Mass integration for recovery of zinc from galvanizing and metal finishing industry using supertargeting approach

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This paper presents an optimization technique, based on Supertargeting Approach, for the synthesis of solvent extraction and ion exchange network, which broadly falls under Mass Exchange Network (MEN). The present work is related to the recovery of zinc from spent pickle liquor and the rinse water, an effluent of galvanizing and metal finishing industry. The minimum composition difference of zinc, \( \varepsilon \), between operating condition and equilibrium condition is found to be a key optimization variable. This paper describes the targeting as well as designing procedures for optimization of present MEN. During the design stage, it has been possible to achieve the targeted results.

**Keywords:** Mass exchange network, Minimum composition difference, Supertargeting

**IPC Code:** C22B9/00

MENs are widely used in chemical, metallurgical and allied industries for the manufacture of food products, recovery of valuable materials, product finishing and hazardous waste and wastewater minimization. El. Halwagi and Manousiouthekis\(^1\) defined the MEN synthesis as, “A method aimed for generating systematically a cost effective network of mass exchangers with the purpose of preferentially transferring certain species from a set of rich streams to a set of lean streams”. Common mass transfer operations are absorption, desorption, adsorption, ion-exchange, solvent extraction and leaching etc.

In 1998, N. Hallale and D. M. Fraser proposed the concept of Supertargeting approach\(^2,3\), based on the Pinch technology. It provided a considerable flexibility to the designer, and permitted him to participate in the decision making process, which is obviously necessary to evolve a practical and useful design. It also saves the designer from setting up superstructure of equations and development of complex codes for solution.

**Problem statement**

A typical problem\(^4\), shown in Fig. 1, has been discussed below to demonstrate the applicability of Supertargeting Approach for recovery of zinc from a metal finishing plant.

Pickling is an important process in a galvanizing and metal finishing industry. A pickle solution, typically hydrochloric acid, is used to remove oxides, scale or corrosion products from the metal surface. The spent pickle liquor contains ZnCl\(_2\) and FeCl\(_2\) as two major contaminants. After the metal leaves the pickling bath it is washed with water to rinse off the clinging film of chemicals adhering to the work piece surface.

To recover ZnCl\(_2\) from spent pickle liquor \( R_1 \) and rinse waste water \( R_2 \), two mass-exchange processes are proposed: Solvent Extraction and Ion Exchange. For solvent extraction, three Mass separating agents (MSAs) are proposed: tributyl phosphate (\( S_1 \)), triisooctyl amine (\( S_2 \)) and di-2-ethyl hexyl phosphoric acid (\( S_3 \)) and for ion exchange, two resins: a strong acid cation resin (\( I_1 \)) and a strong base anion resin (\( I_2 \)) are proposed. These streams are termed as lean...
The resins used in ion exchange operations are to be regenerated with 4% HCl ($H_1$) and 4% NaOH ($H_2$) solutions. Water is used to rinse the resins after regeneration.

The stream data and cost data for this problem are reproduced in Tables 1 and 2, respectively.

As a first guess (base case), the minimum composition difference ($\varepsilon$) for the above stated problem is taken as $10^{-4}$ kg ZnCl$_2$/kg MSA.

Equilibrium relations for recovery of ZnCl$_2$ with MSAs $S_1$, $S_2$ and $S_3$ are given by Eqs (1a), (1b) and (1c), respectively, in the form of $y = mx + b$,

\begin{align*}
y &= 0.845 x_1 + 0.0 \quad \text{... (1a)} \\
y &= 1.134 x_2 + 0.01 \quad \text{... (1b)} \\
y &= 0.632 x_3 + 0.02 \quad \text{... (1c)}
\end{align*}

where $x_1$, $x_2$ and $x_3$ are the compositions of ZnCl$_2$ in lean streams (MSAs) $S_1$, $S_2$ and $S_3$, respectively, and $y$ is the compositions of ZnCl$_2$ in rich streams $R_1$ and $R_2$. As per the requirements of the process, sieve tray columns for solvent extraction and packed columns for ion exchange are proposed.

