PSA OPTIMIZATION, RELIABILITY AND MAINTENANCE

JM AMERICAS HYDROGEN & SYNGAS TECHNICAL TRAINING SEMINAR

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Honeywell
UOP

AGENDA

I. Normal Operation & Optimization

- Controlling product purity & optimization
- Operating checkpoints
- Operator displays
- Performance measurement
  - Recovery
- Safeguarding the adsorbent
- Alarms and Shutdowns

II. Reliability and Maintenance

- PSA Unit Periodic Maintenance & Inspection
- Adsorber Vessel Maintenance
- PSA Control Valve Preventive Maintenance
- PSA Control Valve Service Centers & Potential Upgrades

PSA OPERATIONS: TOPICS

Normal Operation & Optimization

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PSA OPERATIONS: PRODUCT PURITY

- PSA adsorber bed has a fixed capacity to remove impurities
  - e.g. Can load X lbs. of impurities on the adsorbent bed each time the Adsorber is on the Adsorption step
- Impurity loading is a strong function of:
  - Feed Composition → concentration of impurities
  - Feed Flow Rate → rate impurities load on adsorbent
  - Adsorption time – How long the Adsorption step lasts
- Over-loading the adsorbent will result in low product purity

PRODUCT RECOVERY OPTIMIZATION

- Local
  - Operator sets adsorption time. Use during startup, during upsets or when feed flow meter is out of service.
- Capacity
  - Adsorption time calculated from feed rate. Use during normal operation.
  - Capacity control factor is used to optimize operation

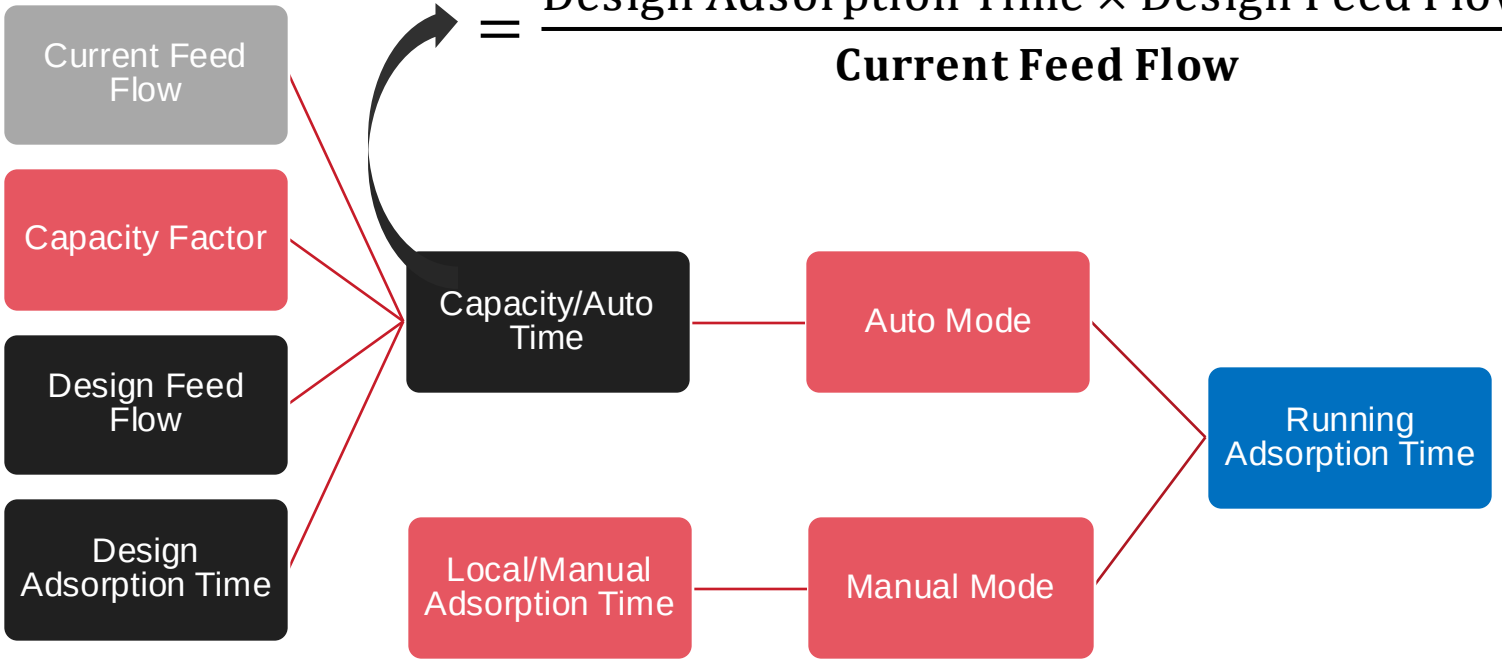
PRODUCT RECOVERY OPTIMIZATION

- To maximize Recovery at low feed rates, adsorption time should be increased
- Use Capacity Control mode and adjustable Capacity Control Factor
- Capacity Control Factor changes can take up to 1 day for the full effect to be seen on the operation of the unit; however, typically, most of the changes occur within the first 4 – 6 hours
- General Guideline:
  - If product purity is above specification, CCF may be increased
  - If product purity is at / near specification, CCF requires no change
  - If product purity is below specification, CCF should be decreased

NOTE: If a “spike” [via analyzer] in product impurities is noticed during stable operation, reduce subcycle time immediately!

OPERATING MODES – TIME CONTROL

$$= \frac{\text{Design Adsorption Time} \times \text{Design Feed Flow}}{\textbf{Current Feed Flow}} \times \textbf{CCF}$$

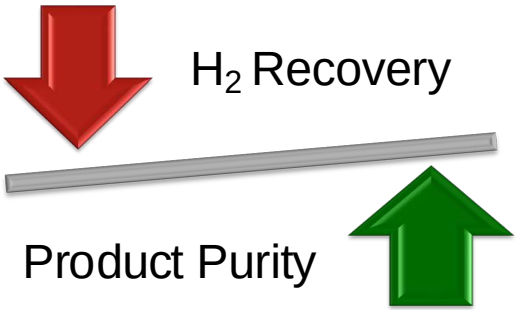


PRODUCT RECOVERY OPTIMIZATION

Adjusting Capacity Control Factor

- CCF – Capacity Control Factor
  - ↑ CCF , ↑ Adsorption time , ↑ impurity loading
  - ↓ CCF , ↓ Adsorption time , ↓ impurity loading
- Hydrogen Recovery [The Main PSA performance metric]
  - ↑ Adsorption time , ↑ H2 in Product , ↓ H2 in Off Gas
- Constant Balance:

Operating at low Adsorption Time is a loss in H_2

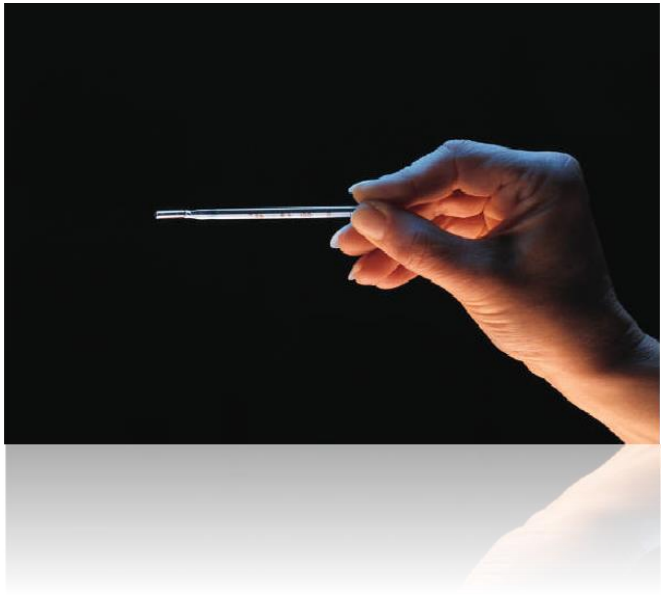


PRODUCT RECOVERY OPTIMIZATION

- Keep a record of the **Capacity Control Factor**

  or

- Of the PSA **Loading** (Flowrate * Tads)



