

# **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

↓ Complexity  
increases

↑ Conceptual  
understanding  
Increases

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

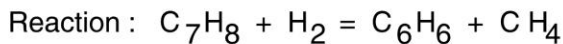
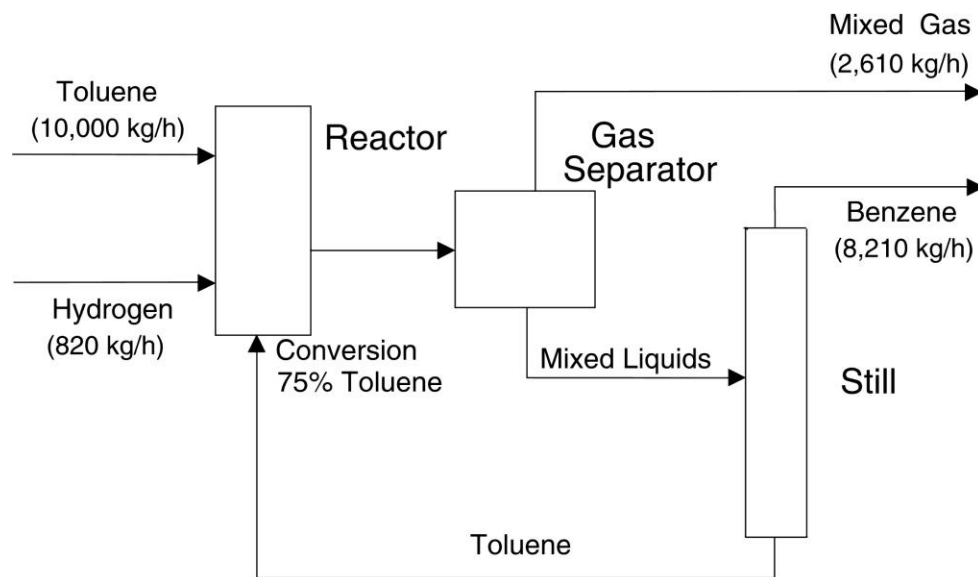


Figure 1.1: Block Flow Process Diagram for the Production of Benzene

# The Block Flow Plant Diagram

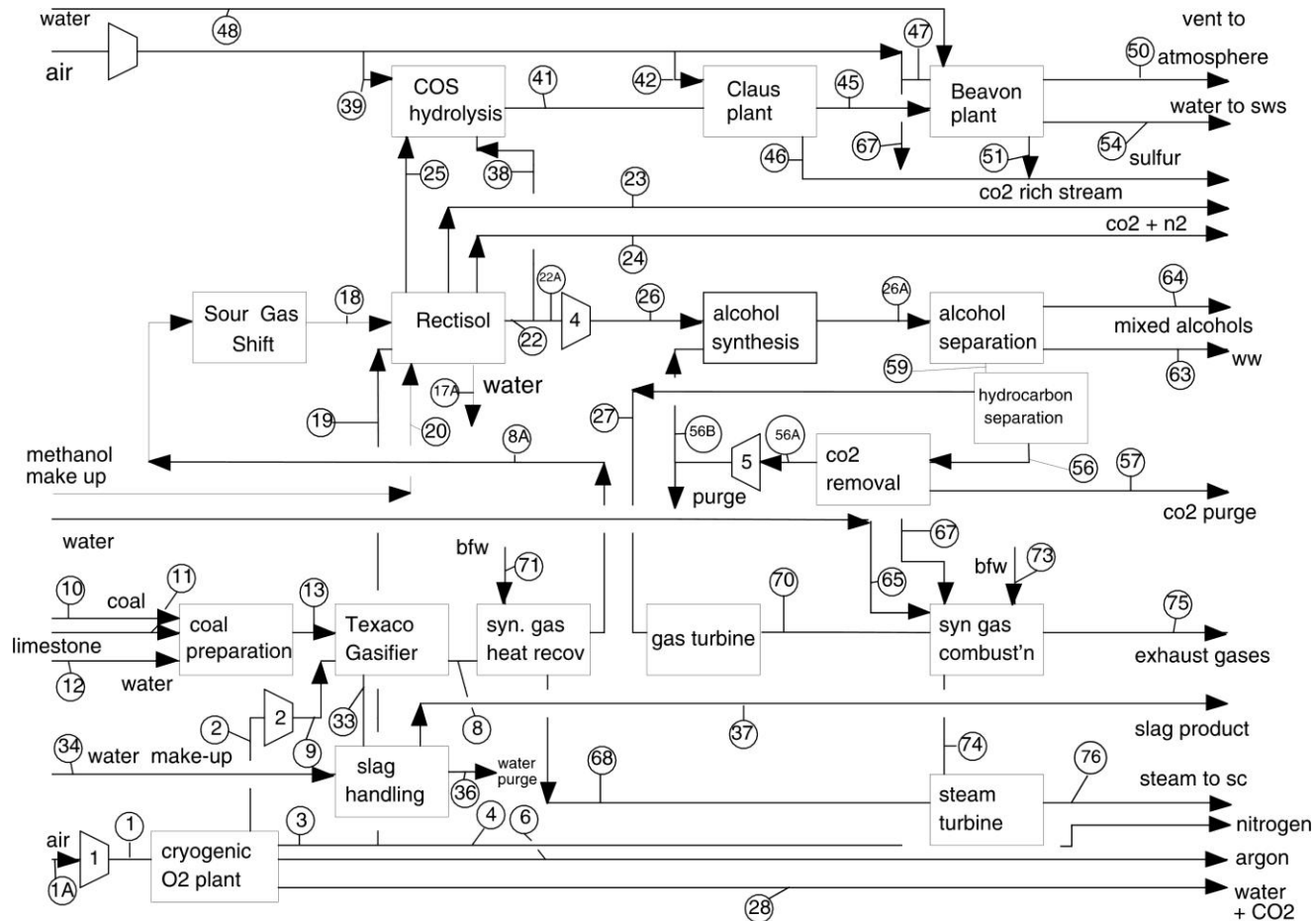


Figure 1.2: Block Flow Plant Diagram of a Coal to Higher Alcohol Fuels Process

# The Process Flow Diagram

- PFD shows all process engineering information
  - Diagram developed in junior year design projects (especially the 2<sup>nd</sup> 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	High Ppres Phase Sep.	Low Pres. Phase Sep.	Tower Feed Heater	Benzene Reboiler	Benzene Column	Benzene Condenser	Reflux Drum	Reflux Pumps	Product Cooler

