

Recovery costs less

Bal K. Kaul, Ajit Sapre and Lei Zhang, ExxonMobil Research and Engineering Co. and Daryl Musselman and Surajit Roy, Quest Air Technologies, describe a new low cost H₂ recovery process.

Hydrogen recovery from fuel gas and hydrogen containing purge gas streams in refinery and chemical processes offers many potential benefits including process uplift, reduced hydrogen costs, avoidance of H₂ plant expansion, and emission reductions, but it requires a cost effective separations technology to be economical. Rapid cycle pressure swing adsorption (RCPSA) technology offers a more compact, less expensive and more energy efficient solution for H₂ recovery compared to conventional PSA technology. RCPSA technology was jointly developed by ExxonMobil Research and Engineering Company (EMRE) and QuestAir Technologies and resulted in a large scale commercial product, the

QuestAir H-6200, currently in commercial demonstration at an ExxonMobil refinery.

Figure 1 shows a full scale commercial unit deployed at an ExxonMobil refinery site. This unit was completely fabricated on a skid in a shop and then transported to the refinery site for tie-ins. Full shop fabrication provides significant cost benefits and allows for better quality control in terms of meeting local site codes, etc. Unlike conventional PSA, the H-6200 plant is compact enough to be entirely skid mounted. The small size and simplicity leads to reduced installation costs, and makes it possible to expand processing capacity to match incremental increases in hydrogen demand. For the ExxonMobil



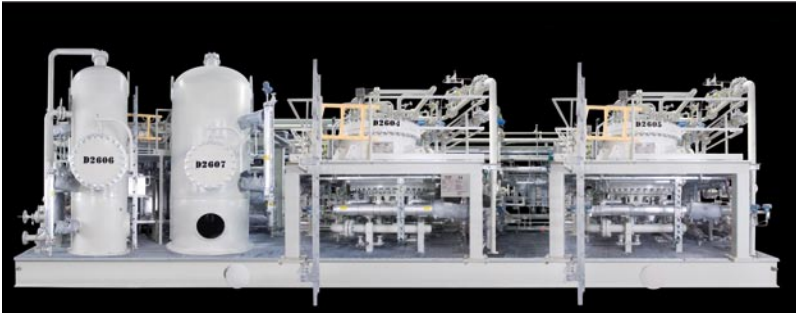


Figure 1. ExxonMobil commercial application of two module RCPSA H-6200 plant skid.

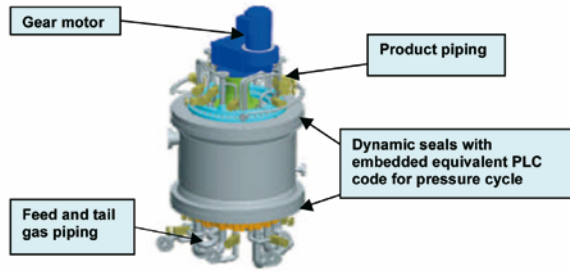


Figure 2. QuestAir RCPSA H-6200 module housing with bed rotor assembly.

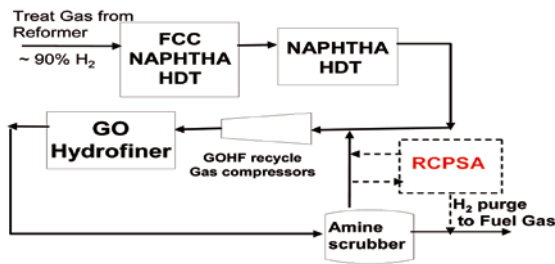


Figure 3a. Application scenario 1: Hydrogen uplift in hydrotreater recycle gas loop.

application, the RCPSA skid shown in Figure 1 has two identical modules to meet the refinery site hydrogen purification demand. An additional skid contains a PLC and control panel (not shown in the figure) to safely optimise operation of the hydrogen purification process.

Despite widespread usage in the industry, conventional PSA processes have several inherent disadvantages. Slow cycle speeds and relatively large adsorbent particles must be used to avoid fluidisation of the adsorbent, resulting in very large systems with high materials and vessel costs. In addition, networks of individual switching valves, with associated instrumentation, control systems and process piping, add complexity and cost to conventional PSA systems.

