Features of double chamber bed and case study

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Abstract A double chamber bed (DCB) was developed in China in 1980 and has been utilised in more than 500 setups. This paper introduces the structure and operation features of DCB, and also the unique structure of DCB leads to its perfect operation features. It can be also considered as the best option in reconstruction projects which can replace other types of ion exchangers, such as fixed bed, double cell fluidized-bed, multi-bed. Four reconstruction project cases were introduced, which were selected from more than twenty plants designed by us. Through the case study, it is concluded that DCB can not only be used to treat different sources of water (river and well), but can also be used to treat water with the ratio of transient hardness to total cation to be less than 0.5 and the ratio of strong to weak anion to be more than 7.0. These findings enlarge the scope of application of DCB.

Keywords Demineralizer; double chamber bed; double chamber ion exchanger; ion exchanger; resin; water treatment

Introduction

Double chamber bed (DCB) is the name of a double chamber fixed-bed ion exchanger. It was developed in China in 1980 (Rui, 1996). For twenty years, the design and production techniques of DCB have been continuously improved and developed, and it is near perfection. With its high quality of effluent water, low chemical consumption and simple operation, DCB has been widely applied in many plants, such as power, chemical, petroleum, metallurgy, textile and so on. It has become the most popular ion exchanger in more than 500 operational setups in China (Tian, 2001).

Water pollution problems are becoming serious, with water quality worsening. In view of this, the older types of ion exchangers, such as fixed bed, double cell fluidized-bed and multi-bed, etc., cannot adapt to the demand, and need to be rebuilt. Reverse Osmosis (RO) is usually the best option, however because of its large investment and high operation cost, it is usually used in small factories. As for the bigger plants, DCB has become the best option. This paper introduces the structure and operational features of DCB and selects four reconstruction project cases from more than twenty plants designed by us to present the design plan and final effects. Finally, the application conditions of DCB are discussed.

Features of DCB

Structural features

Structure. A DCB is a type of strong and weak resin joint application and the structure has absorbed the advantages of other ion exchangers. Figure 1 shows the DCB structure. It mainly consists of an upper influent distributor and bottom drainage, regenerating solution distributor and drainage, and middle perforated plate. The influent distributor and regenerating solution drainage are combined into one header system. The bottom drainage and regenerating solution distributors are combined into one as quartz underlayer and arch perforated plate; the middle perforated plate has tower-shaped double-head nozzles (the perforated plate is carbon steel lined with rubber), and divided the exchanger into two chambers: upper and lower. The upper chamber is filled with weak resin without a compact
layer. It is regenerated in suspension; the lower chamber is filled with strong resin, above which there is a layer of 200–300 mm EPS inert plastic balls. The balls are lighter than resin, and they are filled as a compact layer so as to evenly distribute the flow and prevent the broken resin from logging the nozzles. The heights of strong and weak resins are determined by raw water quality.

Advantages of structure. Compared with a multi-bed, DCB combines two exchangers into one and has the advantages of lower investment costs, lesser area and simpler operational requirements. Compared with a double-layer bed, the DCB overcomes the disadvantages of resin mixture, complicated regenerating operation and higher consumption of resin because of a layer of perforated plate in the middle. Compared with a double cell fluidized-bed (DCF), DCB has drainage of quartz, and can operate discontinuously without a resin trap behind it. Moreover, a weak resin can be regenerated in suspension, so it can discharge parts of impurity and the standard of influent turbidity is not critical.

Operation features
The features of DCB operation and regeneration are shown in Figure 2.

Beginning of operation. The strong resin is in a compressed state. Due to resin expansion after regeneration, the resin surface is at the peak of a strong resin chamber, compressed by plastic inert balls. Weak resin shrinks after regeneration and the height is a minimum.

End of operation. With the increase of operational time, the resin gradually turns from regenerated type to exhausted type. The weak resin expands until completely exhausted and the height increases to a maximum. The strong resin shrinks and a water pad forms between the resin and inert balls. In the end, the strong resin completely exhausted the height reach to a maximum.
Beginning of regeneration. After injecting regeneration solution into counterflow (concentration of NaOH in anion DCB is 2%, temperature is 40–45°C), the weak resin is regenerated in suspension all the time because there is no pressing resin layer. There is a space between strong resin and inert resin, and only a part of the strong resin is in suspension (regenerant flow speed is 4–5 m·h⁻¹).

End of regeneration. The strong resin turns from the exhausted to the regenerated type and expands gradually. After about 3/4 injecting time, strong resin expands to get in contact with inert balls, and is fully compressed. The weak resin is in a state of suspension all the time.