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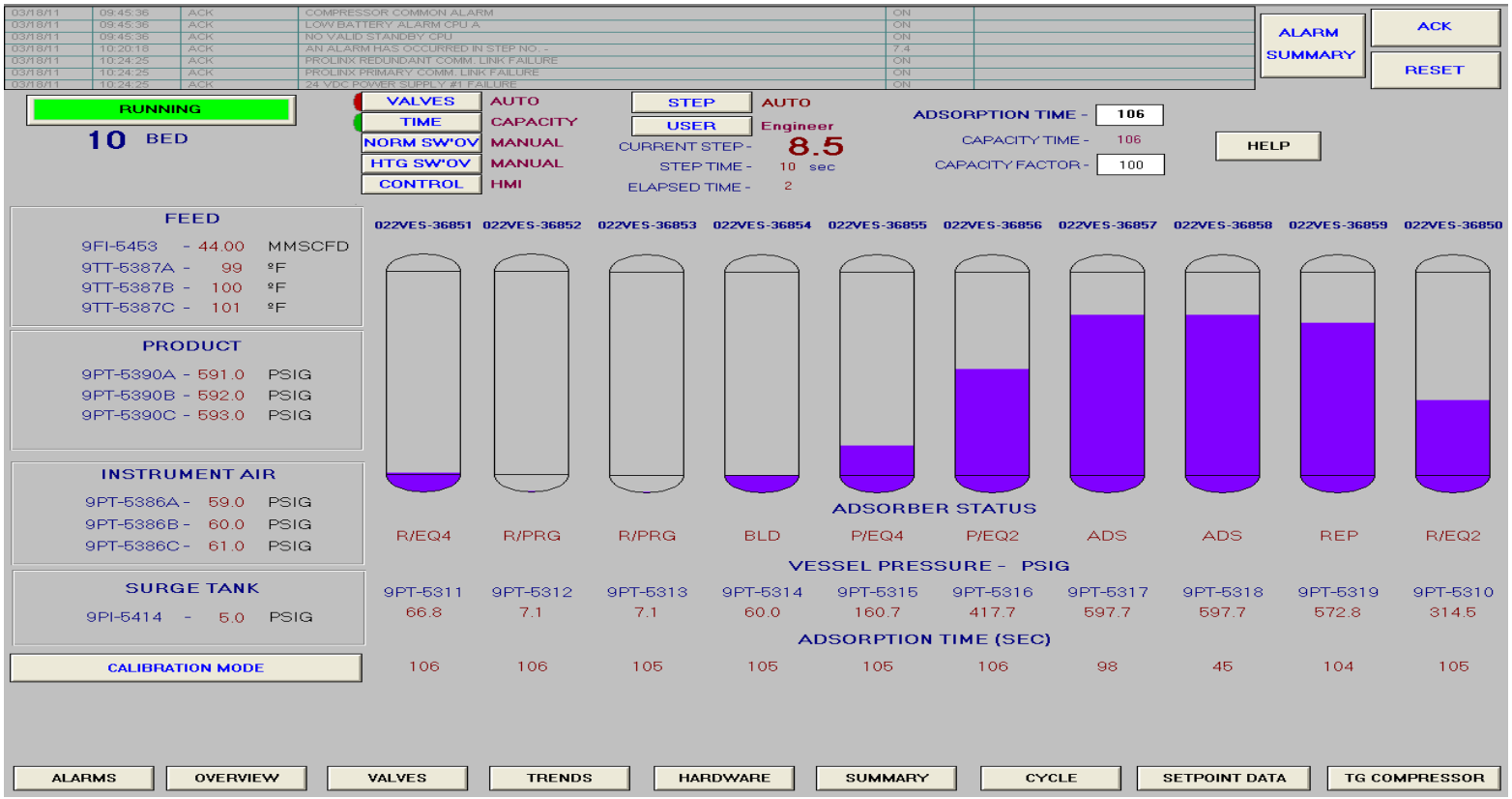
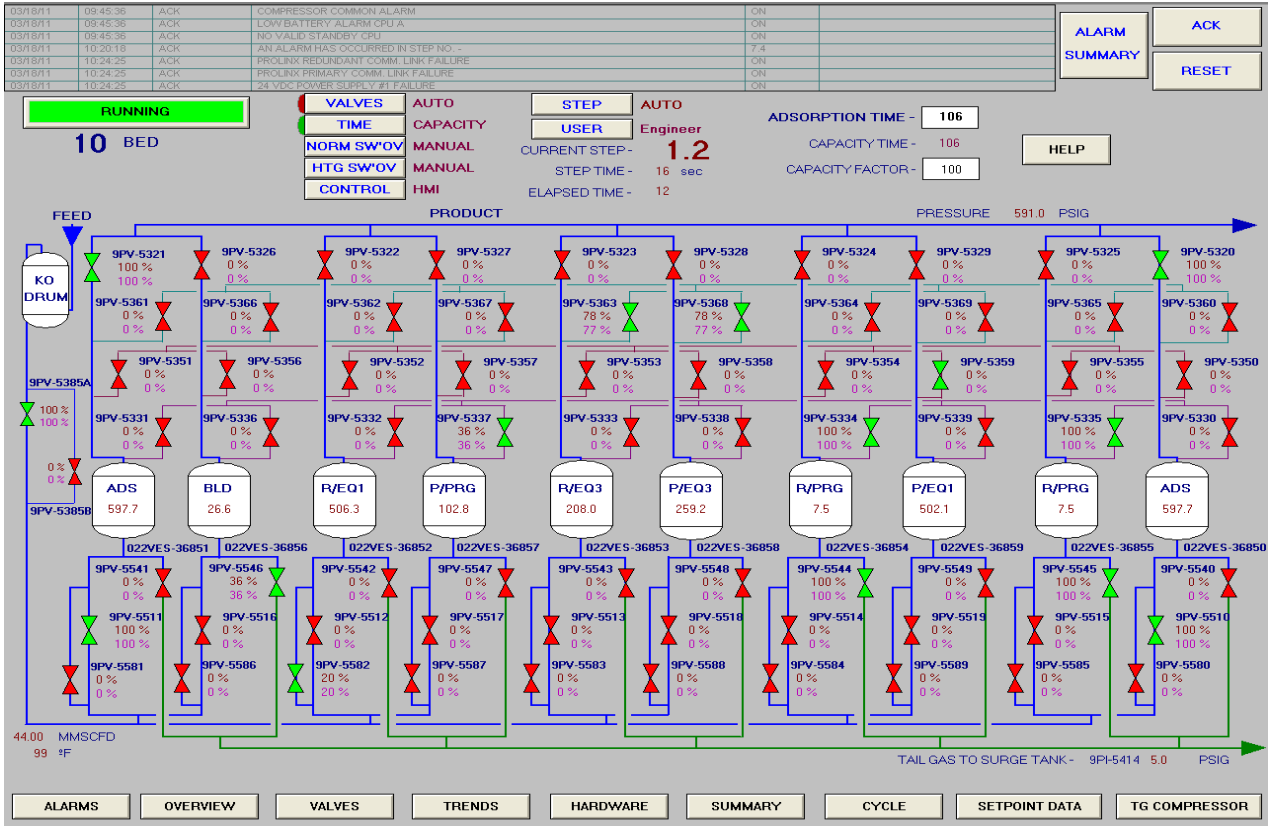
PSA OPERATIONS: CHECKPOINTS

- Check feed, product and tail gas flows and pressure trends for unusual swings
- Compare ending equalization pressures of each bed
- Compare **actual** adsorption times to the **Set** adsorption time
- Monitor Control Loop trends
- Monitor Tail Gas Pressure
- Monitor Product Purity