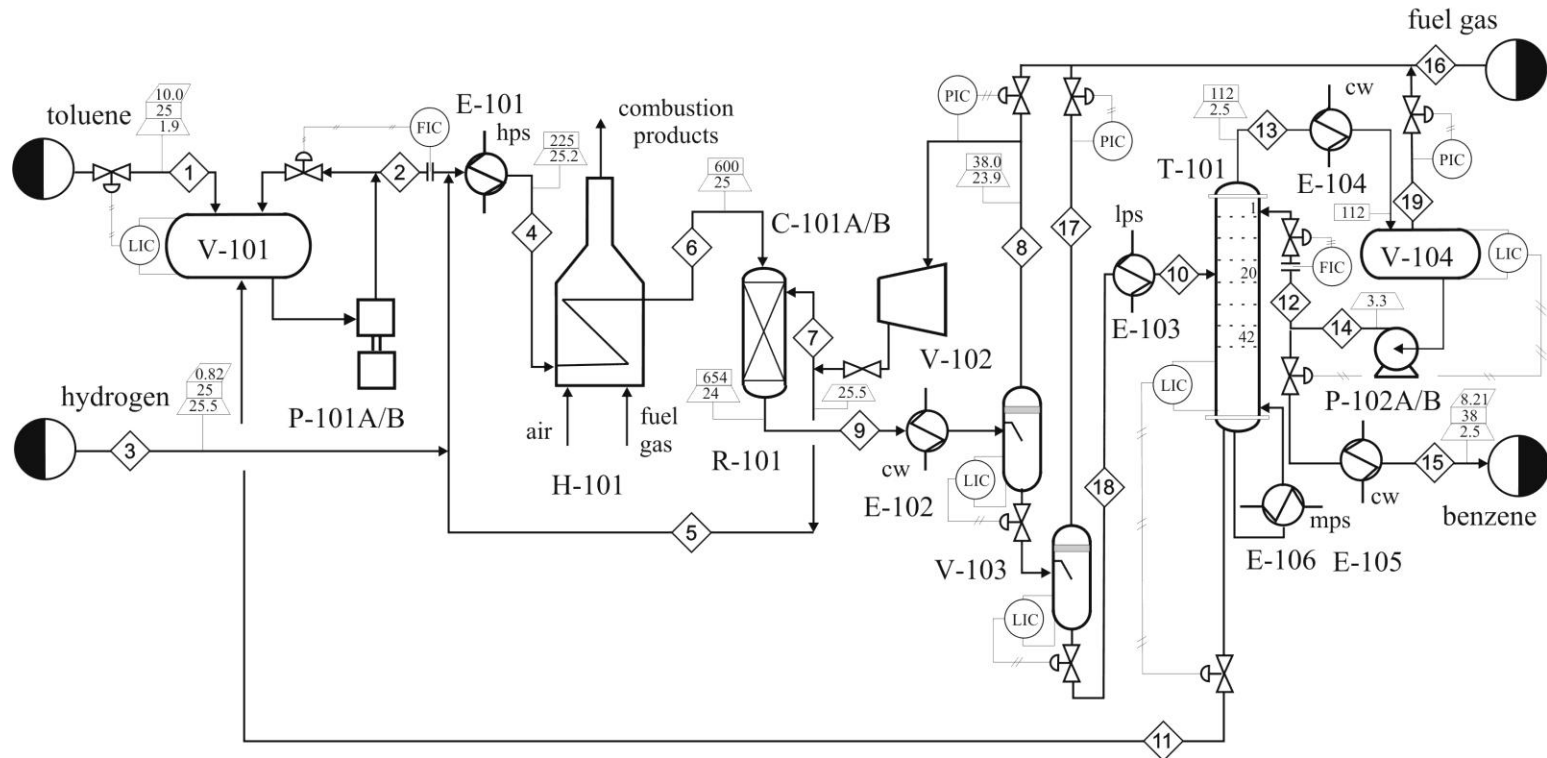


Figure 1.5: Process flow diagram (PFD) for the production of benzene via the hydrodealkylation of toluene

# The Process Flow Diagram (cont'd)

**Table 1.2 : Conventions Used for Identifying Process Equipment**

Process Equipment

General Format **XX-YYY 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	Toluene	Feed	Feed	Reactor	Recycle Gas	Reactor	HighPres	Low Pres.	Tower	Benzene	Benzene	Benzene	Reflux	Reflux	Product
Storage	Feed Pumps	Preheater	Heater		Compressor	Effluent	Phase Sep.	Phase Sep.	Feed	Reboiler	Column	Condenser	Drum	Pumps	Cooler
Drum						Cooler			Heater						

