3-PHASE SEPARATION TROUBLESHOOTING MODULE
INSTRUCTOR LESSON PLAN

Overview

The purpose of gas-oil-water separation (3-phase separation) is to receive flow from drill sites or well pads and separate the gas and water from these streams, yielding a processed oil product typically containing no more than 0.35% basic sediment and water (BS&W).

Competency	**Performance Standards**
Troubleshoot problems with 3-phase separation systems	Performance will be satisfactory when: ☐ Learner recognizes the problem and captures the problem in written form. ☐ Learner evaluates HSE risks involved with continued operation. ☐ Learner recognizes when the HSE hazard/s warrants shutting down equipment. ☐ Learner collects and analyzes data associated with the problem. ☐ Learner rewords problem based on initial observations and reasoning. ☐ Learner identifies possible causes of the problem. ☐ Learner selects most probable cause of the problem, one that explains every observation. ☐ Learner proposes corrective action that is rational and eliminates true cause (when possible). ☐ Learner accurately and completely documents problem and corrective action(s). ☐ Process equipment is stabilized (if simulator-based problem). ☐ System is returned to within $\pm$ 5% of design parameters (if simulator-based problem).
	Conditions: Given a paper-based (P&ID) and/or simulator-based problem, competence will be demonstrated by the completion of troubleshooting steps and subsequent documentation.

Learning Objectives

1. Recall the purpose, applications, and types of 3-phase separators.
2. Recall potential problems associated with 3-phase separators.
3. Describe immediate actions a process technician could take to solve 3-phase separator problems.
4. Explain the relationship between variables for a specific process under normal operating conditions.
5. Given normal and abnormal operating conditions for a specific process:
   - Recognize the problem.
   - Collect and analyze data associated with the problem.
   - Define the problem.
   - Identify possible causes and the most probable cause of the problem.
   - Evaluate the effect of investigative, compensating and corrective actions.
   - Select an appropriate corrective action.
   - Document the problem and corrective action.

Learning Activities

Time Frame	Learning Activity	Teaching Activity	Instructional Materials	Supplies and Equipment	Notes
	PREVIEW learning objectives and performance standards for this competency.		Learning Plan		
	READ information provided in the Introduction section.		Learning Plan		
	LISTEN to the lecture on the purpose and applications of 3-phase separator systems as well as problems associated with 3-phase separator systems (if provided).	Deliver a brief presentation on 3-phase separator systems and associated problems.	Lecture Equipment	Lecture Equipment	Address first two learning objectives.
	REVIEW the process flow, product specifications, equipment specifications, normal operating conditions, and normal design conditions sections for the specified process.	Choose a specific problem/s for learners to solve. Lead discussion of process to assure learners understand all aspects.	Process Description	Process Description	
	COMPLETE the Self-Check Questions worksheet.	Introduce activity. Review worksheet with learners after completion.	Self-Check Questions worksheet	Self-Check Questions worksheet	Reinforce learning objectives 1, 2, and 4.
	BRAINSTORM immediate actions a process technician could take to solve 3-phase separator system problems with a small group of your peers.	Divide learners into groups of 3 to 4. Introduce activity.			
	COMPARE your list of immediate actions for solving 3-phase separator system problems to another group's work.	Write all actions on board or flipchart.	Board or Flipchart		
	LISTEN to instructor expand on actions a process technician could take to solve 3-phase separator system problems.	Lecture on actions not captured and expand on those listed.	Lecture Equipment	Lecture Equipment	Address the third learning objective.

	SOLVE at least one paper-based 3-phase separator system problem including the completion of the Abnormal Operating Conditions table and Troubleshooting Form.	Choose a specific problem/s for learners to solve. Guide learners as needed during the activity. Do a quick de-brief after activity.	Problem Packet	Problem Packet	Information for three Scenarios has been provided for students. Address learning objective 5.
	OBSERVE a normal and/or abnormal condition on the simulator associated with a 3-phase separator system (if simulator is available).	Set up simulation. Guide learners as needed during the activity.	Simulator	Simulator	
	SOLVE at least one simulator-based 3-phase separator system problem including the completion of the Troubleshooting Form (if simulator is available).	Create a problem/s for learners to solve. Program fault for simulator-based problem. Guide learners as needed during the activity. Do a quick de-brief after activity.	Troubleshooting Form	Simulator	One of the Scenarios may be paper and/or simulator-based. Address learning objective 5.

3-PHASE SEPARATOR TROUBLESHOOTING MODULE
PROCESS DESCRIPTION

Introduction

The purpose of gas-oil-water separation (3-phase separation) is to receive flow from drill sites or well pads and separate the gas and water from these streams, yielding a processed oil product typically containing no more than 0.35% basic sediment and water (BS&W).

System Safety

As a process technician working around the oil-gas modules, complying with all established safety procedures, permits, and policies is critical. These systems were put in place to ensure the safety of all the area operators, while maintaining the efficiency and integrity of the area equipment.

Beware of poisonous hydrogen sulfide (H_2S) in the process modules, and always wear personal H_2S monitor where required. H_2S detectors are strategically located around the FS-2 to notify personnel of hazardous concentrations. H_2S can deaden your sense of smell soon after coming in contact with it. Never remain in an area with excessive levels without proper respiratory equipment. Be on the lookout for H_2S when working around open drain sumps.

The crude oil and gas separated in the oil-gas modules are flammable and explosive. Combustible gas detectors are located throughout the oil-gas modules to monitor the atmosphere in the modules, and make sure they are well below the explosive limits. The gas detectors are part of the Fire and Gas Safety System. There are also temperature probes and smoke detectors strategically located in critical areas to provide early detection of fires. Fire and gas control panels in the control rooms receive signals from the monitoring instrumentation, and issue alarms and activate Halon releases in response to hazardous conditions. Always respond properly to all alarms when working in the process modules.

Process Description

The gas-oil separation process separates gas from crude oil in a 4- step separation process. The oil is sent to storage, and the recovered gas is recompressed in a 4-stage centrifugal compressor, and sent to treating. The gas can be used for injection back into the formation, or be made available for artificial lift, or for the production of NGL.

Crude oil is produced from the wells in the first-stage separator. The gas leaving the first stage separator blends with the 4th stage compressor effluent, and is sent to treating.

The oil/water leaves the first-stage separator and enters the second-stage separator. The gas leaving the second stage separator blends with the gas from the 2nd stage compressor is cooled and sent to a knock-out drum before it is compressed in the 3rd stage compressor. The gas from the 3rd stage compressor is cooled and sent to a knockout drum before being compressed in the 4th stage compressor.

The oil/water leaving the second-stage separator blends with the liquid from the 3rd/4th stage suction/knockout drums and flows into the third-stage separator. The gas leaving the third stage separator blends with the gas from the 1st stage compressor and is cooled and sent to a knockout drum before being compressed in the 2nd stage compressor.

The oil/water leaving the third stage separator flows through a crude oil cooler; this maintains the temperature of the oil entering the fourth stage separator. The cooled oil/water enters the fourth-stage separator, where the components are separated and then sent on to storage. The quality of the oil to storage is maintained by controlling the fourth stage separator pressure. The gas leaving the fourth stage separator goes to the 1st stage knockout drum before being compressed in the 1st stage compressor.

Instrumentation

Crude oil is produced from the wells in the first-stage separator, D-101, at 1610 PSIG and 170°F. The gas leaving the separator is about 225 million standard cubic feet per day. The oil leaves the first-stage separator by level control, LIC-101, and enters the second-stage separator, D-201, at ~330 PSIG and 150°F. The gas leaving the separator is about 60 million standard cubic feet per day.

The oil/water leaves the second-stage separator, by level control, LIC-201, and flows into the third-stage separator, D-301, flashing down to a pressure of 55 PSIG and a temperature of about ~127°F. The gas leaving the separator is about 20 million standard cubic feet per day.