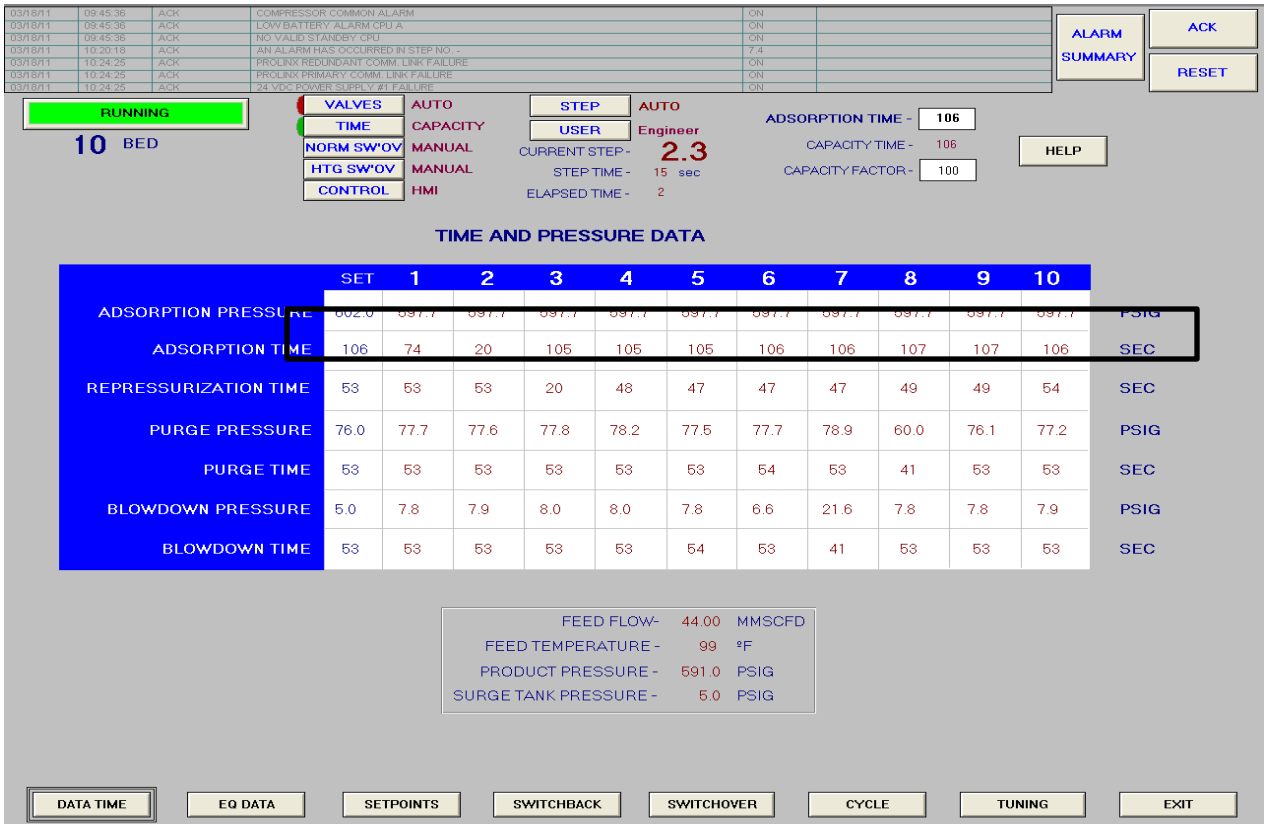
PSA OPERATIONS: OVERVIEW DISPLAY



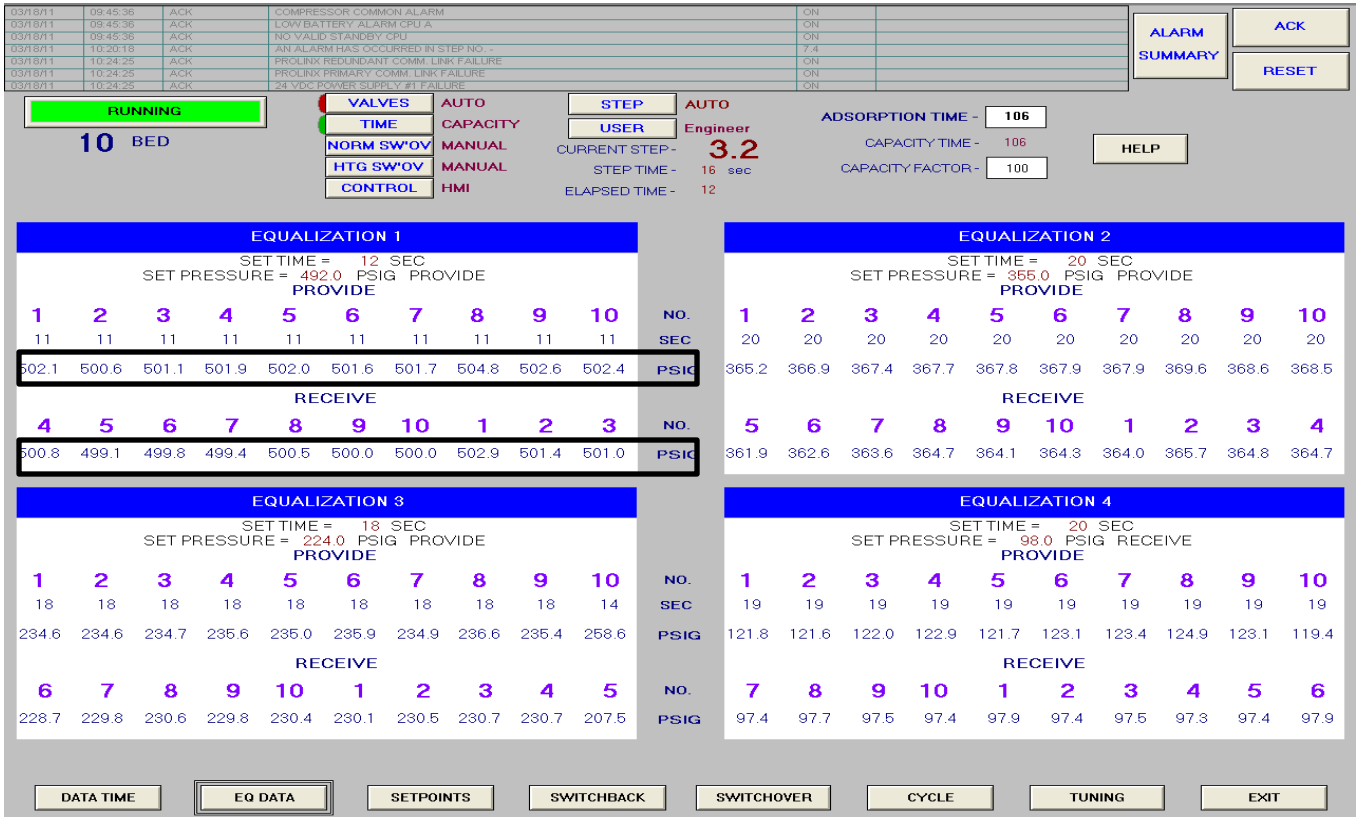
PSA OPERATIONS: VALVE DISPLAY



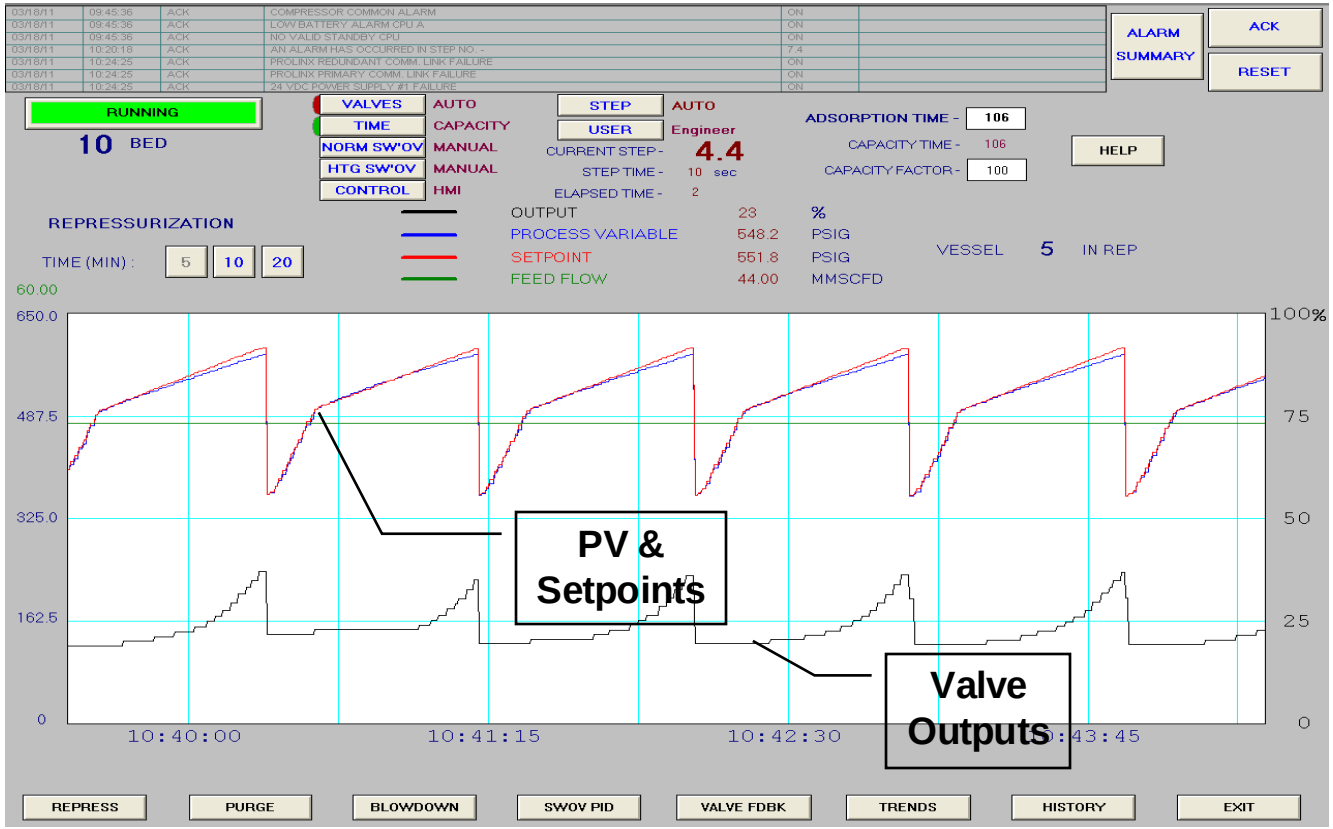
PSA OPERATIONS: DATA TIMES DISPLAY



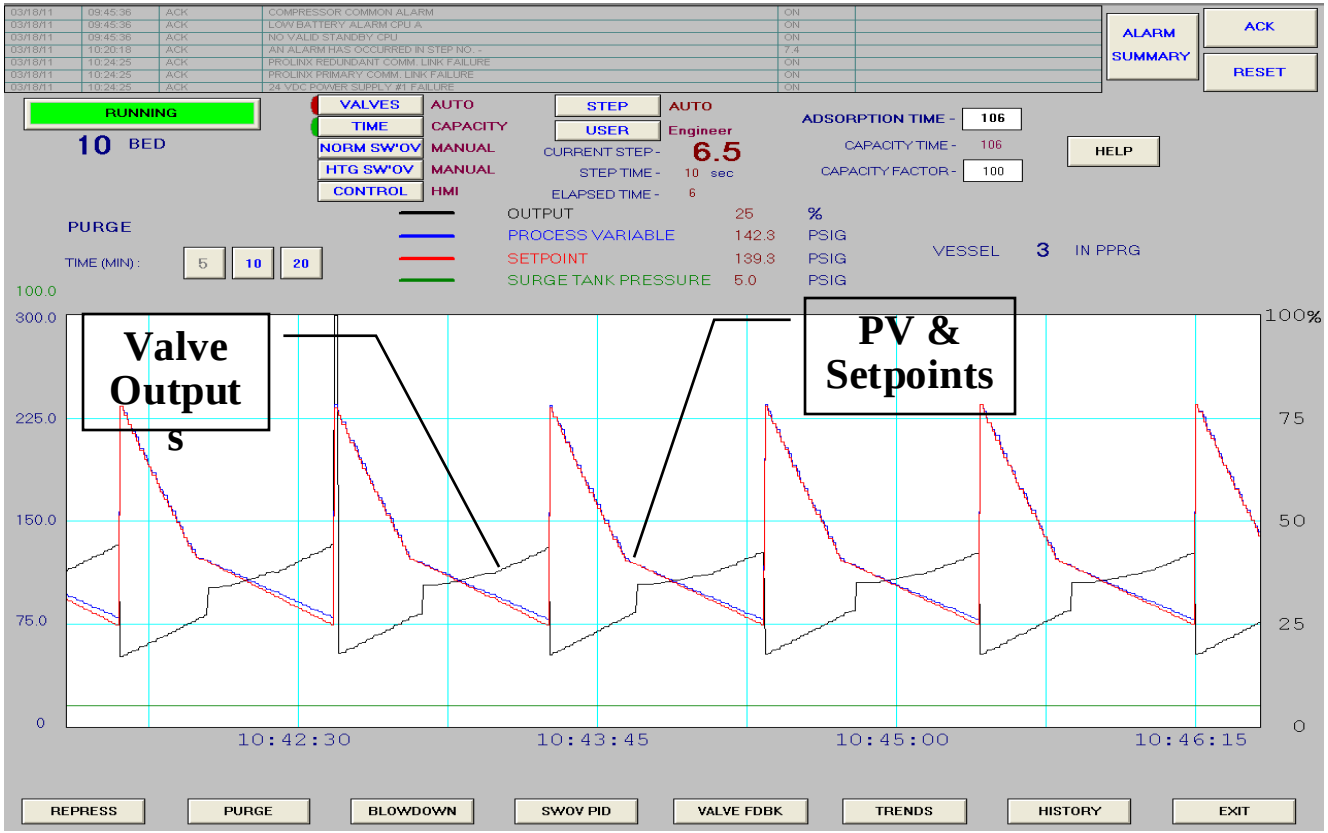
PSA OPERATIONS: EQ DATA DISPLAY



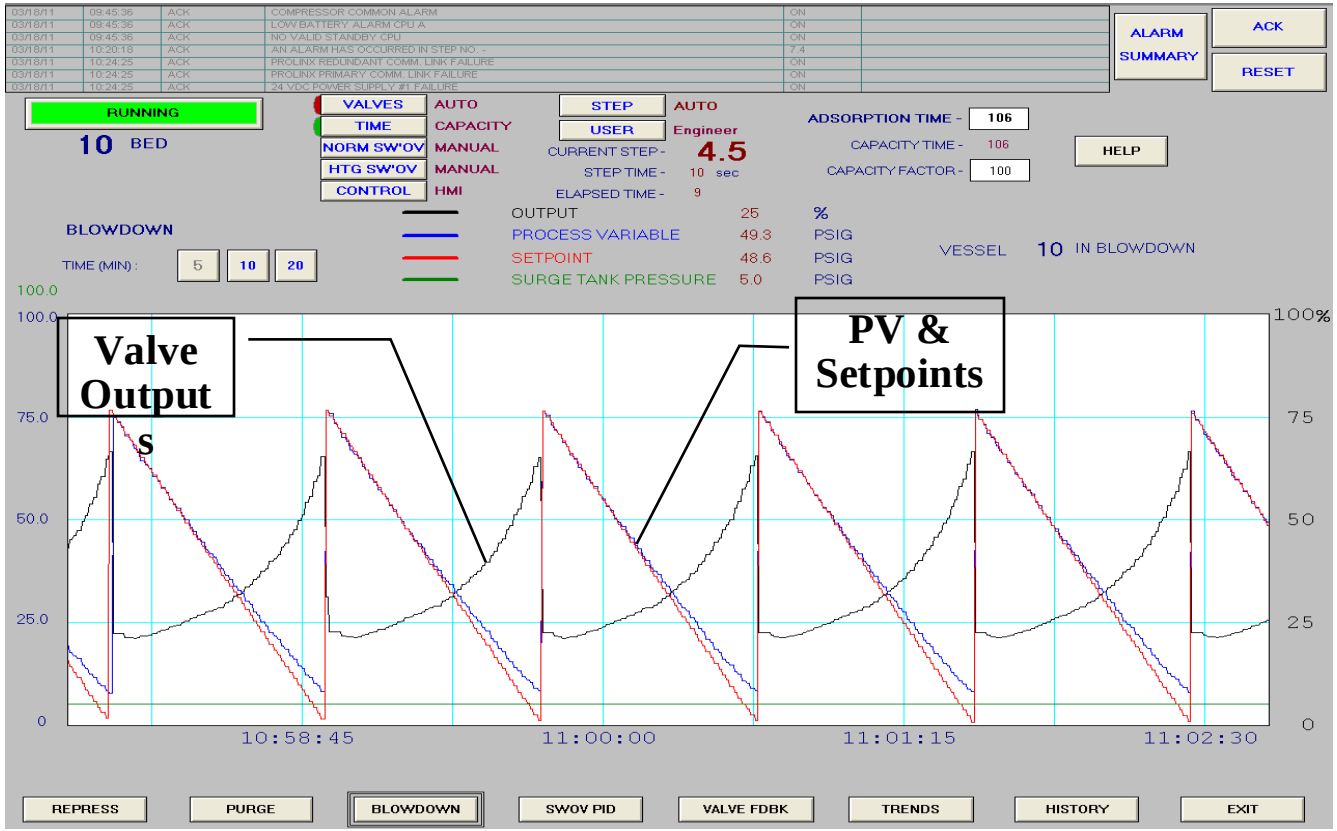
PSA OPERATIONS: REPRESSURIZATION



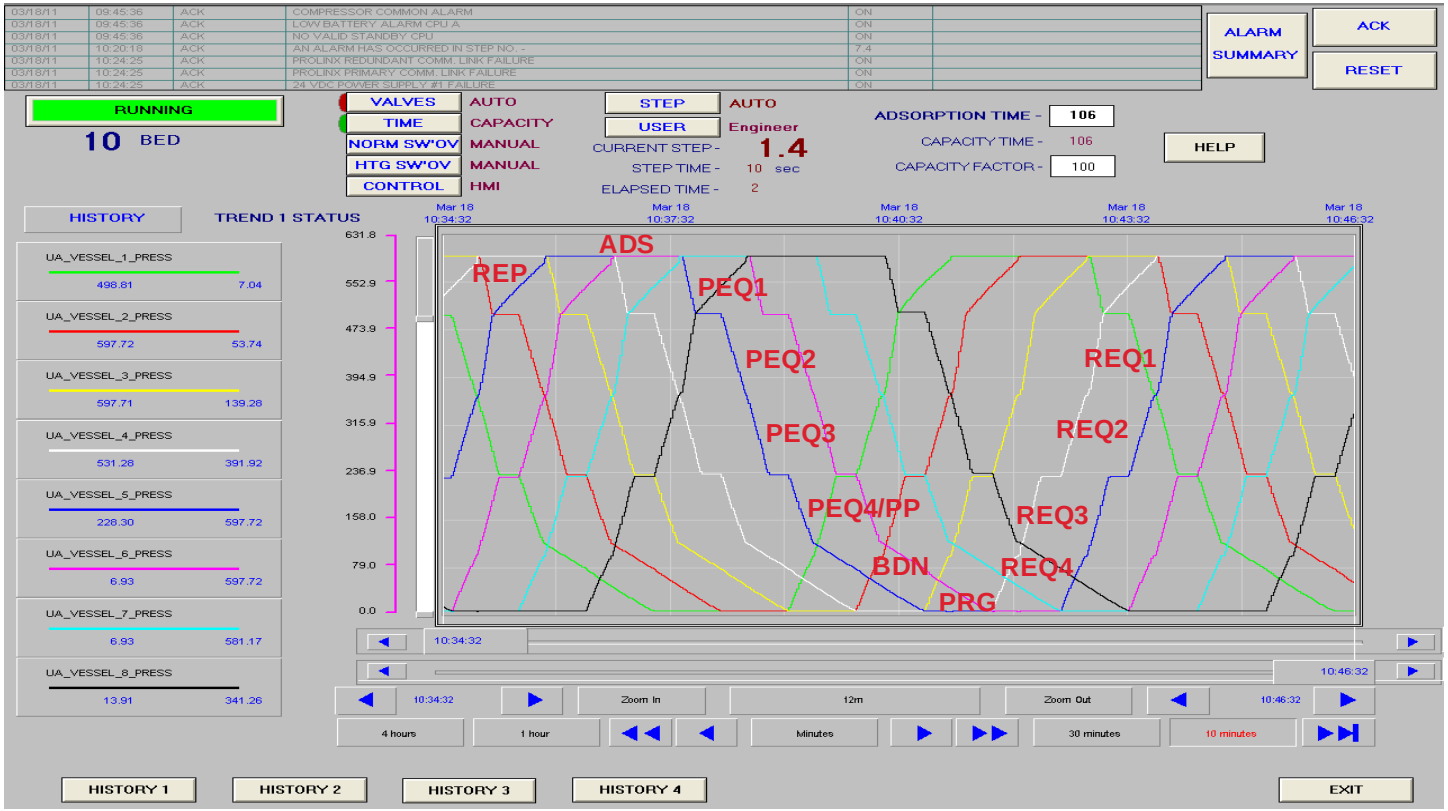
PSA OPERATIONS: PURGE



PSA OPERATIONS: BLOWDOWN



PSA OPERATIONS: TYPICAL VESSEL PRESSURE TRENDS



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PSA OPERATIONS: PERFORMANCE MEASUREMENT

- Material balance around the PSA unit
- Feed, Product, and Tailgas flows with corresponding
  - Pressure and Temperature
- Analyze Feed, Product, and Tailgas
- Hydrogen and Methane Concentration in various streams
- Record Capacity Factor and actual Adsorption Time

PSA OPERATIONS: HYDROGEN RECOVERY

Based on flow balance

- Must have Independent Flow Measurements
- Correction for pressure, temperature, MW
- High probability of error

$$\text{Recovery} = \frac{Q_P \times y_P}{Q_F \times y_F} \times 100$$

y_P = H_2 fraction in product
y_F = H_2 fraction in feed
Q_P = Product Flowrate
Q_F = Feed Flowrate

PSA OPERATIONS: HYDROGEN RECOVERY

Based on Composition

$$H_2 \text{ Recovery} = \frac{(Y_{i,f} - Y_{i,o}) * Y_{H2,p}}{(Y_{i,p} - Y_{i,o}) * Y_{H2,f}} \text{ X } 100$$

Where:

- $Y_{i,f}$ = mole fraction of component i in feed
- $Y_{i,p}$ = mole fraction of component i in product
