Chapter 1
Diagrams for Understanding Chemical Processes

Department of Chemical Engineering

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3 Levels of Diagram

- Block Flow Diagram (BFD)
- Process Flow Diagram (PFD)
- Piping and Instrumentation Diagram (P&ID) – often referred to as Mechanical Flow Diagram

As chemical engineers, we are most familiar with BFD and PFD.

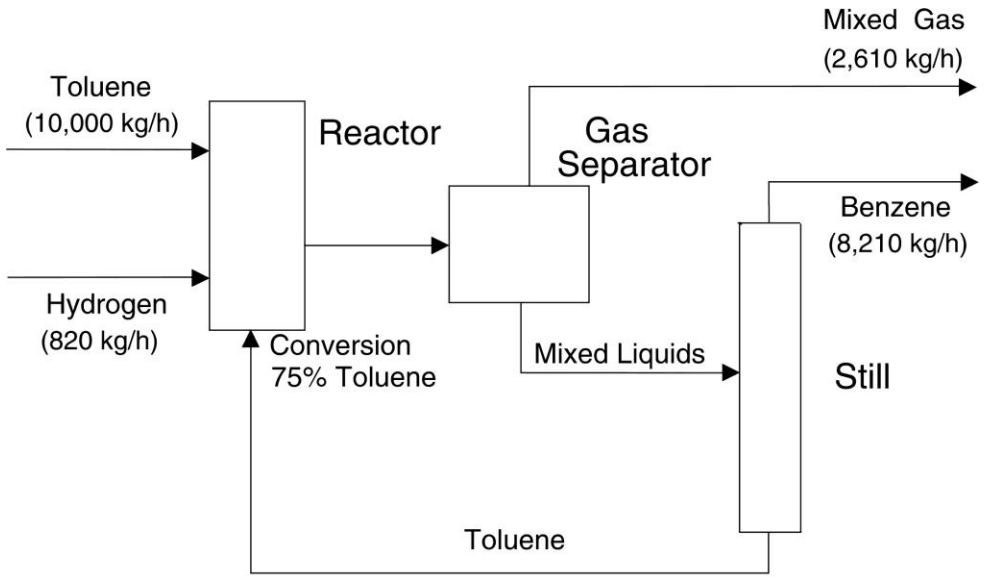
The Block Flow Diagram (BFD)

- BFD shows overall processing picture of a chemical complex
  - Flow of raw materials and products may be included on a BFD
  - BFD is a superficial view of facility – ChE information is missing

Definitions of BFD

- Block Flow Process Diagram
  - Figure 1.1
  - Similar to sketches in material and energy balances
- Block Flow Plant Diagram
  - Figure 1.2
  - Gives a general view of a large complex plant

The Block Flow Process Diagram



Reaction : $C_7H_8 + H_2 = C_6H_6 + CH_4$

Figure 1.1: Block Flow Process Diagram for the Production of Benzene

The Block Flow Plant Diagram

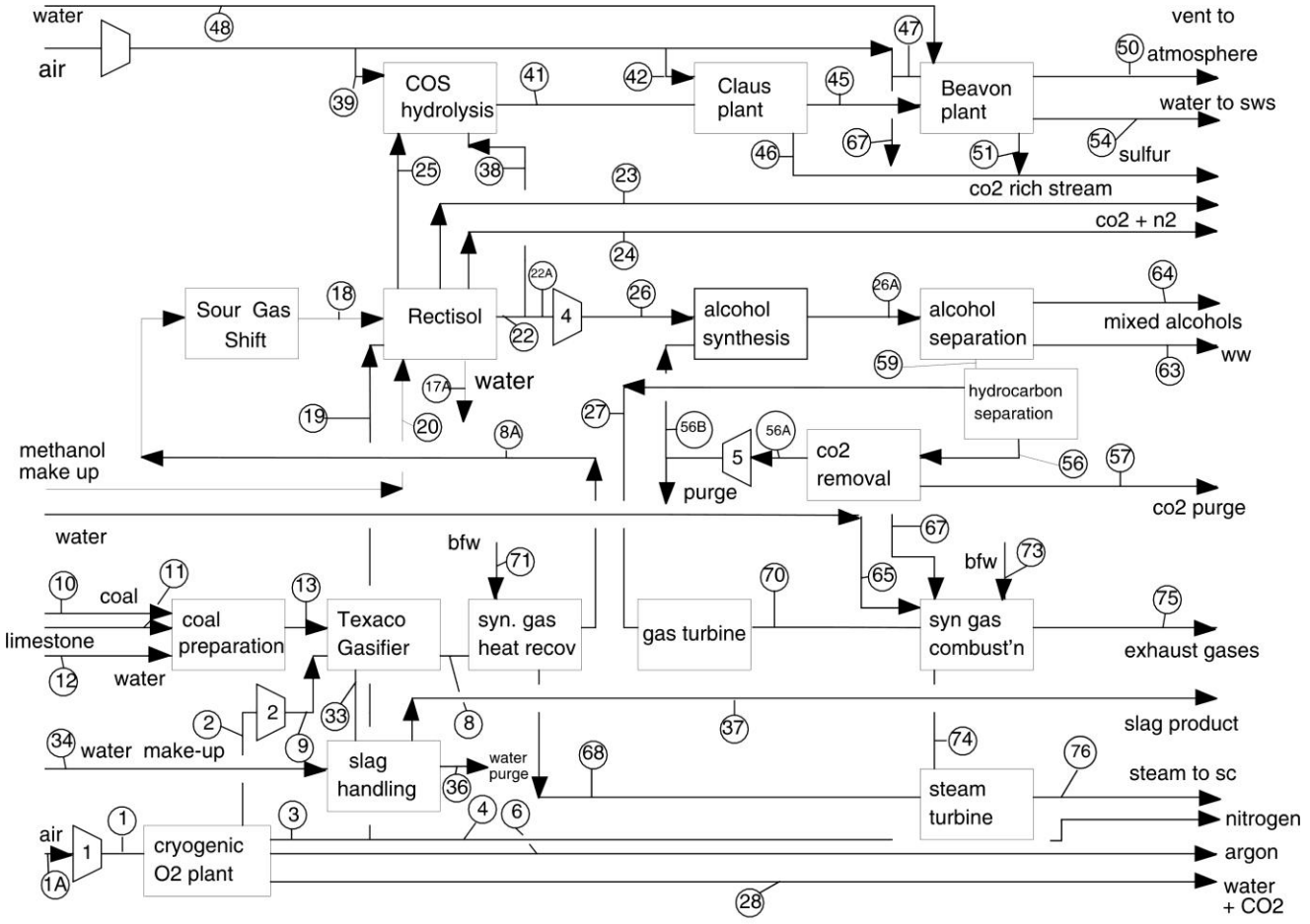


Figure 1.2: Block Flow Plant Diagram of a Coal to Higher Alcohol Fuels Process

The Process Flow Diagram

- PFD shows all process engineering information
  - Diagram developed in junior year design projects (especially the 2nd semester)
  - Often PFD is drawn on large paper – textbook breaks down information into 1 diagram and 2 tables