The aim of the present study is to systematically synthesize a cost effective MEN for recovery of zinc. The first step, during solution of the present problem, is to set the optimum targets in terms of flow rates of MSAs, ideal number of trays, active height and diameter of ion exchange column, number of units of mass exchangers and Total annual cost (TAC) for the MEN. In the second step the design of the MEN is carried out to achieve the optimum targeted values.

**Solution technique**

The details of the different steps, encountered during targeting and designing of MEN using Supertargeting approach, are shown in Fig. 2.

**Targeting of MEN**

**Computation of minimum flow rates of MSAs**

The equation of operating line for recovery of zinc from a rich stream to a lean stream (MSA) is governed by Eq. (2).

$$G (y_s - y_t) = L (x_t - x_s) \quad \text{... (2)}$$

It is desired to reduce the rich stream composition from $y_s$ to $y_t$ and to maximize the lean stream composition. The maximum theoretical composition of lean stream (in terms of concentration of ZnCl$_2$) is achieved when the operating line touches the equilibrium line. However, to achieve this composition one has to use a mass exchanger of infinite size leading to an infinite capital cost of MEN. Thus, for all practical purposes a minimum difference in concentration ($\varepsilon$) of ZnCl$_2$ is required between the operating and equilibrium compositions of lean stream. If a linear equilibrium relationship as denoted by Eq. (1), holds for the distribution of the

---

**Table 1—The stream data**

<table>
<thead>
<tr>
<th>Rich Stream(s)</th>
<th>$G$ (kg/s)</th>
<th>$y^*$ Composition (Mass fraction)</th>
<th>$y^\prime$ Composition (Mass fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>0.2</td>
<td>0.08</td>
<td>0.02</td>
</tr>
<tr>
<td>$R_2$</td>
<td>0.1</td>
<td>0.03</td>
<td>0</td>
</tr>
<tr>
<td>Lean Stream(s)</td>
<td>$L$ (kg/s)</td>
<td>$x^*$ Composition (Mass fraction)</td>
<td>$x^\prime$ Composition (Mass fraction)</td>
</tr>
<tr>
<td>$S_1$</td>
<td>-</td>
<td>0.006</td>
<td>0.06</td>
</tr>
<tr>
<td>$S_2$</td>
<td>-</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>$S_3$</td>
<td>-</td>
<td>0.009</td>
<td>0.05</td>
</tr>
</tbody>
</table>

**Table 2—The cost data**

<table>
<thead>
<tr>
<th>MSAs</th>
<th>Cost (Rs/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>0.97</td>
</tr>
<tr>
<td>$S_2$</td>
<td>7.99</td>
</tr>
<tr>
<td>$S_3$</td>
<td>1.88</td>
</tr>
<tr>
<td>$I_1$</td>
<td>183.479</td>
</tr>
<tr>
<td>$I_2$</td>
<td>485.76</td>
</tr>
<tr>
<td>$H_1$</td>
<td>4.03</td>
</tr>
<tr>
<td>$H_2$</td>
<td>3.5</td>
</tr>
<tr>
<td>Water</td>
<td>3.45</td>
</tr>
<tr>
<td>Equipment</td>
<td>Cost equation (Rs/y)</td>
</tr>
<tr>
<td>Sieve tray columns</td>
<td>198421.68 Nstages</td>
</tr>
<tr>
<td>Packed columns</td>
<td>185039.55 H</td>
</tr>
</tbody>
</table>

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The flow chart of supertargeting method for the targeting and design of MEN.
key component among the various streams over the operating range or its subintervals, then the $\varepsilon$ may be mathematically expressed as:

$$x = (y - b)/m - \varepsilon \quad \ldots (3)$$

The above expression is rearranged and shown in Eq. (4).

$$y = m(x + \varepsilon) + b \quad \ldots (4)$$

The composition of ZnCl$_2$ in rich stream corresponding to that in lean stream is computed using Eq. (4) and the results obtained are shown in Table 3.