- $Y_{i,o}$ = mole fraction of component i in off-gas
- $Y_{H2,p}$ = mole fraction of component H_2 in product
- $Y_{H2,f}$ = mole fraction of component H_2 in feed

POOR RECOVERY OR PRODUCT PURITY

Possible Causes

- Too long adsorption time
- Extended cycle steps
- Instrument problem
- High tail gas pressure
- Excessive feed flow
- Off-spec feed gas
- Inaccurate lab results

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SAFEGUARDING THE ADSORBENT

Avoid rapid repressurization / depressurization

- Proper use of Manual Valve Operation
  - Do not exceed maximum depressurization/repressurization

Eliminate entrained liquids from feed gas

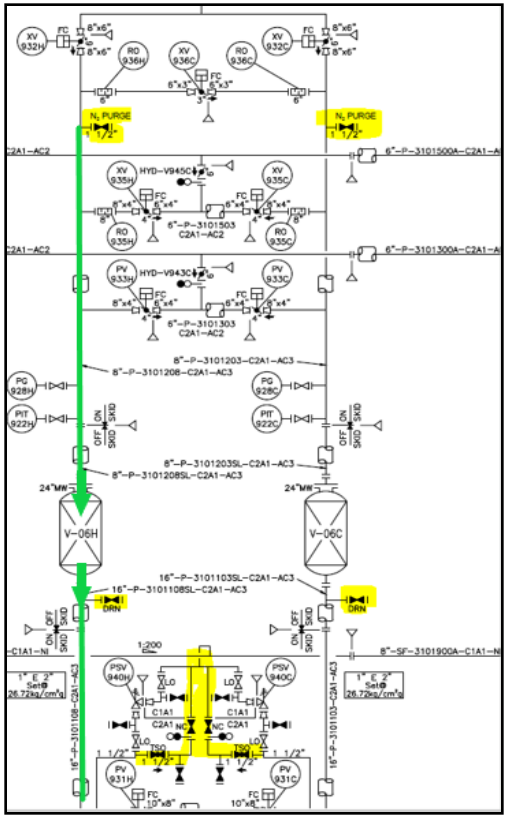
- Check the feed header for liquids prior to each Restart

Keep impurities in their proper adsorbent layer in the bed

- Keep PSA Product at design Specification
- Don't operate with excessive impurity breakthrough in Product
- Don't operate PSA with non-design components in feed without first checking with UOP

SAFEGUARDING THE ADSORBENT

- Always depressurize and purge from top to bottom
- Avoid water in or near product piping
- N_2 for purge shall be dry and CO_2 free



PSA OPERATIONS: TOPICS

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PRESENTATION OVERVIEW - ALARMS AND SHUTDOWNS

Operating Conditions

- Feed Temperature
- Product Pressure
- Instrument Air Pressure
- Feed Flow Rate

Equipment Failures

- Valve Calibration Error
- Valve Feedback Mismatch
- Valve Failure
- Transmitter Failure

