The Effect of Exposure Conditions on Component Life in HCl Solutions

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Introduction

- Metallic parts in chemical handling systems are subject to corrosion by acid gases like hydrogen chloride (HCl) and hydrogen fluoride (HF).
  - Examples include springs in valves and magnets in mag drive pumps
- Fluoropolymers, like PFA, are often used to isolate these parts from acid gas containing liquids to prevent corrosion.
- Acid gases in these liquids can permeate through fluoropolymers and corrode the parts.
- The objective of this study was to determine the HCl permeation rate through the PFA used in Levitronix pump impellers as a function of coating thickness, hydrochloric acid concentration and temperature.
- A parallel study is in progress to determine pump impeller life under controlled conditions.
- The combined results of the 2 studies will be used to predict impeller life under different operating conditions.
Outline

- Diffusion theory
- Experimental procedures
- The effect of operating conditions on permeation rate
  - HCl concentration
  - Temperature
  - PFA thickness
- Life test status
- Predicted relative lifetimes under different operating conditions
- Summary

Pop Quiz

- The permeation rate of HCl through PFA from a 5% solution of HCl in water at 20°C is 1. What is the permeation rate from a 37% solution at 20°C?
  a) \( \frac{5}{37} = 0.14 \)
  b) The same
  c) \( \frac{37}{5} = 7.4 \)
  d) 300,000
Steady-state permeation

\[ M = \frac{PP_v A}{T} \]

Where

- \( M \) = Mass flow rate
- \( P \) = Permeability coefficient
- \( P_v \) = Gas vapor pressure
- \( A \) = surface area available for diffusion
- \( T \) = material thickness

The effect of concentration and temperature on HCl vapor pressure

**Vapor pressure of HCl over selected hydrochloric acid solutions**

<table>
<thead>
<tr>
<th>HCl concentration % by weight</th>
<th>Temperature °C</th>
<th>Vapor pressure atm</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>20</td>
<td>5.5 x 10^{-7}</td>
</tr>
<tr>
<td>6.3</td>
<td>75</td>
<td>2.1 x 10^{-4}</td>
</tr>
<tr>
<td>37</td>
<td>20</td>
<td>0.17</td>
</tr>
<tr>
<td>37</td>
<td>40</td>
<td>0.55</td>
</tr>
<tr>
<td>32</td>
<td>75</td>
<td>0.66</td>
</tr>
<tr>
<td>37</td>
<td>60</td>
<td>1.51</td>
</tr>
</tbody>
</table>

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**Test System Schematic**

- Flow Meter/Controller
- CDA
- Test Specimen
- HCl Solution
- Temperature Controlled Chamber
- Scrubber
### Experimental test matrix

<table>
<thead>
<tr>
<th>HCl concentration</th>
<th>Temperature °C</th>
<th>Vapor pressure atm</th>
<th>Thickness mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.0</td>
<td>74</td>
<td>0.0018</td>
<td>1.5</td>
</tr>
<tr>
<td>20.2</td>
<td>39</td>
<td>0.0014</td>
<td>1.5</td>
</tr>
<tr>
<td>20.2</td>
<td>48.5</td>
<td>0.0029</td>
<td>1.5</td>
</tr>
<tr>
<td>20.2</td>
<td>62</td>
<td>0.0071</td>
<td>1.5</td>
</tr>
<tr>
<td>20.2</td>
<td>74</td>
<td>0.015</td>
<td>1.5</td>
</tr>
<tr>
<td>26.7</td>
<td>30</td>
<td>0.0083</td>
<td>1.5</td>
</tr>
<tr>
<td>26.7</td>
<td>48.5</td>
<td>0.028</td>
<td>1.5</td>
</tr>
<tr>
<td>26.7</td>
<td>63.5</td>
<td>0.067</td>
<td>1.5</td>
</tr>
<tr>
<td>26.7</td>
<td>73</td>
<td>0.113</td>
<td>1.5</td>
</tr>
<tr>
<td>36.2</td>
<td>30</td>
<td>0.25</td>
<td>1.5</td>
</tr>
<tr>
<td>36.2</td>
<td>40</td>
<td>0.43</td>
<td>1.5</td>
</tr>
<tr>
<td>36.2</td>
<td>48.5</td>
<td>0.67</td>
<td>1.5</td>
</tr>
<tr>
<td>36.2</td>
<td>39</td>
<td>0.38</td>
<td>1.0</td>
</tr>
<tr>
<td>36.2</td>
<td>39</td>
<td>0.38</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Example of permeation data – 1.5 mm thick samples with 26.7% HCl
The effect of temperature and HCl concentration on HCl permeation rate through 1.5mm thick samples

