Pressure Swing Adsorption (PSA)

SYSTEMS FOR ULTRA-PURE HYDROGEN &
OTHER INDUSTRY GAS PURIFICATION

IVYS
Purely Driven

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OTHER INDUSTRY GAS PURIFICATION

TABLE OF CONTE

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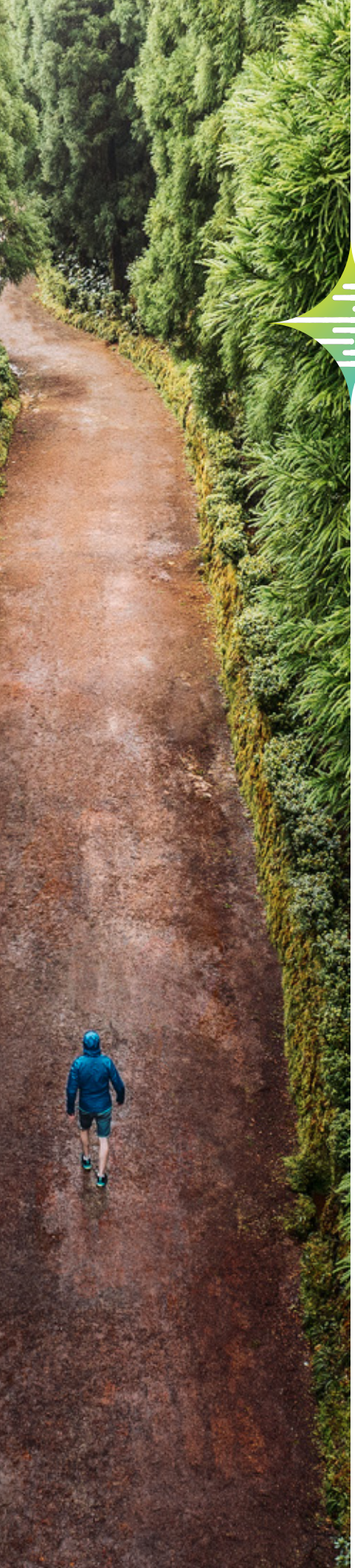
Our Vision



IVYS
Purely Driven

A World Powered by Clean Energy

By providing both high-performance and innovative technological solutions for the purification of renewable gas and by offering a wide range of equipment for the conditioning, compression and filtration of air and gas, Ivys is part of the great line of companies aiming to decarbonize the planet. A sustainable development model that integrates economic growth with social and environmental responsibility.

Our slogan, “Purely Driven,” reflects our vision of a cleaner planet, our continued search for more efficient solutions and our dedication to building an organization of excellence together that stays true to its values.

Moving Toward Ultra-Pure Hydrogen

Ivys’ Hydrogen Purification and Generation Solutions efficiently upgrade hydrogen-containing reformate, petrochemical process gas streams and refinery off-gas streams to pure and ultra-pure hydrogen. Ivys provides the most compact, economical and reliable PSA systems available today.

Ivys' PSA **Technology**

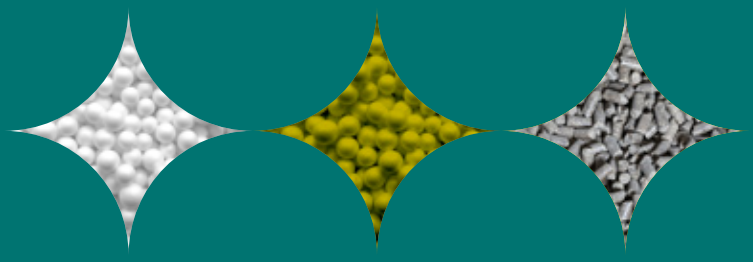
Thanks to its unique rotary valve technology and advanced adsorbents, Ivys' PSA systems feature the most compact, economic and reliable gas purification systems available today, including for ultra-pure hydrogen purification from a variety of feed gases such as methane steam reformate, petrochemical process gas streams, and refinery off-gas streams.

Rotary Valves

Unlike the conventional PSA systems where a bank of many on/off valves are used to control gas flowing into and out from adsorber vessels, Ivys' PSA units use integrated, proprietary rotary valves to realize the same function.