The data available in Table 3 is presented in a slightly different manner in the Problem Table (Table 4), and are subsequently used for computing the flow rates of MSAs. It represents supply and target compositions of ZnCl$_2$ in rich streams arranged in decreasing order and establishes a series of composition intervals in the MEN. As shown in Table 4, a material balance on the ZnCl$_2$ is performed for each interval and the mass surplus is then cascaded from the highest interval to the lowest to obtain the cumulative flow of mass of ZnCl$_2$ ($M'_{\text{cas}}$).

The minimum flow rates of MSAs are computed using Grand Composite Curve (GCC). The GCC, Fig. 3, is drawn between composition of ZnCl$_2$ ($y'$) and cumulative mass flow of ZnCl$_2$ ($M'_{\text{cas}}$) for lean as well as rich stream ($R_1$ and $R_2$). It indicates the availability of MSAs in various composition intervals for solvent extraction as well as ion exchange. From Table 2, it can be seen that $S_1$ is the cheapest amongst the available MSAs. Hence, its use is maximized to bring down the operating cost of MEN. When the values of $x^s$ and $x'^t$ for $S_1$, computed in Table 3, is plotted in GCC, the line representing MSA, $S_1$, touches the rich stream composite curve for $R_1$ and $R_2$ at point $P$, as evident from Fig. 3a. This point is called the pinch point that is clearly shown in Fig. 3b, which is the enlarged view of dotted area of Fig. 3a. It divides the whole problem into two distinct parts: one above the pinch and the other below the pinch. Analyses of both parts are done separately as these are computationally independent. As can be seen in Fig. 3a, MSA, $S_1$, is used above the pinch. The maximum mass of ZnCl$_2$ that can be recovered using $S_1$ is 0.01448 kg/s. Therefore, to achieve this recovery level, the flow rate of $S_1$ comes out to be 0.268 kg/s {0.01448/(0.06-0.006)=0.268}. If used this will consume MSA, $S_1$, completely above the pinch for solvent extraction and no more $S_1$ will be available. At pinch point, $P$, the

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**Table 3**—Composition of ZnCl$_2$ in rich streams and lean streams

<table>
<thead>
<tr>
<th>Stream</th>
<th>$y^r$</th>
<th>$y^l$</th>
<th>$G$</th>
<th>Stream</th>
<th>$x^s$</th>
<th>$x'^t$</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>0.08</td>
<td>0.02</td>
<td>0.2</td>
<td>$S_1$</td>
<td>0.00515</td>
<td>0.05078</td>
<td></td>
</tr>
<tr>
<td>$R_2$</td>
<td>0.03</td>
<td>0</td>
<td>0.1</td>
<td>$S_2$</td>
<td>0.02145</td>
<td>0.03279</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$S_3$</td>
<td>0.02575</td>
<td>0.5166</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4**—Problem table for zinc recovery

<table>
<thead>
<tr>
<th>Interval</th>
<th>$y'$</th>
<th>$G'$</th>
<th>$M'_{\text{int}}$ (kg/s)</th>
<th>$M'_{\text{cas}}$ (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.08</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0.03</td>
<td>-0.2</td>
<td>-0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>0.02</td>
<td>-0.3</td>
<td>-0.003</td>
<td>0.013</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>-0.1</td>
<td>-0.002</td>
<td>0.015</td>
</tr>
</tbody>
</table>

---

Fig. 3a—Grand composite curve for zinc recovery problem

Fig. 3b—Grand composite curve for zinc recovery problem
[enlargement of dotted area of Fig. 3a.]
The composition of ZnCl₂ is 0.00515 for rich stream, \( R_2 \). The corresponding composition of ZnCl₂ for MSA, \( S_1 \), when computed using Eq. (1a), comes out to be 0.006. The remaining mass of ZnCl₂ in rich stream, \( R_2 \), equals to 0.00052 kg/s \{0.015-0.01448=0.00052\}, is to be recovered below the pinch.

