Contents lists available at ScienceDirect

Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

Design of cascade with locally enlarged flow for enrichment of intermediate components of multi-isotope mixtures

A.Yu. Smirnov[a,*], G.A. Sulaberidze[a], Q. Xie[b], V.D. Borisevich[a]

[a] National Research Nuclear University MEPhI, Moscow, Russia
[b] Research Institute of Physical and Chemical Engineering of Nuclear Industry, Tianjin, PR China

ARTICLE INFO

Article history:
Received 3 March 2014
Received in revised form 16 November 2014
Accepted 10 December 2014
Available online 13 January 2015

Keywords:
Isotope mixture
Mass transfer
Separation cascade
Intermediate component

ABSTRACT

A method to produce relatively high concentrations of intermediate components from isotope mixtures in a separation cascade with local extension of a working substance flow at its inner stages is demonstrated. The cascade under consideration consists of two square parts of different width and has 4 external flows: the feed and waste ones and the end and interjacent product flows. The research demonstrates that the cascade with flow extension built by simple reshaping of a square cascade enables provide considerable increasing an intermediate component concentration in an interjacent product flow in comparison with the conventional 4 flows square cascade having the same values of the total and additional flows. In the example, it was examined enrichment of the ^{183}W isotope for which an increase in concentration provided by a cascade with flow extension is about 5 abs% whereas the compared cascades keep at their end product flows almost the same concentration of separating components.

1. Introduction

Over the past decades, stable isotopes of many chemical elements have been widely used in nuclear energy, fundamental research, medicine, industry and many other areas (Proc 7th International Conference on Isotopes, 2011). Unfortunately, their application is often limited by their high cost of production. The greatest difficulties in production are inherent to the stable isotopes with intermediate masses (Sulaberidze and Borisevich, 2001). This is due to fact that in the case of multi-isotope mixtures separation, the intermediate components are produced at both ends of a cascade (conventionally designated as "heavy" and "light" ones) together with the utmost components, the components with the smallest and largest mass numbers. As a result, increase in the concentrations of the intermediate components in the light and heavy fractions of a three-flow (one ingoing and two outgoing flows) cascade is limited by the maximum achievable values (Sulaberidze and Borisevich, 2001).

There exist a number of specific methods for enrichment of intermediate components of multi-isotope mixtures designed to achieve maximum concentrations in the outgoing flows of a three-flow cascade. These methods are based on enrichment of a mixture in a target isotope by a series of sequential operations in the same cascade. Alternatively, we can use the so-called dual cascade, where the product flow from the first cascade serves as a feed flow of the second one (Vetsko et al., 1987). In addition, some features of a "long" cascade can be used, where the concentration distributions of intermediate components have the maximum at its internal stages (Sulaberidze and Borisevich, 2001; Sulaberidze et al., 2006). This feature allows switching on an additional product flow at the point of the highest intermediate target component concentration inside the cascade. It results in higher enrichment

* *Corresponding author*. Tel.: +7 499 3239276.
E-mail address: a.y.smirnoff@rambler.ru (A.Yu. Smirnov).
http://dx.doi.org/10.1016/j.cherd.2014.12.012

of this component as compared with that at the cascade ends. However, all the above mentioned methods have certain drawbacks limiting their application for intermediate components extraction.

Obviously, at least two separation campaigns are required for sequential enrichment of a target component in the same cascade, which significantly increases both the time of production and its cost. Designing of dual cascades for production of intermediate components largely depends upon required volume. For a long cascade with an additional product flow the concentration of the intermediate component in the additional product flow extracted from the stage inside a cascade appears insufficient for the particular application.

As is known, the model cascade theory is widely used to study the regularities of the multicomponent selective mass transfer in separation of multicomponent isotope mixtures in cascades (Sulaberidze et al., 2006; De la Garza et al., 1961; De la Garza, 1963; Yamamoto and Kanagawa, 1987; Wu and Fu, 1998; Von Halle, 1987; Agostini, 1994; Zeng et al., 2012; Scopatz, 2013; Wood and Megliorini, 2012; Song et al., 2010). On the base of this theory, it was demonstrated the fundamental possibility of obtaining relatively high concentrations of intermediate components in the additional product flow within the cascade having an "extension" of a working substance flow at its internal stage. The basic principle of such a cascade work can be explained by the following statement: changing a gradient of a working substance flow at one of the internal stages of a cascade leads to change of the concentration gradients of all mixture components over cascade stages. With the help of one of the model cascades (a Q-cascade), it was shown (Zeng et al., 2012) that increasing the concentration of the intermediate target component can be achieved at the internal cascade stages by selection of a certain gradient flow function. Besides, an additional product flow at one of these cascade stages enables to achieve a higher target component concentration as compared to the maximum achievable one (Smirnov et al., 2010; Smirnov and Sulaberidze, 2013).