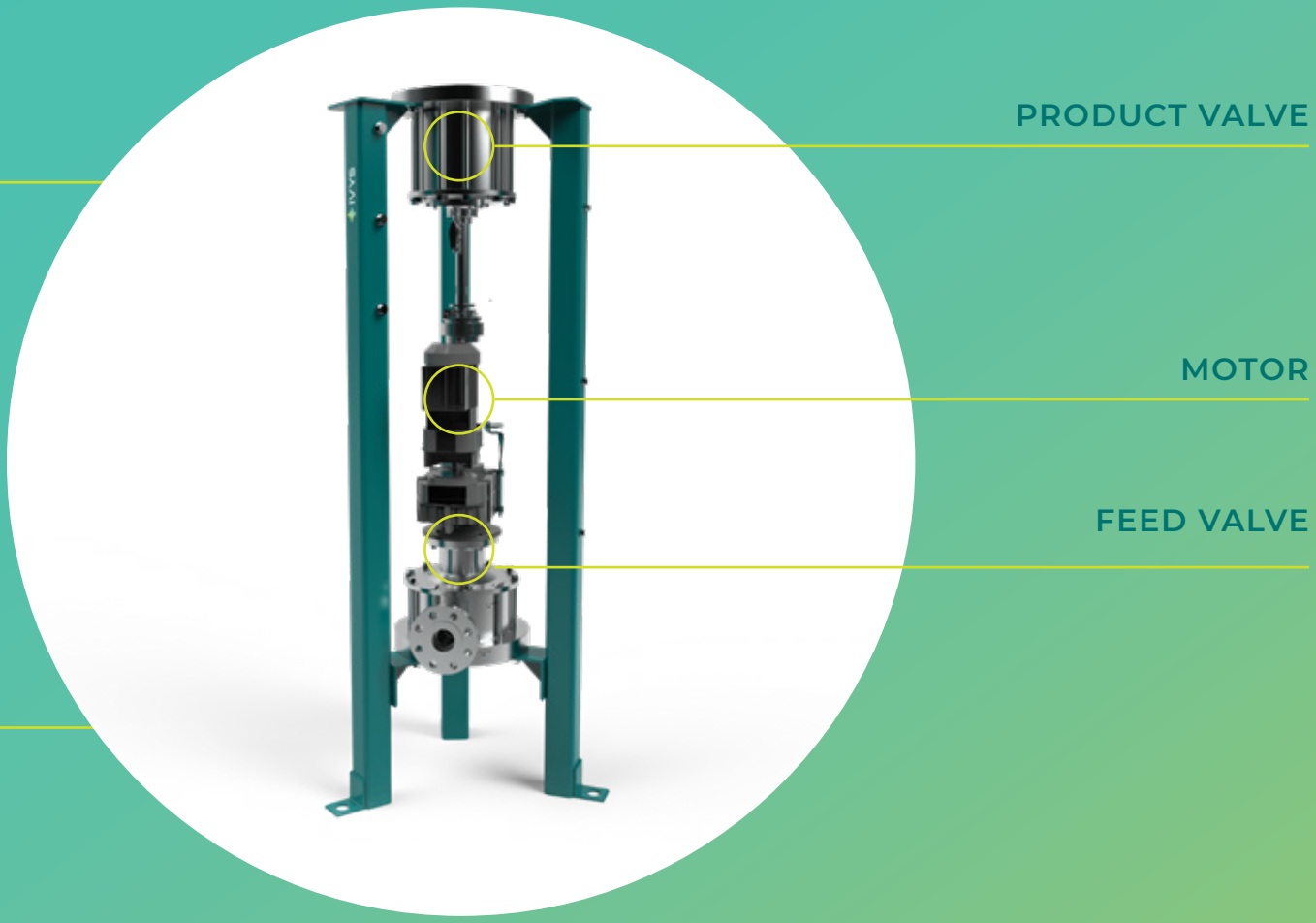
IVYS' ADSORBENTS

All Ivys' adsorbents are supplied in Ivys' brand name. They are field-tested for the unique fast-cycle operation of Ivys PSA.