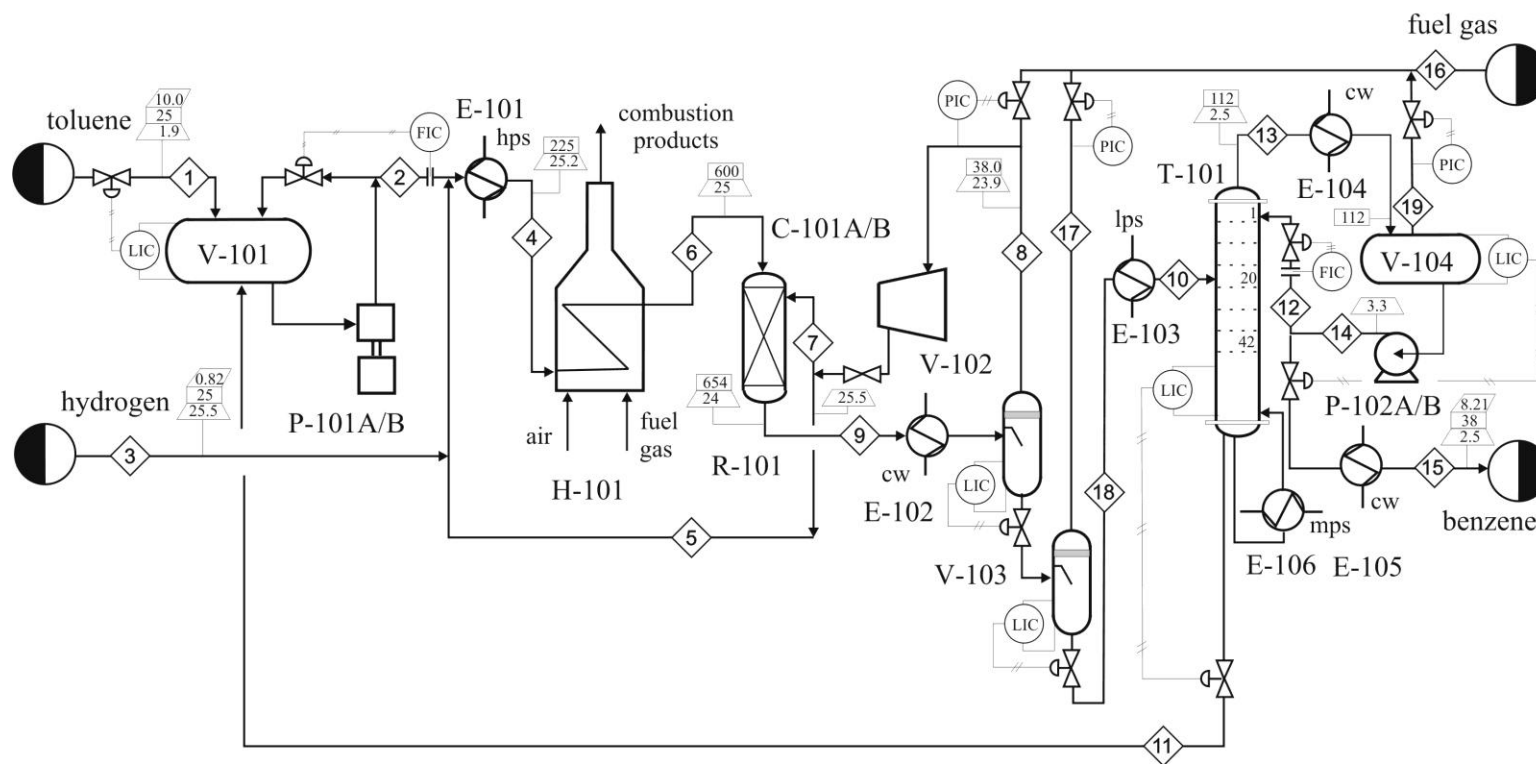


Figure 1.5: Process flow diagram (PFD) for the production of benzene via the hydrodealkylation of toluene

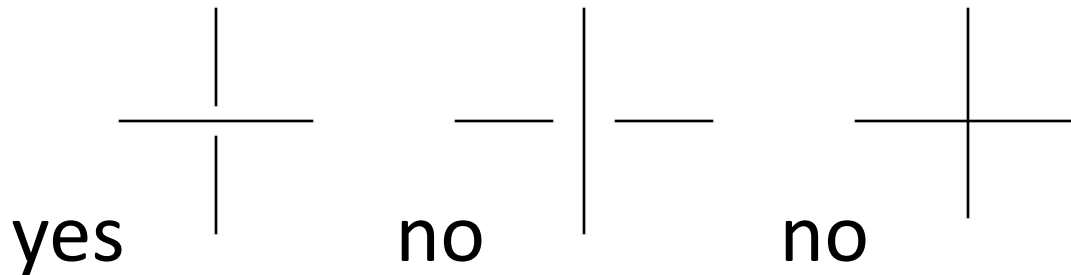
# Equipment Numbering (cont'd)

Thus, T-905 is the 5<sup>th</sup> tower in unit nine hundred P-301 A/B is the 1<sup>st</sup> 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	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	Toluene	Feed	Feed	Reactor	Recycle Gas	Reactor	HighPpres	Low Pres.	Tower	Benzene	Benzene	Benzene	Reflux	Reflux	Product
Storage	Feed Pumps	Preheater	Heater		Compressor	Effluent	Phase Sep.	Phase Sep.	Feed	Reboiler	Column	Condenser	Drum	Pumps	Cooler
Drum						Cooler			Heater						