Process Upsets

- Pressure Deviation
- Extended Loop
- Long Adsorption Time

ALARMS AND SHUTDOWNS: FEED TEMPERATURE

- There is a range of acceptable operating temperatures
- Operating inside of this range, it is possible to change the adsorption time to maintain product purity
- Operating outside of this range, adsorption **(high temp)** or desorption **(low temp)** is very different from the design and could damage the adsorbent
- Depending on PSA feed design
  - There is a high-temperature alarm and shutdown
  - There is a low-temperature alarm and shutdown

ALARMS AND SHUTDOWNS: PRODUCT PRESSURE

- If the PSA unit is operated at a pressure less than design, the amount of purge gas is less than design
- When the amount of purge gas is below a certain level, the impurities are not removed from the adsorbent, and damage could result
- There is an alarm and a shutdown for low product pressure
- There is only an alarm for high product pressure

ALARMS AND SHUTDOWNS: INSTRUMENT AIR PRESSURE

- If the instrument air pressure is too low, it is possible the valves will not close, or remain closed
- This could produce an undesired flow path between vessels which could result in physical damage to the adsorbent
- There is an alarm and a shutdown for low instrument air pressure
- There is only an alarm for high instrument air pressure

ACTIONS: CHECK EXTERNAL PSA CONTROLS

Feed

- Is temperature stable?
- Does the pressure control valve to flare remain closed during stable operation?
- If applicable, is the Knockout Drum level control operating properly?

Product

- Check the operation of the Product pressure control valve
  - Is the Output stable for stable Feed Flow?
  - What is the typical fluctuation in Pressure? [Typical: < 10 PSIG]
- Temperature
  - Slowly increasing or Sharp increase in temperature means an impurity is in the incorrect adsorbent layer [Decrease Adsorption Time immediately]

Off Gas

- Pressure fluctuations [Typical: < 3 PSIG]

ALARMS AND SHUTDOWNS: EQUIPMENT FAILURES

Equipment Failure

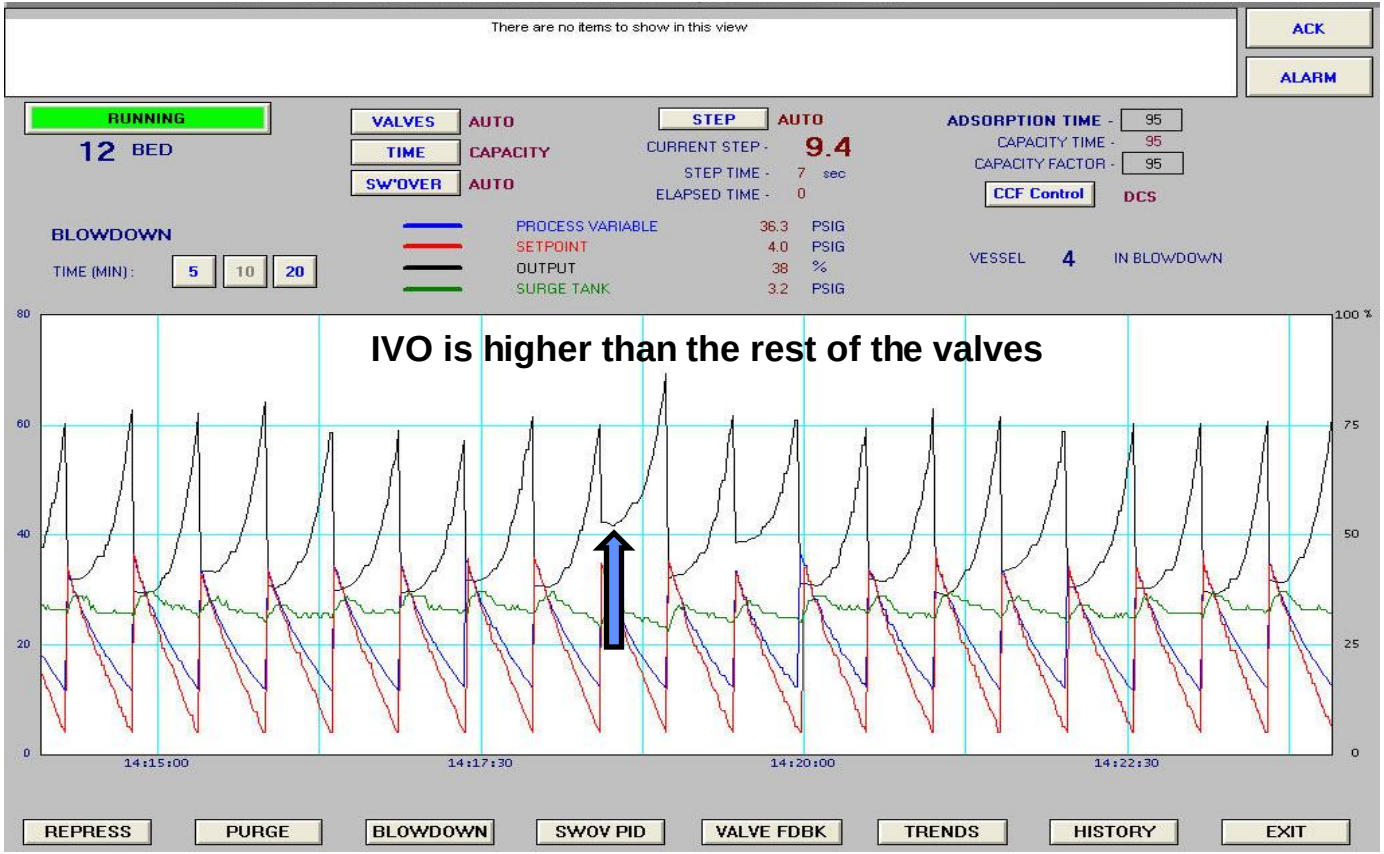
- Valve Calibration Error
- Valve Feedback Mismatch
- Valve Failure
- Transmitter Failure

A Valve and Transmitter Failure will cause a switchover but a Valve Feedback Mismatch or Calibration Error trigger an alarm and do not cause a switchover.

ALARMS AND SHUTDOWNS: VALVE CALIBRATION ERROR ALARM

- The initial valve output (IVO) for each valve for the purge, repressurization, and blowdown control loops
- is continuously adjusted to compensate for differences in calibration and process changes
- The valves in each series are compared with each other. When one of them differs from the average by more than a set value, a valve calibration error is generated
- There is no switchover action taken for a valve calibration alarm

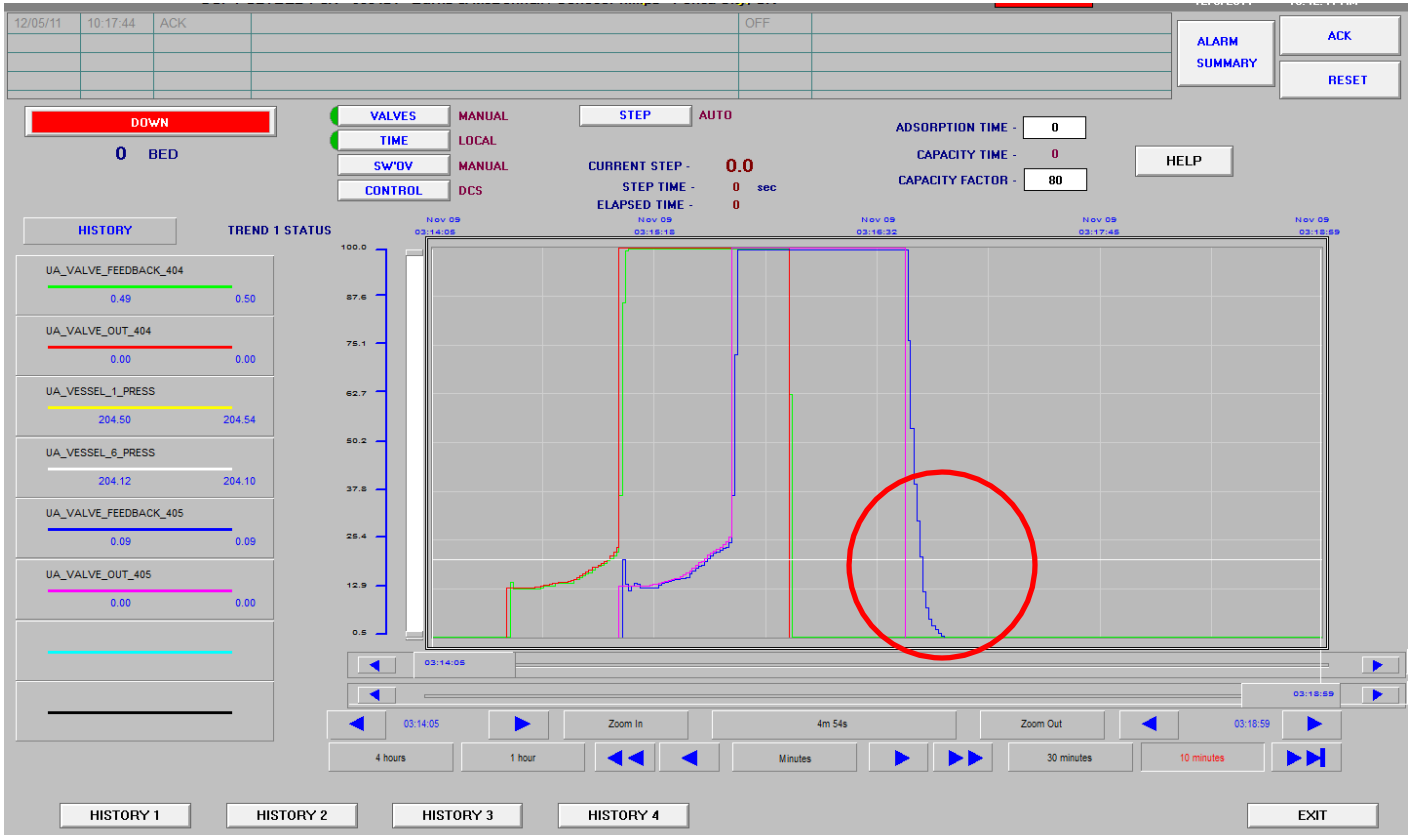
VALVE CALIBRATION ERROR ALARM EXAMPLE



ALARMS AND SHUTDOWNS: VALVE FEEDBACK MISMATCH ALARM

- All positioned valves have feedback sensor which monitor the position of the valve.
- If the feedback status does not agree with the commanded position of the valve a feedback alarm is generated.
- No switchover action is taken based on a feedback mismatch alarm, when a valve is being commanded to Open