RCPSA, like conventional PSA, relies on the ability of adsorbent materials to selectively adsorb contaminants from a pressurised gas stream. When the pressure is reduced, or 'swung', the contaminants are released. RCPSA technology provides a step change improvement in gas separation process by using novel structured adsorbents and simple multi-port rotary valves. Structured adsorbent beds consist of durable sheets separated by precise parallel passages which allow gas to pass through

the structure with minimal pressure drop. The rotary valves can easily and reliably manage the thousands of switching actions per minute required to achieve cycle speeds of 50 cycles per minute or more. This combination allows much greater productivity to be achieved from a given mass of adsorbent material by cycling the process more rapidly than can be done with conventional packed fixed bed adsorbers. These and other features of RCPSA result in its size being a fraction of the size of a conventional PSA.

The inherently intermittent nature of the PSA process means that a single adsorption bed can only deliver purified product gas for a portion of its cycle. Several adsorption beds are typically used in conventional PSA systems to provide a less intermittent product flow. However, with the slow cycle speed used in these conventional systems, product and exhaust gases flow still exhibit significant pulsations.

To ensure a continuous supply of product gas, the QuestAir H-6200 is equipped with structured adsorbent beds (more efficient than in conventional PSA systems) which are cycled slightly out of phase in a balanced, sequential manner through identical operating cycles. QuestAir's patented structured adsorbent and rotary valve technology also allow for much higher cycle speeds than a conventional PSA system. Each bed goes through one complete PSA cycle (similar to the conventional PSA process) at least once per revolution. The steady succession of individual beds, combined with rapid pressure cycle, result in a near continuous process in a compact rotary bed PSA machine. The process efficiency is enhanced due to the greater number of beds, since a more sophisticated cycle is achieved. Pressure pulsations and intra cycle stream concentration variations are diminished to such an extent that large surge vessels for product and exhaust gas are not required.

In addition to providing a continuous supply of product gas, the RCPSA operating cycle also includes advanced features such as pressure equalisation between beds to minimise energy losses and an advanced flow control system to allow adjustment for peak operating performance.

The adsorption bed rotor assembly, stator, seals, and housing make up the QuestAir RCPSA H-6200 module (Figure 2). The adsorption beds are housed in a rotor driven by a gear motor and variable speed drive arrangement.

The RCPSA H-6200 module contains a set of rotary flow control interfaces ('dynamic seals'), which are central to its operation. The function of these 'valves' is to perform a switching function routing gas in a sequential manner to and from the adsorption beds. This is achieved through opening and closing of ports between the rotor and stationary stator. One seal controls gas flow into the bottom end of the adsorption beds ('feed seal') while the other seal simultaneously controls the flow at the top end of the beds ('product seal').

Product, feed, and tail gas pipes, various instrumentation, flow, and pressure control devices outside of the module are used for transportation and control of gas in and out of the module, process management, and startup/shutdown duties. These devices are controlled by

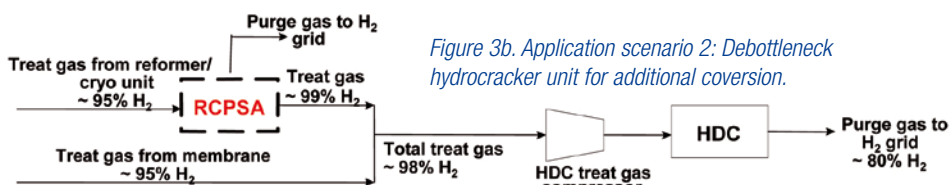


Figure 3b. Application scenario 2: Debottleneck hydrocracker unit for additional coverage.

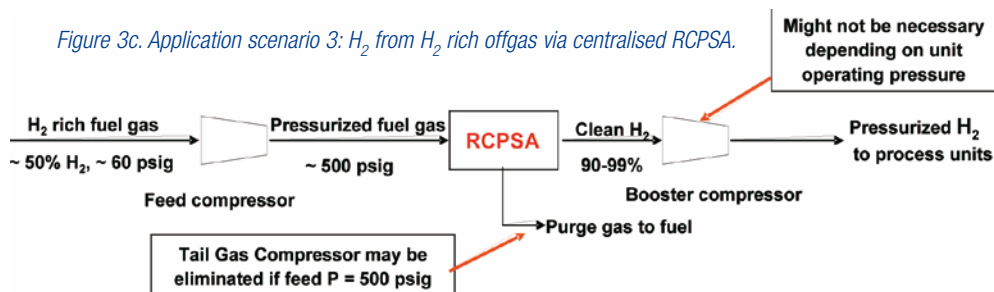


Figure 3c. Application scenario 3: H₂ from H₂ rich offgas via centralised RCPSA.

reduced emissions, debottlenecking existing PSAs, etc.