The oil/water leaves the third-stage separator under level control, LIC-301, and flows through crude oil cooler, E-402, which maintains the temperature of the oil at l00°F by controller TIC-401. The cooled oil enters the fourth-stage separator, D-401, flashing down to a pressure of 8.5 PSIG. The fourth stage separator first removes the water by LIC-403, and then the oil is sent to storage by LIC-401. The flow rate of oil to storage is measured by FI-402. The quality of the oil to storage is maintained by controlling the temperature, TIC-401, and pressure, PIC-402, on the fourth-stage separator.

The gas coming from the fourth stage separator, D-401, about 6 million standard cubic feet per day is scrubbed in the 1st stage knockout drum, D-402, to knock out any liquids that might be entrained in the gas, before it goes to the first-stage compressor which compresses the gas from 8.5 PSIG up to 75 PSIG, raising the temperature from 100°F to 234°F. Anti-surge controller, FIC-401, controls a spillback to the compressor suction, which is cooled in E-401 by TIC-402. Gas leaves the first-stage compressor and passes through a pressure controller, PIC-402, which maintains the pressure of the first stage suction of the compressor. The set point on this controller is used to vary the vapor pressure of the oil going to storage.

After the gas goes through the control valve PIC-402, it is blended with the gas coming from the 3rd-stage separator, about 21 million standard cubic feet per day. The gas is cooled to 75°F in E-301 controlled by TIC-302, and enters the 2nd stage knock-out drum D-302 before entering the 2nd stage compressor, which compresses the gas from 54 PSIG to 503 PSIG, raising the temperature to 304° F. Anti-surge controller FIC-301, controls a spillback to the compressor suction. Gas leaves the 2nd stage compressor and passes through a pressure controller, PIC-302, which controls the pressure of the third stage separator.

After the gas goes through the control valve PIC-302, the gas is blended with the gas coming from the second stage separator, about 60 million standard cubic feet per day. The gas is cooled to 75°F in E-201 controlled by TIC-202, and enters the 3rd Stage Knock-out drum D-202 before entering the 3rd stage compressor, which compresses the gas from 330 PSIG to 870 PSIG, raising the temperature to 219°F. Anti-surge controller, FIC-201, controls a spillback from the 4th stage compressor discharge to the 3rd stage compressor suction. The liquid coming from the 4th stage knock out drum D-102 returns to D-202 knock out drum.

The gas leaving the 3rd stage compressor is then cooled to 75°F in E-201 controlled by TIC-102, and enters the 4th stage knock-out drum, D-102, before entering the 4th stage compressor, which compresses the gas from 850 PSIG to 1610 PSIG. The gas leaves the compressor and blends with the first stage separator gas, 225 million standard cubic feet per day, and passes through PIC-101, to gas treating.

The anti-surge control protection for the 1st, 2nd, and 3rd/4th stages is FIC-201, FIC-301 and FIC-401, which maintain a minimum inlet suction flow rate for each stage of the compressor. If the inlet flow rate falls below the minimum flow rate, the compressor may go into surge, depending upon the exact conditions of the inlet conditions.

The compressors are further protected by high level shutdowns in the four suction knock out drums, D-102, D-202, D-302 and D-402. If the level of any one of these drums exceeds 90%, the compressor will shut down.