- High capacity and selectivity
- Long lifetime >10 years under designed process and operating conditions
- Competitive cost
- Reduced quantity for the same capacity due to smaller absorber vessel size as a result of faster cycle time

HOW IT WORKS



Ivys' PSA units have one rotary valve (feed valve) connected to the bottom of adsorber vessels and another rotary valve (product valve) connected to the top of the vessels. Feed gas enters the bottom of each bed and the product exits via the top of the vessel, while the separated contaminants are removed in an exhaust stream from the bottom of the bed.

During operation, feed gas is allowed to flow through a passage in the feed valve to at least one vessel while, at the same time, purified product gas is allowed to flow from the vessel through the product valve passage to the product line. Other flows are similarly connected and controlled through the same feed and product rotary valves. As the two valves rotate simultaneously, gas flows are gradually switched from one vessel to the next to realize the desired cycle of pressurization, production, equalization, purging and regeneration, and produce a stable and continuous purified gas flow.

The valve rotation speed controls product gas purity and recovery and is typically in the range of 0.2 to 1.0 CPM (cycles per minute). There are five types of standardized rotary valve designs depending on the application conditions.

ADVANTAGES

Ivys' PSA systems offer unmatched proprietary advantages compared to conventional PSA systems.

These advantages include:

Compact
At least 3-5 times smaller compared to conventional PSA with the same capacity due to reduced PSA vessel size and the use of the rotary valves.

Easy and fast installation
Skid mounted systems with adsorbent preloaded in factory enable "plug-N-play" installation.

Simple control and operation
Only one parameter, the rotary valve speed, needs to be controlled during normal operation.

Flexible capacity
Operation capacity can be matched by adjusting rotary valve speed to maximize recovery while meeting product purity requirements.

High recovery
Triple equalization cycle design ensures high product recovery.

Reliable
Availability is typically greater than 99.5 % due to the significantly reduced number of moving parts and long service intervals compared to conventional PSA systems.

Low OPEX
Electrical power is the only utility required for normal operation. Power consumption is typically less than 1 kW.

Our Gas Purification Solution

H3100 Series

HIGH PRESSURE

The H3100 Series PSA systems use the high pressure G0 rotary valves and have 6 adsorber vessels.

When it comes to the lowest cost of ownership, the H-3100 has no match. The most compact, economic and reliable PSA system available today, the H-3100 has proven itself globally.

Usage recommandation

Recommended for medium throughput fueling needs where operating feed flows are up to 9,800 scfm/15,500 Nm3/h with higher operating pressures, up to 450 psig (31 barg).

System specifications

Rotary valve model	**G0**
Bed Diameter (in)	14-48
Number of bed	6
Max Pressure (psig/barg)	450/31
Feed Flow (scfm/Nm3/h)	9,800/15,500

H3200 Series

LARGEST CAPACITY RANGE

Best of breed in its capacity range, the H3200 series PSA is configured for a range of sizes to meet the application requirements in various markets.

Usage recommandation

The G2 PSA systems are recommended for small to medium capacity needs where feed gas flows are up to 600 scfm/950 Nm3/h with operating pressures up to 300 psig (21 barg).

The G3 or G4 rotary valve PSA systems can easily handle higher capacity needs where operating feed flows are up to 18,350 scfm/29,000 Nm3/h with operating pressures up to 250 psig (17 barg). A single valve tower configuration is used for feed flows up to 6,500 scfm/10,000 Nm3/h and a multi-valve tower configuration is used for higher feed flows.

System specifications

Rotary valve model	G2	G3	G4
Bed Diameter (in)	2-12	14-20	20-42
Number of bed	9	9	9
Max Pressure (psig/barg)	300/21	250/17	250/17
Feed Flow (scfm/Nm3/h)	600/950	1,950/3,100	18,350/29,000

H3300 Series

SMALLEST FOOTPRINT

The H3300 PSA system is designed with cost and footprint in mind.

