Nuclear Science and Technology

Calculation, design and manufacture of system box-type mixer-settler used in rare earth solvent extraction process at laboratory scale

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Abstract: This report presents the process of calculating, designing and manufacturing a box-type mixer-settler system used for rare earth solvent extraction process on laboratory scale. The basic design parameters of the mixer-settler were calculated from two-phase flow rates, the contacting phase ratio and mixing time in mixer, the phase separation time in settler, the densities, and the viscosities of two phases. A detailed design of a 20-stage mixer-settler system was based on established calculation results. The dimension design of mixer-settler includes the dimension definition of effective volume, the structure, the size of the mixer and settler chambers, the structural dimension of various phase openings and their location, and the impeller design. A mixer-settler system was built based on design parameters. This system is used for rare earth solvent extraction process on the laboratory scale.

Keywords: *rare earth solvent extraction, mixer-settler...*

I. INTRODUCTION

Liquid-liquid extraction is a separation technology that is based on the distribution of one or more components between two immiscible or almost immiscible liquids. Generally, one of the liquid phases is an aqueous solution, and the other is an extractant dissolved in organic solvent. The extraction equipment is able to make two phases repeat dispersing-mass transferring-agglomerating process procedure and achieve the two basic functions of reasonable mixing and effective separation of two phases.

The phase separation experiences three steps: The agglomeration among the mixed phase drops by gravity force in the dispersing zone of the settler; the larger agglomerated drops move into the deep of the two phases under the function of the liquid flow; the agglomeration and collection of the drops are finished at the phase interface [1-3]. The separated two phases flow in opposite direction to upper stage and the next stage, respectively, to repeat the same procedure for the purpose of the extraction-separation.

The mixer-settler, a class of mineral process equipment, can effectively achieve the purpose of liquid-liquid extraction. A mixer-settler consists of a mixing chamber, a stirrer drove by a motor and installed in the mixing chamber, in which two phases is mixed, and a quiescent settling box that allows the mixed phase to separate by gravity.

The mixer-settler of solvent extraction has very strong characteristics of process technology, and its performance is influenced by different operation conditions and the properties of organic and aqueous phases. Therefore, one type of common mixer-settler cannot be used for the different

purposes and processes with excellent effectiveness and efficiency.

The mixer-settlers widely used in the process of solvent separation of rare earths are the box-type mixer-settler with simple structure, high efficiency, and smaller floor area [4-10]. In industry of solvent extraction-separation of rare earths, when the process lines of solvent extraction-separation of rare earths are designed, the next step is to design the suitable and reasonable mixer-settler or extractor of the processes. The design of mixer-settlers can determine if the targets of the designed processes are achieved and the fixed investment is reasonable including the building and the organic phase and aqueous phase of rare earths required to fill the cells. The following discussion focuses on the box-type mixersettler.

II. CONTENT

A. Material and method

Simple box-type mixer-settler is one of the earliest solvent extraction equipment used in industry with the development of the nuclear industry. One unit of mixer-settler, or one stage of mixer-settler, consists of one mixer and one settler (settling compartment), which is separated by partitioning plate from a rectangle box; multiunits of the mixer-settlers cascaded together are one set of mixer-settler. Normally, one set of mixer-settler contains 10 units or 10 stages of mixer-settler but depends on the unit size.

The basis of mixer-settler design is the specific characteristics of the extraction system. The basic design parameters of the mixer-settler are two-phase flow rates, the contacting phase ratio and mixing time in mixer, the phase separation time in settler, the densities, and the viscosities of two phases.

Table I. The basis of mixer-settler design

The basic design parameters	Values
Total two-phase flow rates	170 ml/min
The contacting phase ratio aqua/organic	1/4 (volume)
The mixing time in mixer	3 minutes
The phase separation time in settler	15 seconds
The viscosity of solvent	2.2545 mPa.s

The dimension design of mixer-settler includes the dimension definition of effective volume, the structure, the size of the mixer and settler chambers, the structural dimension of various phase openings and their location, and the impeller design.

Calculation of the dimension of the mixer:

✓ The effective volume of mixer is shown in the following equation [3]:

$$V_{eff} = f \times (Q_{aqu} + Q_{org}) \times t \qquad (1)$$

Where: V_{eff} - The effective volume of mixing chamber, m³.

Q_{aqu} - The flow rate of aqueous phase including aqueous recycled rate, m³/min.