Normal Operating Parameters

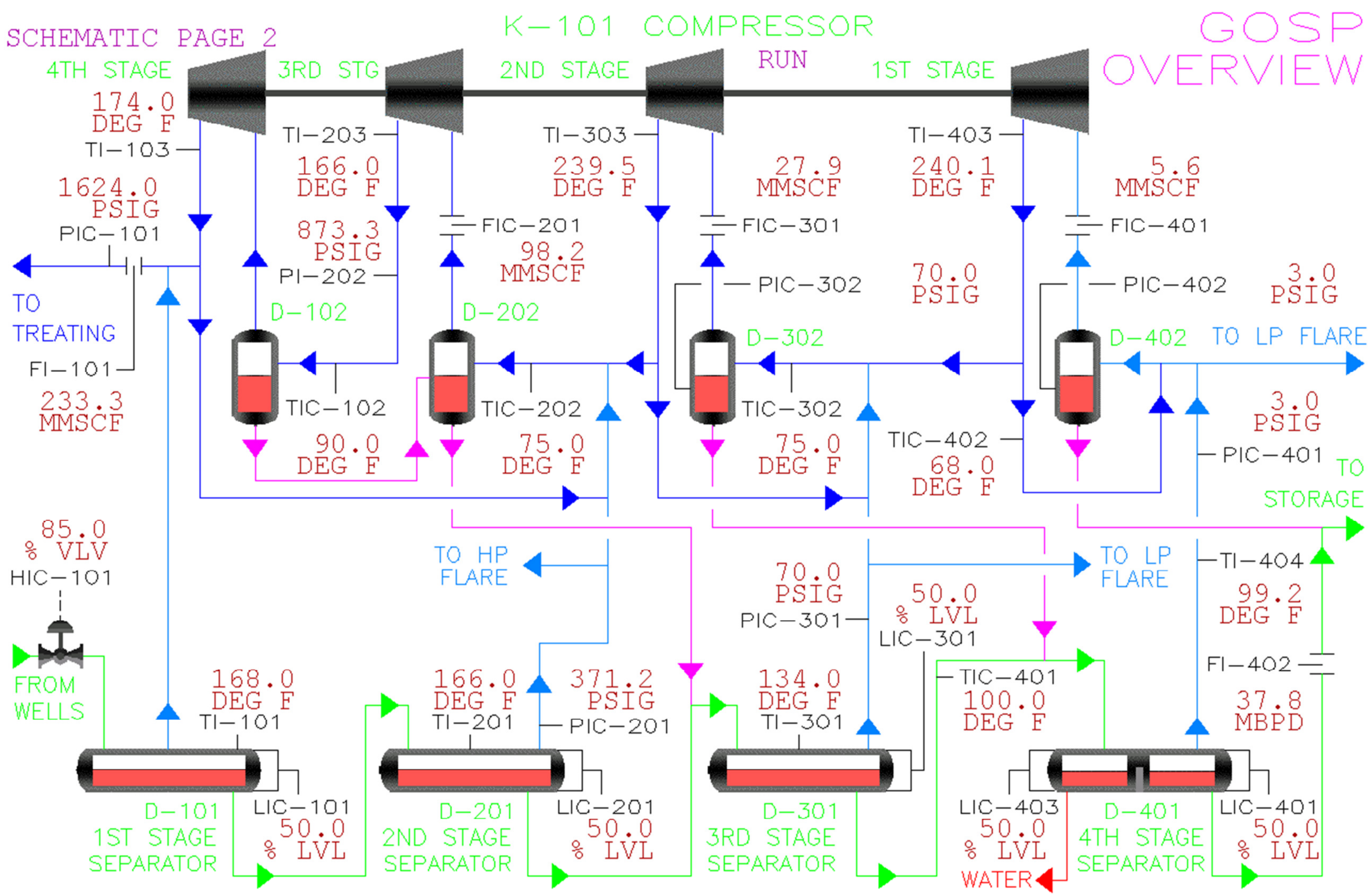


Figure 1. **Module Overview DCS Screen**

Courtesy of Simtronics Corporation

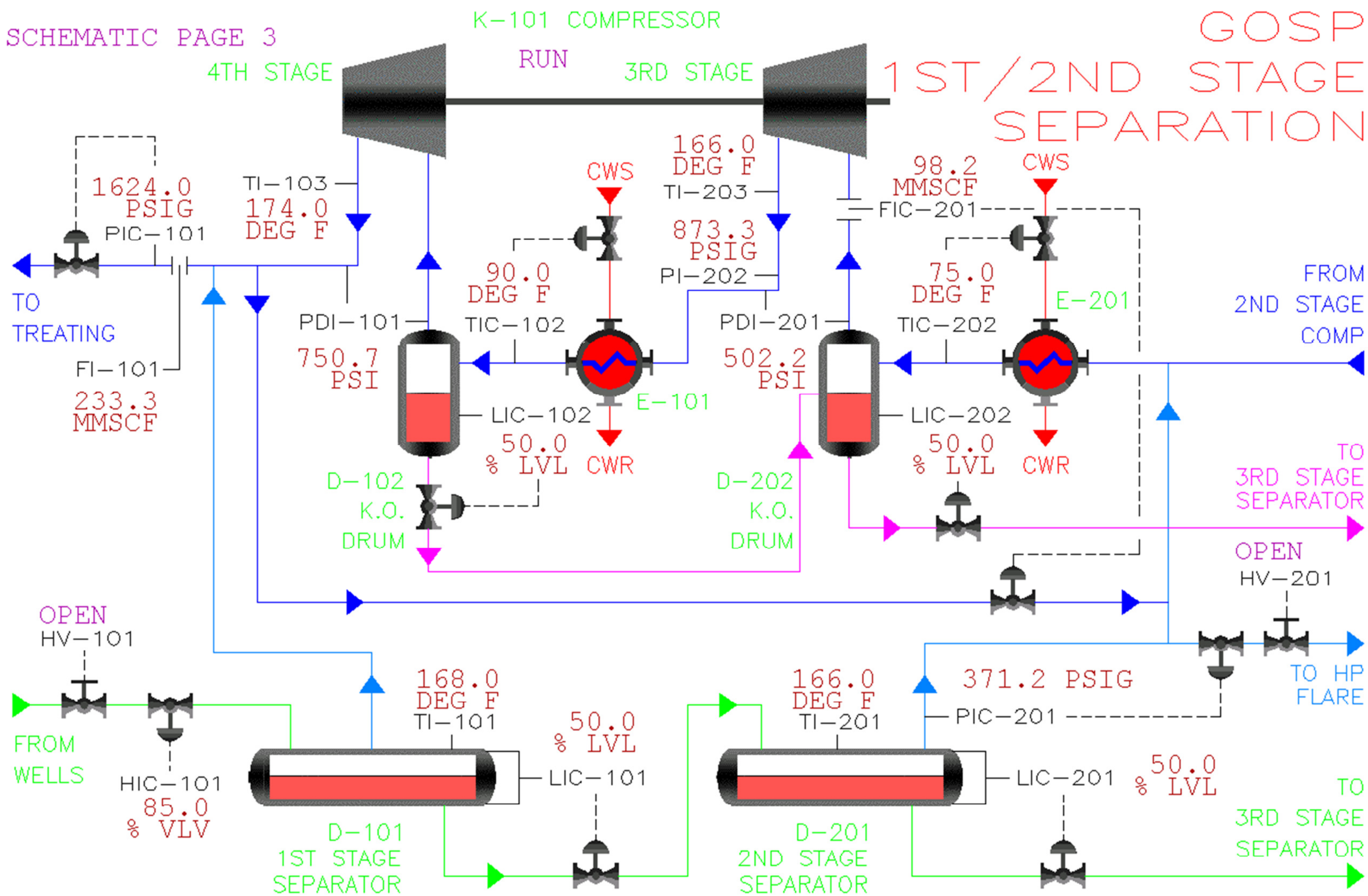


Figure 2. **1st and 2nd Stage Separation**

Courtesy of Simtronics Corporation

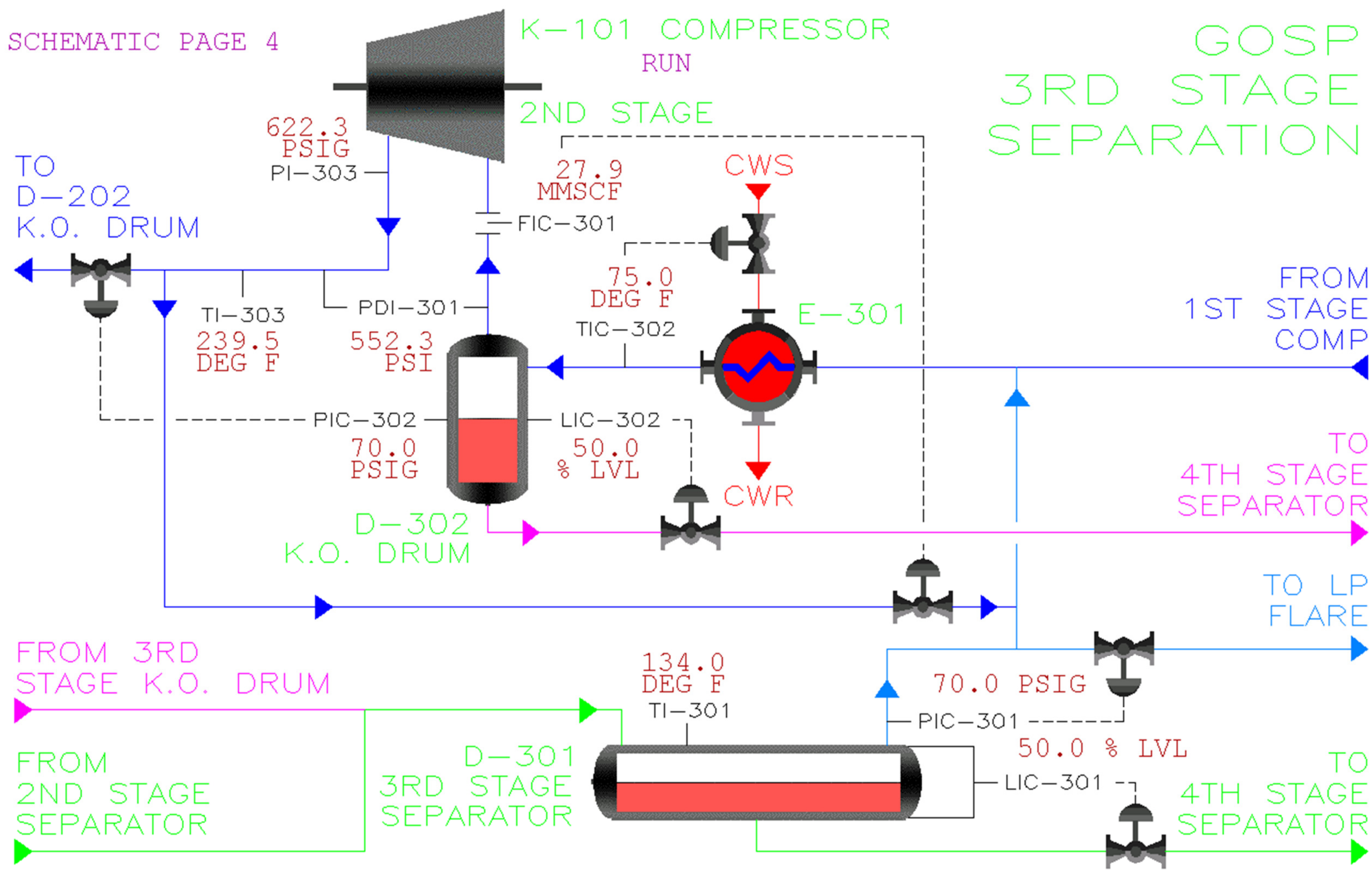


Figure 3. **3rd Stage Separation**

Courtesy of Simtronics Corporation

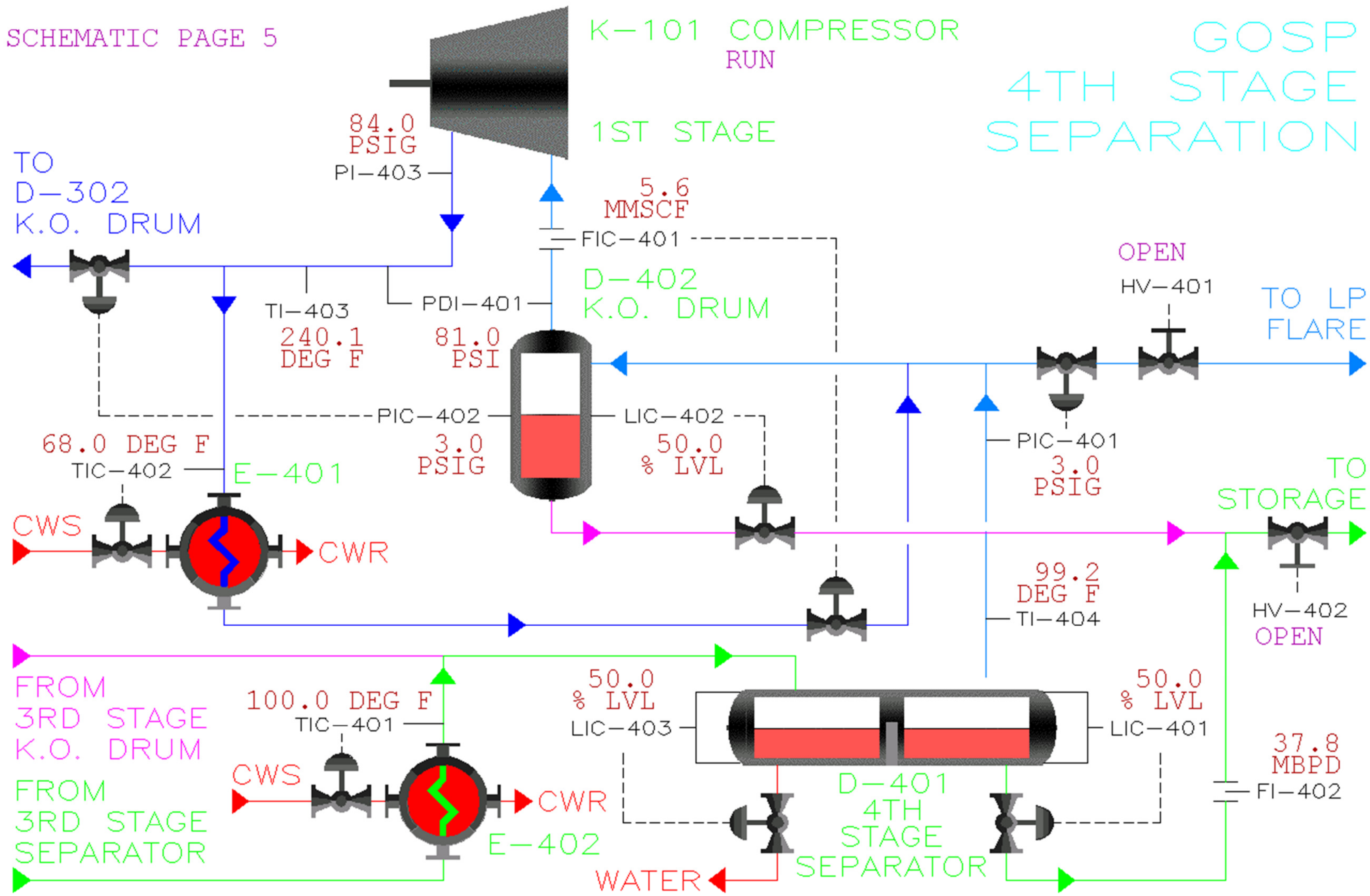


Figure 4. **4th Stage Separation**

Courtesy of Simtronics Corporation

Normal Design Conditions

The following table provides normal values and output percentages for instrumentation associated with the specified process during normal operating conditions.

Table 1. Normal Values and Output Percentages for Instrumentation at Normal Operating Conditions

Tag ID	Description	Normal Value	Eng. Units	Output Percent
FI-101	GAS TO TREATING	233.3	MMSCF	
FI-402	OIL TO STORAGE	37.8	MBPD	
FIC-201	3RD STG INLET	98.2	MMSCF	0
FIC-301	2ND STG INLET	27.9	MMSCF	0
FIC-401	1ST STG INLET	5.6	MMSCF	0
HIC-101	1ST STG INLET	85.0	% VLV	85
HV-201	2ND STG TO FLARE			OPEN
HV-100	OIL FROM WELLS			OPEN
HV-401	LP GAS TO FLARE			OPEN
HV-402	OIL TO STORAGE			OPEN
LIC-101	1ST STG SEPARATOR	50.0	% LVL	57.8
LIC-102	4TH STG KO DRUM	50.0	% LVL	26.2
LIC-201	2ND STG SEPARATOR	50.0	% LVL	42.5
LIC-202	3RD STG KO DRUM	50.0	% LVL	18.5
LIC-301	3RD STG SEPARATOR	50.0	% LVL	44
LIC-302	2ND STG KO DRUM	50.0	% LVL	13.6
LIC-401	4TH STG SEPARATOR	50.0	% LVL	41
LIC-402	1ST STG KO DRUM	50.0	% LVL	0.1
LIC-403	4TH STG WATER	50.0	% LVL	26.5
PDI-101	4TH STG COMPR	750.7	PSIG	
PDI-201	3RD STG COMPR	502.2	PSIG	
PDI-301	2ND STG COMPR	552.3	PSIG	
PDI-401	1ST STG COMPR	81	PSIG	
PI-202	3RD STG COMPR	873.3	PSIG	
PI-303	2ND STG COMPR	622.3	PSIG	
PI-403	1ST STG COMPR	84	PSIG	
PIC-101	1ST STG SEPARATOR	1624	PSIG	43.2
PIC-201	2ND STG SEPARATOR	371.2	PSIG	0
PIC-301	3RD STG SEPARATOR	70	PSIG	0
PIC-302	2ND STG SUCTION	70	PSIG	13
PIC-401	4TH STG SEPARATOR	3	PSIG	0
PIC-402	1ST STG SUCTION	3	PSIG	

Tag ID	Description	Normal Value	Eng. Units	Output Percent
TI-101	1ST STG SEPARATOR	168	DEG F	
TI-103	4TH STG COMPR	174	DEG F	
TI-201	2ND STG SEPARATOR	166	DEG F	
TI-203	3RD STG COMPR	166	DEG F	
