Investigation of breakthrough curve of 10K cryogenic adsorber in helium refrigerator

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Abstract

High pure quality helium is required in helium refrigerator and cryogenic adsorber is essential in cryogenic engineering system, while there is lacking of cryogenic adsorption data below 20K which causes inconvenience when it comes to the design of cryogenic adsorber. The paper mainly deals with the design of a cryogenic adsorber in a helium refrigerator which works at 250W@4.5K. Isothermal and nonlinear dispersion plug flow model is built to investigate the breakthrough curve of trace hydrogen in helium. It can help in lateral design of cryogenic adsorber.

Introduction

A certain amount of crude helium needs to be resupplied into helium liquefier constantly so as to maintain the pressure of system because of the helium liquefaction. While usually, the added helium is not pure enough, thus helium purifier is essential for sake of the stable operation of the cryogenic system. In one helium refrigerator together with the liquefaction of helium which works at 250W@4.5K, there’s one cryogenic adsorber which works at 10K, the working condition of the adsorber is shown in Table 1.

Table 1  Cryogenic adsorber design parameters

<table>
<thead>
<tr>
<th>Inlet temperature (K)</th>
<th>Inlet pressure (bara)</th>
<th>Resupply Gas flow rate/g·s⁻¹</th>
<th>Allowed max Pressure Drop/Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10</td>
<td>3.3</td>
<td>500</td>
</tr>
</tbody>
</table>

In the design of the cryogenic adsorber, we primarily come across these difficulties:

(1) Lacking of adsorption data below 20K.
(2) The competitive adsorption of impure gas in the crude helium.
(3) Design of the adsorber with static gas adsorption data needs to be checked with adsorption dynamics, using breakthrough curve method.

Based on the problems above, hydrogen adsorption data at 10K is obtained with the potential theory, it’s showed in Figure 1. Because helium is the majority of the gas mixture, the competitive adsorption of helium and hydrogen should be evaluated. Helium adsorption data comes from Krishnamoorthy et al[3].

Adsorption dynamics

\[
D_{L} \frac{\partial^{2} C_i}{\partial z^{2}} + u \frac{\partial C_i}{\partial t} + \frac{1 - \varepsilon_b}{\varepsilon_b} \rho_f \frac{\partial q_i}{\partial t} = 0
\]

B.C. \[
D_{L} \frac{\partial C_i}{\partial z} |_{z = 0} = -u \left[ C_i |_{z = 0} - C_i |_{z = 0}^{+} \right] \frac{\partial C_i}{\partial z} |_{z = L} = 0
\]

I.C. \[
C_i (z, 0) = 0; q_i (z, 0) = 0
\]

\[
C_i (z, 0) = c_{i,in}; q_i (z, 0) = q_{i,in}
\]

Breakthrough curve

From Figure 1 and Figure 2, we can get the adsorption capacity of hydrogen and helium at 10K is 0.556m³/g and 0.95×10⁻³m³/g respectively. Therefore, the adsorption of helium can be neglected. It’s assumed that the concentration of hydrogen is 7ppm in the crude helium, the total gas pressure is 10bara, temperature is 10K, and gas flow rate is 3.282g/s. The adsorbent is granular activated carbon, packed bed density is 514kg/m³, bed porosity is 0.4; the depth of the adsorption column is 200cm, the inner diameter of the column is 68cm.

Conclusions

1. The adsorption of hydrogen at 10K is obtained with potential theory and the cryogenic adsorber which works at 10 is designed.
2. Isothermal and nonlinear plug flow model is applied to study the breakthrough curve, it shows that axial dispersion has little influence on the breakthrough time.
3. More accurate model accounting for the resistance of heat and mass transfer should be applied in the further study.