Such cascade configuration solves the inherent problems of the above schemes for intermediate component extraction. In particular, it is demonstrated the possibility to obtain higher concentration of an intermediate target component in a Q-cascade with flow extension compared to a three-flow cascade or a cascade of the monotonous profile with an additional product flow.

Besides, the total flows in both cascades appear to be the same and the isotope products in the flows at their ends have practically equivalent concentration of the desired intermediate isotope component (Smirnov and Sulaberidze, 2013). This suggests that such cascades with "extension" may be used for production along with the main product with enriched component, the limited amounts of an additional isotope product with a relatively high concentration of a target intermediate component, whose concentration does not exceed the maximum achievable values in the conventional cascades.

The results in (Smirnov et al., 2010; Smirnov and Sulaberidze, 2013) were obtained within the theory of the inapplicable in practice model Q-cascade characterized by the continuous flow distribution along the cascade stages. When designing practical separating cascades, the flow profile in model cascades is approximated using sections with constant length feed flows of their stages. The most convenient substitute for the model Q-cascade is the Square Cascade (SC) with the same feed flow at all its stages. A more sophisticated scheme of a Q-cascade approximation is the so-called Square-Off Cascade (SOC), which consists of several square sections, the feed flow at each of them is constant. In the most general case, the feed flows in various sections of a SOC may be unequal. The example of an approximation of a Q-cascade with a monotonous cascade profile by means of square sections is given in (Sulaberidze and Borisevich, 2001).

The major purpose of this paper is to demonstrate an advantage of a cascade for separation of intermediate components from multi-component isotope mixtures consisting of a few square sections with various working substance flows (section widths) below referred as a Cascade with Flow Extension (CFE) in contrast to a SC. The paper describes a mathematical model and a method of check up calculation for such cascade for simplicity composed of two pieces with different widths. It is demonstrated that the intermediate tungsten isotope ^{183}W produced in a CFE from the natural mixture has higher concentration than that in a SC having the same total flow as the former one.

2. Mathematical model of the process

In our research the Q-cascade with flow "extension" (QFE) is replaced with a CFE consisting for simplicity of two square profile pieces of various widths. Note that in such a cascade, in contrast to the monotonic decrease of a feed flow in the direction from the feed flow point to the ends of the cascade, which is typical for a SOC, an increase in a feed flow in the last part of the enriching section of the cascade takes place in a CFE under consideration.

An example of a flow distribution in CFE is shown in Fig. 1.

Here F is a feed flow, W is waste flow, P is the main product flow, E is an additional product flow; C_i^F, C_i^W, C_i^P, C_i^E are the corresponding component concentrations in these flows; $f-1$ is a number of stages in a "stripping" section of the cascade; K is a broadening coefficient, L is a feed flow at cascade stages in the cascade parts 3 and 4, s_0 is a number of the border stage between the cascade parts 2 and 3, s_E is a number of the stage where the additional product is withdrawn.

The quantitative view of the function $L(s)$ describing the distribution of a feed flow along cascade stages is represented by a solid line in Fig. 1. The external feed flow to a cascade under consideration enters to the stage with the f number. Thereby the number of separation stages in a "stripping" section of the cascade is equal to $(f-1)$. The boundaries of the cascade sections, i.e. a distance between the points of the ingoing/outgoing external flows in the cascade, is shown in Fig. 1 by a dash line. In this case, as flow extension is called an abrupt in the K-times increase in a working substance flow in the cascade with respect to the value of the L flow which is

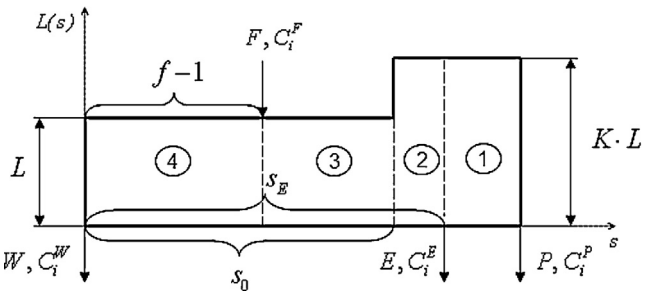

Fig. 1 – Schematic drawing of a cascade with extension consisting of two square pieces of a flow profile.