TI-301	3RD STG SEPARATOR	134	DEG F	
TI-303	2ND STG COMPR	239.5	DEG F	
TI-403	1ST STG COMPR	240.1	DEG F	
TI-404	4TH STG SEPARATOR	99.2	DEG F	
TIC-102	4TH STG SUCTION	90	DEG F	4.2
TIC-202	3RD STG SUCTION	75	DEG F	37.1
TIC-302	2ND STG SUCTION	75	DEG F	25.4
TIC-401	PRODUCT COOLER	100	DEG F	10
TIC-402	1ST STG RECYCLE	68	DEG F	0

Operational Issues

Foaming

When pressure is reduced on certain types of crude oil, tiny bubbles of gas are encased in a thin film of oil when the gas comes out of solution. This may result in foam, or froth, being dispersed in the oil and creates what is known as *foaming* oil. In other types of crude oil, the viscosity and surface tension of the oil may mechanically lock gas in the oil and can cause an effect similar to foam. Oil foam is not stable or long-lasting unless a foaming agent is present in the oil.

Foaming greatly reduces the capacity of 3-phase separators because a much longer retention time is required to adequately separate a given quantity of foaming crude oil. Foaming crude oil cannot be measured accurately with positive-displacement meters or with conventional volumetric metering vessels. These problems, combined with the potential loss of oil or gas because of improper separation, emphasize the need for special equipment and procedures in handling foaming crude oil.

The main factors that assist in *breaking* foaming oil are:

- Settling
- Agitation (baffling)
- Heat
- Chemicals
- Centrifugal force

Paraffin

Paraffin deposition in 3-phase separators reduces their efficiency and may render them inoperable by partially filling the vessel and/or blocking the mist extractor and fluid passages. Paraffin can be effectively removed from separators by use of steam or solvents. However, the best solution is to prevent initial deposition in the vessel by heat or chemical treatment of the fluid upstream of the separator. Another deterrent, successful in most instances, involves the coating of all internal surfaces of the separator with a plastic for which paraffin has little or no affinity. The weight of the paraffin causes it to slough off of the coated surface before it builds up to a harmful thickness.