Figure 3a, b and c show some example applications of RCPSA, outlining better ways to manage refinery processing units either by increasing the hydrogen purity, or by minimising burning of hydrogen in the fuel gas. In application scenario 1 (Figure 3a), RCPSA helps to increase the hydrogen purity in the hydrodesulfurisation recycle loop by

either QuestAir supplied control systems, or by owner/operator supplied control systems.

RCPSA technology has the capability to optimise hydrogen purity suitable for specific applications rather than producing high purity hydrogen (99+%) independent of the application demand, as is the case with a conventional PSA. The tunable H₂ purity will help to maximise the H₂ recovery based on the local H₂ demands and provide optimal H₂ balance throughout the refinery H₂ network. RCPSA's novel features allow for obtaining higher hydrogen recoveries up to 5 - 10% more than a conventional PSA and very stable downstream operation due to the use of high performance adsorbents, advanced process cycles, reduced system dead volume for RCPSA. All above RCPSA processes advantages provide significant commercial benefits. The high H₂ recovery from process streams can be of significant value to the refinery operation. Assuming hydrogen value at US\$ 3/000 ft³ using a natural gas price of US\$ 6/MMBTU and a hydrogen fuel to value of 300 btu/ft³, recovery of an additional 1 MMSCFD of H₂ with the H-6200 RCPSA would generate an additional US\$ 500 000 annual benefit for a refinery. In the high feed pressure (P > 500 psig) applications, RCPSA can be stably operated without a tail gas compressor, resulting in significant reduction of total installed costs in comparison to conventional PSA. Flexible product purity, enhanced recovery and better control of RCPSA can result in capital and operating cost savings of up to several million US\$/yr.

A H₂ pinch analysis of the refinery can be used to design optimised RCPSA schemes for several potential applications, including:

- Increasing H₂ concentration in a recycle loop of hydrofiners (e.g., diesel) for better desulfurisation.
- Increasing H₂ concentration to hydrocrackers for improved product yields.
- Recovering H₂ from fuel gas streams to debottleneck H₂ plants.
- Improving H₂ purity to debottleneck reformers and provide higher purity H₂ to enhanced downstream process performance.
- Minimising the burning of hydrogen in the fuel gas for

minimising the hydrogen lost in the purge streams. This higher purity in the recycle loop generally results in making a greater volume of low sulfur products such as diesel. Compact size and skid mounted technology allows the RCPSA to be located close to the process unit thereby minimising tie-in and H₂ distribution costs. In the case of the first commercial application, the feed to RCPSA is the purge stream from the hydrodesulfurisation recycle loop at 8 MMSCFD and 55% H₂ purity. The RCPSA plant will be operating at 230 - 500 psig and 110 °F. The H₂ product purity will be at 90% with recovery of 71 - 85%. The overall process improvement will be an increase of recycle gas purity by approximately 10%. This can be further translated to approximately 5% gain of HDS capacity and valuable upgrade from fuel oil to diesel. Assuming the uplift of 1000 bpd diesel production from fuel oil, the total benefit of US\$ 2 million/yr can be achieved based on US\$ 5.5 spread of LS diesel/heating oil using average 2006 USGC pricing.

In application scenario 2 (Figure 3b), RCPSA is used to debottleneck a hydrocracker by increasing hydrogen purity by approximately 3 percentage points resulting in improved conversion to products and thereby creating a product uplift. In application scenario 3 (Figure 3c), all hydrogen rich fuel streams are processed at a centralised location to produce high purity hydrogen for use in the hydroconversion units. This will provide low cost H₂ for refinery operating units, reduce the new H₂ plants capacity requirement and/or turn down the existing H₂ plant, and reduce the CO₂ emissions (CO₂ emissions at approximately 7500 t per MMSCFD of H₂ generated via steam methane reforming).

Proper management of hydrogen molecules within refineries and chemical plants is becoming increasingly important. Due to the introduction of stringent sulfur specifications in fuel products, RCPSA technology is going to allow plants to avoid the expensive option of building new hydrogen plants by bringing back into the refinery hydrogen molecules currently downgraded to fuel. The modular design of skid mounted RCPSA is helping refiners to manage hydrogen molecules closer to the processing units as needed, a new paradigm for distributed technology application in refineries.

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