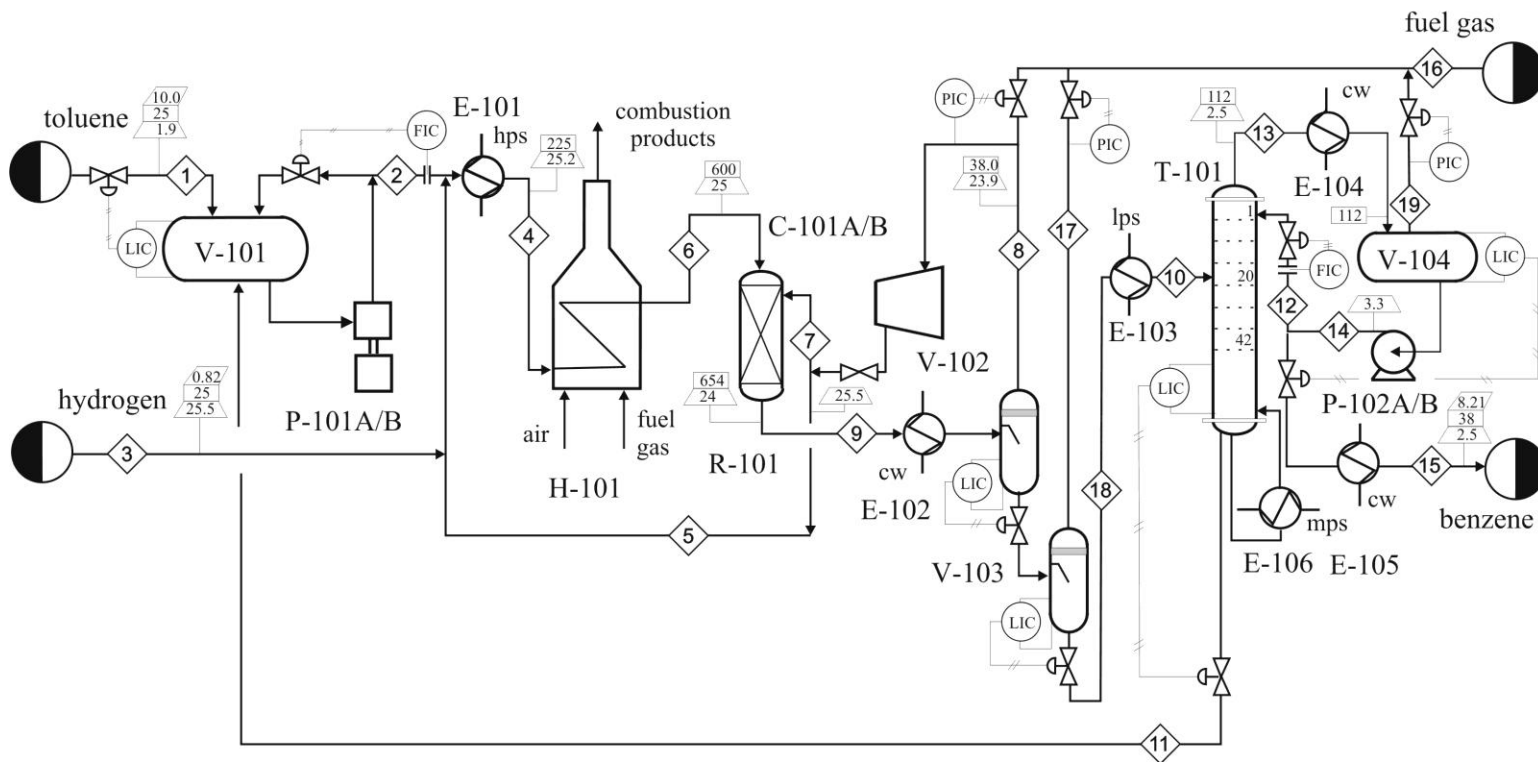


Figure 1.5: Process flow diagram (PFD) for the production of benzene via the hydrodealkylation of toluene

# 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	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	Toluene	Feed	Feed	Reactor	Recycle Gas	Reactor	HighPres	Low Pres.	Tower	Benzene	Benzene	Benzene	Reflux	Reflux	Product
Storage	Feed Pumps	Preheater	Heater		Compressor	Effluent	Phase Sep.	Phase Sep.	Feed	Reboiler	Column	Condenser	Drum	Pumps	Cooler
Drum						Cooler			Heater						