In general, paraffinic oils are not a problem when the operating temperature is above the cloud point (temperature at which paraffin crystals begin to form). The problems arise, however, during a shutdown, when the oil has a chance to cool. Paraffin comes out of solution and plates surfaces. When production is restored, the incoming fluid may not be able to flow to the plated areas to dissolve the paraffin. In addition, temperatures higher than the cloud point are required to dissolve the paraffin.

Solids and salt

If sand and other solids are continuously produced in appreciable quantities with well fluids, they should be removed before the fluids enter the pipelines. Salt may be removed by mixing water with the oil, and after the salt is dissolved, the water can be separated from the oil and drained from the system.

Vertical vessels are well suited for solids removal because of the small collection area. The vessel bottom can also be cone-shaped, with water jets to assist in the solids removal. In horizontal vessels, sand jets and suction nozzles are placed along the bottom of the vessel, typically every 5 to 8 ft. Inverted troughs may be placed on top of the suction nozzles as well to keep the nozzles from plugging. This type of system is sometimes difficult to use while the vessel is in operation because of the effect of the jetting and suction on separation and level control.

Corrosion

Produced well fluids can be very corrosive and cause early failure of equipment. The two most corrosive elements are hydrogen sulfide and carbon dioxide. These two gases may be present in the well fluids in quantities from a trace up to 40 to 50% of the gas by volume.

Level controls

Stable control of gas/oil interfaces is important for good separation.

Typically, the spacing between the different levels is at least 4 to 6 in. or a minimum of 10 to 20 seconds of retention time. The location of the lowest levels must also consider sand/solids settling. These levels are typically 6 to 12 in. from the vessel bottom. Minimum water/oil pad thicknesses are approximately 12 in. Note that these minimum settings may dominate the vessel sizing as opposed to the specified retention times.

3-PHASE SEPARATION TROUBLESHOOTING MODULE
SELF-CHECK QUESTIONS

Name: ____ Date: __________________________

Directions: Complete the following worksheet using the listed indicators. Indicate the INITIAL RESPONSE of the process variable to the condition listed:

Indicator

Initial Response of Process Variable

↑ Increases

↓ Decreases

--- remains constant

Initial Response of the Process Variable	Initial Process Variable Response to Following Process Events				
	FT-201 failure	TT-401 reads high	TIC-302 fails	Compressor PIC-101 fails low	K-101 fails low
FI-101 GAS TO TREATING	↑	---	---	↓	↑
FIC-201 3RD STG INLET	↓	↓	↑	↑	↓
FIC-301 2ND STG INLET	↑	↓	↑	↑	↓
FIC-401 1ST STG INLET	↑	↓	↑	↑	↓
LIC-101 1ST STG SEPARATOR	↓	---	---	↑	↓
LIC-102 4TH STG KO DRUM	↓	↓	↑	↓	↓
LIC-202 3RD STG KO DRUM	↓	↓	↑	↑	↑
LIC-301 3RD STG SEPARATOR	↑	↓	↑	↑	↑
PI-202 3RD STG COMPR	↑	---	---	↑	↓
PI-403 1ST STG COMPR	↑	↑	↑	↓	↓
PIC-101 1ST STG SEPARATOR	↓	---	---	↑	↓
PIC-201 2ND STG SEPARATOR	↑	---	↑	↑	↑
PIC-301 3RD STG SEPARATOR	↑	↓	↑	↑	↑
PIC-401 4TH STG SEPARATOR	↑	↓	↑	↑	↑
PIC-402 1ST STG SUCTION	↑	↓	---	---	
TI-303 2ND STG COMPR	↓	↑	↑	↓	↓
TIC-302 2ND STG SUCTION	↑	↓	↑	↑	↑
TIC-402 1ST STG RECYCLE	↑	↑	---	---	↑

3-PHASE SEPARATION TROUBLESHOOTING MODULE
SCENARIO #1 (PAPER-BASED)

Scenario Statement

Instrument technicians are working in all the separation and compression modules verifying control loop settings.

Troubleshoot this problem and complete the Troubleshooting Form.