The Process Flow Diagram (cont'd)

- The topology of the process – showing the connectivity of all the streams and the equipment
  - Example for toluene HDA – Figures 1.3 and 1.5
  - Tables 1.2 and 1.4 – list information that should be on the PFD but cannot fit
  - Use appropriate conventions – consistency is important in communication of process information

    ex. Table 1.2

The Process Flow Diagram (cont'd)

V-101	P-101A/B	E-101	H-101	R-101	C-101 A/B	E-102	V-102	V-104	E-103	E-106	T-101	E-104	V-103	P-102A/B	E-105
Toluene Storage Drum	Toluene Feed Pumps	Feed Preheater	Feed Heater	Reactor	Recycle Gas Compressor	Reactor Effluent Cooler	HighPpres Phase Sep.	Low Pres. Phase Sep.	Tower Feed Heater	Benzene Reboiler	Benzene Column	Benzene Condenser	Reflux Drum	Reflux Pumps	Product Cooler

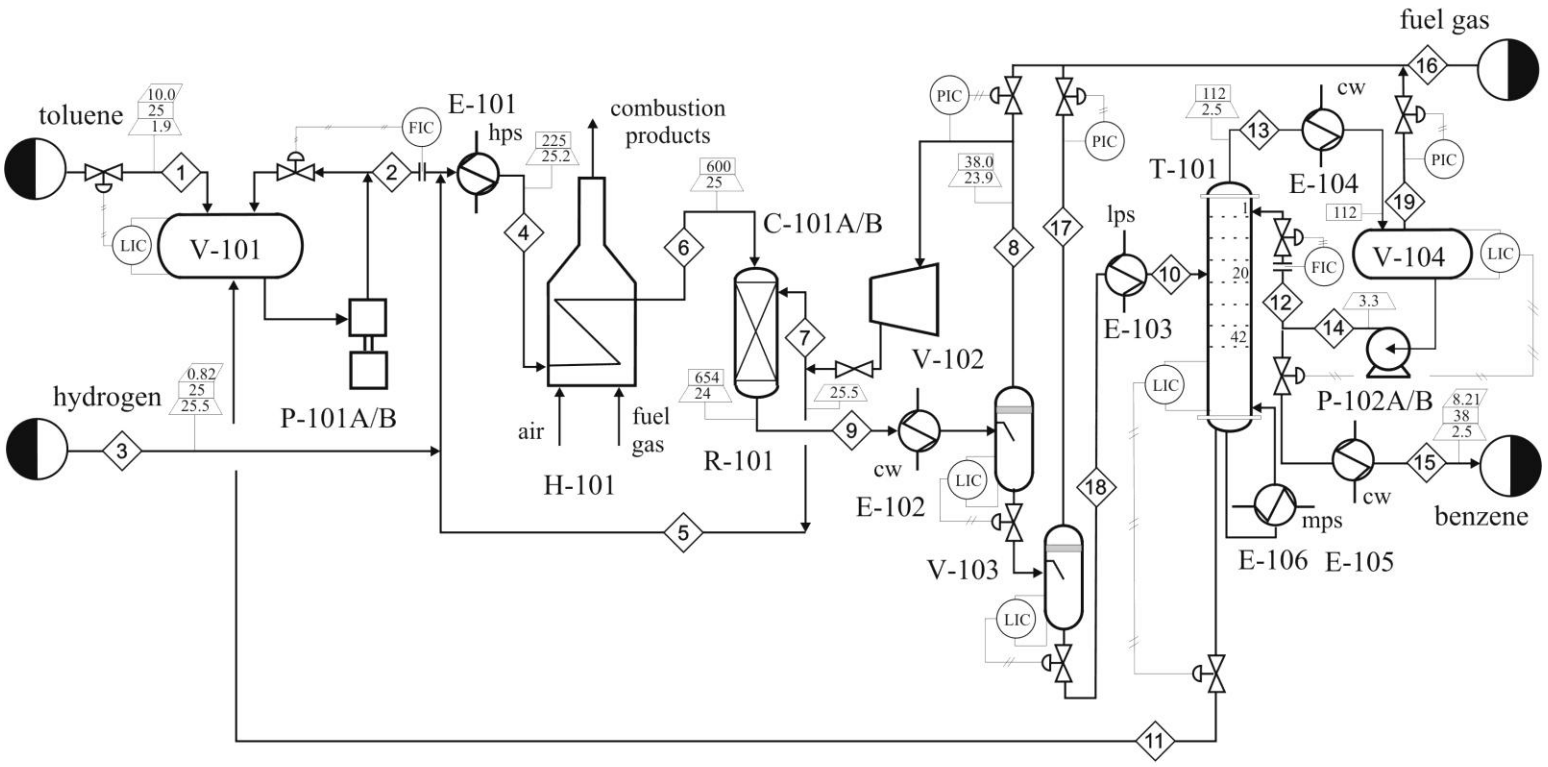


Figure 1.5: Process flow diagram (PFD) for the production of benzene via the hydrodealkylation of toluene

The Process Flow Diagram (cont'd)

Table 1.2 : Conventions Used for Identifying Process Equipment

Process Equipment	General Format **XX-YZZ A/B**
	XX are the identification letters for the equipment classification
	C - Compressor or Turbine
	E - Heat Exchanger
	H - Fired Heater
	P - Pump
	R - Reactor
	T - Tower
	TK - Storage Tank
	V - Vessel
	Y designates an area within the plant
	ZZ are the number designation for each item in an equipment class
	A/B identifies parallel units or backup units not shown on a PFD
Supplemental Information	Additional description of equipment given on top of PFD

Equipment Numbering

- XX-YZZ A/B/…
  - XX represents a 1- or 2-letter designation for the equipment (P = pump)
  - Y is the 1 or 2 digit unit number (1-99)
  - ZZ designates the equipment number for the unit (1-99)
  - A/B/… represents the presence of spare equipment

V-101	P-101A/B	E-101	H-101	R-101	C-101 A/B	E-102	V-102	V-104	E-103	E-106	T-101	E-104	V-103	P-102A/B	E-105
Toluene Storage Drum	Toluene Feed Pumps	Feed Preheater	Feed Heater	Reactor	Recycle Gas Compressor	Reactor Effluent Cooler	HighPpres Phase Sep.	Low Pres. Phase Sep.	Tower Feed Heater	Benzene Reboiler	Benzene Column	Benzene Condenser	Reflux Drum	Reflux Pumps	Product Cooler