The remaining available MSAs for further recovery of ZnCl₂ from rich stream, \( R_2 \), are \( S_2, S_3, I_1, I_2, H_1 \) and \( H_2 \). Based on costs of MSAs, given in Table 2, the MSA, \( S_3 \), is the next cheapest lean stream. However, it cannot recover ZnCl₂ because, as can be seen from Table 3, it operates at a higher concentration of ZnCl₂ than that available in rich streams below the pinch. For the same reason \( S_2 \) also cannot be used for the recovery of ZnCl₂. Therefore, MSAs, \( I_1 \) and \( I_2 \), are proposed for further removal of ZnCl₂ from \( R_2 \) using ion exchange process below the pinch. MSA, \( I_1 \), is recommended for removal of Zn⁺⁺ ions and then MSA, \( I_2 \), is used for removal of Cl⁻ ions. MSAs, \( H_1 \) and \( H_2 \) are proposed for regeneration of \( I_1 \) and \( I_2 \) respectively. The shaded area of Fig. 1 is further developed and refined as shown in Fig. 4. It now only deals with rich streams, \( R_1 \) and \( R_2 \), and MSAs, \( S_1, I_1, I_2, H_1 \) and \( H_2 \).

For MSA, \( S_1 \), tray type solvent extraction column and that for \( I_1 \) and \( I_2 \) packed bed type ion exchangers are used.

**Number of trays target**

Above the pinch MSA, \( S_1 \), is used to extract ZnCl₂ from rich streams \( R_1 \) and \( R_2 \) using a tray type solvent extraction column. The number of trays, for these columns is targeted as follows:

**Grid diagram**

The network design procedure uses a special diagram named as “Grid Diagram”, shown in Fig. 5, to represent MEN during its synthesis which is created using data given in Tables 3 and 4. This is used for targeting number of trays and to show the stream population in each interval above and below the pinch. As evident from Fig. 5, MSA, \( S_1 \), is exclusively used above the pinch.

The ideal number of trays in each interval is computed analytically using Kremser equation⁶, Eq. (5) and are reported in Table 5.

![Fig. 4—Enlargement of shaded area of Fig. 1](image)

![Fig. 5—The grid diagram](image)

<table>
<thead>
<tr>
<th>Ideal number of trays for rich streams above the pinch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rich stream (s)</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\text{If } A\neq 1, \quad N_{\text{stage}} &= \frac{\log \left[ \frac{y^{in} - mx^{in} - b}{y^{out} - mx^{in} - b} \left( \frac{1}{1-A} \right)^{1/A} \right]}{\log A} \quad \ldots \quad (5a) \\
\text{If } A=1, \quad N_{\text{stage}} &= \frac{y^{in} - y^{out}}{y^{in} - mx^{in} - b} \quad \ldots \quad (5b)
\end{align*}
\]
where, \( A = \frac{L}{mG} \)

As evident from Figs 4 and 5, below the Pinch only rich stream \( R_2 \) exists. The active height and diameter of ion exchanger can be targeted as given below:

**Active height and diameter of ion exchanger**

**Removal of Zn\(^{2+} \) from \( R_2 \) using MSA \( I_1 \)**

Assuming the ion exchange operation to be carried out for 7 days and with two beds (one in operation and one in standby). Amount of \( \text{ZnCl}_2 \) to be processed per second comes out to be 0.000515 kg \{\{(0.00515-0)*0.1\}. Similarly, total amount of \( \text{ZnCl}_2 \) to be processed per week equals to 311.4 kg and thus total number of moles of \( \text{ZnCl}_2 \) is 2285.4.