Abnormal Operating Conditions

Scenario #1 DCS Screens Abnormal Operating Conditions at 2 Minutes

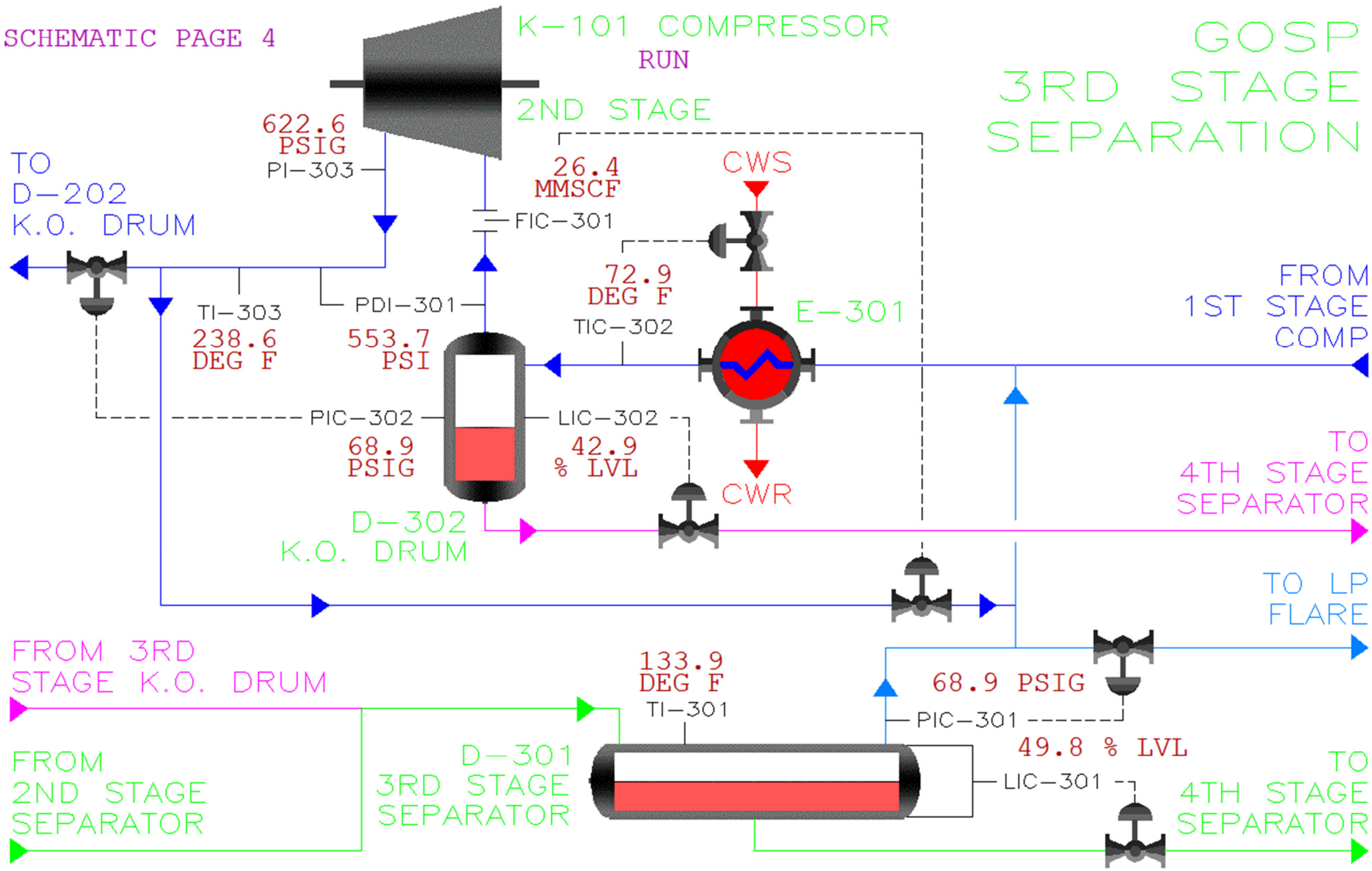


Figure 5. **Scenario #1 – 3rd Stage Separation DCS Screen at 2 minutes**

Courtesy of Simtronics Corporation

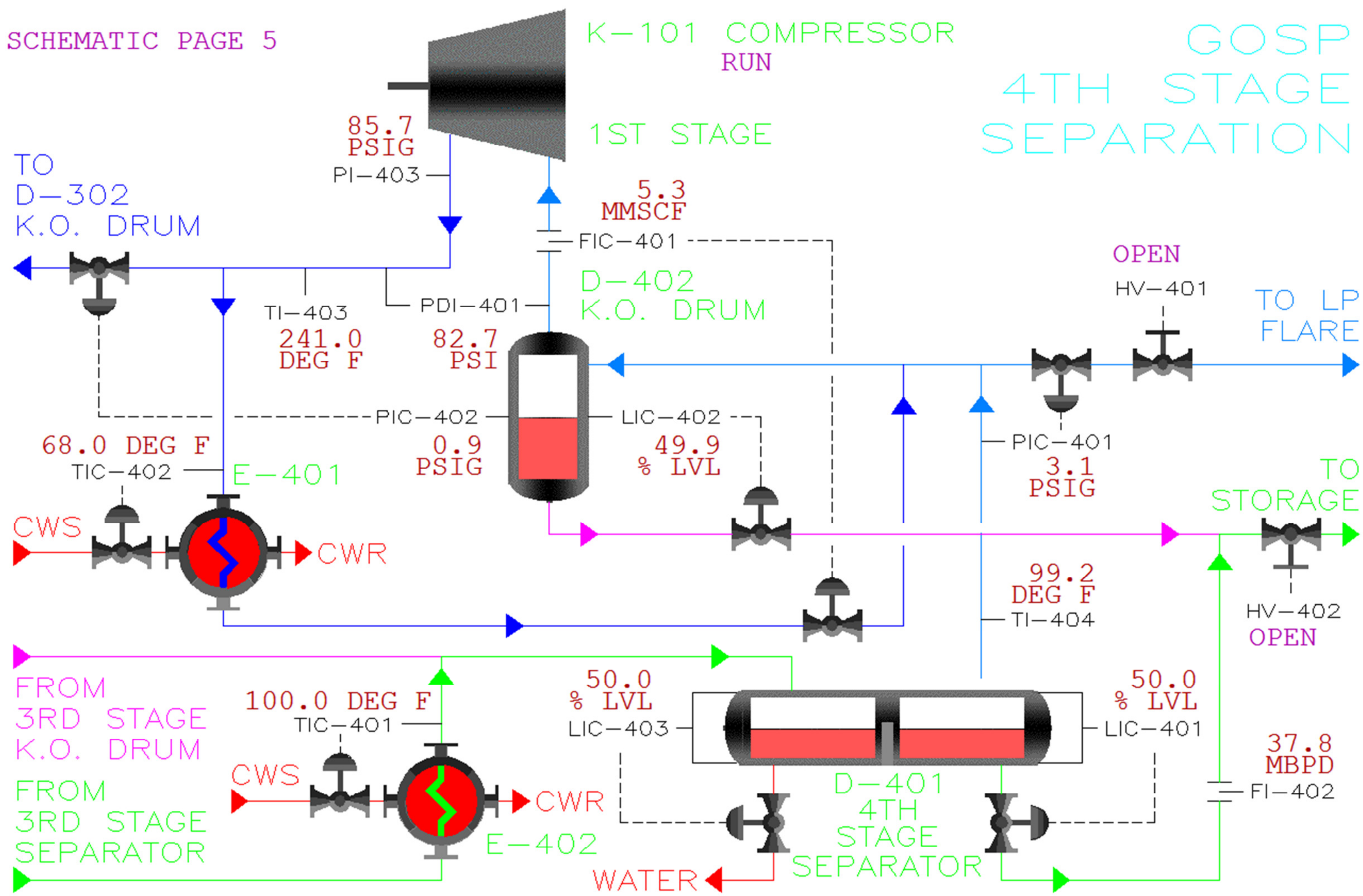
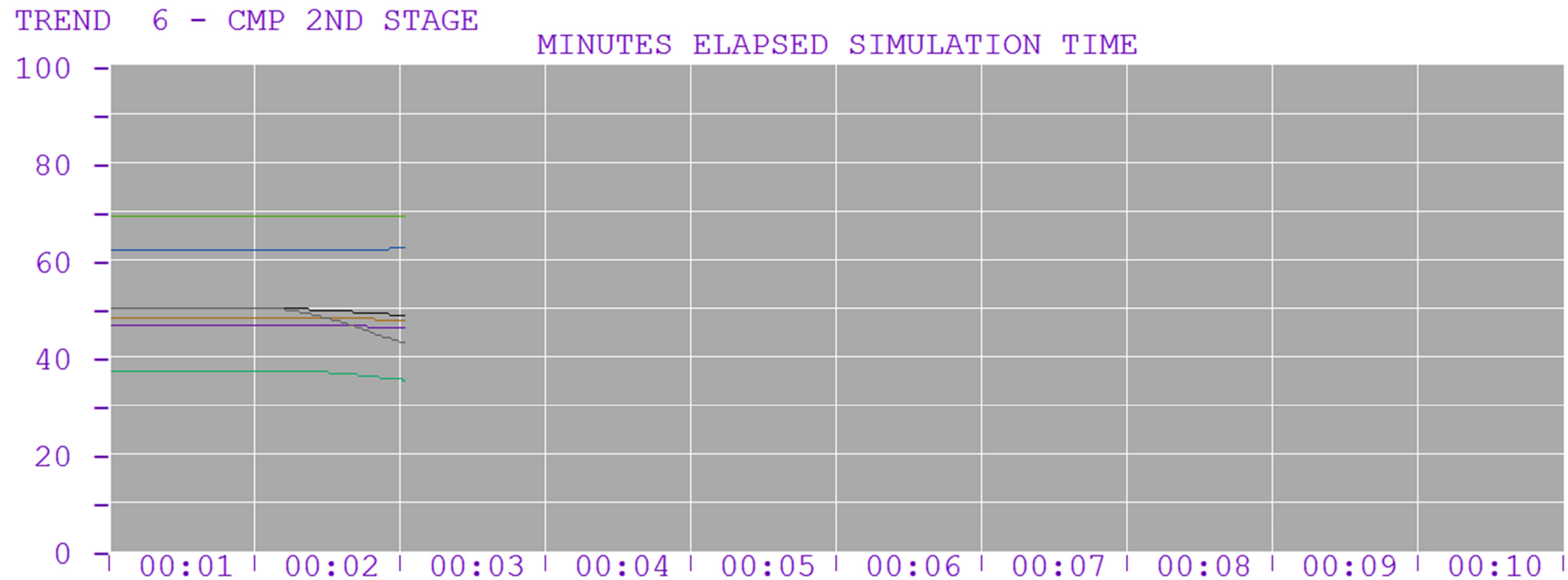


Figure 6. **Scenario #1 – 4th Stage Separation DCS Screen at 2 minutes**

Courtesy of Simtronics Corporation



	TI-303	PIC-302	FIC-301	PDI-301	PI-303	TIC-302	LIC-302
	DEG F	PSIG	MMSCF	PSI	PSIG	DEG F	% LVL
	2ND STG	2ND STG	2ND STG	2ND STG	2ND STG	2ND STG	2ND STG
SP/Y		70.0	20.0			75.0	50.0
PV/X	238.6	68.9	26.4	553.7	622.6	72.9	42.9
OUT %		11.9	0.0			23.9	9.1
		AUTO	AUTO			AUTO	AUTO