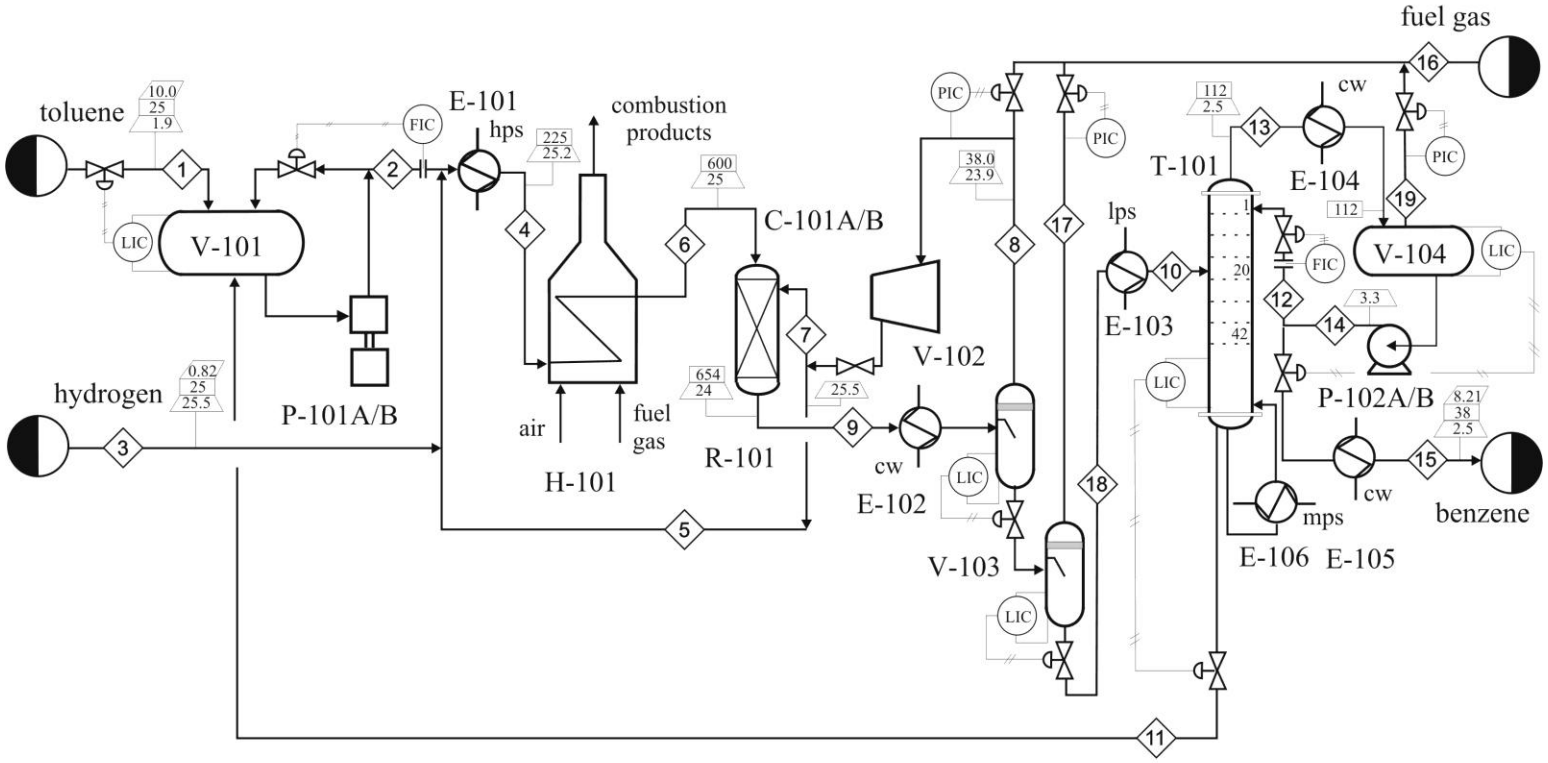


Figure 1.5: Process flow diagram (PFD) for the production of benzene via the hydrodealkylation of toluene

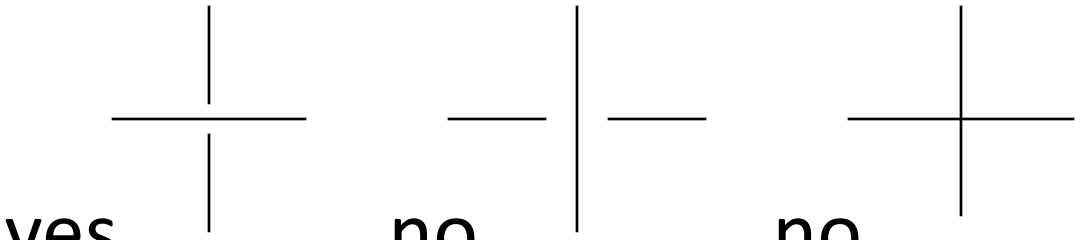
Equipment Numbering (cont'd)

Thus, T-905 is the 5th tower in unit nine hundred P-301 A/B is the 1st Pump in unit three hundred plus a spare

- Use unambiguous letters for new equipment
  - Ex. Turbine use Tb or J not T (for tower)
  - Replace old vessel V-302 with a new one of different design - use V-319 (say) not V-302 – since it may be confused with original V-302

Stream Numbering and Drawing

- Number streams from left to right as much as possible
- Horizontal lines are dominant



V-101 Toluene Storage Drum | P-101A/B Toluene Feed Pumps | E-101 Feed Preheater | H-101 Feed Heater | R-101 Reactor | C-101 A/B Recycle Gas Compressor | E-102 Reactor Effluent Cooler | V-102 HighPpres Phase Sep. | V-104 Low Pres. Phase Sep. | E-103 Tower Feed Heater | E-106 Benzene Reboiler | T-101 Benzene Column | E-104 Benzene Condenser | V-103 Reflux Drum | P-102A/B Reflux Pumps | E-105 Product Cooler