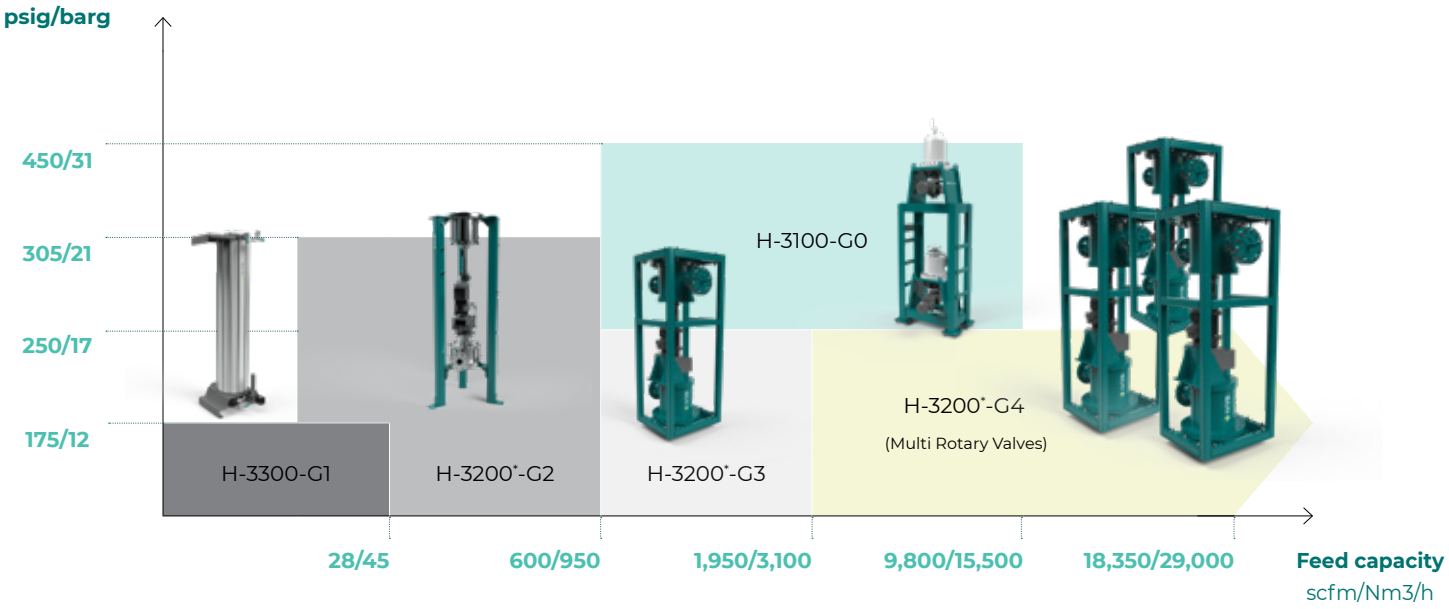
Due to its unique rotating bed design, many of the high maintenance, high-cost components necessary for conventional PSA systems have been eliminated resulting in a footprint unrivaled by anything in its capacity range and a cost that is the lowest in Ivys' PSA systems.

Usage recommandation

The H3300 PSA is designed to be tightly integrated and thus particularly suitable for applications where space is a prime. One example of the applications is MSR-based on-site hydrogen generation for hydrogen refueling. Recommended for low capacity applications where feed gas flows are from 2 up to 28 scfm/3 to 45 Nm3/h with operating pressures up to 175 psig (12 barg).

System specifications

Rotary valve model	**G1**
Bed Diameter (in)	3
Number of bed	9
Max Pressure (psig/barg)	175/12
Feed Flow (scfm/Nm3/h)	28/45



*H-3200 process & PSA cycle are common but equipment sizing varies.