Figure 7. **Scenario #1 – 2nd Stage Compression Trend 6 at 2 minutes**

Courtesy of Simtronics Corporation

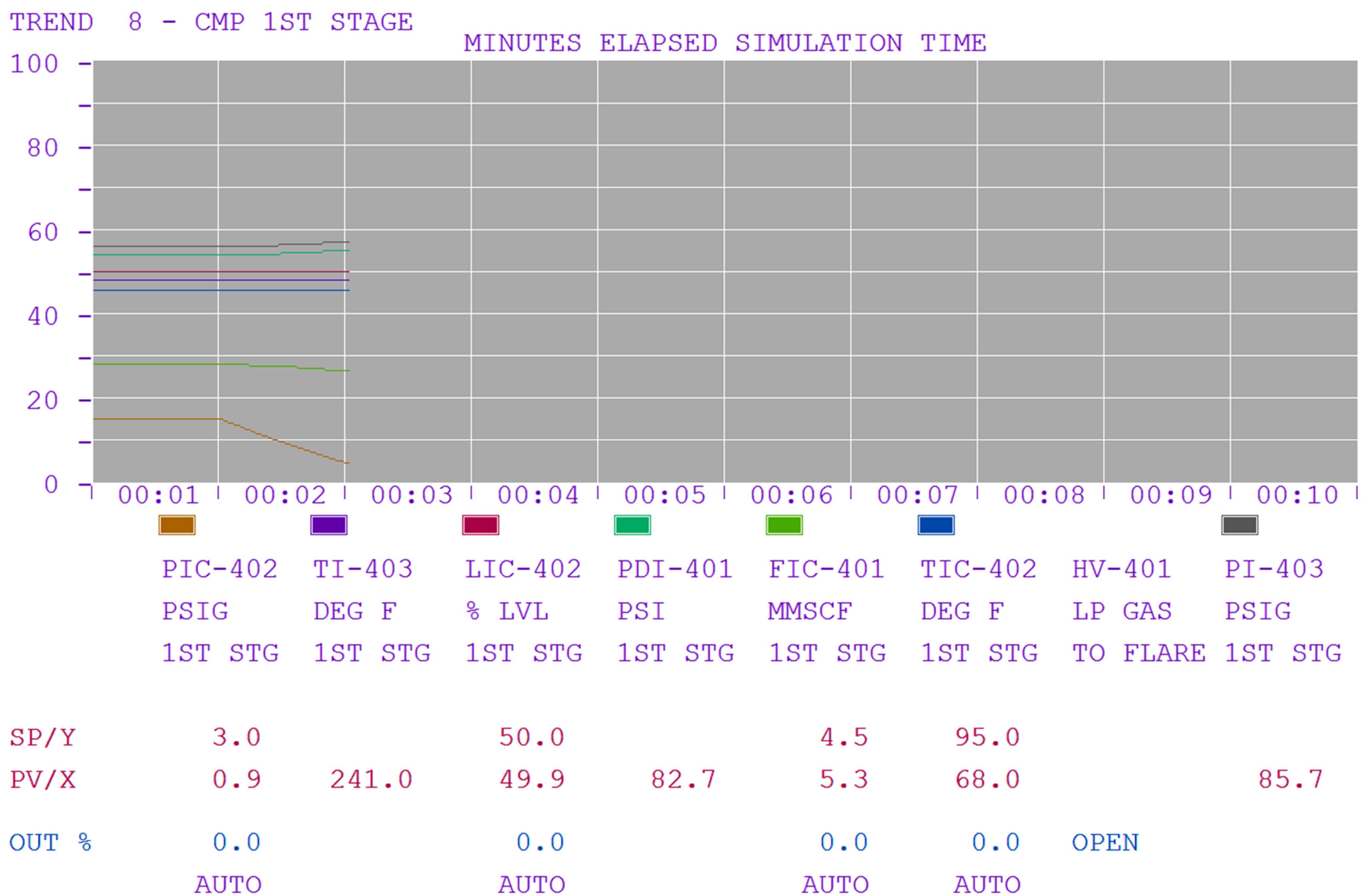


Figure 8. **Scenario #1 – 1st Stage Compression Trend at 2 minutes**

Courtesy of Simtronics Corporation

Scenario #1 DCS Screens Abnormal Operating Conditions at 10 Minutes

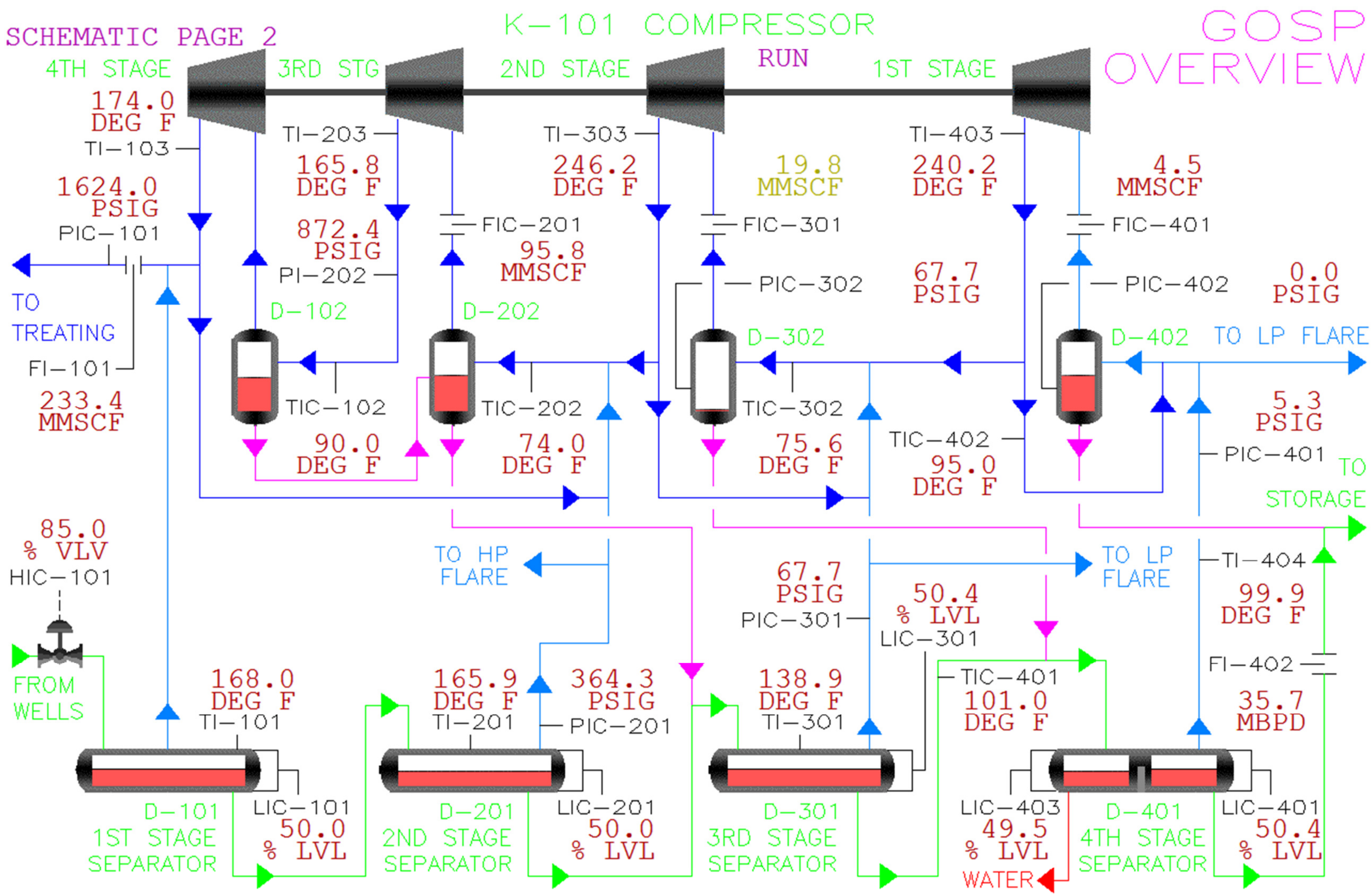