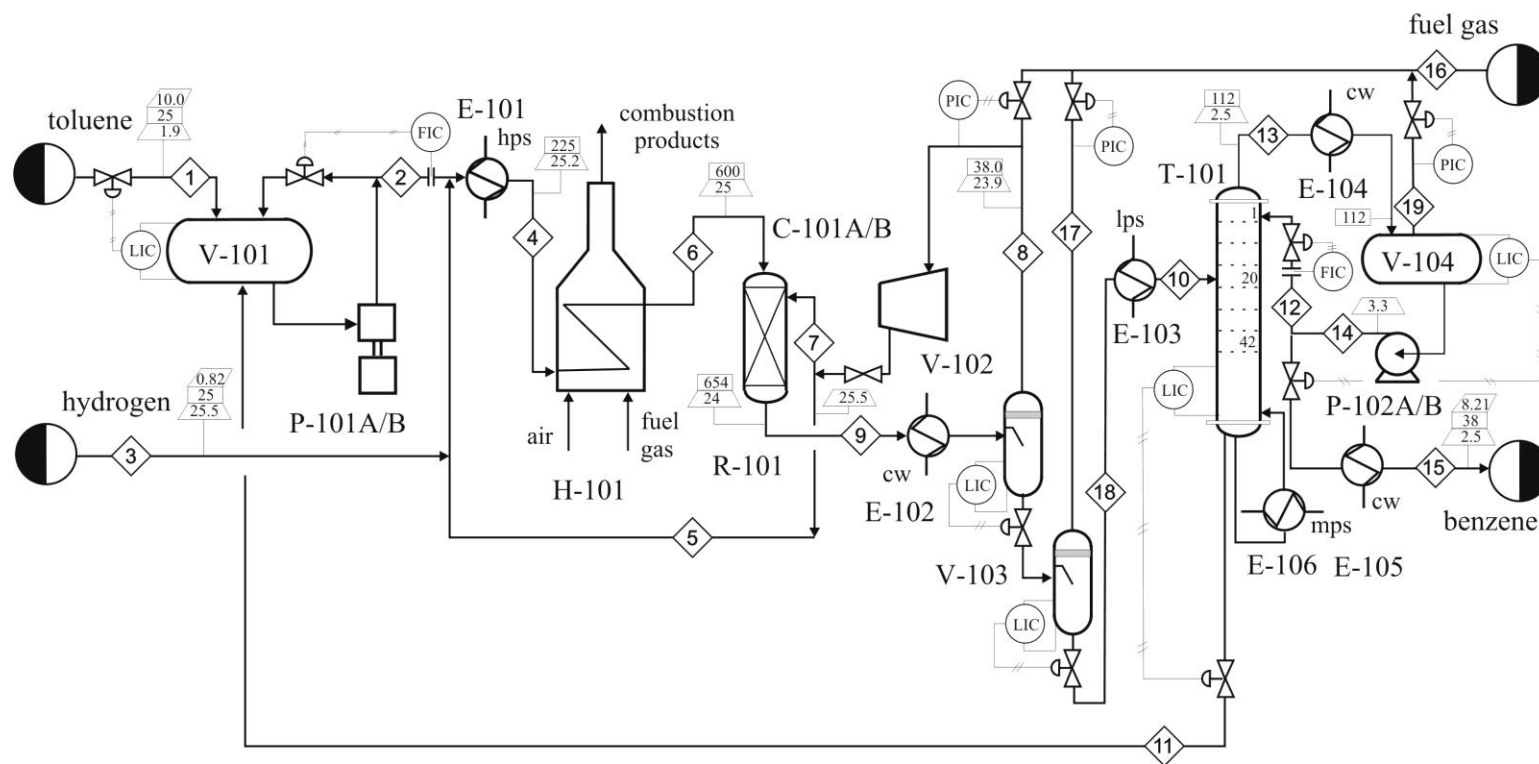
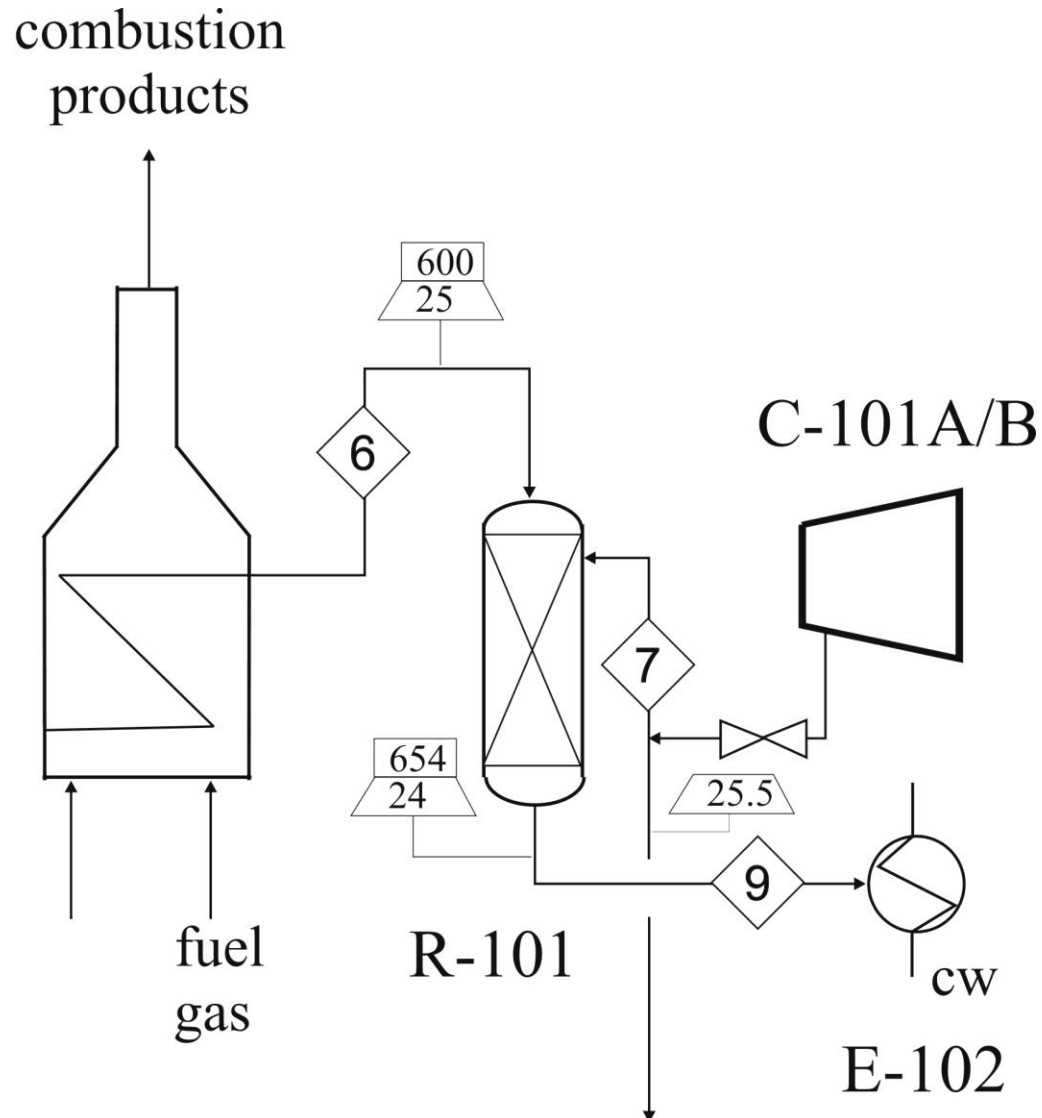


Figure 1.5: Process flow diagram (PFD) for the production of benzene via the hydrodealkylation of toluene

# Stream Information - Flags



# The Process Flow Diagram (cont'd)

Table 1.4: Information in a Flow Summary

## **Essential Information**

Stream Number  
Temperature ( $^{\circ}\text{C}$ )  
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 ( $\text{m}^3/\text{h}$ )  
Significant Physical Properties  
    Density  
    Viscosity  
    Other  
Thermodynamic Data  
Heat Capacity  
Stream Enthalpy  
K-values  
Stream Name