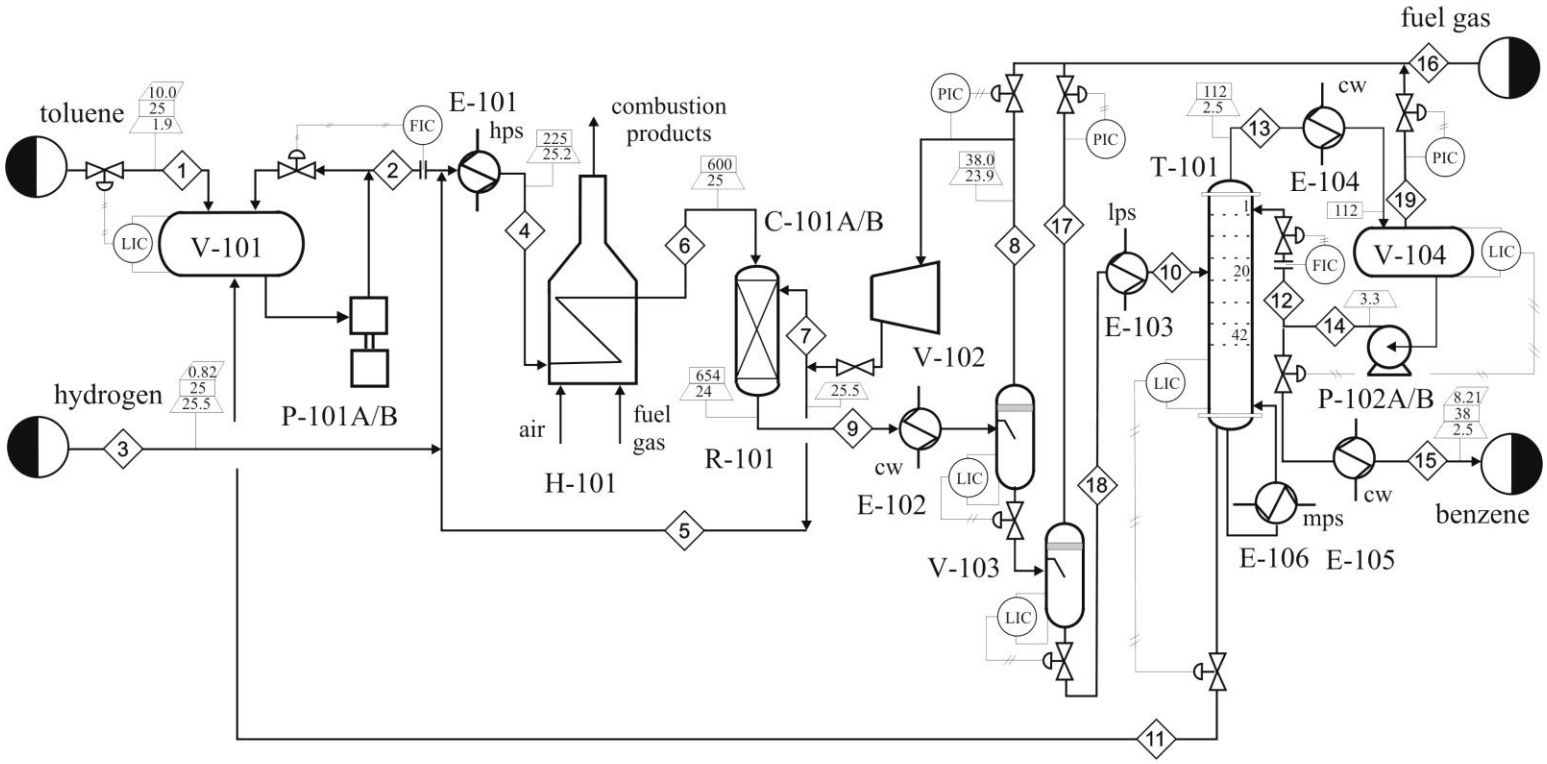


Figure 1.5: Process flow diagram (PFD) for the production of benzene via the hydrodealkylation of toluene

Stream Numbering and Drawing (cont'd)

- Add arrows for
  - Change in direction
  - Inlet of equipment
- Utility streams should use convention given in Table 1.3, lps, cw, fg, etc.

Stream Information

- Since diagrams are small, not much stream information can be included
- Include important data – around reactors and towers, etc.
  - Flags are used – see toluene HDA diagram
  - Full stream data, as indicated in Table 1.4, are included in a separate flow summary table – see Table 1.5

V-101 Toluene Storage Drum | P-101A/B Toluene Feed Pumps | E-101 Feed Preheater | H-101 Feed Heater | R-101 Reactor | C-101 A/B Recycle Gas Compressor | E-102 Reactor Effluent Cooler | V-102 HighPpres Phase Sep. | V-104 Low Pres. Phase Sep. | E-103 Tower Feed Heater | E-106 Benzene Reboiler | T-101 Benzene Column | E-104 Benzene Condenser | V-103 Reflux Drum | P-102A/B Reflux Pumps | E-105 Product Cooler

