NE585 – Nuclear fuel cycle analysis
Project 3 – Front end of the nuclear fuel cycle

Name

University of Idaho ▪ Idaho Falls Center for Higher Education

Nuclear Engineering and Industrial Management Department

email

2025.10.07

Total – 200

Preface

Refer to these references to start for aqueous reprocessing –

(1) Countercurrent equilibrium extraction –Benedict

(2) Nuclear fuel reprocessing

(3) Principles of stagewise separation process calculations

(4) Liquid-liquid extraction example problem I

(5) Liquid-liquid extraction example problem II

Use standard assumptions –

- Constant distribution coefficient
- Complete mixing
- Fresh solvent

Required for full credit – In problems 3 – 8, please address how the solution will affect the engineering design of a commercial scale PUREX facility.

1 Volume flow

(10)

Derive an expression for $\frac{F}{P}$ and $\frac{W}{P}$ explicitly in terms of $x_F,\ x_P,\ x_W$.

2 SWU

(10)

Plot $\frac{SWU}{P}$ and $\frac{SWU}{F}$ as a function of x_P. There is an interesting implication(s) of this curve, which we talked about, in terms of the JPCOA. What is it? Note that medical isotopes require $x_P = 0.20$.

3 Extract concentration

(20)

Prove that the extract concentration (y_N) can be expressed as -

$$y_N = \frac{\beta^N - 1}{\beta - 1}(Dx_1 - y_0) + y_0.$$

4 Material balance

(20)

Now eliminate x_1 by applying an 'overall material balance' to the above expression; i.e., a material balance on stage 1 and stage N.

5 Extraction factor

(20)

Finally, using the definition of fractional recovery of the extractable component (ρ) and extraction factor (β), into the result from (4) above, and eliminate y_N.

6 Decontamination factor

(20)

Derive the contamination factor (f_{AB}) based on the result in (5) for both $y_0 = 0$ and $y_0 \neq 0$. What does the decontamination factor actually mean? How does the efficiency compare if $y_0 = 0$ or $y_0 \neq 0$?

7 Maximum decontamination factor

(25)

(a) Consider a multistage extraction system with two extractable components. What is the theoretical maximum for the decontamination factor? (*Assume* $y_0 = 0$.)

- $\beta_A > 1, \quad \beta_B > 1$
- $\beta_A > 1, \quad \beta_B < 1$
- $\beta_A < 1, \quad \beta_B > 1$
- $\beta_A < 1, \quad \beta_B < 1$

(b) Then, if the extraction factor for U is 5 and for Tc is 0.01. What is the decontamination factor? What does it physically mean?

8 Extraction limit

(25)

Show *with math* that for an extraction factor less than unity, complete extraction is impossible, even if an infinite number of stages is available. When (or would) there be a case where the extraction factor would be less than unity?

9 Uranium tails

(50)

How are uranium tails managed? Critically discuss this issue.

10 BONUS – Enrichment

(50)

What would be the speed and radius of a gas centrifuge that would make it equivalent to gas diffusion? What are the dimensions of the gas centrifuge? Which is better? Compute the separation factor and *solve* for velocity and radius.

11 BONUS – Cost analysis

(50)

Taking the cost equation, what is the driver or limited factor for cost? What needs to happen for an enrichment plant to be profitable? What challenges are there? Feel free to make graph(s).

$$c_P = [V_P - V_F - (x_P - x_F)\frac{V_F - V_W}{x_f - x_w}]c_S + (\frac{x_P - x_W}{x_F - x_w})c_F$$

c_P = enriched U price

c_S = SWU price

c_F = natural uranium price

$V_i = V(x_i)$; i.e., value function

Tables

Figures