System Configurations

	G0 H3100	G1 H3300	G2 H3200	G3 H3200	G4 H3200
NUMBER OF BEDS	6	9	9	9	9
BED DIAMETER	14”-48”	3”	2"-12”	14"-20”	20"-42”
MAXIMUM OPERATING PRESSURE	450 psig	175 psig	300 psig	250 psig	250 psig
FEED CAPACITY (Nm3/h)	1,200-15,500	10 -45	25-950	1,450 -3,100	4,500-29,000
FEED GAS TEMP (°C)	10-60 with 20-50 preferred				
DESIGN STANDARDS	North America: ASME, NFPA, NEC, CSA/Europe: PED, ATEX, IEC				
VOLTAGE	120Vac/1ph/60Hz, 240Vac/3ph/50 or 60Hz, 380Vac/3ph/50Hz, 480Vac/3ph/60Hz				
POWER CONSUMPTION	0.25-1 kw typical				
DESIGN LIFE	15+ years with scheduled maintenance, 10+years for adsorbents				
RECOMMENDED SERVICE	Inspection every 2.5 years; Minimum seal life 5 years				

Typical Hydrogen Source Gas

Feed Process Gas (vol%)	H_2	CO	CO_2	CH_4	CH_{2-3}	CH_{4+}	N_2	H_2O Vapor
MSR SYNGAS	60-80	0-10	10-20	0-10				Sat.
ATR SYNGAS	40-60	0-10	15-25	0-10			0-20	Sat.
CPOX SYNGAS	30-50	0-10	15-25	0-10			0-30	Sat.
GASIFICATION GAS	20-60	0-20	0-20	0-20	0-10	0-5	0-10	Sat.
REFINERY OFF-GAS	30-90	0-30	0-30	0-30	0-30	0-5		Sat.
H_2 POLISHING	90-99							Sat.
AMMONIA CRACKING	60-75						25-50	

Performance

H2 PURITY	Up to 99.9999%.
RECOVERY	80-90% typical. Recovery depends strongly on feed gas composition, pressure and product purity requirements.
TURNDOWN	40-100%
AVAILABILITY	>99.5%
APPLICATIONS	· Hydrogen purification for FCEV hydrogen refueling station, fuel cell power generation, hydrogen production and recovery for petrochemical processes, and metal and electronics manufacturing; · Helium production and recovery; · CO2 capture from combustion flue gas and industrial process gas; · Other speciality gas purification.

Specifications

H-series Frame Size	Vessel Outside Diameter	Rotary Valve / # of Beds	Max Op. Pressure		Feed Flow Capacity[1]		Dimensions[3]						Weight[2]	
							Width		Depth		Height			
			PSIG	BARG	SNFM	Nm3/hr	ft	m	ft	m	ft	m	lbs	kgs
H-3100	14"	G0-6 BED	450	31	750	1,200	10.5	3.2	9.0	2.7	12.0	3.6	15,000	6,800
	16”				1,000	1,600	10.7	3.3	9.1	2.8	12.0	3.6	16,000	7,300
	18”				1,250	2,000	10.9	3.3	9.3	2.8	12.0	3.6	17,000	7,700
	20”				1,600	2,550	11.1	3.4	9.5	2.9	12.0	3.6	19,000	8,600
	24”				2,300	3,700	11.6	3.5	10.0	3.0	12.0	3.6	21,000	9,500
	30”				3,800	6,000	12.6	3.8	11.0	3.3	12.0	3.6	24,000	11,000
	36”				5,350	8,500	13.6	4.1	12.0	3.6	16.2	4.9	28,000	12,700
	42”				7,400	11,700	14.6	4.4	13.0	4.0	16.2	4.9	32,000	14,500
	48”				9,800	15,500	15.6	4.7	14.0	4.3	16.2	4.9	36,000	16,300
H-3200	2"	G2-9 BED	300	21	15	25	4.7	1.4	3.7	1.1	7.6	2.3	3,850	1,750
	4”				65	100	4.7	1.4	3.7	1.1	7.6	2.3	3,900	1,800
	6”				145	230	4.7	1.4	3.7	1.1	7.6	2.3	4,550	2,050
	8”				275	430	5.3	1.6	5.3	1.6	9.5	2.9	4,900	2,200
	10”				420	670	5.5	1.7	5.3	1.6	9.5	2.9	5,100	2,300
	12”				600	950	6.3	1.9	5.8	1.8	9.5	2.9	5,400	2,450
H-3200	14”	G3-9 BED	250	17	900	1,450	18.4	5.6	8.4	2.6	13.6	4.1	18,500	8,400
	16”				1,200	1,950	18.6	5.6	8.5	2.6	13.6	4.1	20,000	9,100
	18”				1,600	2,550	18.8	5.7	8.8	2.7	13.6	4.1	21,500	9,800
	20”				1,950	3,100	19.0	5.8	9.0	2.7	13.6	4.1	23,000	10,500
H-3200	24”	G4-9 BED	250	17	2,800	4,500	21.0	6.4	10.5	3.2	14.0	4.3	28,000	12,700
	30”				4,500	7,100	23.5	7.2	12.0	3.6	14.0	4.3	32,500	14,750
	36”				6,650	10,500	27.0	8.2	13.5	4.1	18.3	5.6	37,000	16,800
	42”				8,850	14,000	30.0	9.1	15.0	4.6	18.3	5.6	41,500	18,850
	48”				11,700	18,500	33.0	10.1	16.5	5.0	18.3	5.6	46,000	20,900
	54”				14,900	23,500	37.0	11.3	18.0	5.5	18.3	5.6	52,000	23,600
	60”				18,350	29,000	42.0	12.8	19.5	5.9	18.3	5.6	57,000	25,900
H-3300	3”	G1-9 BED	175	12	28	45	2.6	0.9	2.8	0.9	7.3	2.2	1,500	700