Q_{org} - The flow rate of organic phase, m³/min.

t - Mixing time in mixer, min.

f - Correct coefficient, generally f = 1.1, for small size mixer-settler, f =1.0.

✓ The total height of the mixer is [3]:

$$H_{tot} = \frac{H_{eff}}{0.8} + 0.1 H_{eff} = 1.35 H_{eff} \quad (2)$$

$$H_{eff} = \frac{V_{eff}}{X \times X} \quad (3)$$

Where: X - The side length of the square, m.

H_{eff} - The effective height of the mixer

✓ The size of the opening can be calculated by following equation [2]:

$$Q_{tot} = r \times F \times \sqrt{2g\Delta p} \quad (4)$$

Where: Q_{tot} - Total flow rate, m³/min.

r - The coefficient of flow rate, 0.6.

F - The area of the cross section of the opening, m².

g - Acceleration gravity, 9.8 m/s.

Δp - Pressure difference, m (water column); small value of Δp should be adopted, 0.002 for small mixer; and 0.005 for industry mixer.

✓ Dimension of the mixed phase opening [2]:

$$d = \sqrt{\frac{4 \times F}{\pi}} \quad (5)$$

Calculation of the dimension of the settler: The length of the settler can be calculated [2]:

$$A' = \frac{Q\prime}{Q/A} \quad (6)$$

$$A' = L' \times L'' \quad (7)$$

$$L'' = \frac{A\prime}{L\prime} \quad (8)$$

Where: A' - Designed clarification area, m².

Q' - Treatment amount required, m³/h, L/min.

Q/A - The rate of clarification corresponding to certain ΔH, m³/h.m².

L' - The width of the settler, m, cm.

L'' - The length of the settler, m, cm.

**Calculation of the stirrer:** the diameter d of the stirrer can normally be calculated by following equation [2]:

$$d = (1/3 \sim 2/5)D \quad (9)$$

Where: D - the diameter of the mixer chamber.