Slide 11


Permeability coefficient

\[ M = \frac{PPVTA}{T} \]

Where

- \( M \) = Mass flow rate
- \( P \) = Permeability coefficient
- \( PPV \) = Gas vapor pressure
- \( A \) = surface area available for diffusion
- \( T \) = material thickness

Permeability coefficient units

Gas volume – thickness

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Area in contact with gas – Time - Vapor pressure

\[ \frac{cm^3 (g) \cdot \text{mm}}{m^2 \cdot \text{day} \cdot \text{atm}} \]

Slide 12

The effect of temperature and concentration on the HCl permeability coefficient - 1.5 mm samples

The effect of thickness on the HCl permeability coefficient
Effect of variables on HCl permeation rate

• Permeation rate
  – Is proportional to the HCl vapor pressure
  – Is inversely proportional to the coating thickness
  – Increases with temperature

Quiz

• The permeation rate of HCl through PFA from a 5% solution of HCl in water at 20°C is 1. What is the permeation rate from a 37% solution at 20°C?
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  d) 300,000
Quiz

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Impeller life tests

- In progress
- BPS3 pump circulating 37% HCl at room temperature
  - PVDF housing
  - ECTFE impeller magnet encapsulation
  - Running for 5 years
- BPS1, BPS3 and BPS4 pumps are circulating 30-32% HCl at 75°C.
  - Pump body
    - BPS3 – PFA
    - BPS1 and BPS4 - PTFE
  - PFA impeller magnet encapsulation
  - Running for 9 months
- No failures in either test.
**Predicted component life based on HCl permeation rate**

(assumes that failure rate is proportional to permeation rate)

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**Predicted component lifetimes at selected conditions**

<table>
<thead>
<tr>
<th>HCl concentration</th>
<th>Temperature °C</th>
<th>Predicted relative lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>7,000,000</td>
</tr>
<tr>
<td>6.3</td>
<td>75</td>
<td>3,100</td>
</tr>
<tr>
<td>37</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>32</td>
<td>40</td>
<td>2.7</td>
</tr>
<tr>
<td>37</td>
<td>75</td>
<td>1</td>
</tr>
<tr>
<td>37</td>
<td>60</td>
<td>0.6</td>
</tr>
</tbody>
</table>

* - Assumes that failure rate is proportional to permeation rate.
Predicted impeller lifetime at selected conditions

- No failures for 9 months (0.75 years) at 75°C with 30-32% HCl.
- Model predicts lifetimes for failure due to permeation of:
  - 37% HCl at room temperature
    - Predicted lifetime is $22 \times 0.75 \text{ years} = > 16 \text{ years}$
  - SC2 (6.3% HCl at 75°C)
    - Predicted lifetime is $3,100 \times 0.75 \text{ years} = > 2,000 \text{ years}$

Summary

- The permeation rate of HCl through PFA of varying thickness was measured at selected temperatures and HCl concentrations.
- The permeation rate:
  - Was proportional to the HCl vapor pressure
  - Was inversely proportional to the coating thickness
  - Increased with temperature
- A model based on these variables was developed to predict component failure rate resulting from HCl permeation.
- The model, combined with on-going life test data, predicts pump lifetimes > 10 years under typical use conditions.