Case Study: LifeCycle Solutions
Membranes for Oil Refineries

Optimizing oil refinery hydrogen production through a PRISM Hydrogen membrane system by modifying the control scheme.
Background

A USA-based refinery customer operates hydrogen membrane separators that were installed in the mid 1980’s. Since their installation, many changes were made to the plant which have changed the feed conditions to the hydrogen membrane unit. The feed load to the membrane separators would regularly change due to the plant operating mode and feed stock. This required operators to make frequent manual adjustments to the hydrogen membrane system to modify the number of operating separators. When these adjustments weren’t made, the membrane separators were exposed to damaging operating conditions that would result in hydrocarbon condensation or high velocity gas through the membrane vessels. The customer requested Air Products aid in finding a solution that would help them to operate the old membrane system under the new feed conditions and reduce damage to the hollow fiber membranes, increasing membrane separators’ life.

Air Products identified a control upgrade that could be performed which would only require minimal changes to control valves, some instrumentation, and add a control algorithm to the DCS. The upgrade would utilize the existing pretreatment equipment and membrane separator arrangement, and allow the system to automatically respond to changing feed conditions, targeting a constant hydrogen recovery performance. These changes help to increase membrane operating life by reducing exposure to damaging operating conditions and not depending on operator intervention to adjust the membrane separator flow arrangement.
Description of the Process

The hydrogen membrane system is an older design and in its current form there is no way to monitor and control the hydrogen recovery as the throughput changes. Therefore, the proposed control upgrade also involves instrumentation to estimate, control, and limit the hydrogen recovery in the system to maintain proper performance and prevent damage to the hollow fiber membranes.

In the original configuration, the feed gas to the PRISM® Membrane System is under flow control. A Pressure Indicator and Control valve upstream of the PRISM® Unit controls the feed pressure to the membrane system by constantly diverting some of the hydrogen feed to a fuel gas header. This allows for steady pressure control of the PRISM® Hydrogen Membrane Unit by opening and closing to absorb rate swings and maintain feed pressure to the hydrogen membrane system. However, this scheme results in some hydrogen always being lost to the fuel gas system.

Proposal

If the PRISM® Unit itself were capable of capacity control, then the feed flow to the Membrane Unit could be allowed to vary in order to absorb any rate fluctuations in the system, while at the same time eliminating the constant loss of hydrogen to the fuel gas header.

The proposed control strategy involves a Pressure Indicator and Controller (PIC) and Flow Indicator and Controller (FIC) together with a signal lo-select block to control existing membrane non-permeate control valve. The membrane feed flow controller will use the existing membrane feed flow orifice plate and transmitter, and a new pressure transmitter would be installed on the non-permeate side of the membrane but upstream of the non-permeate control valve.

The existing pressure letdown valve to the 100 PSIG fuel gas header, will be set with its pressure set point 100-150 psi above that of the membrane non-permeate PIC, to keep it closed under normal operating conditions. If hydrogen compressor throughput falls off, the PIC portion of the membrane PIC / FIC lo-select controller will take over and use FV-241 to maintain pressure in the system by closing back to reduce flow through the membranes.

As hydrogen flow from the compressor is restored, the PIC / FIC will gradually open the non-permeate control valve, ramping up the flow through the membrane system until the membrane flow throughput limit is reached. At this point, the flow through the membranes will be limited in lo-select by the FIC as pressure in the system builds. Only when the pressure reaches the upstream pressure control valve set-point will the fuel gas header letdown valve come open to control the system pressure.

Under this new scheme, the feed conditions and flow to the membrane system will be changing which means that the number of membrane separators required to be online at any given time may also be changing. Membrane separators are brought onstream or taken offline by opening or closing the 2” manual block valves on the individual membrane separator permeate outlets.

If too few membrane separators are onstream, then hydrogen recovery will be low due to insufficient active membrane area. If too many membrane separators are onstream, then hydrogen recovery could be operating too high, which can pose a problem for the membranes. As hydrogen is recovered from the high-pressure gas passing over the membranes, the gas stream becomes more concentrated in hydrocarbons. If hydrogen recovery gets too high, the dew point of the non-permeate stream can increase until hydrocarbons start to condense on the membrane fiber, coating the fibers and permanently affecting membrane performance.

In the existing system, the non-permeate stream from the membrane system splits three different ways and the flow
rates of the three individual streams are measured individually. A new non-permeate flow meter on the combined stream is required to allow more accurate measurement of the non-permeate stream flow. A new control valve on the membrane permeate stream, manipulated by a feed-flow-to-non-permeate-flow ratio controller, will maintain constant hydrogen recovery by controlling the membrane permeate flowrate in response to feed flow changes.

The control consists of
- measuring the flow ratio of feed to non-permeate
- controlling this ratio at a fixed value by applying a variable amount of backpressure to the permeate side of the membrane separators

If the membrane separators are operating in a high back-pressure condition for long periods of time, this creates an inefficient mode of operation, although not a concern for the membranes themselves. Hydrogen membrane separators operating with high backpressure will produce a permeate stream of lower hydrogen purity than desired.