B. Results

**Table II.** Design parameters of the mixer-settler system

| Parameters	Values	
	Calculation	**Manufacture**
The effective height of the mixer, H$_{eff}$, mm	80	80
The total height of the mixer, H$_{tot}$, mm	113	120
The effective volume of mixing chamber, l	0.512	0.512
Dimension of the mixed phase opening, d, mm	5.5	5.5
The width of the settler, L', mm	80	80
The height of the settler, H, mm	113	120
The length of the settler, L'', mm	265	350
The diameter of the stirrer, d, mm	50	50
Flow phase gap, mm		10
Motor power, 3 phase, kW		1.25
Rotation speed, rpm (Speed control by inverter)		1440
Material	Poly vinyl clorua (PVC)	
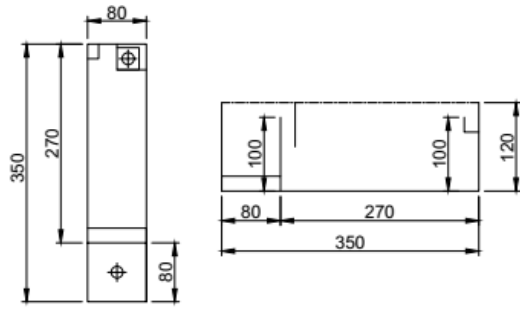
(a) Basic size
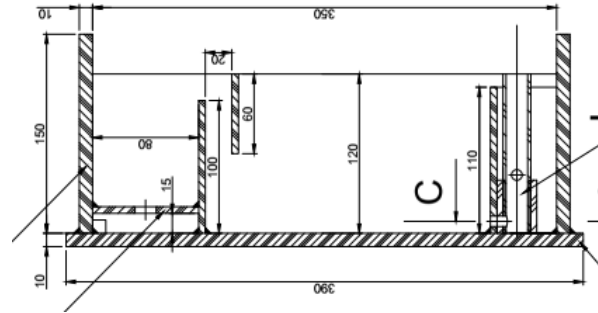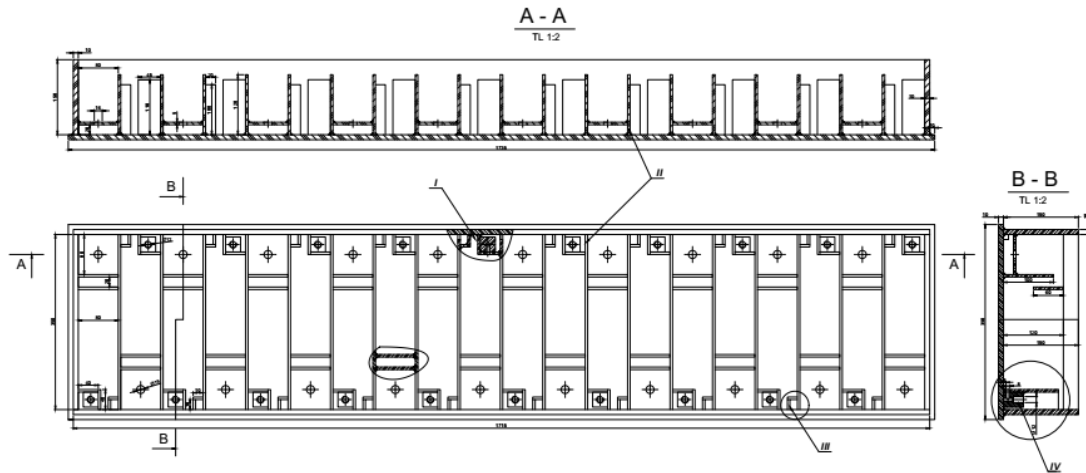
(b) Detail design
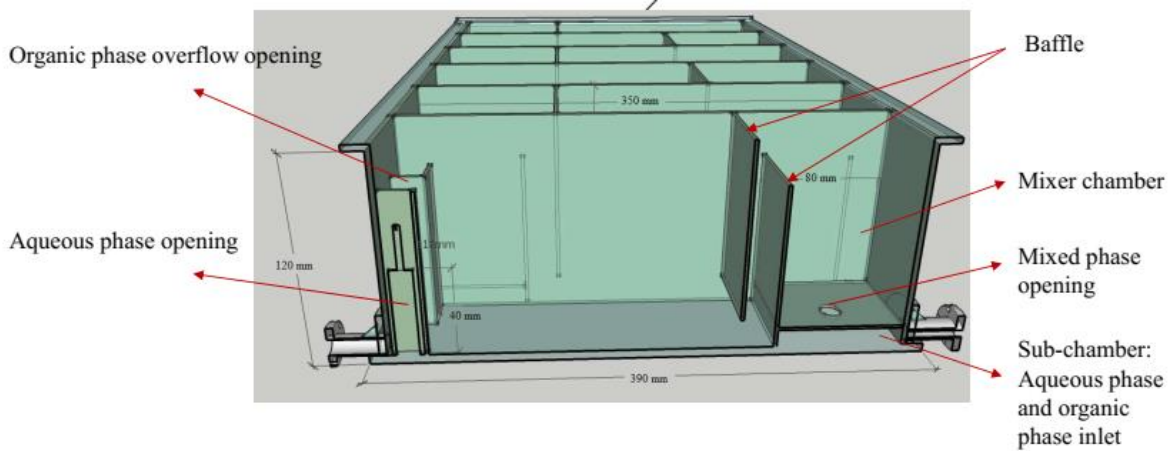
(c) Structure basic
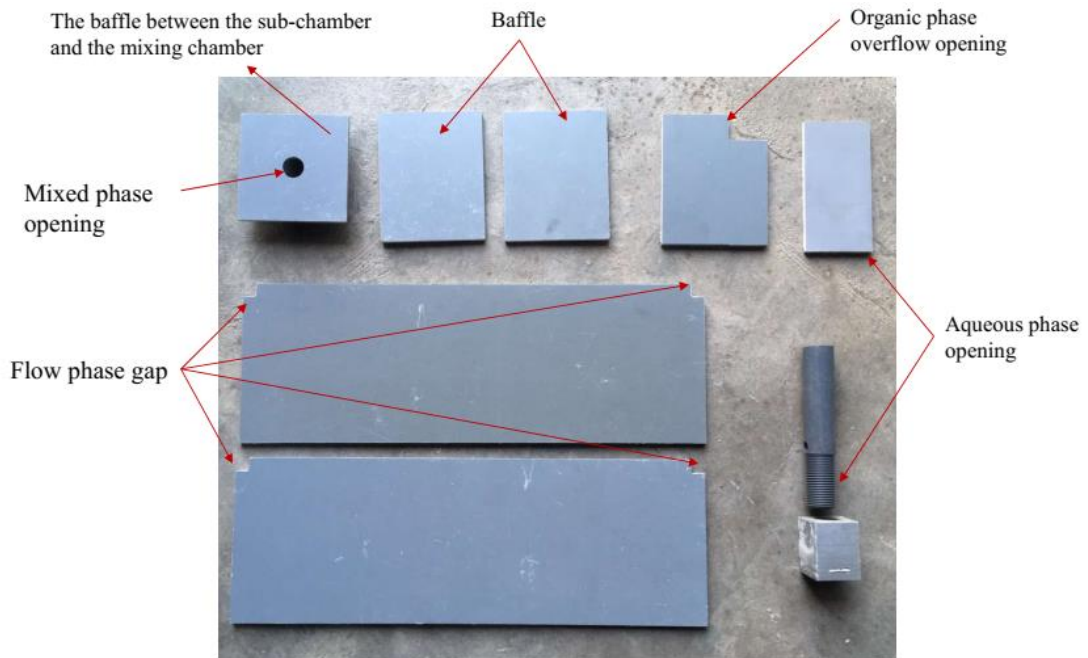
(d) Item detail of 1-stage mixer-settler

