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Improvement in deuterium recovery from water–isotope mixture by thermal diffusion in the device of branch columns

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HIGHLIGHTS

- Recovery of deuterium by thermal diffusion from water–isotope mixture has been investigated.
- The undesirable remixing effect can be reduced by employing the device of branch columns.
- Deuterium recoveries were compared with that in a single column of the same total column length.
- Considerable recovery improvement is obtainable in the device of branch columns, instead of in a single-column device.

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ABSTRACT

Deuterium recovery from water–isotopes mixture using thermal diffusion can be improved by employing the branch column device, instead of single column devices, with the same total column length. The remixing effect due to convection currents in a thermal diffusion column for heavy water enrichment is thus reduced and separation improvement increases when the flow rate or the total column length increases. The improvement in separation can reach about 50% for the numerical example given.

1. Introduction

It was realized that deuterium (D) is the optimal nuclear fuel for fusion reactors, which may play an important role in fulfilling the word's energy requirement in the distant future. The thermal diffusion process is one of the feasible methods for isotope mixture separation. For hydrogen isotope separation, this method is particularly attractive because of the large molecular weight ratio [1]. The practical application of thermal diffusion effect for separating isotopes was introduced by Clusius and Dickel [2,3]. An excellent column theory treatment was given by Furry et al. [4,5]. The enrichment of heavy water from water isotope mixtures (H_2O–HDO–D_2O) in a thermal diffusion column was studied both theoretically and experimentally [6]. Yamamoto et al. [7–9] used continuous-type cryogenic-wall thermal diffusion columns to successfully separate H–D and H–T gas mixtures.

It was pointed out that the convective currents in the thermal diffusion column have two conflicting effects: a desirable cascading effect and an undesirable remixing effect [10,11]. Accordingly, the improvement in deuterium recovery from water–isotope mixtures in thermal diffusion columns inclined for reducing the remixing effect, have been investigated in the previous work [12,13]. An flexible way of reducing the remixing effect in a thermal diffusion column was also reported for deuterium recovery from hydrogen isotope mixtures by dividing a single thermal-diffusion column of column length L (Fig. 1) into a device with three branch columns of column length $L/3$(Fig. 2) [14]. The purpose of this work is to develop and investigate the separation theory for deuterium recovery from water–isotopes using triple-branch thermal-diffusion columns, and compare its performance with a single column device, with the same total column length L.

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Nomenclature

A_F constant defined by Eq. (7)
A_{F1} A_F with C_F replaced by C_{F1}
A_{B1} A_F with C_F replaced by C_{B1}
A_{T1} A_F with C_F replaced by C_{T1}
B column width (cm)
C fractional mass concentration
C_F C in the original feed stream
C_{F1} C in the mixed feed stream of the branch-column device
C_T C in the top product stream of the single-column device
$C_{T,i}$ C_T in ith column of the branch-column device, i = 1, 2, 3
C_B C in the bottom product stream of the single-column device
$C_{B,i}$ C_B in ith column of the branch-column device, i = 1, 2, 3
D mass diffusivity (cm^2/s)
g gravitational acceleration (cm^2/s)
H transport coefficient defined by Eq. (5) (g/s)
I_D, I_{III}, I_{II} improvement in performance defined by Eqs. (34), (36) and (37)
$J_{x,OD}, J_{x,TD}$ mass flux in x direction due to ordinary diffusion, thermal diffusion ($g/m^2/s$)
$J_{z,OD}$ mass flux in z direction due to ordinary diffusion ($g/m^2/s$)
L column length in a single column, or total column length in branch-column device (cm)
K transport coefficient defined by Eq. (6) (g/cm/s)
K_{eq} mass fractional equilibrium constant of H_2O–HDO–D_2O system
$\bar{T}$ average absolute temperature of fluid (K)
ΔT temperature difference between hot and cold surfaces (K)
x axis perpendicular to the flat plates (cm)
z axis parallel to the transport direction (cm)