Figure 9. **Scenario #1 – 3-Phase Separator System Overview at 10 ½ minutes**

Courtesy of Simtronics Corporation

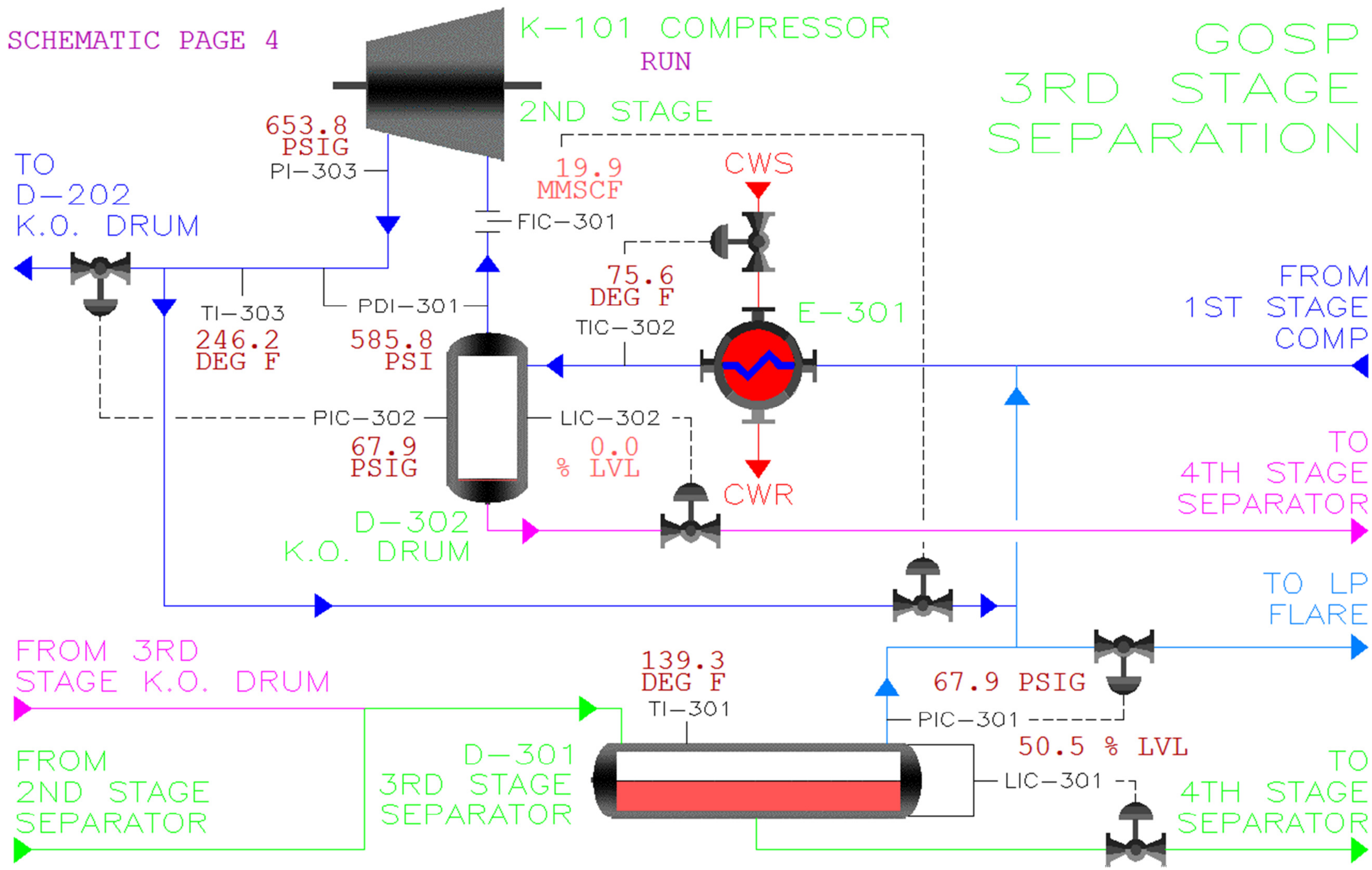


Figure 10. Scenario #1 – 3rd Stage Separation DCS Screen at 10 ½ minutes

Courtesy of Simtronics Corporation

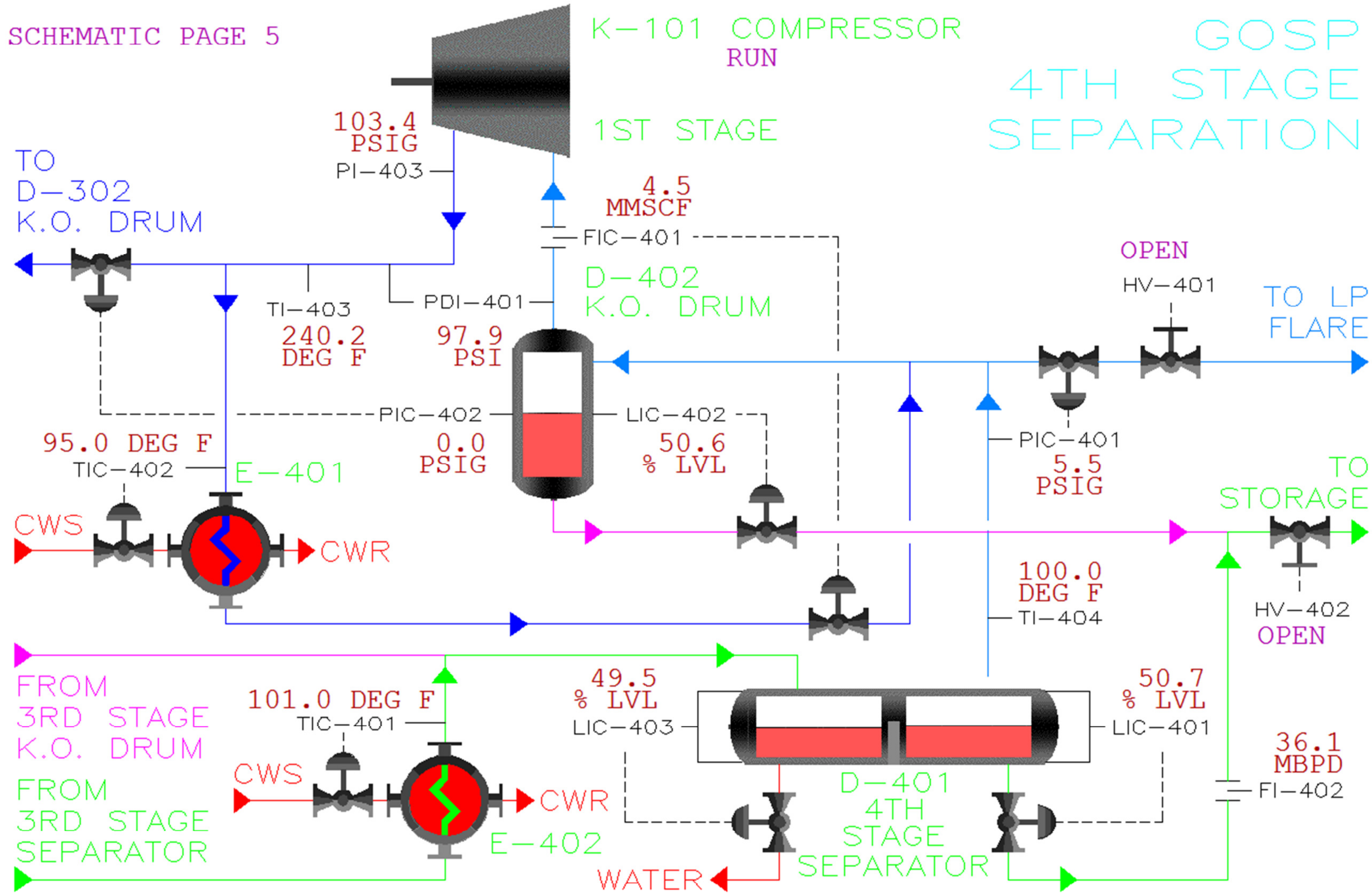


Figure 11. Scenario #1 – 4th Stage Separation DCS Screen at 10 ½ minutes

Courtesy of Simtronics Corporation