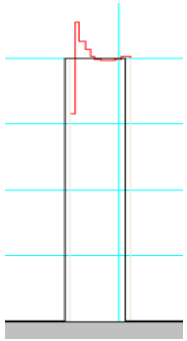
VALVE FEEDBACK MISMATCH ALARM



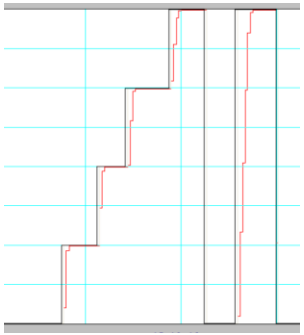
VALVE FEEDBACK MISMATCH CAUSES

Overshoot

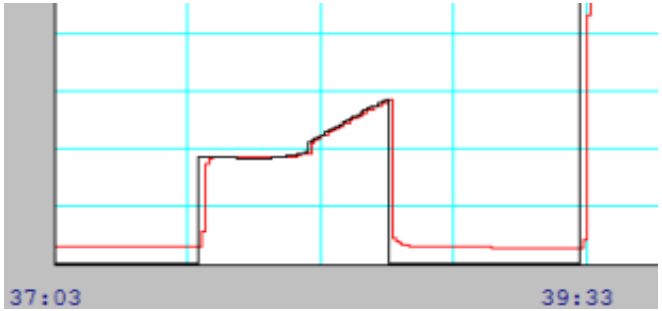
- Valve Booster
- Recalibration



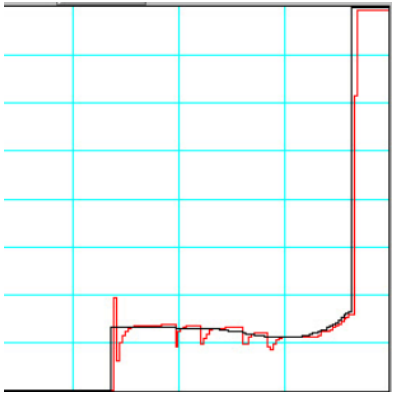
Ramping or Positioner Gain



Incorrect zero / full span



Hunting



ALARMS AND SHUTDOWNS: VALVE FAILURE ALARM

- There is a routine in the PLC which monitors each control loop for deviations
- If the control loop monitoring shows the vessel pressure to be following its setpoint, the valve is assumed to be functioning properly
- If there is a feedback mismatch alarm for a valve, and a pressure monitoring error for that vessel, a valve failure alarm is generated
- An automatic switchover request is generated for a valve failure alarm

ALARMS AND SHUTDOWNS: TRANSMITTER FAILURE ALARM

- If the raw input from a pressure or temperature transmitter is 0, a transmitter failure alarm is generated
- If the failed transmitter is one of the adsorber vessel transmitters, an automatic switchover request is generated

ALARMS AND SHUTDOWNS: PROCESS UPSETS

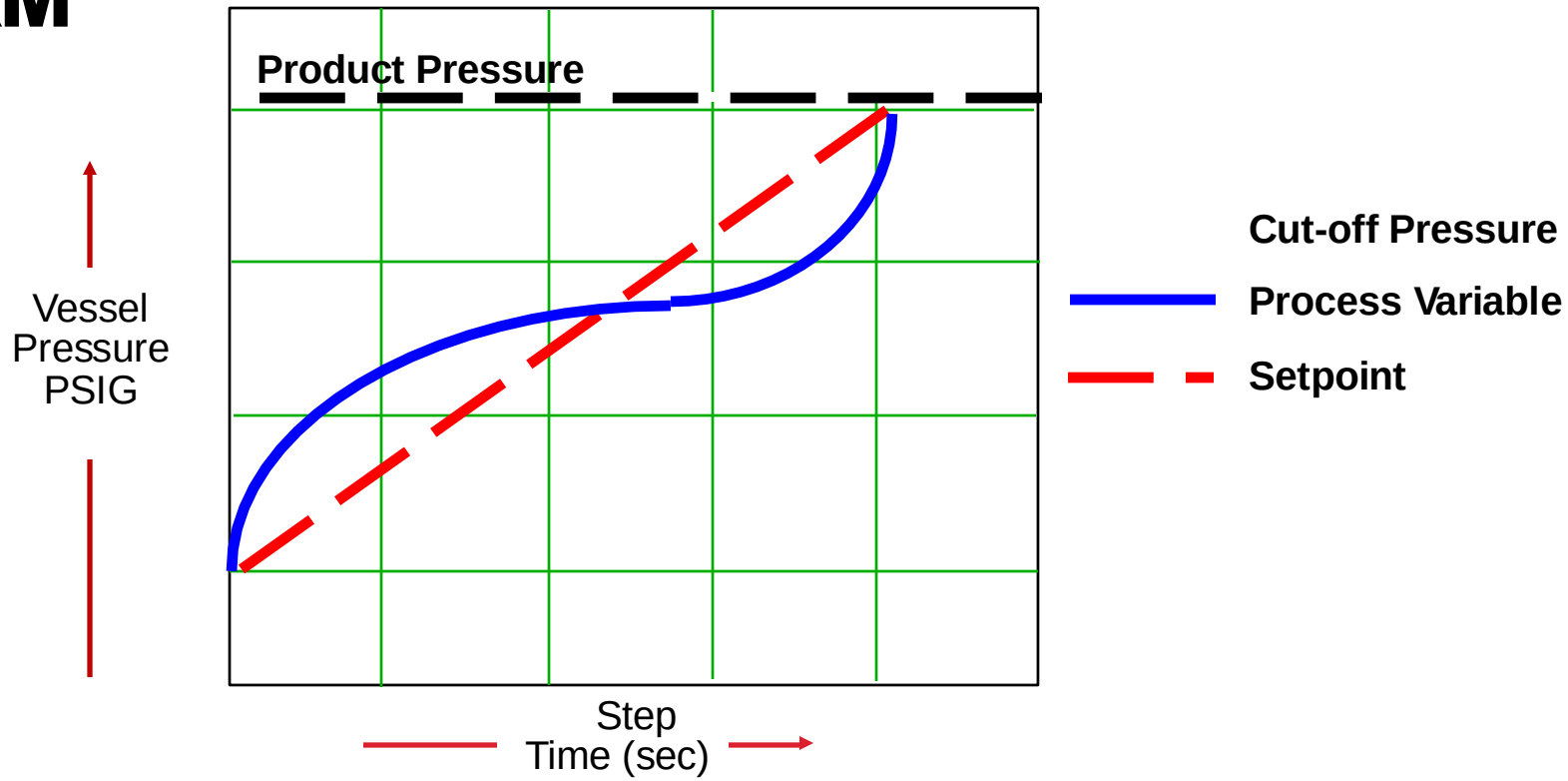
Process Upsets

- Pressure Deviation Repressurization
- Pressure Deviation Purge
- Pressure Deviation Blowdown
- Extended Repressurization
- Extended Purge
- Extended Blowdown
- Long Adsorption Time

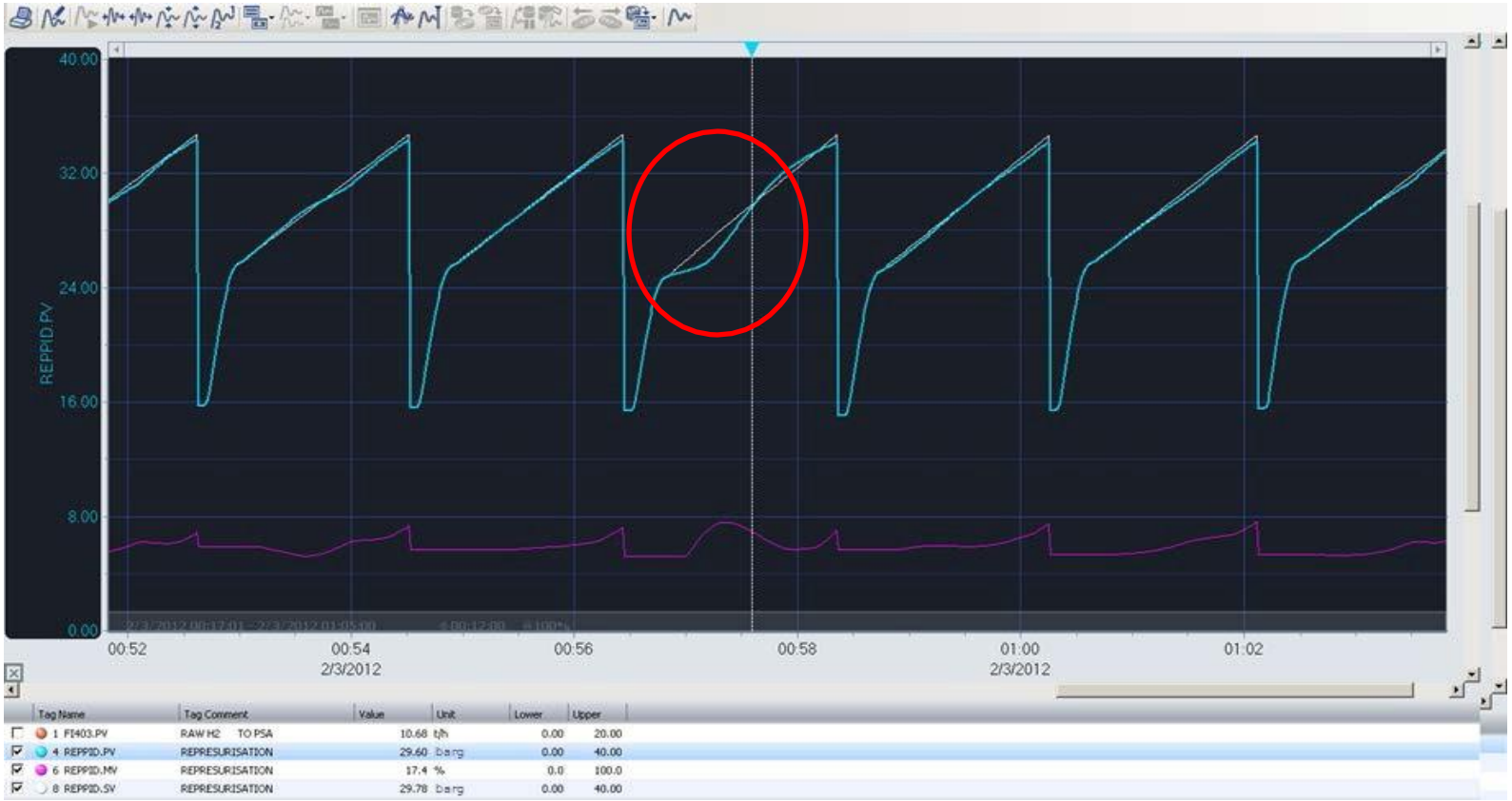
ALARMS AND SHUTDOWNS: PRESSURE DEVIATION ALARMS

- Used for provide purge, repressurization and blowdown
- When the vessel pressure deviates from the setpoint by more than 15 PSIG (Provide purge, Repressurization) or 5 PSIG (Blowdown)
  - Typical values
- This alarm is common during startup, after a switchover, or when rapidly changing the adsorption time
- A switchover is not caused by a Pressure Deviation Step Alarm