Fig. 1. Detailed design and structure of 1-stage mixer-settler.
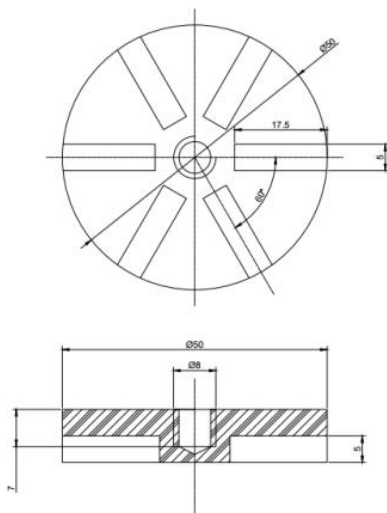
(a) Basic design

(b) Manufacture image

Fig. 2. Design and manufacture of 20-stage mixer-settler.

Fig. 3. Design and manufacture impeller: one-layer blade (6 open straight blades) type.
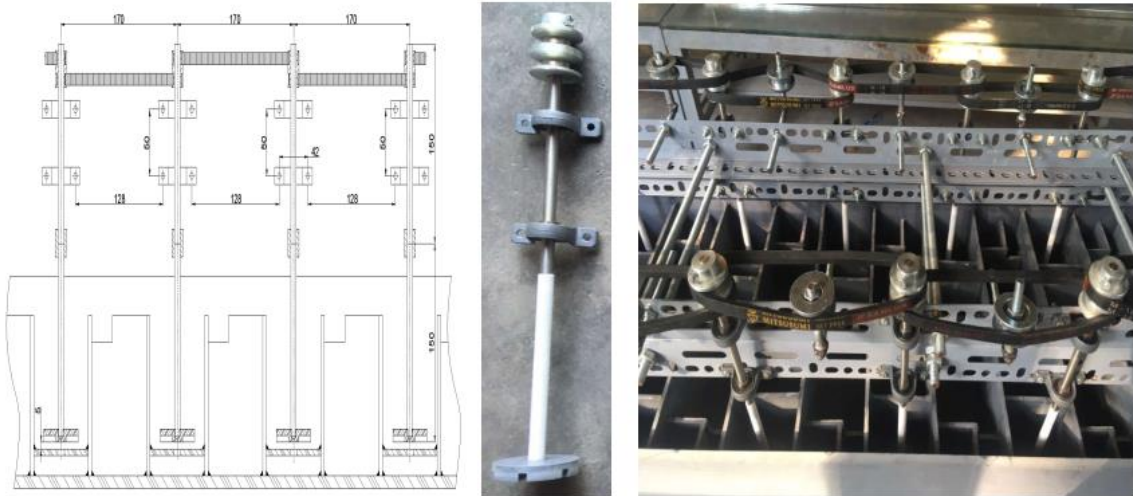
Fig. 4. Design and manufacture of the stirrer system.

Fig. 5. The 20-stage mixer-settler system after finish.

C. Discussion

The purpose of this report is to design a box-type mixing-settler system for laboratory-scale rare earth solvent extraction. Input parameters include stage volume of 2.5 L; mixer chamber volume of 0.5 L; 3-minute mixing time in mixer chamber.

From the design requirements, the parameters of the mixer-settler were calculated (Table II). The material used is PVC, with high

strength, resistance to chemicals (solvents PC88A/IP2028, alkaline and acids solutions). The manufacturing details were matched by CNC instruments with high precision.