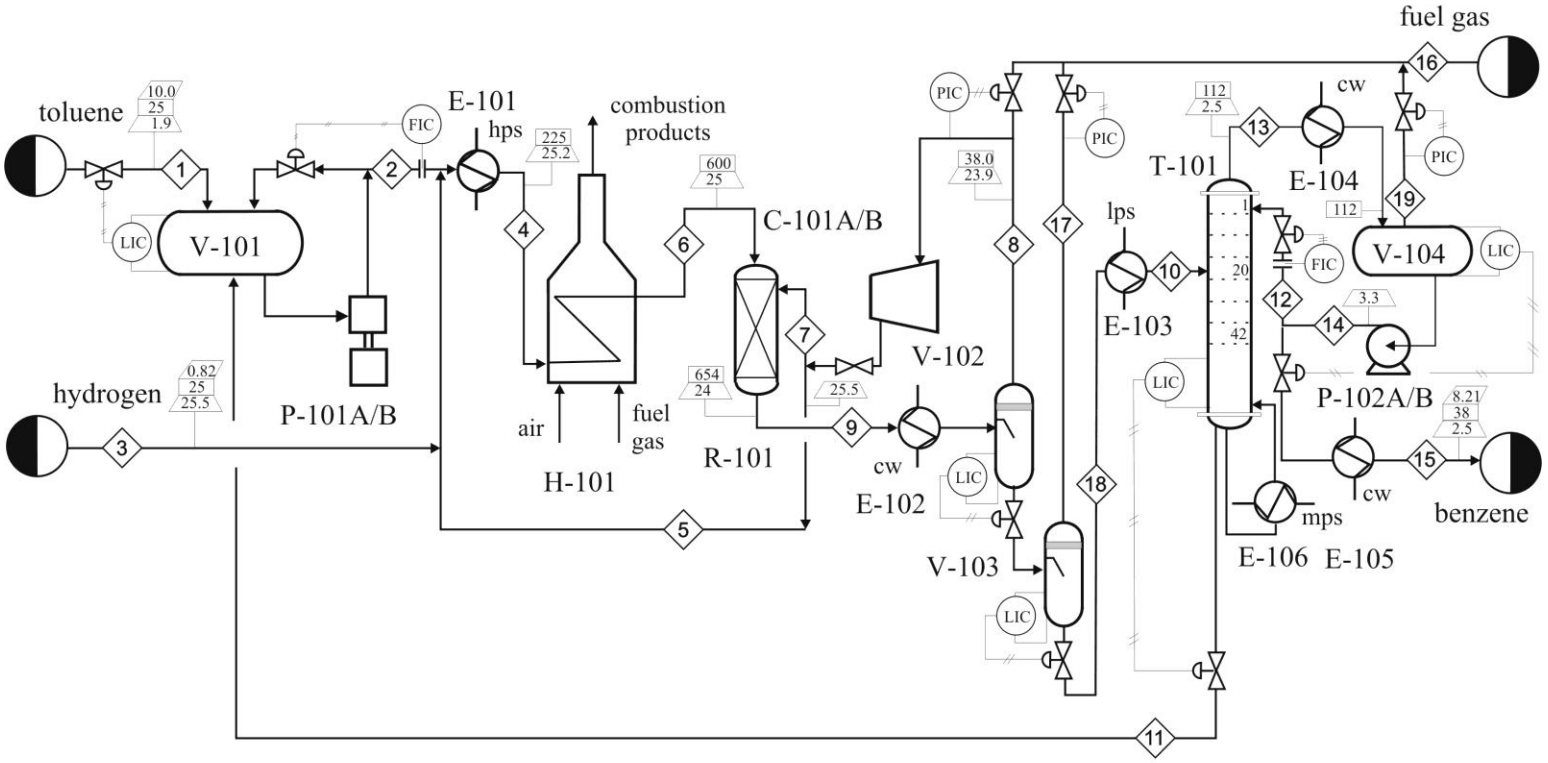
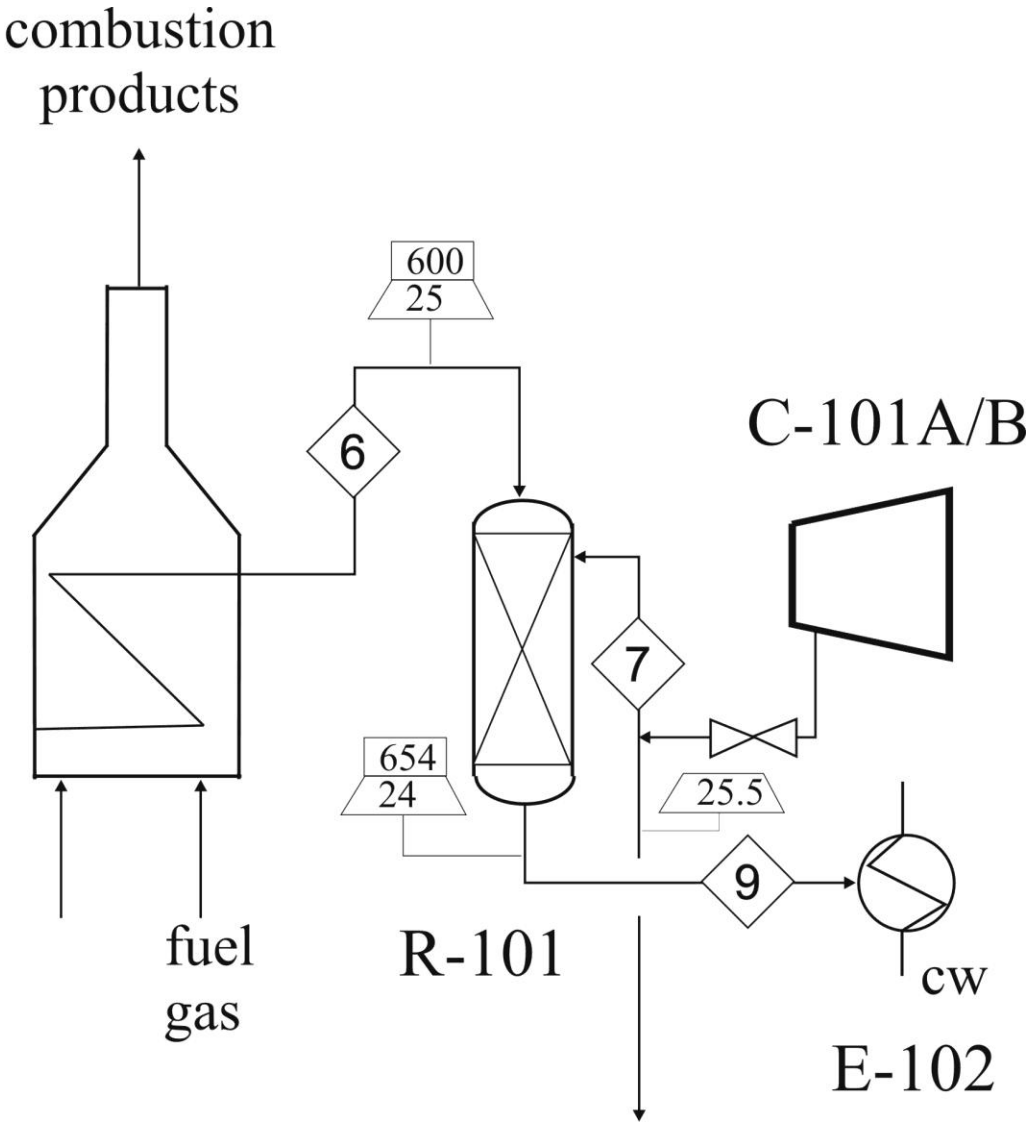


Figure 1.5: Process flow diagram (PFD) for the production of benzene via the hydrodealkylation of toluene

Stream Information - Flags



The Process Flow Diagram (cont'd)

Table 1.4: Information in a Flow Summary

Essential Information

Stream Number
Temperature (°C)
Pressure (bar)
Vapor Fraction
Total Mass Flow Rate (kg/h)
Total Mole Flow Rate (kmol/h)
Individual Component Flow Rates (kmol/h)

Optional Information

Component Mole Fractions
Component Mass Fractions
Individual Component Flow Rates (kg/h)
Volumetric Flow Rates (m^3/h)
Significant Physical Properties
- Density
- Viscosity
- Other

Thermodynamic Data
Heat Capacity
Stream Enthalpy
K-values
Stream Name

The Process Flow Diagram (cont'd)