Zinc ions, present in rich stream \( R_2 \), create bonds with MSA, \( I_1 \), using following chemical reaction:

\[
2(R\text{-SO}_3\text{H}^+) + \text{Zn}^{2+} + 2\text{Cl}^- \rightarrow (R\text{-SO}_3)^2\text{Zn}^{2+} + 2\text{H}^+ + 2\text{Cl}^- \quad \ldots \quad (6)
\]

This reaction, Eq. (6), indicates that one mole of \( \text{Zn}^{2+} \) requires two moles of \( I_1 \). Therefore, total number of moles of \( I_1 \) required is 4570.8. In order to compensate non-ideal operating conditions, it is recommended to apply a safety factor to operating capacity. Typical safety factor\(^6\) is 5% for cation. Hence, total number of moles of \( I_1 \) required for removal of 4799.4 moles of \( \text{Zn}^{2+} \) comes out to be 883.09 kg. The density of \( I_1 \) is 750 kg/m\(^3\) and correspondingly the volume of \( I_1 \) equals to 1.18 m\(^3\). The porosity of resin bed is 0.4 and thus total volume of resin bed comes out to be 1.97 m\(^3\). Assuming the ratio of resin height to diameter of ion exchanger\(^6\) as 3/2, the height and diameter of ion exchanger are 1.77 and 1.19 m, respectively.

The regeneration reaction of \( I_1 \) with \( \text{HCl} \) is as follows:

\[
2\text{H}^+ + 2\text{Cl}^- + (R\text{-SO}_3)^2\text{Zn}^{2+} \rightarrow 2(R\text{-SO}_3\text{H}^+) + \text{ZnCl}_2 \quad \ldots \quad (7)
\]

Equation (7) clearly shows that one mole of \( I_1 \) is regenerated with two moles of \( \text{HCl} \). Therefore, 4799.4 moles of \( \text{HCl} \) are required. If chemical efficiency of regeneration\(^6\) for \( I_1 \) is 130% then total number of moles of \( \text{HCl} \) required for regeneration of 4799.4 moles of \( I_1 \) comes out to be 6239.2. Correspondingly, total volume of 4% \( \text{HCl} \) solution (generally 4% \( \text{HCl} \) solution is used for regeneration) is 5.69 m\(^3\). Assuming that the counter current regeneration flow\(^6\) to be 6 m/h, the regeneration time comes out to be 54 min.

Regeneration is followed by rinse process. The total rinse water requirement\(^6\) is assumed to be 3 Bed Volume, which completes rinse process in 55 min. Thus, total time for regeneration and rinse process is 1 h 49 min.

**Removal of Cl\(^- \) from \( R_2 \) using MSA \( I_2 \)**

Similar computation is carried out for design of ion exchanger for removal of Cl\(^- \) from rich stream \( R_2 \) with MSA \( I_2 \). The reaction of Cl\(^- \) with \( I_2 \) is given as:

\[
2\text{R-N}^+(\text{CH}_3)_3\text{OH}^- + 2\text{H}^+ + 2\text{Cl}^- \rightarrow 2\text{R-N}^+(\text{CH}_3)_3\text{Cl}^- + 2\text{H}_2\text{O} \quad \ldots \quad (8)
\]

The regeneration reaction of \( I_2 \) with \( \text{NaOH} \) is

\[
2\text{R-N}^+(\text{CH}_3)_3\text{Cl}^- + 2\text{Na}^+ + 2\text{OH}^- \rightarrow 2\text{R-N}^+(\text{CH}_3)_3\text{OH}^- + 2\text{NaCl} \quad \ldots \quad (9)
\]

The salient steps for designing of ion exchanger are listed below:

1. Assume that the safety factor to operating capacity\(^6\) is 10% for anion.
2. Total number of moles of \( I_2 \) required for removal of 4570.9 moles of Cl\(^- \) is 5027.9.
3. Total volume of resin bed equals to 3.12 m\(^3\).
4. Assuming the ratio of height to diameter of ion exchanger\(^6\) as 3/2. The height and diameter of ion exchanger are 2.05 and 1.38 m, respectively.
5. Assuming the chemical efficiency\(^6\) for regeneration of \( I_2 \) is 150%, the required number of moles of 4% \( \text{NaOH} \) solution comes out to be 7541.919.
6. Assuming the counter current regeneration flow\(^6\) to be 6 m/h it takes 52 min to complete regeneration the resin.
7. Assuming the total rinse water requirement equals to 4 Bed Volume\(^6\), it takes 1 h and 26 min to complete rinse operation. Thus, total time required for regeneration and rinse processes is 2 h and 18 min.