ALARMS AND SHUTDOWNS: REPRESSURIZATION PRESSURE DEVIATION ALARM



PRESSURE DEVIATION ALARM EXAMPLE



ALARMS AND SHUTDOWNS: EXTENDED STEP

Repressurization

- When the pressure of the vessel on repressurization is within 5 PSIG the product pressure, the step advances

Provide Purge

- When the pressure of the vessel providing purge is within 10 PSIG of the cutoff, the step advances

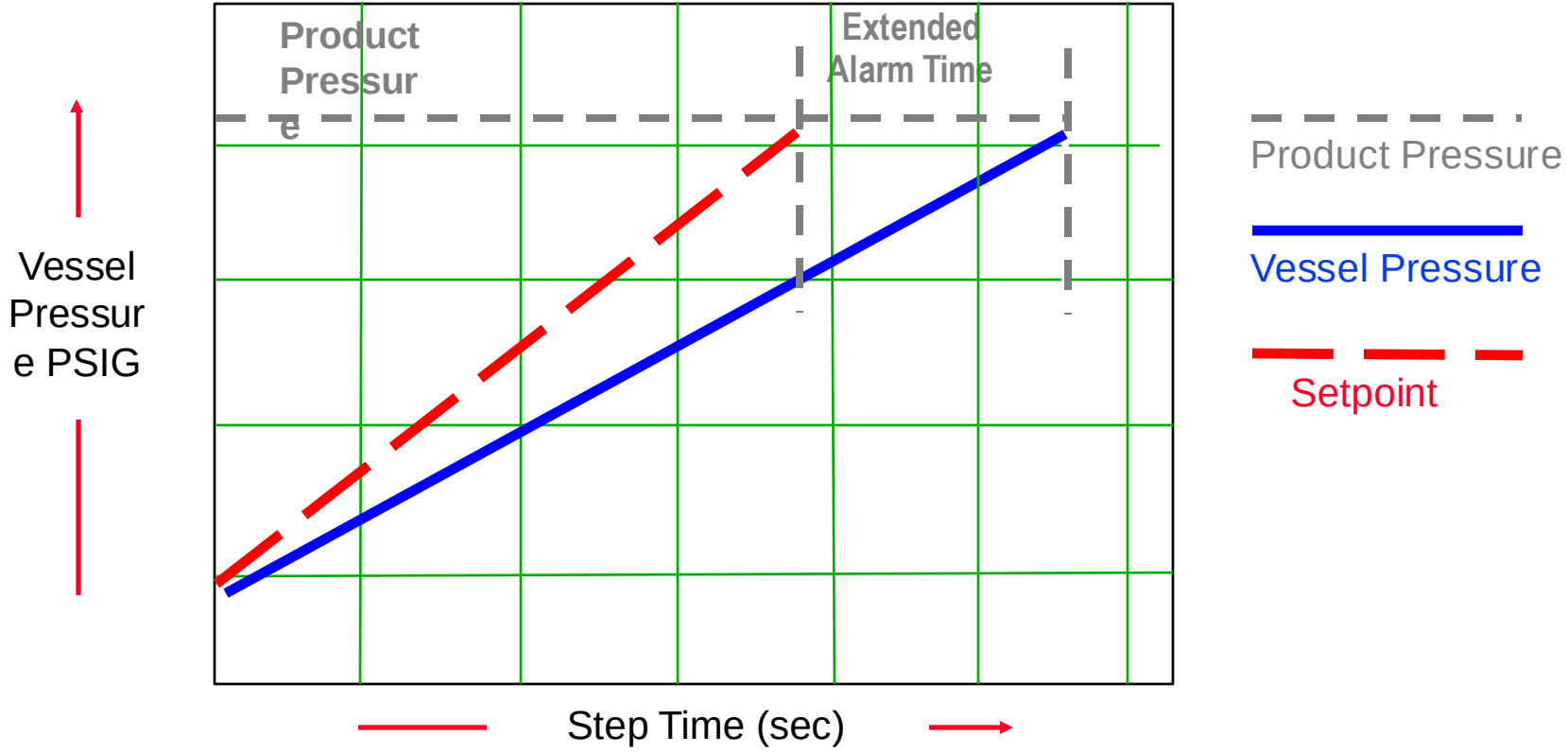
Blowdown

- When the pressure of the vessel blowing down is within 10 PSIG of the surge tank pressure, the step advances

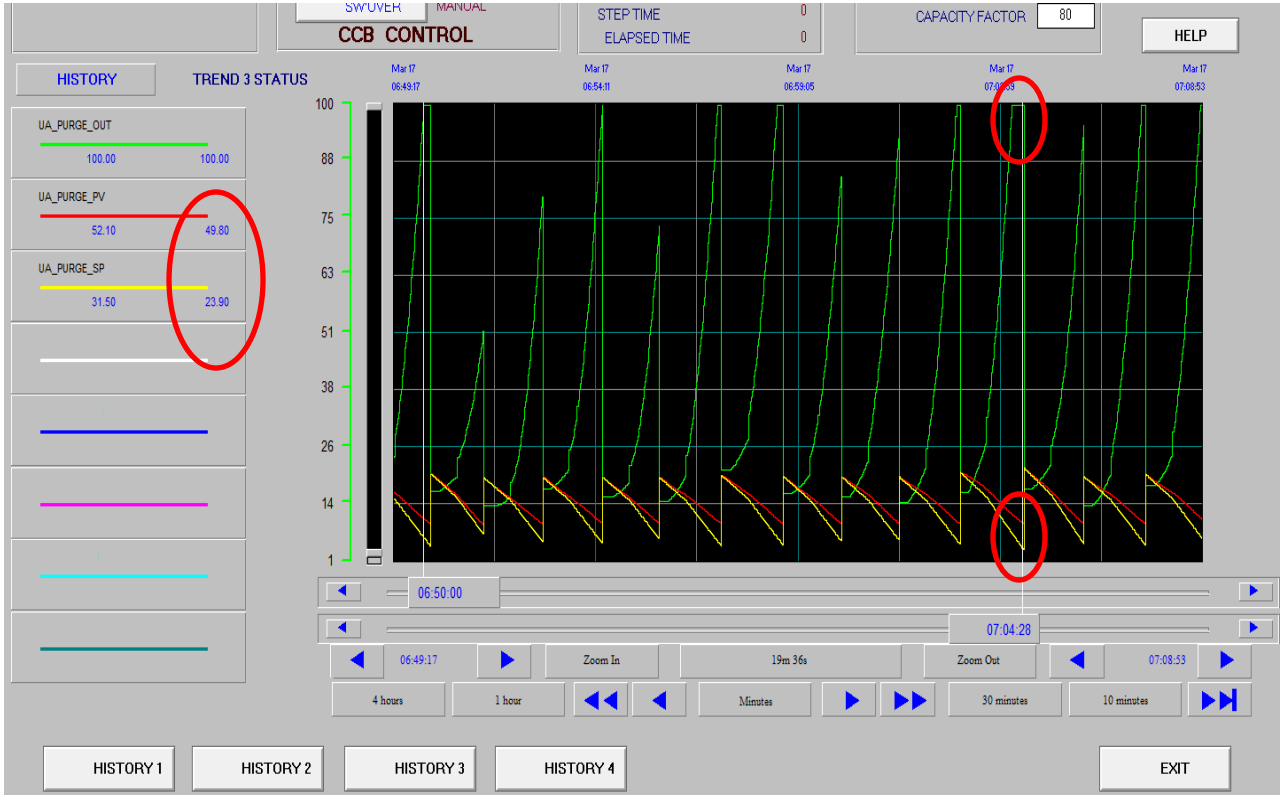
ALARMS AND SHUTDOWNS: EXTENDED STEP

- The step will extend to meet these criteria, and the cycle will remain in that step until the condition is satisfied
- If the step doesn't advance, an extended step alarm will be generated after 15 seconds
- **If in Automatic Switchover** – PSA will **automatically** switchover to alternate cycle at first switchable step
- **If in Manual Switchover** – the operator must **manually** switchover affected vessels, otherwise PSA will shutdown on Long Adsorption (Cycle) time

ALARMS AND SHUTDOWNS: EXTENDED REPRESSURIZATION ALARM



ALARMS AND SHUTDOWNS: EXTENDED PURGE EXAMPLE



ALARMS AND SHUTDOWNS: LONG ADSORPTION (CYCLE) TIME

- When a vessel remains in the adsorption step longer than the set time, it is possible to permanently damage the adsorbent
- A Long Adsorption Time alarm is generated when a vessel has been on the adsorption step for **120%** of the set adsorption time
- A Long Adsorption Time shutdown is generated when the vessel has been on the adsorption step for **150% to 200%** of the set adsorption time
- It is important to note that the cause of the Long Adsorption Time alarm is not the vessel on adsorption

RELIABILITY AND MAINTENANCE: TOPICS

Reliability and Maintenance

- PSA Unit Periodic Maintenance & Inspection
- Adsorber Vessel Maintenance
- PSA Control Valve Preventive Maintenance
- PSA Control Valve Service Centers & Potential Upgrades

RELIABILITY AND MAINTENANCE: TOPICS

Why preventive maintenance is important:

- Helps avoid unscheduled shutdowns between turnarounds
- Improves performance and reliability
- Keep operators focused on what's critical for good unit performance

PSA PERIODIC INSPECTION

Check every shift:

- Physical damage of Unit
- Signs of H2O in instruments and/or lines
- Feed and Vessel drains for liquids

Check every week:

- Valves for packing leaks (Do Not Overtighten!)

