of feed, or in other words, achieving a higher recovery factor, while also improving the Division factor.

Results and discussion

In this study, the goal is to separate ^{136}Xe from natural Xenon to 90% concentration in the final product using 150 centrifuges. The specifications of the assumed machines are given as the following. The minimum and maximum amount of feed flow rates to the gas centrifuge with values of 9 mg/s and 20 mg/s, respectively, and the unit separation factor relation is $1.32*f^{-0.045}$. f represents the feed flow rate of the single centrifuge. The optimization process is done based on a 33 stages cascade. After optimizing the squared-off cascade, the optimized configuration of the cascade has been shown in figure 2. As can be seen, the ascending arrangement is the appropriate one for the end component. Because ^{136}Xe is an end component, therefore it can be separated to a high enrichment of 90 % only in one step. The optimized parameters and the results of ^{136}Xe separation are presented in Table 1. As shown in this table, the PSOGSA can found higher capacity, 8.7 mg/s, for the cascade. In addition, a higher division factor, 0.9903 and better recovery, 0.9981 are the results of the PSOGSA algorithm in relation with the ALO results for the corresponding parameters, 0.99 and 0.9963.

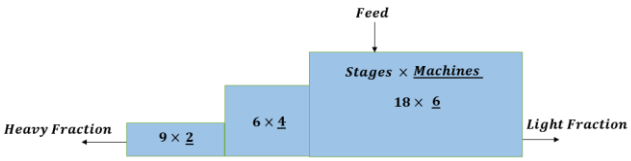

Figure 2. the optimized configuration of the 3-section squared-off cascade

Table 1. The optimized parameters and the results of ^{136}Xe separation by ALO and PSOGSA

Item	Parameters	PSOGSA	ALO
1	Feed (mg/s)	8.7	8
2	N_F	16	22
3	$\theta_{Cascade}$	0.9021	0.9021
4	θ_1	0.4984	0.5219
5	$\lambda_{1,2}$	0.4590	0.3571
6	$\lambda_{2,3}$	0.2890	0.4084
7	D (mg/s)	0.9903	0.99
8	Total Feed (kg/y)	274.36	252.29
9	Total Product (kg/y)	26.86	24.699
10	Total Recovery (%)	0.9981	0.9963

Conclusions

The methodology based on PSOGSA and ALO algorithms was proposed in this study to examine the performance of 3-section squared-off cascade with the constraint of 150 machines in the enrichment of ^{136}Xe. The obtained results show the promising capabilities of the PSOGSA algorithm and it outperforms the ALO in terms of some parameters such as Recovery, D and the amount of total final product.

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