From the above steps, we find that the volume of resin will change in a cycle. The water pad, which appears on the strong resin layer at the end of operation, is beneficial to distribute water flow evenly, and it has no adverse effect on effluent water quality. It is beneficial to distribute regenerant flow evenly so that the weak resin is in suspension for the whole stage of regeneration. In addition, the weak resin is very easy to be regenerated, and so the regeneration can reach above 95%. Moreover, the regenerating dosage of strong resin is usually four or five times that of a single bed because of the use of a weak resin. So the strong resin will have much higher degree of regeneration. The advanced structure of DCB leads to its excellent operational features. It has the following advantages.

Adapt to wide range of water quality. For the stronger resin, it can obtain high water quality. A small amount of ions leakage is permitted behind the weak resin, so it can adapt to larger changes of raw water quality. Even in two kinds of water sources (river and well, salinity changes from 200 to 1,300 mg·L⁻¹), it can achieve good technical and economical effects.

Higher operation exchange capacity. For weaker resin with high exchange capacity (always twice that of strong resin), the average exchange capacity of the cation bed is near 1,500 mol·m⁻³ and the anion is about 760 mol·m⁻³.

Higher effluent quality. Normally, sodium in the effluent of the cation bed is only 10 to 20 g·L⁻¹, conductivity of the anion bed is 0.25–0.45 s·cm⁻¹ and SiO₂ is 7 to 15 g·L⁻¹, the water quality is better than the others.

Lower consumption of regenerant. Weak resin is regenerated with waste regenerant from strong resin, so the specific consumption of acid and alkali is only 1.1 to 1.3 times the theoretical amount. Meanwhile, the concentration of effluent is low, this can prevent environmental pollution and decrease the expenses of waste disposal.

Simple system, convenient and reliable operation. The operation procedure has only four steps: regenerating, replacement, rinsing and running. Compared with countercurrent regeneration fixed bed and double-layer bed, it omits the procedures such as subsurface reverse flush, blow-off, blocking pressure and so on.

Lower operation pressure difference and larger production. Operation flow rate will reach 25–30 m·h⁻¹ because the resin becomes flexible and can be cleaned with each regeneration. On the contrary, countercurrent regeneration in fixed bed and double layer bed is only 15–20 m·h⁻¹.

Strong ability to prevent pollution. The upper weak resin can be regenerated in suspension and part of the dirt can be rinsed every time (for influent distributor and regenerating solu-
tion drainage is common), so the cleaning period is long, the cation bed is once a year and the anion bed can be cleaned once within two years. In contrast, the DCF is usually cleaned once a month. A double-layer bed needs a subsurface reverse flush every operation period and a large backwash every 20–30 days. With fewer rinse times, there is little attrition of the resin and the makeup rate of the resin is only 2% per year with more rinse times is 5%–10%.

The principle of DCB is described as follows.

In DCB, two types of resin should be in optimal ratio so that they have equal operation time, and their exchange capacity can be used sufficiently. In general, the volume ratio is in direct proportion to the ions they absorbed and is in inverse ratio with their exchanger capacity.

\[
\frac{V_W}{V_S} = \frac{E_S}{E_W} \times \frac{I_W}{I_S}
\]

(1)

where \( V, E, I \) represent resin volume, work exchange capacity and absorbed ion quantity respectively; \( W \) and \( S \) represent weak and strong resin.

For cation DCB:

\[
I_W = H_C - \alpha \quad I_s = C_S k - H_C + \alpha
\]

where: \( H_C \) is the transient hardness in raw water, mmol·L\(^{-1}\); \( C_S k \) is the total cation in raw water, mmol·L\(^{-1}\); \( I_s \) is the average leakage of transient hardness from weak cation resin, mmol·L\(^{-1}\).

For anion DCB:

\[
I_W = C_F - \beta \quad I_s = C_S i + C_{CO_2} + \beta
\]

where \( C_F \) is the strong acid anions in raw water, mmol·L\(^{-1}\); \( C_S i \) is active silicon in raw water, mmol·L\(^{-1}\); \( C_{CO_2} \) is carbon dioxide in anion bed effluent, mmol·L\(^{-1}\); \( I_s \) is the average leakage of acidity from weak anion resin, mmol·L\(^{-1}\).