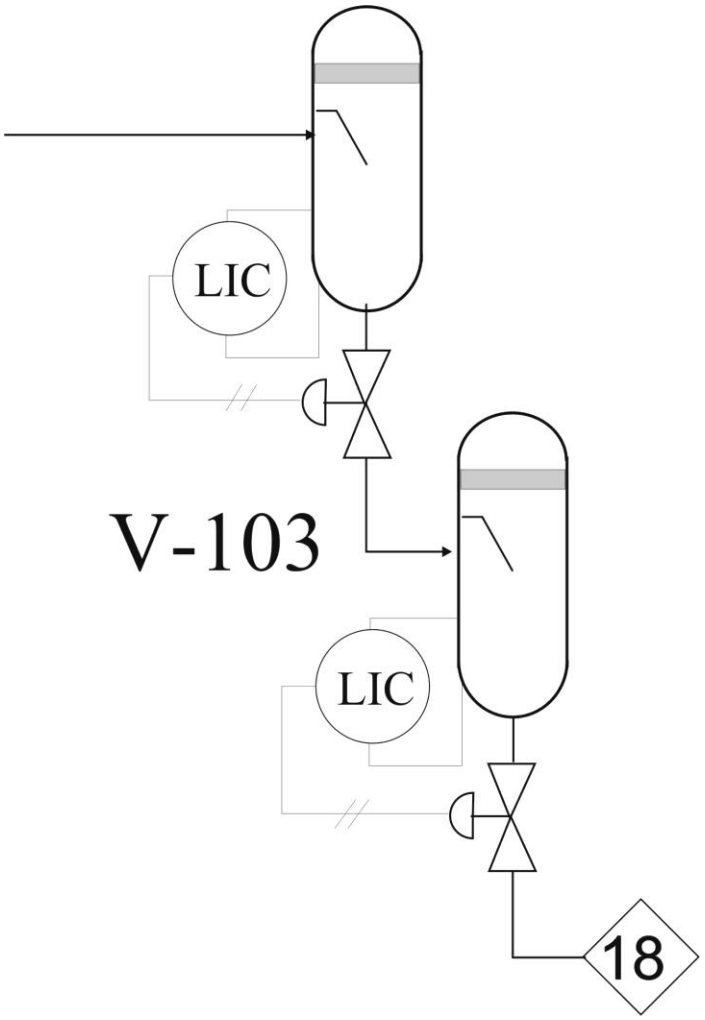
A Portion of Table 1.5

Stream Number	1	2	3	4	5	6	7	8	9	10
Temperature (°C)	25	59	25	225	41	600	41	38	654	90
Pressure (bar)	1.90	25.8	25.5	25.2	25.5	25.0	25.5	23.9	24.0	2.6
Vapor Fraction	0.0	0.0	1.00	1.0	1.0	1.0	1.0	1.0	1.0	0.0
Mass Flow (tonne/h)	10.0	13.3	0.82	20.5	6.41	20.5	0.36	9.2	20.9	11.6
Mole Flow (kmol/h)	108.7	144.2	301.0	1204.4	758.8	1204.4	42.6	1100.8	1247.0	142.2
Component Mole Flow (kmol/h)										
Hydrogen	0.0	0.0	286.0	735.4	449.4	735.4	25.2	651.9	652.6	0.02
Methane	0.0	0.0	15.0	317.3	302.2	317.3	16.95	438.3	442.3	0.88
Benzene	0.0	1.0	0.0	7.6	6.6	7.6	0.37	9.55	116.0	106.3
Toluene	108.7	143.2	0.0	144.0	0.7	144.0	0.04	1.05	36.0	35.0

Basic Control Loops

- Often the basic control loops (those involving maintaining material balance and reactor controls) are included on the PFD; instrumentation and other control loops are not shown

Basic Control Loops



Equipment Information

- Equipment are identified by number and a label (name) positioned above the equipment on the PFD
- Basic data such as size and key data are included in a separate table (Equipment Summary Table) Table 1.7 (and Table 1.6) in TBWS

Equipment Information

A Section of Table 1.7: Equipment Summary

Vessel	V-101	V-102
Temperature (ºC)	55	38
Pressure (bar)	2.0	24
Orientation	Horizontal	Vertical
MOC	CS	CS
Size		
Height/Length (m)	5.9	3.5
Diameter (m)	1.9	1.1
Internals		s.p. (splash plate)

PFD Summary

- PFD, Equipment Summary Table, and Flow Summary Table represent a “true” PFD
- This information is sufficient for a preliminary estimation of capital investment (Chapter 7) and cost of manufacture (Chapter 8) to be made

The Piping and Instrument Diagram(P&ID)

P&ID – Construction Bible

- Contains: plant construction information (piping, process, instrumentation, and other diagrams)
- P&ID information is explained in Tables 1.8 and 1.9
- Conventions for instrumentation are shown in Figure 1.10

P&ID

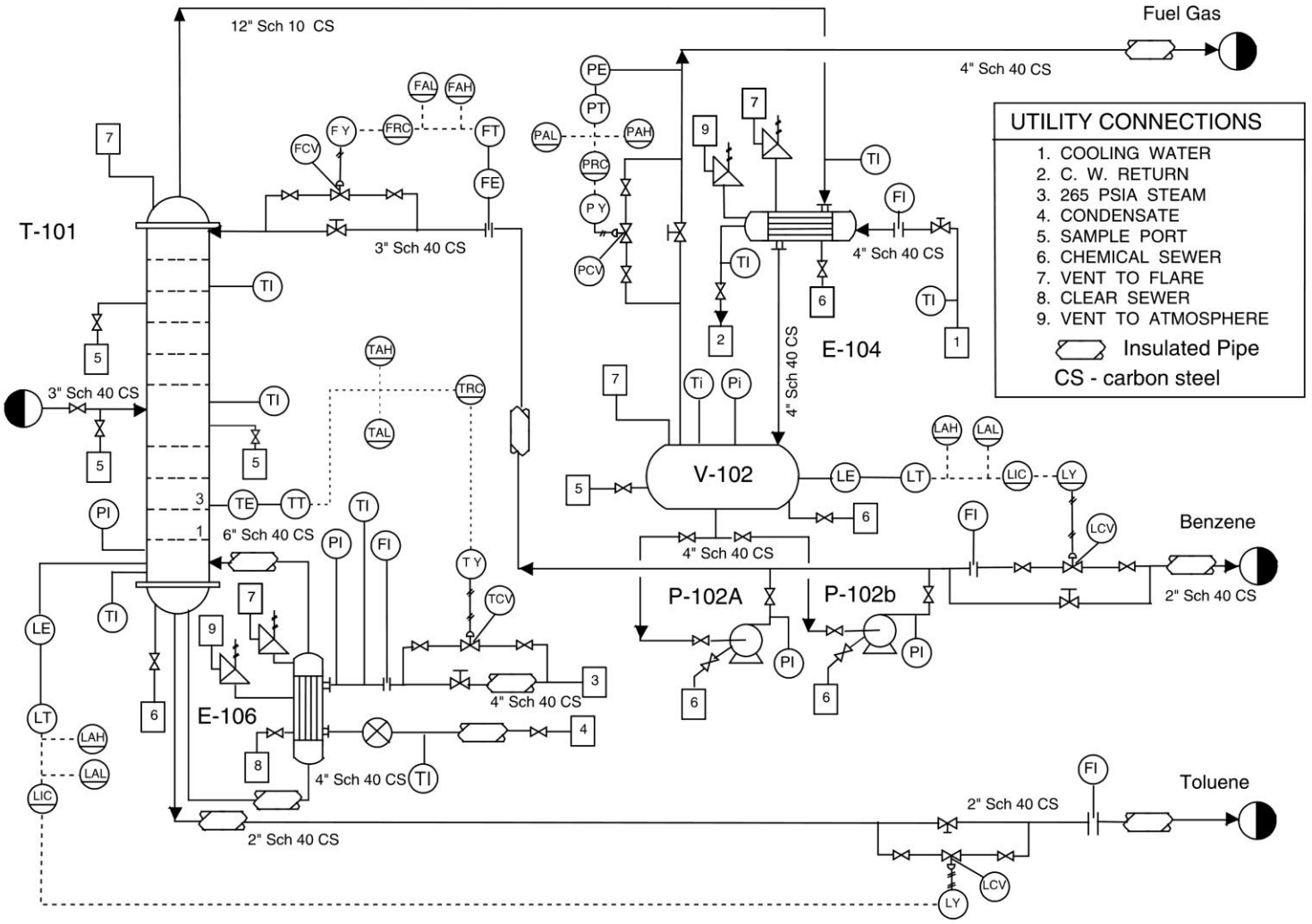


Figure 1.7 : Piping and Instrumentation Diagram for Benzene Distillation (adapted from Kauffman, D, Flow Sheets and Diagrams," AIChE Modular Instruction, Series G: Design of Equipment, series editor J. Beckman, AIChE, New York, 1986, vol 1, Chapter G.1.5, AIChE copyright © 1986 AIChE, all rights reserved)