# The Process Flow Diagram (cont'd)

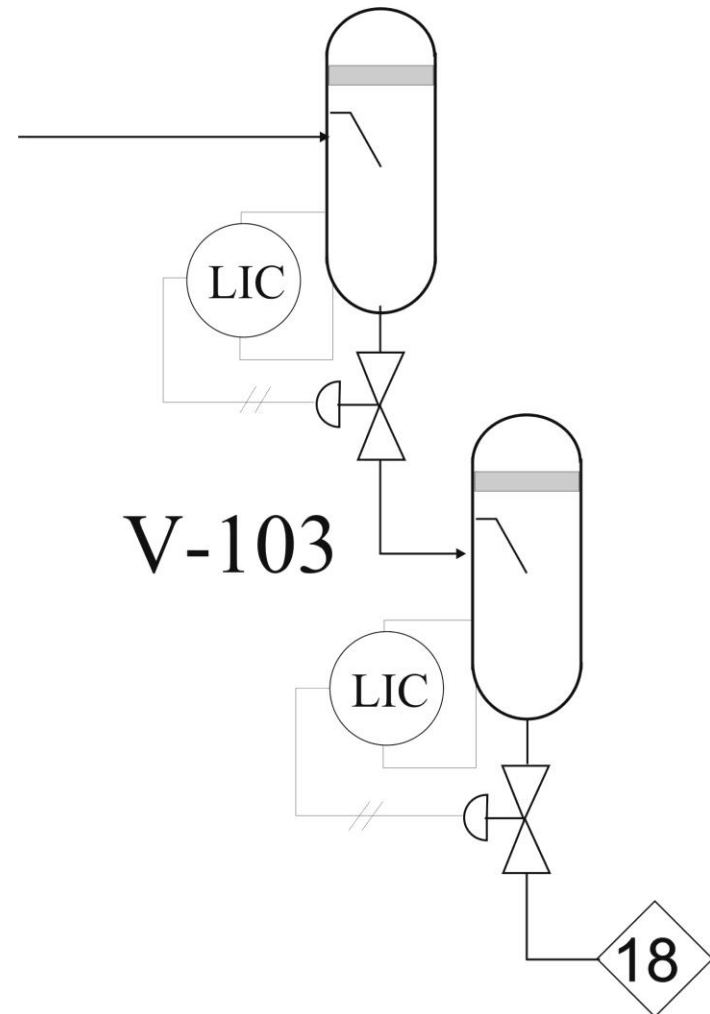
A Portion of Table 1.5

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

<b>Vessel</b>	V-101	V-102
Temperature (°C)	55	38
Pressure (bar)	2.0	24
Orientation	Horizontal	Vertical
MOC	CS	CS
<b>Size</b>		
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