[1]Specifications listed above are typical values. Each PSA will be sized individually to customer process requirements.

[2]Weight = empty

[3]Dimensions don't include surge tanks which are sized based on customer process data.


E-Cell

USA

G0 H_2 PSA

SOURCE	Refinery Off-Gas
SCALE	1,300 NCMH
FEED GAS	59 % H_2
	38.9 % CH_4
	0.5 % N_2
	2.09 % CO
	2.03 % C_2H_4
PRODUCT PURITY	≥ 99.999 %

JAPAN

G0 H_2 PSA

SOURCE	Refinery Off-Gas
SCALE	6,150 NCMH
FEED GAS	95.4 % H_2
	0.09 % CH_4
	3.1 % CO
	0.5 % CO_2
	0.17 % N_2
PRODUCT PURITY	99.999 %

Case

USA

Methane G0 PSA

SOURCE	Chemical Plant Off-Gas
SCALE	1,675 NCMH feed 1010 NCMH product
FEED GAS	79 % CH_4
	2.4 % CO_2
	7.8 % C_2
	5.3 % C_3
	5.3 % C_4+
PRODUCT PURITY	99 %

USA

G0 He Purification

SOURCE	Helium
SCALE	~ 1,629 Nm^3/h
FEED GAS	97.5 % HE
	1.3 % CH_4
	0.1 % H_2O
	11.1 % N_2
	250 psig
PRODUCT PURITY	99.999 %

Studies

FAQs

We have compiled a list of questions with answers that are commonly asked by our customers. If you have a question that is not addressed below, please contact Ivys.

How does a PSA work?

A PSA or Pressure Swing Adsorption System works on the principle of preferential “adsorption” or adhesion of certain gas molecules onto a solid adsorbent material under pressure, and the reversible nature of the process to release the adsorbed molecules at low pressure.

Pressurized feed gas is introduced to a vessel filled with adsorbents and the gas stream is purified as certain molecules are adsorbed onto the material inside the vessel. The “purified” product gas flows from the top of the vessel at pressure. Once the vessel has reached its adsorbent capacity, the gas flow is “switched” to a fresh column and the pressure is reduced in the loaded vessel to release the adsorbed molecules at low pressure as “exhaust” gas, thereby regenerating the adsorbent for another cycle. This process is fully reversible and repeats itself to provide a continuous flow of purified gas. Multiple beds are used to allow for near continuous process flows.

How is the PSA controlled?

The operation of the PSA is controlled by pressure and cycle speed to achieve the desired flow and purity. Gas flows in a Ivys PSA are controlled by a set of rotary valves rather than the on-off switching valves found on a conventional PSA system. The rotational speed of the rotary valves is controlled by an analog signal from a PLC (Programmable Logic Controller) to the variable speed drive motor which turns the rotary valves. Operation, turndown, and product gas purity control are achieved by adjusting only the rotary valve rotational speed.