Look at V-102 on P&ID

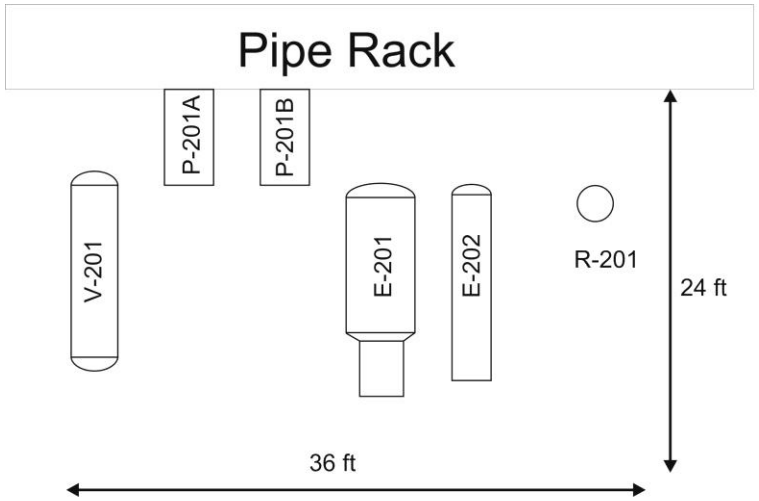
V-102 contains an LE (Level Element)

- LE senses liquid level in separator and adjusts flow rate leaving
- LE opens and closes a valve depending on liquid level
- LE and valve represent a feedback control loop

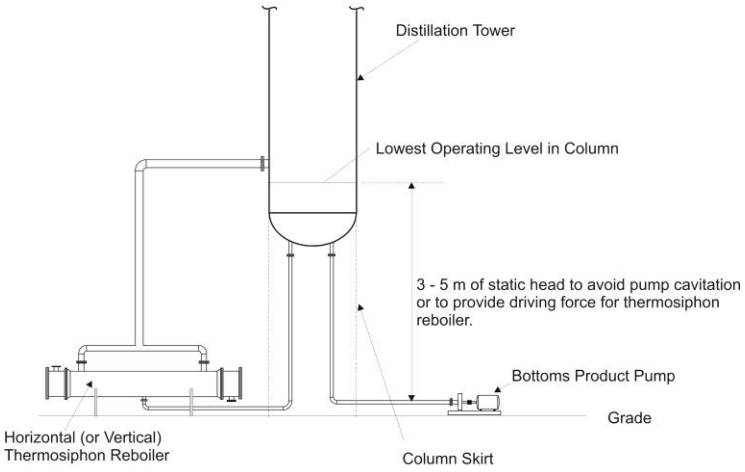
Other Common Diagrams

- Plot Plans – plan or map drawn looking down on plant (drawn to scale with all major equipment identified)
- Elevation Diagrams – show view from side and give information about equipments distance from ground

Other Common Diagrams



Section of Plot Plan



Section of Elevation Diagram

Other Common Diagrams (cont'd)

- Piping Isometrics – show piping in 3-dimensions
- Vessel Sketches – show key dimensions of equipment and locations of inlet and outlet nozzles etc.

Scale Models and Virtual Plants

- 25 years ago physical models were used for review
- Now virtual or electronic models are generated using software (3-d plant diagrams)
- Purpose of Models – catch errors such as
  - Piping clashes
  - Misaligned piping
  - Equipment not easily accessed
  - Sample points not easily reached by operators

OPERATOR AND 3-D IMMERSIVE TRAINING SIMULATORS

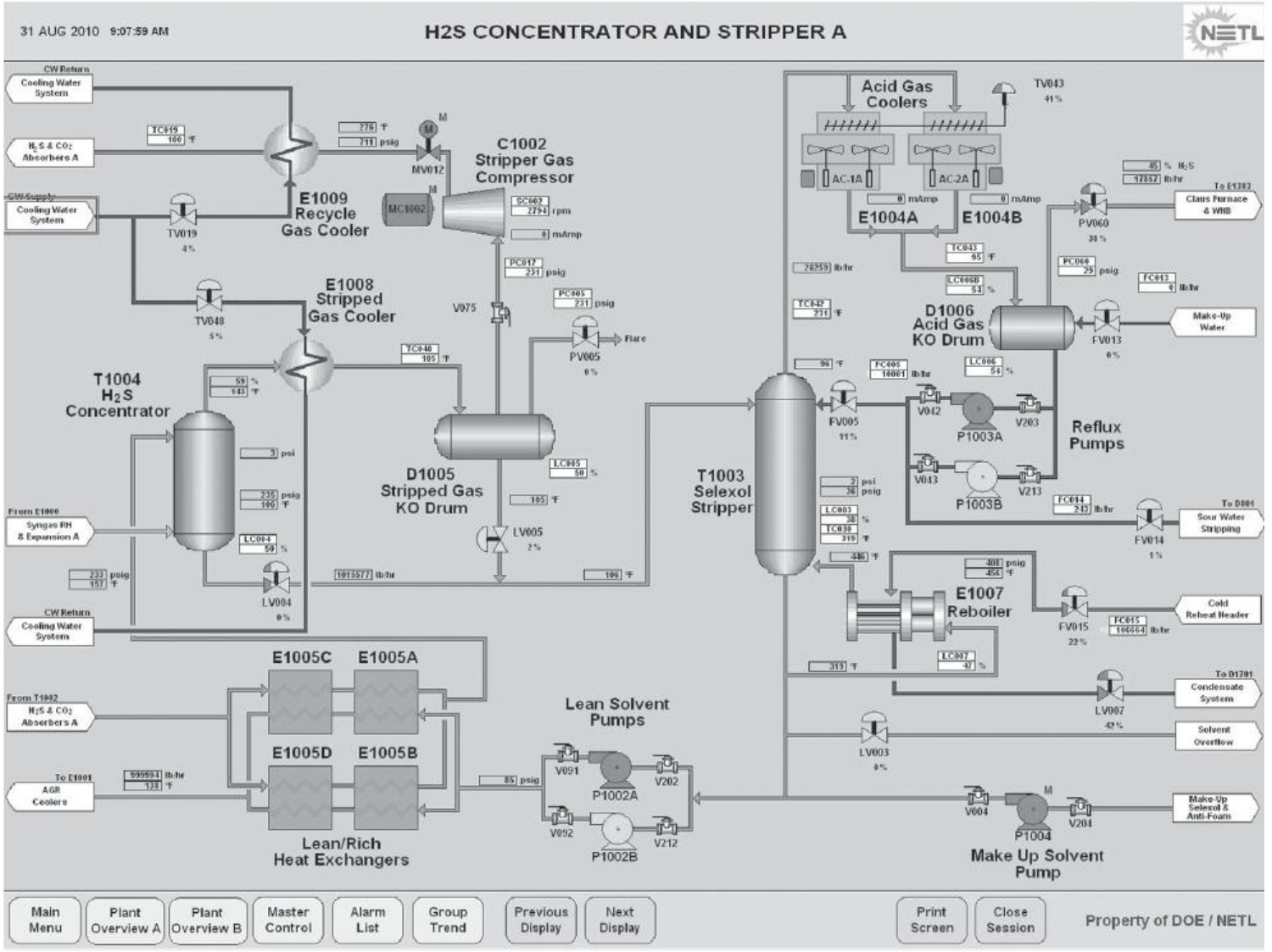


Figure 1.16 Example of an HMI Interface for an OTS (Reproduced by Permission of the DOE's National Energy Technical Laboratory and Invensys Systems Inc., Property and Copyright of Invensys plc, UK)