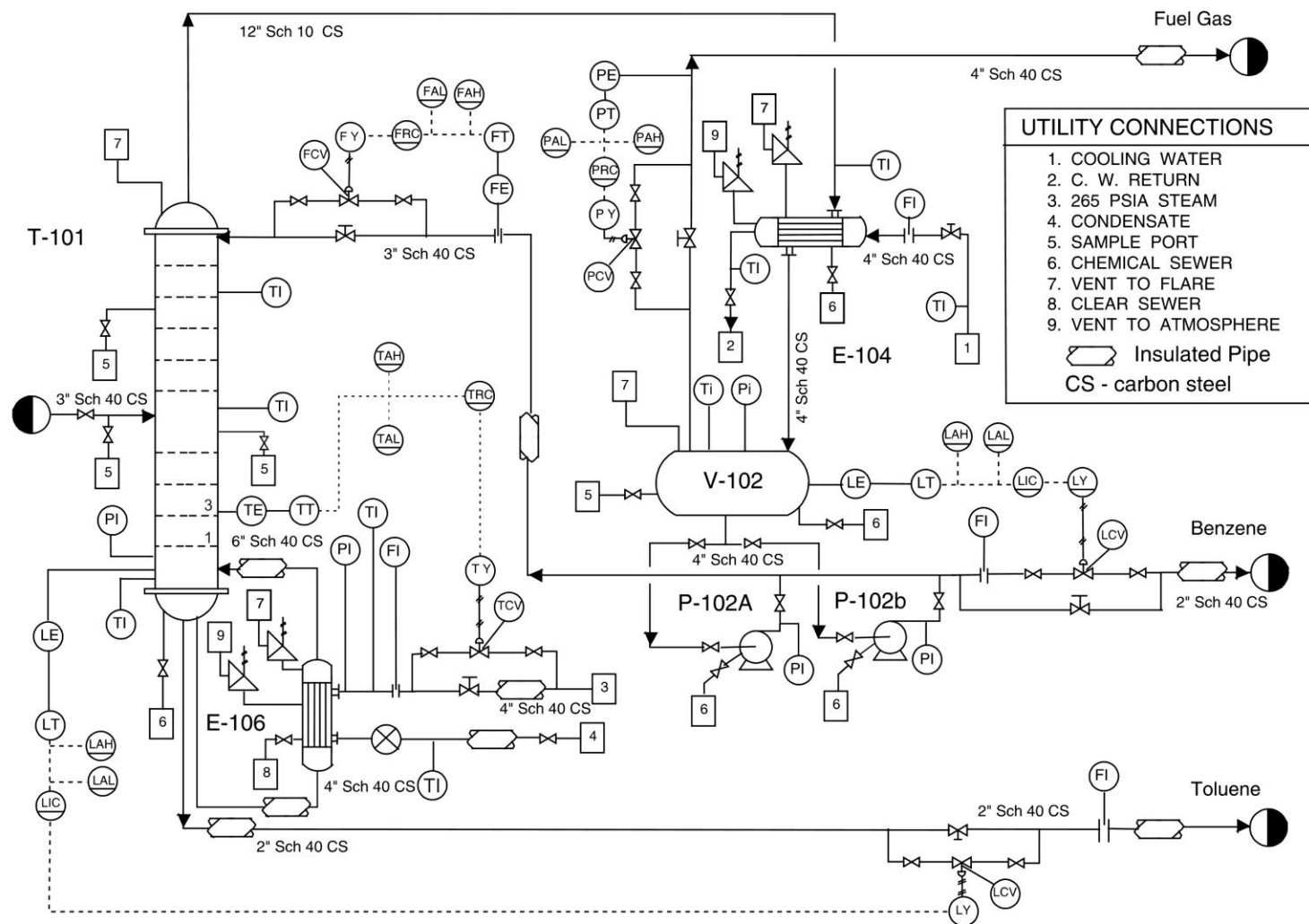


Figure 1.7 : Piping and Instrumentation Diagram for Benzene Distillation (adapted from Kauffman, D, Flow Sheets and Diagrams," AIChE Modular Instruction, Series G: Design of Equipment, series editor J. Beckman, AIChE, New York, 1986, vol 1, Chapter G.1.5, AIChE copyright © 1986 AIChE, all rights reserved)

# Look at V-102 on P&ID

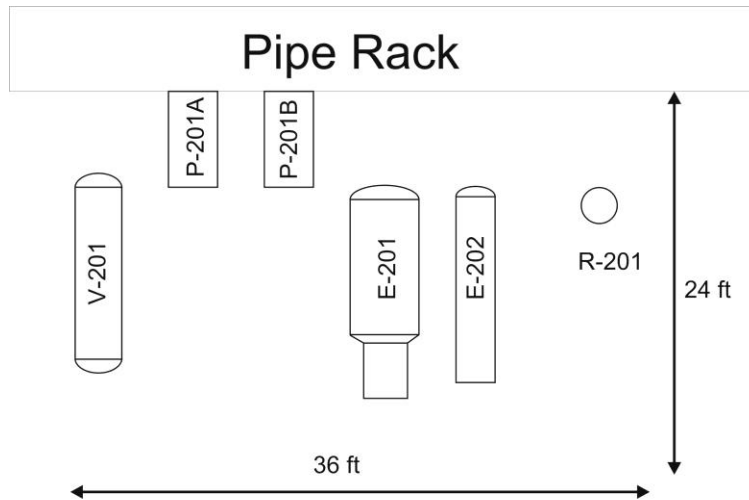
V-102 contains an LE (Level Element)

- 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

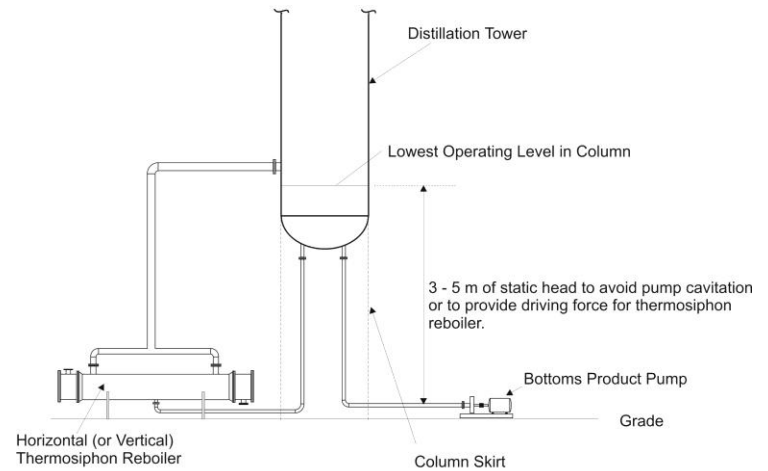
# Other Common Diagrams

- 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

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# H2S CONCENTRATOR AND STRIPPER A

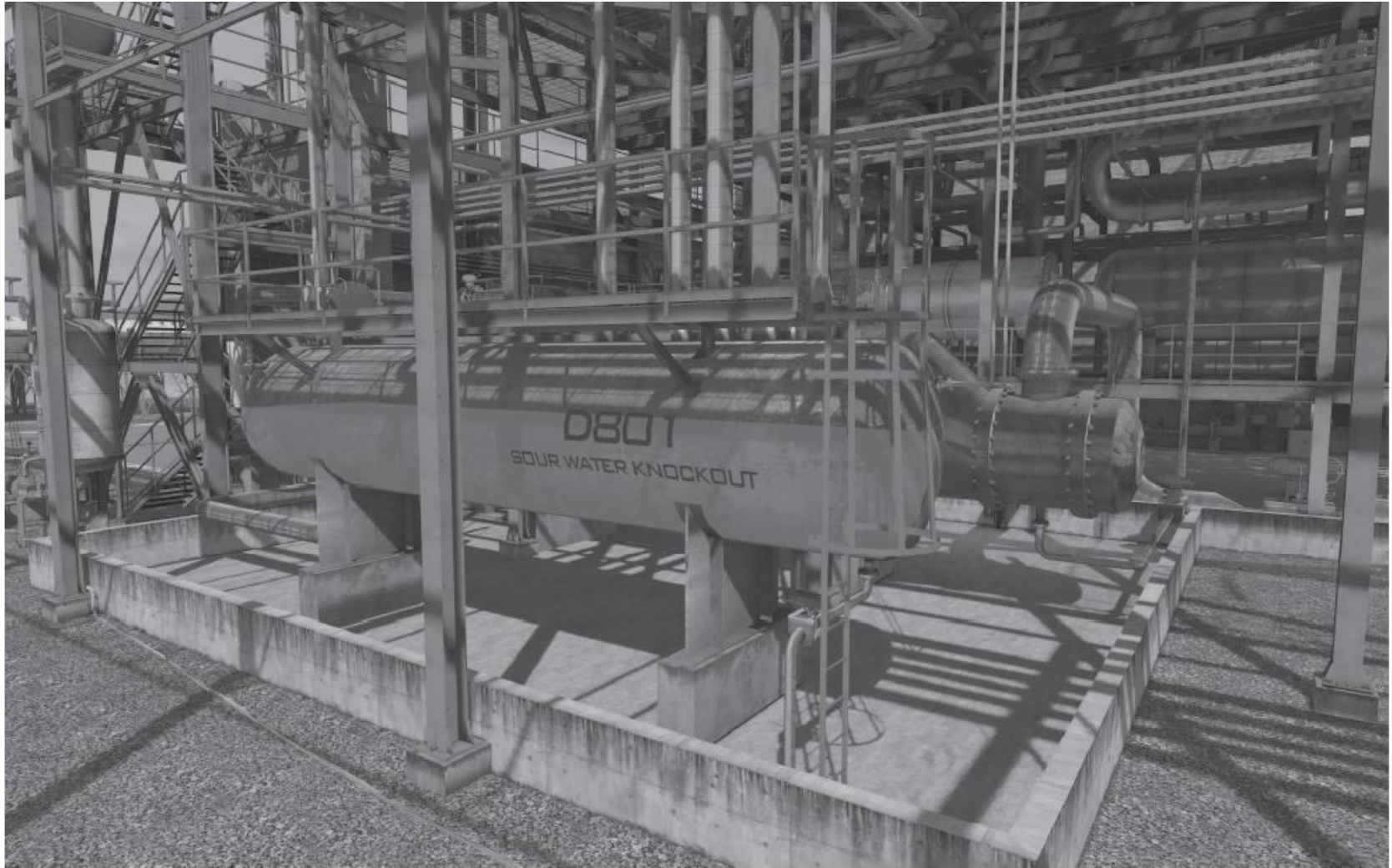
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The diagram illustrates the H<sub>2</sub>S Concentrator and Stripper A process. Key components and flows include:

- Inputs:** H<sub>2</sub>S & CO<sub>2</sub> Absorbers A, CW Return Cooling Water System, From E1006, From T1002, To E1001 AGR Coolers.
- Process Flow:** H<sub>2</sub>S gas flows through the T1004 H<sub>2</sub>S Concentrator, then through the E1009 Recycle Gas Cooler and E1008 Stripped Gas Cooler. It is then compressed by the C1002 Stripper Gas Compressor and flows into the D1005 Stripped Gas KO Drum. The gas then enters the T1003 Selexol Stripper, which is heated by the E1007 Reboiler. The stripped gas is then cooled by the E1004A and E1004B Acid Gas Coolers and flows into the D1006 Acid Gas KO Drum. The gas is then sent to the Class Furnace & WRB.
- Outputs:** To E1004, To E1001, To E1002, To E1003, To E1004, To E1005, To E1006, To E1007, To E1008, To E1009, To E1010, To E1011, To E1012, To E1013, To E1014, To E1015, To E1016, To E1017, To E1018, To E1019, To E1020, To E1021, To E1022, To E1023, To E1024, To E1025, To E1026, To E1027, To E1028, To E1029, To E1030, To E1031, To E1032, To E1033, To E1034, To E1035, To E1036, To E1037, To E1038, To E1039, To E1040, To E1041, To E1042, To E1043, To E1044, To E1045, To E1046, To E1047, To E1048, To E1049, To E1050, To E1051, To E1052, To E1053, To E1054, To E1055, To E1056, To E1057, To E1058, To E1059, To E1060, To E1061, To E1062, To E1063, To E1064, To E1065, To E1066, To E1067, To E1068, To E1069, To E1070, To E1071, To E1072, To E1073, To E1074, To E1075, To E1076, To E1077, To E1078, To E1079, To E1080, To E1081, To E1082, To E1083, To E1084, To E1085, To E1086, To E1087, To E1088, To E1089, To E1090, To E1091, To E1092, To E1093, To E1094, To E1095, To E1096, To E1097, To 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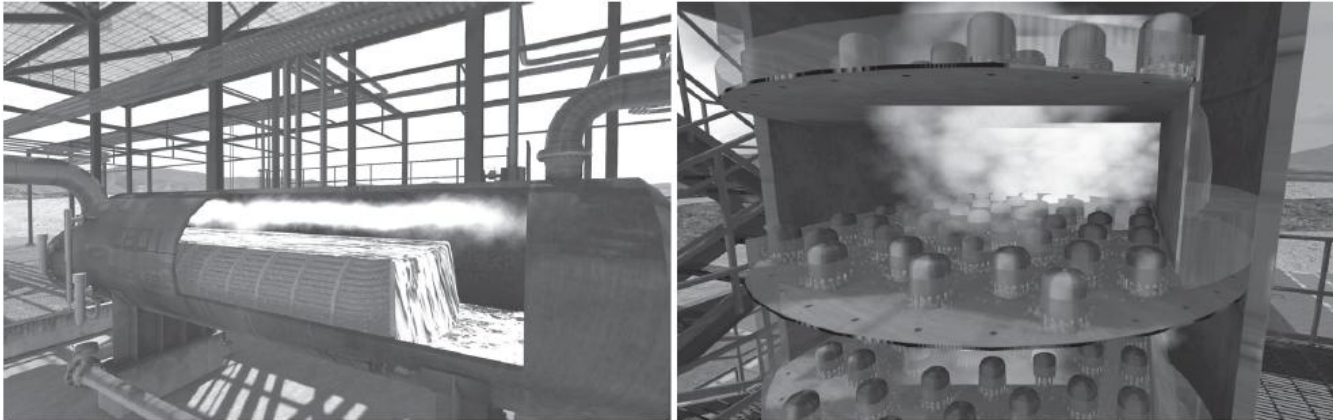
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# OPERATOR AND 3-D IMMERSIVE TRAINING SIMULATORS



**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)