Check every month:

- Signs of corrosion
- Flange leaks
- Air filters
- Consistent readings between control system transmitter and local gauges
- Consistent readings between valve position and signal

PSA PERIODIC INSPECTION

Maintenance required every 2 to 3 years:

- Replace control valve soft goods, shaft bearings, packing and actuator spring
- Calibrate positioners, transmitters and switches
- Bench test all safety valves
- Check downstream piping, process tubing, Tail Gas Drum & Product Filter for signs of adsorbent carryover
- Check instrument air and process tubing for leaks; blow out any debris in these lines
- Touch-up skid structural base to limit corrosion
- Replace worn and exposed insulation
- Check electrical cables for wear and/or damage

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PSA ADSORBER VESSEL MAINTENANCE

Why Maintenance of PSA Adsorbers is necessary:

- PSA Adsorbers are in cyclic service
  - Typical pressure swing:
    - 375 psig → 5 psig→ 375 psig… every couple of minutes
- Effects of fatigue can cause crack initiation and growth

PSA ADSORBER VESSEL MAINTENANCE

What can cause crack initiation and growth?

- High localized stresses
- Material hardness exceeding 200 Brinell
- Weld or parent plate imperfections
- Vessel out-of-roundness
- Damage caused by misuse

PSA ADSORBER VESSEL MAINTENANCE

Primary Goals of an Inspection Program

- To assure that vessels are acceptable for continued operation
- To find cracks while they are small enough to easily repair, and to avoid unscheduled shutdowns

PSA ADSORBER VESSEL MAINTENANCE

What to Inspect

- Shells and heads for corrosion
- Weld surfaces and the weld heat affected zone (HAZ) are the most critical areas
- Longitudinal seams are most susceptible to cracks
- Cracks are more likely to initiate on the internal surfaces
- Peaking, or out-of-roundness of shell courses can significantly increase crack growth rates

While issues are more likely to be seen in older vessels, all vessels can develop these issues, so it is important to have an inspection plan in place from the start of operation.

PSA ADSORBER VESSEL MAINTENANCE

Establish an Inspection Interval

- Every two to three years is the recommended inspection period

Establish Inspection Methods

- Use external ultrasonic testing on randomly chosen vessels as a screening mechanism
- During reloads, enter the vessel and perform magnetic particle testing

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Reliability and Maintenance

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PSA CONTROL VALVE PREVENTIVE MAINTENANCE

Why preventive maintenance is important:

- PSA Control Valves experience severe service conditions:
  - High-pressure cyclic service
  - High reliability required:
    - Fast stroke speeds
    - Tight shutoff requirements

PSA CONTROL VALVE MAINTENANCE

Examples of typical PSA Control Valve issues:

- Seat or stem leaks
- Proximity switch out of adjustment
- Positioner issues:
  - “Sticking” block and spool
  - Diagnostic error messages
- Actuator spring failures
- Limit stops out of adjustment
- Valve shaft failures

SYMPTOMS: Varying stroke speeds and Unit inefficiencies

PSA CONTROL VALVE MAINTENANCE

Good Plant Maintenance Practices

- Training maintenance personnel on adjustments of positioners, proximity switches, and limit stops is the key to best PSA service
- Use proper “original equipment” parts
- Ensure integrity of air and other supplies; maintain upstream air filters
- Record control valve issues to detect trends in the data
- Utilize support services available from UOP or directly from the control valve manufacturers

PSA CONTROL VALVE MAINTENANCE

Control Valve Rebuilds

- Every 2 to 3 years, as a part of a regularly scheduled turnaround, it is recommended that a Qualified Service Center rebuild each control valve:
  - Replace soft goods (seats, packing, gaskets)
  - Replace shaft bearings
  - Adjust proximity switches
  - Adjust limit stops
  - Calibrate positioners
  - Perform valve seat leak test
  - Ensure all replacement parts are the latest technology
- Make sure to inform Service Center that they'll be working on a PSA valve

PSA CONTROL VALVE MAINTENANCE

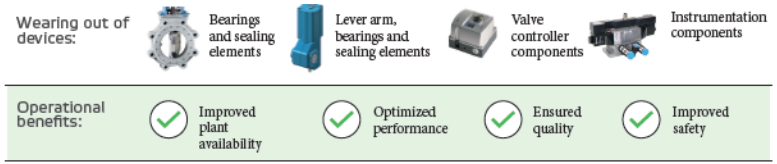
Valmet

Jamesbury™ valve maintenance recommendations for PSA units

Components	Elements	Recommended maintenance 3 years / 750,000 cycles	Recommended maintenance 6 years / 1,500,000 cycles
Valve	Disc	Check *	Check *
	Shaft	Check *	Check *
	High cycle spare parts set (includes bearings, seat and seals)	Replace	Replace
	Torsion spring	Replace	Replace
	No play coupling bolts and nuts	Replace	Replace
Actuator	Lever arm	Check *	Replace
	High cycle spare parts set	Replace	Replace
	Spring assembly	Check *	Replace after 4,500 kcycles
	Cylinder	Check *	Check *
Valve controller, Neles™ ND9000™	Complete device	Download and analyse diagnostics Calibration and reset counters	Download and analyse diagnostics Calibration and reset counters Replace after 4,500 kcycles
	Spool valve	Replace	Replace
	Prestage	No action	Check *
	Position feedbacksystem (linear valves)	Replace	Replace
Valve controller, NDX™	Complete device	Download and analyse diagnostics	Download and analyse diagnostics
		Calibration and reset counters	Calibration and reset counters
	Prestage bottom filter	Replace	Replace
	Silencers	Replace	Replace
	Pneumatic set	No actions	Replace
Limit switch	Complete device	Check *	Check *
Solenoid valve	Complete device	Check *	Replace
Booster / quick exhaust valve	Complete device	Check *	Replace
Air filter	Complete device	Replace	Replace

During maintenance Valmet technicians check parts that are not mentioned here and replace damaged parts if possible. Valmet technicians also make recommendations for future inspection and maintenance. Device condition monitoring helps determine whether a particular valve needs attention.

* Replace if needed



PSA CONTROL VALVE MAINTENANCE

Results of Valve Servicing

- Reset valves to “as-new” condition
- Significantly improves overall PSA Unit performance
- Valve warranty extension of 2 years after the initial 3 year period
- UOP can package valve servicing with a PSA “tune-up”

RELIABILITY AND MAINTENANCE: TOPICS

Reliability and Maintenance

- PSA Unit Periodic Maintenance & Inspection
- Adsorber Vessel Maintenance
- PSA Control Valve Preventive Maintenance
- PSA Control Valve Service Centers & Potential Upgrades

POTENTIAL PSA CONTROL VALVE UPGRADES

Control Valve Packing Replacement

- Flowserve Globe Valves
- Valmet or Flowserve Butterfly Valves

General valve component upgrades

- Implementation of new technologies

MARK ONE GLOBE VALVES

Packing Options:

- Twin Safeguard Fugitive Emissions Packing (UOP Std.)
  - Retrofit kit available
  - Live-loaded design

Twin Sureguard Packing

- Retrofit kit available
- Live-loaded combination of carbon-filled and virgin Teflon V-rings
- Minimizes packing wear, reducing scheduled maintenance

Twin PTFE Packing (V-rings)

VALDISK HIGH-PERFORMANCE BUTTERFLY VALVE

Packing Options:

- TFM V-Rings (UOP Std.)
- Live-Loaded Packing (UOP Std.)
- Double Packed Live-Loaded Packing (Optional)
- Monitoring port (Optional)

VALDISK HIGH-PERFORMANCE BUTTERFLY VALVE

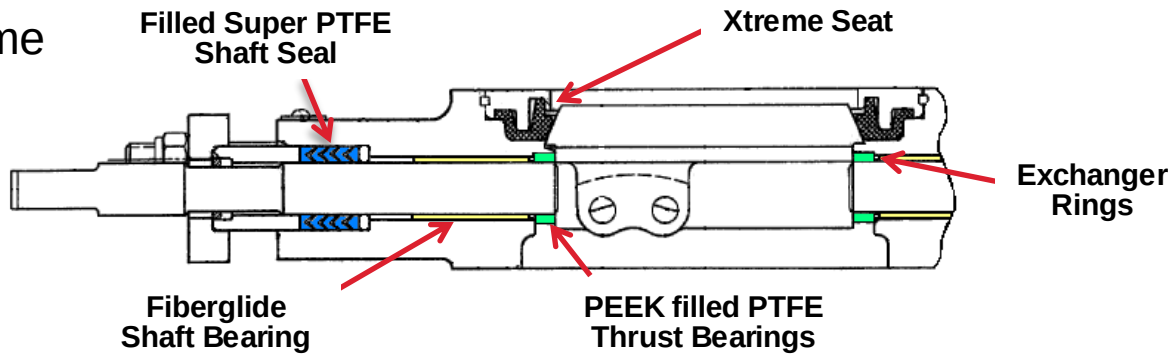
Latest UOP Supply (potential upgrades for older units):

- New UHMWPE Seat Design
  - Higher cycle life
- High cycle shaft bearings
  - MBT (Metal Backed Teflon) with Nitronic 60 Backing
- Inconel 718 Shaft
  - Standard diameter
- Duplex pins
  - Peened in place
- Valtek VR High Cycle Actuator
  - Modulating valves

VALMET HIGH PERFORMANCE BUTTERFLY VALVE

Latest UOP Supply (potential upgrades for older units):

- High cycle bearing and seal upgrade
  - Fiberglide bearings and excluder rings
  - Filled “super PTFE” shaft seals
  - PEEK filled PTFE thrust bearings
- Shaft material upgrade – Inconel
- Improved seat material – Xtreme



THANK YOU

Honeywell
UOP

CONTACT FOR SPECIFIC UNIT PROBLEMS

PLEASE CONTACT

James Tuckowski
James Radtke

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IF YOU EXPERIENCE PSA EMERGENCY AFTER NORMAL OPERATING HOURS PLEASE CALL PSA 24-HOUR HOTLINE +1 847 375 7666.