In general, \( I_s \) is so small that it can be omitted. Eq. (1) can translate into following:

\[
\frac{V_W}{V_S} = \frac{E_S}{E_W} \times \frac{1}{1/ (H_C/ C_S k ) - 1}
\]

(2)

\[
\frac{V_W}{V_S} = \frac{E_S}{E_W} \times \frac{C_F}{C_S i + C_{CO_2}}
\]

(3)

For a certain resin \( E \) is constant, so in cation DCB the resin volume ratio of strong to weak is determined by the ratio of transient hardness (TH) to total cation (TC); in anion DCB the ratio is determined by the anions ratio of strong (SA) to weak (WA).

**Case study**

**Case 1: river and well as water source**

DCB in power plant A has a history of 20 years, it takes river water as dominant water source, whose quality is better and its salinity is only 100–300 mg·L\(^{-1}\). In the flood or dry season about 4–5 months per year, the source is shifted to deep well water, which has salinity as high as 500 mg·L\(^{-1}\) and a maximum value of 1,050 mg·L\(^{-1}\) as shown in Table 1. Therefore, the operating period of the exchanger becomes shorter, and the regenerating is more frequent. In order to make the equipment adapt to two types of water sources and have a longer operating period and lower dose of regenerant, the manager selected DCB as the substitution. Table 1 shows that the ratio of two water sources respectively is: River TH/TC = 0.57 SA/WA = 6.96 and Well TH/TC = 0.41 SA/WA = 6.78.
The above data show that ion ratio is close though the salinity of river and well is different, so the resin ratio is close. The actual operational data showed that apparent economic benefit has got in two sources. From 1980 to now, the average capacity of the cation bed is 1,600 mol·m⁻³, and acid consumption is only 40 g·mol⁻¹ and sodium in the effluent is 20 g·L⁻¹. Anion bed capacity is 850 mol·m⁻³ and alkali consumption is only 44 g·mol⁻¹, the conductivity of effluent is 0.3–0.5 s·cm⁻¹ and SiO₂ is 6–10 g·L⁻¹.

**Case 2: double cell-fluidized bed is rebuilt to DCB**

Power plant B is a thermo-electric plant. The water source is a river. The former design was DCF. It was not satisfied for its short operational period, small production, and high consumption. The plant manager decided to reconstruct it. Two sets of cation DCF were rebuilt to DCB, and two sets of co-counter flow anion bed were replaced by DCB, a set of alkaline solution heaters was set also.

After being rebuilt in 1996, acid and alkali consumption decreased rapidly. The acid consumption of the cation bed decreased from 80 g·mol⁻¹ to 48 g·mol⁻¹, regenerating water reduced from 52 tons to 25 tons; the alkali consumption of the anion bed decreased from 82 g·mol⁻¹ to 49 g·mol⁻¹, regenerating water declined from 27 tons to 16 tons. Meanwhile, periodic water production increased from 250 tons to 800 tons, rate of consumption of regenerant is only 1/5 of the former design, and saved the acid and alkali consumption; the economic effect is apparent.

**Case 3: counter flow regenerating bed is rebuilt to DCB**

The water source of Power plant C changed heavily after the third phase project had run. Strong acid anions (chlorine and sulphate) concentration increased heavily, the anion bed operational period decreased apparently. For the deminalizer system is a unit operation, when the anion bed is exhausted, the cation bed should be regenerated at the same time, so the regeneration time is frequent and the regenerant consumption is high. The manager decided to rebuild four sets of fixed bed to DCB, and buy a set of resin cleaning vessels additionally.

The whole project finished in 1999. After rebuilding, the period increased from 20 hours to 60 hours, periodical water production increased from 1,300 tons to 5,300 tons. Acid consumption of the anion bed decreased from 100 g·mol⁻¹ to 44 g·mol⁻¹, alkali consumption decreased from 95 g·mol⁻¹ to 48 g·mol⁻¹, sodium in the effluent of the cation bed is 20–30 g·L⁻¹, SiO₂ of effluent is below 10 g·L⁻¹, conductivity is only 0.3–0.6 s·cm⁻¹, which can save 165,000 USD per year.