**Minimum number of unit (mass exchanger) target**

The minimum number of units\(^2\), that is mass exchangers, is targeted using Eqs (10a) and (10b). These equations are applied above and below the pinch separately and then are summed up to get the total minimum number of units target required for the network.

\[
U_{\text{min, pinch}} = U_{\text{min, above pinch}} + U_{\text{min, below pinch}} \quad \ldots \quad (10a)
\]
The minimum number of units target comes out to be 6. Two above the pinch and the rest four below the pinch.

Cost targeting

Operating cost

The annual operating cost is targeted by multiplying the flow rate of MSAs, $S_1$, $H_1$, $H_2$ and water with corresponding cost figures given in Table 2. The annual operating costs for $I_1$ and $I_2$ depend on their working lives. Assuming that $I_1$ and $I_2$ are to be regenerated once in a week, the total lives of $I_1$ and $I_2$ can be taken as 20 and 4 years, respectively. The annual operating costs for $I_1$ and $I_2$ are computed by multiplying the amount of $I_1$ and $I_2$ required in one year with corresponding cost figures, given in Table 2. The total operating cost (TOC) is given in Table 6.

Capital cost

The annual capital cost is computed by multiplying the number of trays and active heights of packed beds with corresponding costs, given in Table 2. The details of total capital cost (TCC) targeting of the MEN are given in Table 7.

The TOC and TCC targets, for the base case value of $\varepsilon$ (0.0001), are Rs. 14524591/y and Rs. 3413384/y, respectively which when added together makes the TAC target, for the base case value of $\varepsilon$, to be Rs. 17937975/y.

Supertargeting

The “$\varepsilon$” is an important variable for design of MEN and considerably influences the TAC. With the increase in the value of $\varepsilon$, the required flow rate of lean stream (MSA) increases, leading to an increase in the TOC whereas the TCC decreases due to the increase in the driving force for mass transfer between operating and equilibrium conditions. Thus, the problem is a perfect case for optimization and calls for the determination of optimum value of $\varepsilon$, leading to the lowest TAC. While searching for an optimum value of $\varepsilon$, its numerical value is varied from 0.0001 to 0.002 in discrete steps, anticipating that optimum value of $\varepsilon$ will be detected within this range, and TAC is retargeted based on the procedure discussed above. The Supertargeting curve, Fig. 6, shows that minimum value of TAC corresponds to a value of $\varepsilon$ equal to 0.0002, which is obviously the optimum $\varepsilon$ value. For present optimum $\varepsilon$ value, the optimum targeted values of flow rate of $S_1$, ideal number of

![Fig. 6—Supertargeting for recovery of zinc](image)

Table 6—Operating cost of network

<table>
<thead>
<tr>
<th>Stream</th>
<th>Operating cost (Rs/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>8239740.5</td>
</tr>
<tr>
<td>$I_1$</td>
<td>16202.847</td>
</tr>
<tr>
<td>$I_2$</td>
<td>305075.59</td>
</tr>
<tr>
<td>$H_1$</td>
<td>1218320.25</td>
</tr>
<tr>
<td>$H_2$</td>
<td>1439820.75</td>
</tr>
<tr>
<td>Water</td>
<td>3305430.75</td>
</tr>
</tbody>
</table>