A new pressure transmitter on the permeate line between the membrane separators and the new permeate back pressure control valve will alarm to the control room when the stream becomes over pressurized, indicating that the membrane system is operating at low capacity. In this condition, two (or more) membrane separators should be manually taken offline (by closing their 2” manual permeate block valves) to ensure optimal membrane performance, in the form of highest possible hydrogen purity in the permeate stream.

Conversely, when membrane feed flow is restored, there will be insufficient membrane area available for permeation and the permeate control valve may go fully open trying to maintain the feed-to-non-permeate ratio. If the valve is wide open, backpressure will be minimal. This will sound a low-pressure alarm, indicating that two (or more) membranes should be manually brought onstream (by opening their 2” manual permeate block valves) to maintain the desired hydrogen recovery.

A pressure differential calculation block in the DCS will monitor the difference between the feed pressure and non-permeate pressure to calculate the pressure drop through the system. An excessively high pressure drop indicates that the membranes have reached their hydraulic throughput limit (i.e. feed flow limit) and will sound an alarm.
**Implementation**

For best performance and proper control of the membrane system, Air Products recommended that all of the proposed control upgrades be implemented. This ensures that the membranes are adequately protected from hydrocarbon condensation due to over-recovery of hydrogen during rate changes in the Unit.

However, if schedule and/or cost dictates that only some of the upgrades can be implemented, the relative priorities of the specific control upgrades can be classified as Priority 1, Priority 2, and Priority 3 as follows:

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<th>Priority</th>
<th>Item</th>
<th>Notes</th>
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<td>1.</td>
<td>New Non-Permeate Pressure Transmitter</td>
<td>New control scheme adjusts membrane system throughput for varying Unit rates. Feed-to-nonpermeate dP alarm notifies operator of excessive flow to membrane system. Implement PIC / FIC with signal lo-select logic in DCS for membrane system control. Evaluate &amp; update calibration range of existing feed flowmeter FC-241. No protection of the membranes for over-recovery of hydrogen; varying membrane throughput with no H2 recovery indication can lead to hydrocarbon condensation and membrane damage.</td>
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<td>2.</td>
<td>New non-permeate Flow Element and Transmitter</td>
<td>New control scheme adjusts membrane system throughout varying unit rates. Feed-to-non permeate alarm notifies operator of too much flow to membranes. Plus, feed/NP flow ratio alarm notifies operator that hydrogen recovery is off target; more or less membrane area needs to be put online. Implement DCS logic to calculate feed-to-non permeate flow ratio; alarm on high or low ratio. Still no automatic protection of the membranes from over-recovery of hydrogen.</td>
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<td>3.</td>
<td>New Permeate Backpressure Control Valve</td>
<td>Incorporates all recommended upgrades. Permeate pressure alarm notifies operator that membrane area should be put online for optimal performance. Feed-to-NP ratio controller automatically manipulates permeate backpressure control valve to protect membranes from over-recovery of hydrogen. New Permeate Pressure Transmitter</td>
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**Results:**

Air Products provided onsite training to the refinery operators and process engineers for the new control system and reviewed basic operating principles. Field engineers also reviewed membrane operating set points to help ensure that protective operating limits are understood and not exceeded.

The customer has implemented all of the priority items to the new control protocol and reported that the membrane system is more stable and obtains greater hydrogen recovery on a regular basis. None of the membrane separators were replaced or updated in this project - only the controls were modified to increase performance.

This chart indicates that average daily percentage of hydrogen recovery from the system, calculated as a percentage of yield vs. the total hydrogen input volumes.
Why choose Air Products?

We have the most experience in designing and building spec-compliant systems for ammonia loop purge applications. Some of the first PRISM Membrane separators were commissioned in 1977. Over 500 PRISM Membrane Systems for Process Gas applications are operating around the world. These include 230 systems in ammonia purge gas recovery, 90 systems in oil refinery applications, 60 systems for carbon monoxide purification, 50 systems for methanol purge gas recovery and 50 in other petrochemical applications.

When you choose Air products, you are choosing the leader in membrane design, experience, and value.

LifeCycle Solutions

Who we are.

LifeCycle Solutions is the aftermarket service and engineering department of Air Products PRISM Membranes. Headquartered in Kristiansand, Norway, this team of highly skilled engineers and technicians are dedicated to ensuring that PRISM Membrane systems are operating at peak performance in process gas applications.

What we do.

The hydrogen separation membranes are tested and evaluated for performance and compared to their original design specifications. A comprehensive report detailing your membrane system’s performance is provided to your site engineers with specific recommendations to increase efficiency. Our team of experts will model the changes with cost estimates and project potential payback potential. This means that your team can use the ROI calculation to make solid business decisions.

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