G0 Rotary Valve

How do the rotary valves work?

The PSA has one rotary valve (feed valve) connected to the bottom of each bed and one rotary valve (product valve) connected to the top of each bed. Feed gas is allowed to flow through a passage in the feed valve to at least one bed while, at the same time, purified product gas is allowed to flow from the bed through the product valve passage to the product line. Other flows are similarly connected through the rotary valve for exhaust, purge, equalizations, etc.

As the two valves rotate together, gas flows are gradually switched from one bed to the next to produce the efficient PSA cycle. Although this cycle is much faster than conventional PSAs (with the inherent advantages), this is still a very slow rotational speed of 1.0 to 0.3 RPM (Rotations Per Minute).

What is the maximum turndown?

The maximum turndown is typically 40%. However, in some installations, Ivys has provided capacity turndowns to below 25% of maximum design capacity.

How is purity measured and controlled?

The PSA operator normally provides the gas analysis equipment needed to measure and monitor PSA product purity going to their customer depending on their specific needs (i.e. accuracy, frequency, and what components

to analyze). The PSA is commissioned to operate at the unit's design purity at the time of its performance test, including any turndown operation points. If conditions during ongoing operation change more than the 2.5% specified, adjustment of the PSA cycle speed may be required. In certain situations, an online gas analyzer with a proportional output signal can be used as a control loop input signal to automatically adjust the PSA cycle speed depending on measured purity. This is best deployed when the feed conditions are expected to change frequently, and the measuring instrument is well within its detection and drift limits.

What kind of adsorbents do you use?

Ivys uses many different types of commercially available adsorbents such as activated alumina, silica gel, zeolites and carbon materials. The type and amount of each adsorbent are selected for your specific application and conditions as determined by our process engineers using advanced process models for Ivys' specific Fast Cycle PSAs.

What is the life expectancy of the adsorbents/what can damage the adsorbents?

The lifetime of Ivys' adsorbents is longer than 10 years under designed process and operating conditions.

Ivys' adsorbents have been in operation without degradation in many cases for the life of the plant. Adsorbents can be damaged through misoperation such as excess gas flows which "lift" the material causing attrition and breakdown of the beads.

Also, liquids of any kind can strongly adhere to the adsorbent and reduce its working capacity.

What levels of contamination can the PSA tolerate (H2O, VOCs, H2S, etc.)?

The level of contaminants the PSA can tolerate depends on the components in question and the specific application. Please provide a list of contaminants, with the typical concentrations of each, to an Ivys Specialist to review. Examples of gas components that can lead to contamination include high levels of H2S, strong acids, high molecular weight hydrocarbons, etc. The PSA is designed to operate with gas streams saturated in water, but liquid water should be removed prior to the PSA.

G1 Rotary Valve

What safety or protective systems do you supply with the PSA?

Ivys uses a HAZOP (Hazard and Operability) study method to identify and address risks associated with our systems. A gradual feed pressurization control prevents the adsorbent from being lifted during restarts; a feed coalescing filter protects the rotary valves and the adsorbent from liquids and particulates and safety relief devices on each bed protects the plant for a fire case safety relief.

What is the system reliability?

Ivys' PSAs have accumulated over 25,000,000 commercial operating hours (over 50,000,000 valve hours), with more than 350 plants in continuous duty.

The rotary valves are highly reliable, with recommended service intervals of 5 years, and an inspection at 2.5 years. Ivys' PSA installations have proven avaibility beyond 99.9%.

How long does commissioning take?

The commissioning of an Ivys' PSA typically takes between 3 to 5 days for small systems and 1 to 2 weeks for larger installations.

What are the operating costs?

The operating costs vary depending on the PSA platform and the options selected. Operating costs for the PSA include power to the motor, which is typically under <0.5 kW for small PSA 3200 systems, up to 5 kW for larger PSA 3100 installations.

What about spare parts and other consumables?

Other operating consumables include feed filter elements and gear motor oil changes once every 2-3 years. Rotary valve seals typically will be inspected and, if necessary, replaced, every 5 years.

How can I tell if there is a problem with the rotary valves?