The cross section of the mixer was square. A front chamber was designed under the bottom of the mixing chamber with a converging opening on the center of partitioning plate between the front chamber and mixing chamber. Both organic and aqueous phases were suctioned into the mixing chamber by impeller. In order to obtain the better mixing effect and improve the mass-transfer efficiency, the baffles should be installed on the four inner surfaces of the mixing chamber for the large mixer-settler [10].

In order to obtain the better settler effect, a grid tray or baffle with lots of openings on it could be installed near to the inlet of the settler to uniformly distribute the mixed-phase flow into the settler and speed up the mixed microdrops to agglomerate and finish the phase separation. The grid tray could be made from the multilayer nets [10].

The stirrer was one-layer blade (6 open straight blades) type. The flow mainly was the radialflow. In cylinder tank, the flow was turbulence flow in the condition of nonbaffle when baffle was installed; there was no turbulence flow and the main flow was updown flow. In design, the depth of the stirrer is $y = (1/3\sim1/2)H$. A big liquid head will be formed if the bottom impeller was too close to the converging opening; in this situation, air will be suctioned into the mixer to result in organic lose by entrainment and worsening the operation. If the distance were too long, there would not be enough suction force to suction two phases into the mixer; thus, the circulation of the mixed phase in the mixer would not meet the design requirement. Therefore, the stirrer was designed to be adjustable (up or down) for

adjusting the distance between the bottom impeller on the stirrer to the converging opening in certain range.

III. CONCLUSIONS

A detailed design of a 20-stage mixer-settler system was based on established calculation results. The cross section of the mixer was square, a front chamber was designed under the bottom of the mixing chamber with a converging opening on the center of partitioning plate between the front chamber and mixing chamber. The total height of the mixer, the effective volume of mixing chamber and the dimensions of the mixed phase opening were 120 mm, 0.512 L and 10 mm, respectively. The length of the settler was 350 mm. The stirrer was one-layer blade (6 open straight blades) type, diameter of the stirrer was 50 mm. A mixer-settler system was built based on design parameters by PVC material. This system was used in rare earth solvent extraction process at the laboratory scale.

ACKNOWLEDGEMENTS

REFERENCES

[1]. Z. Li, Y. Li, F. Weiyang, J. Yang (Eds.), "Liquid-Liquid Extraction Process and Equipment" (in Chinese), *Atomic Energy Press*, Beijing, pp. 312–421, 1993.

[2]. V. Santos-Moreau, L. Brunet-Errard, M. Rolland, "Numerical CFD simulation of a batch stirred tank reactor with stationary catalytic basket", *Chem. Eng. J.* 207–208, 596–606, 2012.

[3]. M.O. Shabani, A. Mazahery, "Computational fluid dynamics (CFD) simulation of liquid-liquid mixing in mixer settler", *Archives of metallurgy and materials.* Vol 57, 173-178, 2012.

[4]. F. Zizhong, "Extractors used in domestic rare earth industry", *Hydrometall. China (in Chinese)* 28 (2), 119–122, 2009.

[5]. F. Zizhong, Q. Sun, S. Liu, Y. Wang, "Development and application of full countercurrent mixer-settler", *Hydrometall*. China (in Chinese) 27 (2), 124-128, 2008.

[6]. N. Kamei, S. Hiraoka, Yoshihito, et al., "Effects of impeller and baffle dimensions on power consumption under turbulent flow in an agitated vessel with paddle impeller", *Kagaku Kogaku Ronbunshu* 22, 249–256, 1996.

[7]. M. Xie, G. Zhuo, Y. Peiqing, "Comparison of power number for paddle type impellers by three methods", *Chem.Eng*. (in Chinese) 38 (10), 167 – 170, 2010.

[8]. Q. Han, J. Yang, L. Cheng, Q. Lin, "A Device of Circulation of Aqueous-Phase in Local-Stage for Box-Type Extraction Cell", *Chinese Patent*, CN 102912127A, 2012.

[9]. L. Lizhu, B. Zhao, H. Xie, "Study on high efficient mixer-settler, Proceedings of 3rd Conference of Chinese Rare Earth Society", *Hydrometall*. China (in Chinese) 1, pp. 283–286, 1994.

[10]. Y. Wang, X. Jiang, G. Xu, Y. Zhang, "Some measures about enhancing efficiency of mixer-settler extractor", *Hydrometall*. China (in Chinese) 28 (1), 53–55, 2008.