Greek symbols
α reduced thermal diffusion constant
β $-\left(\frac{1}{\rho}\right)\left(\frac{\partial \rho}{\partial T}\right)$ evaluated at $\bar{T}$ ($1/K$)
Δ $C_{B3} - C_{T2}$, degree of separation obtained in the branch-column device
$\dot{\Delta}$ $C_B - C_T$, degree of separation obtained in the single-column device
σ mass flow rate (g/s)
ω half of plate spacing (cm)
μ absolute viscosity (g cm/s)

Subscripts
I, II, III, D H_2O, HDO, D_2O, D

2. Theory

2.1. Separation D_2O in a single column

Consider a flat-plate thermal diffusion column with column length L and column width B, as shown in Fig. 1. The column consists essentially of two vertical plates separated by a very narrow open space (2ω). One of the plates is heated and the other cooled. When this column is employed for separating water–isotope mixture [H_2O(I)–HDO(II)–D_2O(III)], the thermal diffusion effect causes

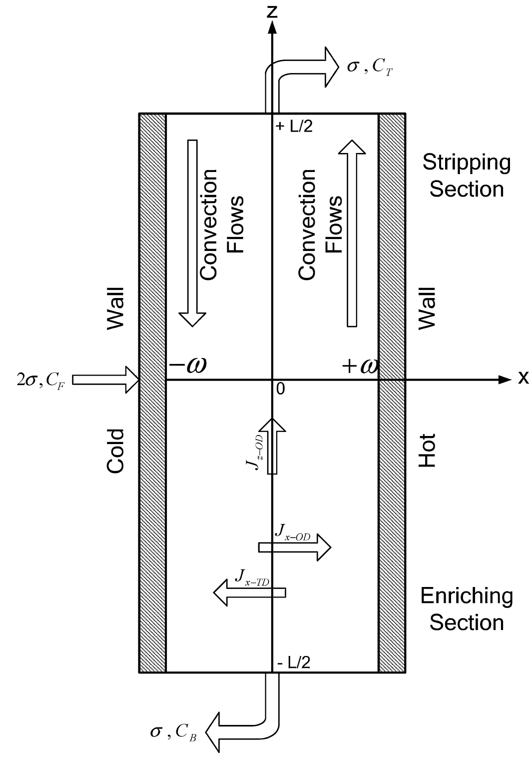

Fig. 1. Single-column device with column length L.

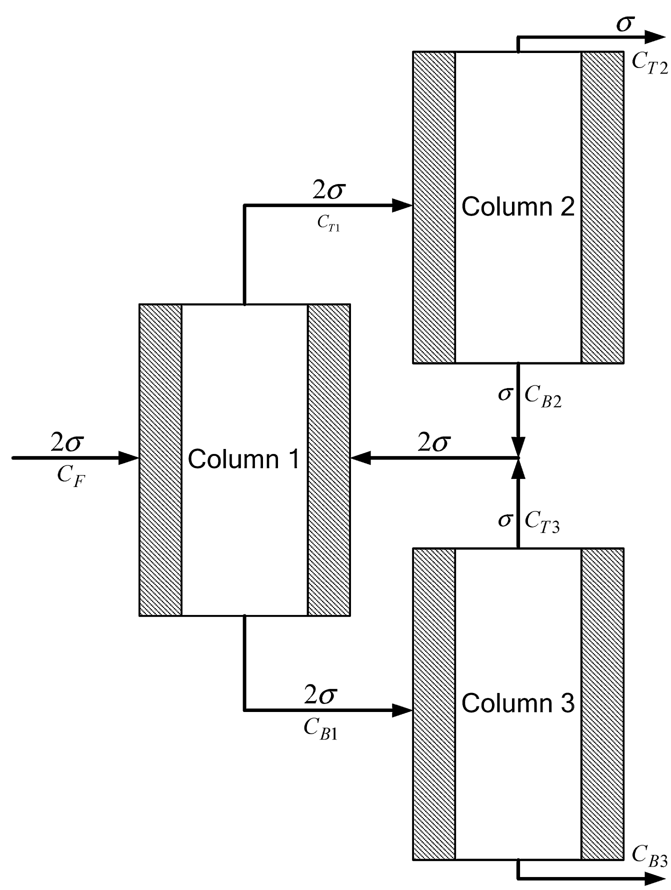

Fig. 2. Triply branch-column with column length L/3.