Ivys' rotary valves have been proven to be very robust and have been rigorously tested for quality prior to leaving Ivys' facilities. In the highly unlikely event where the rotary valves stop turning, an alarm is triggered. This could be caused by a power outage, drive or motor fault, or high torque at the rotary valves. Of a few faults of this kind, the power supply or drive has been corrected and normal operation resumed without a requirement for Ivys field service.

If rotary valve leakage should occur, the PSA would experience a lower-than-expected product gas recovery. However, product gas purity would be maintained, so plant operation is not interrupted. Monitoring will provide operating staff with the ability to trend performance and schedule Ivys inspection/service at a convenient time.

Can the product gas become contaminated?

Ivys' rotary valves are designed so that rotary valve leakage cannot contaminate the product gas. Also, in the event that the PSA is shut down suddenly, there is no rotary valve position that would allow product gas contamination. If the PSA is purged with an inert gas for maintenance or extended shutdown, Ivys' standard start-up procedures prevent contamination of the inert gas into the product gas.

Can particulates be present in the product gas?

As with most gas processing equipment, small particles may be present in the product line during the initial start-up, but they are not generated during normal operation of the PSA.

How can I tell if the PSA adsorbents are degraded?

Typically, PSA adsorbents will last the life of the plant. If the PSA is operated under conditions where flows or contaminants substantially exceed the unit's design conditions, the adsorbents can become deactivated and a loss of product gas recovery and/or capacity would be observed.

Are there any hazardous materials in the PSA?

No hazardous materials are present in most PSA systems. A MSDS (Material Safety Data Sheet) is provided with the IOM (Installation, Operation and Maintenance) manual with every Ivys PSA.

What electrical power requirements are necessary?

The PSA can be configured to handle a number of power sources. Our typical electrical power requirements are 120 VAC/1 ph/60 Hz, 230/400 VAC/3 ph/4 wire/50 Hz, 200 VAC/3 ph/3 wire/50 Hz, or 480 VAC/3 ph/60 Hz for the PSA motor. For instruments we typically require 120 VAC/60 Hz 1 ph, 220 VAC/50 Hz/1 ph, or 110 VAC/50 Hz/1 ph with some instruments requiring low voltage DC power, typically from a PLC/DCS source.

G2 Rotary Valve

G3/4 Rotary Valve

What if gas conditions change or I want to operate at different product purity levels?

Once the PSA cycle is tuned at the time of commissioning, the cycle speed can be re-programmed or adjusted to the desired level of product purity, even with a different feed gas composition. If operating conditions change drastically (i.e. feed pressure changes), the PSA may require re-tuning by Ivys for the new conditions.

What signals do I need to send to the PSA?

The signals required to operate Ivys' PSA include a 4 to 20 mA signal to the variable speed drive for the rotary valve motor, and signals to the instruments included on the PSA. Typical Ivys PSA installations require no more than 10 I/O signals.

What is the PSA's start-up time?

The typical start-up time for pressurizing an Ivys' PSA is 15 minutes. Under normal start-up conditions product purity is achieved once pressurization is complete. Restarts can be considerably shorter.

What happens after an emergency stop of the PSA?

After an emergency stop, the motor to the PSA stops and the feed and product isolation valves close. The PSA remains under pressure and the adsorber beds are stopped within their bed cycles. After the resolution of the emergency stop, the PSA is re-started and the unit resumes normal operation at the point where it stopped. If the E-stop lasts for more than an hour or two, the system should be de-pressurized per Ivys shutdown procedure to remove residual contaminants.

Can the PSA operate outdoors?

The PSA is designed for outdoor operation with a protection rating of IP 53 or better. The design operating ambient temperature is from 4 to 48°C (40 to 118°F). For more extreme environments, a cold weather option (heat tracing with insulation) can be included to allow operation at ambient temperatures as low as -40°C.

What feed and exhaust pressure should be used for best performance?

This will depend on specific conditions but, generally, lower exhaust and higher feed pressure will improve performance and reduce PSA size. Typical conditions for feed pressure range from 4 barg to 27 barg with a slow an exhaust pressure as possible.

IVYS
Purely Driven

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