**Case 4: serial bed is rebuilt to DCB**

The former system of power plant D is multi-bed and it includes weak acid cation fixed bed, strong acid cation fixed bed, decarbonator, weak base anion fixed bed, and strong base anion fixed bed. The water source is deep well, the salinity is 754 mg·L⁻¹, sodium is 7.8

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**Table 1 Water quality of four plants**

<table>
<thead>
<tr>
<th>Plant</th>
<th>K⁺</th>
<th>Na⁺</th>
<th>Hardness</th>
<th>HCO₃⁻</th>
<th>CF⁻/NO₃⁻</th>
<th>SO₄²⁻</th>
<th>SiO₂</th>
<th>TDS</th>
<th>TH/TC</th>
<th>SA/WA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mmol·L⁻¹</td>
<td>mmol·L⁻¹</td>
<td>mmol·L⁻¹</td>
<td>mmol·L⁻¹</td>
<td>mmol·L⁻¹</td>
<td>mmol·L⁻¹</td>
<td>mmol·L⁻¹</td>
<td>mg·L⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A River</td>
<td>0.63</td>
<td>4.10</td>
<td>2.70</td>
<td>0.70</td>
<td>1.39</td>
<td>0.19</td>
<td>332</td>
<td>0.57</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>Well</td>
<td>0.93</td>
<td>7.05</td>
<td>3.34</td>
<td>1.13</td>
<td>1.99</td>
<td>0.35</td>
<td>530</td>
<td>0.41</td>
<td>6.8</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>4.48</td>
<td>3.45</td>
<td>2.75</td>
<td>2.80</td>
<td>2.73</td>
<td>0.32</td>
<td>503</td>
<td>0.34</td>
<td>12.9</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.9</td>
<td>4.15</td>
<td>2.45</td>
<td>0.87</td>
<td>1.52</td>
<td>0.33</td>
<td>314</td>
<td>0.49</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>7.87</td>
<td>4.95</td>
<td>5.05</td>
<td>4.38</td>
<td>3.48</td>
<td>0.25</td>
<td>754</td>
<td>0.39</td>
<td>21.8</td>
<td></td>
</tr>
</tbody>
</table>

* WA refers to SiO₂ + residual CO₂
mmol·L⁻¹, and the sodium ratio is 61% to total cation. This type of water can lead to sodium leakage in the cation bed effluent and excessive conductivity in anion bed effluent. The conductivity is always above 110 s·cm⁻¹ (the standard is below 10 s·cm⁻¹).

To solve the problem, the plant tried a lot of ways but took no effect, and decided to rebuild. The first selection is RO, but the investment is so large that the plant cannot afford it. At last, DCB was selected. The diameter of cation and anion DCB is 2,500 mm and 2,800 mm respectively, and the resin ratio of weak/strong is 650 mm/2,150 mm and 2,150 mm/850 mm respectively, there are 300 mm EPS inert plastic balls above the strong resin.

The project was finished in autumn of 2000 and water quality is very good, the effluent conductivity of anion DCB is below 0.8 s·cm⁻¹, the standard is 1.5 s·cm⁻¹, and the periodical water production is increased, and the operation cost is decreased rapidly.

**Application field of DCB**

DCB is one type of strong and weak resin application united. When water quality is adapted to a multi-bed, double bed, DCF or other bed, it is also adapted to DCB, and the effect is better than them. This can be deduced from above examples.

It is concluded that the applicable water quality of DCB is as follows: TH/TC is between 0.48 and 0.85 for cation bed and SA/WA is below 7.0 for anion bed (Feng, 1992). Actually, even if the ratio is not in this range, the effect is good. Case 2 shows that when the value of TH/TC is only 0.34 and SA/WA is 21.8, the effect is good. The reason is that the exchange capacity of weak resin is twice that of strong resin, it can lighten the burden of strong resin though the resin volume ratio is not the optimal value, so the water quality will improve and the acid (alkali) consumption will decrease. For this reason, DCB is suitable for most districts.

Another viewpoint is that the ratio of the upper and lower chambers of DCB is determined by water quality, so it is not suitable for changeable water sources. Actually, DCB is compliant with water quality change, because it permits ions leakage of weak resin, so when water quality changes in a limited range, it will have no bad effect. Moreover, if the ions change proportionally, it will have no effect, such as case 1.

It is certain that there are circumstances DCB is not suitable, for example, the economy is not apparent when salinity is very low (<200 mg·L⁻¹), cation DCB is not suitable for very low transient hardness and anion DCB is not suitable for very small strong anion ions. But actually these two circumstances are very irregular.

**Conclusions**

The structure of DCB leads to its high water quality, lower chemical consumption and simple operation. Compared with other beds, it has evident advantages, and is the first selection for the project.

From the four cases, it can be concluded that DCB can not only adapt to two types of water quality (river and well), but also adapt to water sources in which the ratio of transient hardness to total cation ions is less than 0.5 and the ratio of strong to weak anions is more than 7.0, this expands the application field of DCB.

**References**

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