Table 7—Capital cost targeting for network

<table>
<thead>
<tr>
<th>Rich stream</th>
<th>MSA(s)</th>
<th>Number and type of Mass transfer unit</th>
<th>Height of fixed bed (m)</th>
<th>Number of trays target</th>
<th>Capital cost (Rs/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above pinch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_1$</td>
<td>$S_1$</td>
<td>One tray type extractor</td>
<td>4</td>
<td></td>
<td>793686</td>
</tr>
<tr>
<td>$R_2$</td>
<td>$S_1$</td>
<td>One tray type extractor</td>
<td>6</td>
<td></td>
<td>1190530</td>
</tr>
<tr>
<td>Below pinch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_2$</td>
<td>$I_1$ &amp; $H_1$</td>
<td>Two fixed bed ion exchangers</td>
<td>1.77</td>
<td></td>
<td>658740</td>
</tr>
<tr>
<td>$R_2$</td>
<td>$I_2$ &amp; $H_2$</td>
<td>Two fixed bed ion exchangers</td>
<td>2.05</td>
<td></td>
<td>767914</td>
</tr>
</tbody>
</table>
trays, active heights of ion exchangers, minimum number of units and TAC are 0.2678 kg/s, 8, 1.77 m, 2.05 m, 6 and Rs.17851660/y, respectively.

For the present problem the contribution of TOC towards TAC is about 82% whereas, that of TCC is merely 18%. Further, the plot shows that the rate of increase of TOC is almost nullified by the rate of decrease of TCC around the optimum value of \( \varepsilon \) leading to a flat TAC near it. It provides freedom to a designer to select any value of \( \varepsilon \) from the flat zone without incurring substantial financial loss. However, the selection of a particular value of \( \varepsilon \) in this flat zone may be governed by operating criteria other than the financial one.

**Designing of MEN**

Once complete targeting for the problem is carried out, the whole MEN is designed for the optimum value of \( \varepsilon \). It is interesting to note that after the design stage the final network, depicted in Fig. 7, shows the same values of parameters as has been obtained during targeting stage, a priori to design, for optimum value of \( \varepsilon \) (0.0002). These parameters include: the number of trays in extractor, height of fixed bed ion exchanger, total number of units, etc. Therefore, actual TAC of the network after design is the same as that of the targeted value of TAC. Hence, this network can be safely chosen for final selection.

**Schematic diagram of proposed MEN**

The schematic flow sheet for recovery of zinc, shown in Fig. 1, is reproduced in Fig. 8 with MEN.

**Conclusions**

(i) The Supertargeting method using Pinch Technology, which was earlier developed for design of MEN, with some modifications, can easily be used for targeting and designing of optimum MEN.

(ii) Targeting procedure can generate reliable targets with comparatively little efforts, which subsequently can be screened to get optimum TAC corresponding to the optimum value of \( \varepsilon \). Finally, the design of MEN can be done for this optimum value of \( \varepsilon \). This helps in reducing the numerical efforts in designing of optimum MENs. Further, it can be seen that the value of TAC after the final design is very close to the targeted value of TAC, which reiterates the reliability of the targeting values.

(iii) In many cases depending upon the shape of plots of capital cost versus \( \varepsilon \) and operating cost versus \( \varepsilon \), the TAC versus \( \varepsilon \) curve may assume a flat shape in the region of optima.

**Nomenclature**

\[ b = \text{constant in equilibrium relation, dimensionless} \]
\[ D = \text{diameter of packed column, meter} \]
\[ G = \text{flow rate of rich stream, kg/s} \]
\[ H = \text{active height of packed column, meter} \]
\[ L = \text{flow rate of MSA, kg/s} \]
\[ m = \text{coefficient in equilibrium relation, dimensionless} \]
\[ N_{\text{stages}} = \text{number of ideal trays} \]
\[ N_s = \text{number of stream} \]
\[ U_{\text{min}} = \text{minimum number of units for the MEN, dimensionless} \]
\[ x = \text{lean stream composition of ZnCl}_2, \text{ (mass fraction)} \]
\[ y = \text{rich stream composition of ZnCl}_2, \text{ (mass fraction)} \]
Greek letters

\( \varepsilon \) = minimum composition difference

Superscripts

\( \text{in} \) = inlet composition
\( \text{out} \) = outlet composition
\( s \) = supply composition
\( t \) = target composition
\( ' \) = composition of zinc in rich stream corresponding to that in lean stream

References