OPERATOR AND 3-D IMMERSIVE TRAINING SIMULATORS

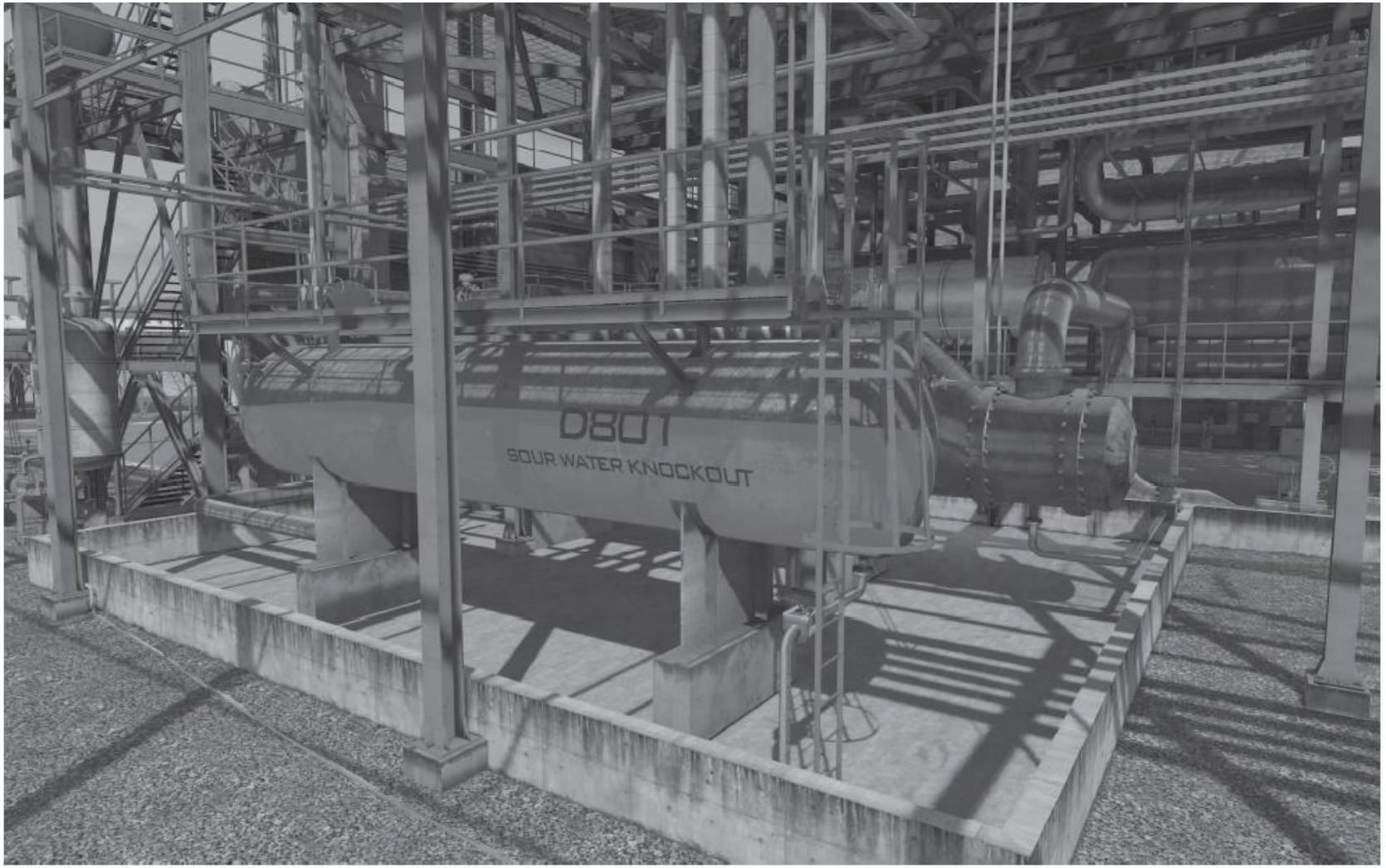


Figure 1.17 An Example of a Computer-Generated Image of a Horizontal Drum (Reproduced by Permission of the DOE's National Energy Technical Laboratory and Invensys Systems Inc., Property and Copyright of Invensys plc, UK)

OPERATOR AND 3-D IMMERSIVE TRAINING SIMULATORS

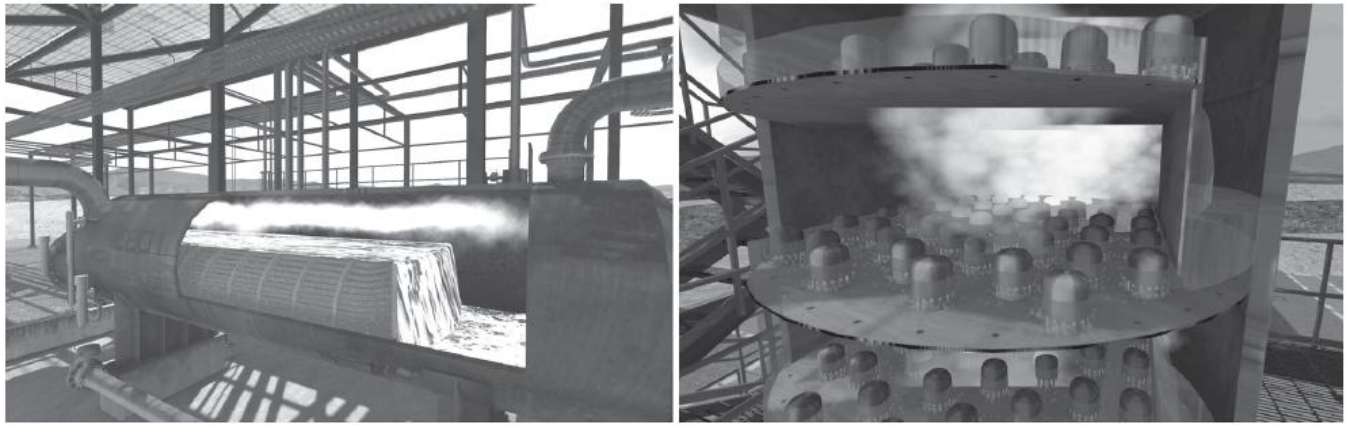


Figure 1.18 Augmented Reality in ITS: (a) Reboiler (b) Bubble-Cap Distillation Column (Reproduced by Permission of the DOE's National Energy Technical Laboratory and Invensys Systems Inc., Property and Copyright of Invensys plc, UK)