

Flowsheets

A plant design is made up of words, numbers, and pictures. An engineer thinks naturally in terms of the sketches and drawings which are his "pictures."

Thus, to solve a material balance problem, he will start with a block to represent the equipment and then will show entering and leaving streams with their amounts and properties. Or ask him to describe a process and he will begin to sketch the equipment, show how it is interconnected, and what the flows and operating conditions are.

Such sketches develop into flow sheets, which are more

elaborate diagrammatic representations of the equipment, the sequence of operations, and the expected performance of a proposed plant or the actual performance of an already operating one. For clarity and to meet the needs of the various persons engaged in design, cost estimating, purchasing, fabrication, operation, maintenance, and management, several different kinds of flowsheets are necessary. Four of the main kinds will be described and illustrated.

2.1. BLOCK FLOWSHEETS

At an early stage or to provide an overview of a complex process or plant, a drawing is made with rectangular blocks to represent individual processes or groups of operations, together with quantities and other pertinent properties of key streams between the blocks and into and from the process as a whole. Such block flowsheets are made at the beginning of a process design for orientation purposes or later as a summary of the material balance of the process. For example, the coal carbonization process of Figure 2.1 starts with 100,000 lb/hr of coal and some process air, involves six main process units, and makes the indicated quantities of ten different products. When it is of particular interest, amounts of utilities also may be shown; in this example the use of steam is indicated at one point. The block diagram of Figure 2.2 was prepared in connection with a study of the modification of an existing petroleum refinery. The three feed stocks are separated into more than 20 products. Another representative petroleum refinery block diagram, in Figure 13.20, identifies the various streams but not their amounts or conditions.

2.2. PROCESS FLOWSHEETS

Process flowsheets embody the material and energy balances between and the sizing of the major equipment of the plant. They include all vessels such as reactors, separators, and drums; special processing equipment, heat exchangers, pumps, and so on. Numerical data include flow quantities, compositions, pressures, temperatures, and so on. Inclusion of major instrumentation that is essential to process control and to complete understanding of the flowsheet without reference to other information is required particularly during the early stages of a job, since the process flowsheet is drawn first and is for some time the only diagram representing the process. As the design develops and a mechanical flowsheet gets underway, instrumentation may be taken off the process diagram to reduce the clutter. A checklist of the information that usually is included on a process flowsheet is given in Table 2.1.

Working flowsheets are necessarily elaborate and difficult to represent on the page of a book. Figure 2.3 originally was 30 in. wide. In this process, ammonia is made from available hydrogen supplemented by hydrogen from the air oxidation of natural gas in a two-stage reactor F-3 and V-S. A large part of the plant is devoted to purification of the feed gases of carbon dioxide and unconverted methane before they enter the converter CV-1. Both commercial and refrigeration grade ammonia are made in this plant. Compositions of 13 key streams are summarized in the tabulation.

Characteristics of the streams such as temperature, pressure, enthalpy, volumetric flow rates, etc., sometimes are conveniently included in the tabulation. In the interest of clarity, however, in some instances it may be preferable to have a separate sheet for a voluminous material balance and related stream information.

A process flowsheet of the dealkylation of toluene to benzene is in Figure 2.4; the material and enthalpy flows and temperature and pressures are tabulated conveniently, and basic instrumentation is represented.

2.3. MECHANICAL (P&I) FLOWSHEETS

Mechanical flowsheets also are called piping and instrument (P&I) diagrams to emphasize two of their major characteristics. They do not show operating conditions or compositions or flow quantities, but they do show all major as well as minor equipment more realistically than on the process flowsheet. Included are sizes and specification classes of all pipe lines, all valves, and all instruments. In fact, every mechanical aspect of the plant regarding the process equipment and their interconnections is represented except for supporting structures and foundations. The equipment is shown in greater detail than on the PFS, notably with regard to external piping connections, internal details, and resemblance to the actual appearance.

The mechanical flowsheet of the reaction section of a toluene dealkylation unit in Figure 2.5 shows all instrumentation, including indicators and transmitters. The clutter on the diagram is minimized by tabulating the design and operating conditions of the major equipment below the diagram.

The P&I diagram of Figure 2.6 represents a gas treating plant that consists of an amine absorber and a regenerator and their immediate auxiliaries. Internals of the towers are shown with exact locations of inlet and outlet connections. The amount of instrumentation for such a comparatively simple process may be surprising. On a completely finished diagram, every line will carry a code designation identifying the size, the kind of fluid handled, the pressure rating, and material specification. Complete information about each line—its length, size, elevation, pressure drop, fittings, etc.—is recorded in a separate line summary. On Figure 2.5, which is of an early stage of construction, only the sizes of the lines are shown. Although instrumentation symbols are fairly well standardized, they are often tabulated on the P&I diagram as in this example.

2.4. UTILITY FLOWSHEETS

These are P&I diagrams for individual utilities such as steam, steam condensate, cooling water, heat transfer media in general,

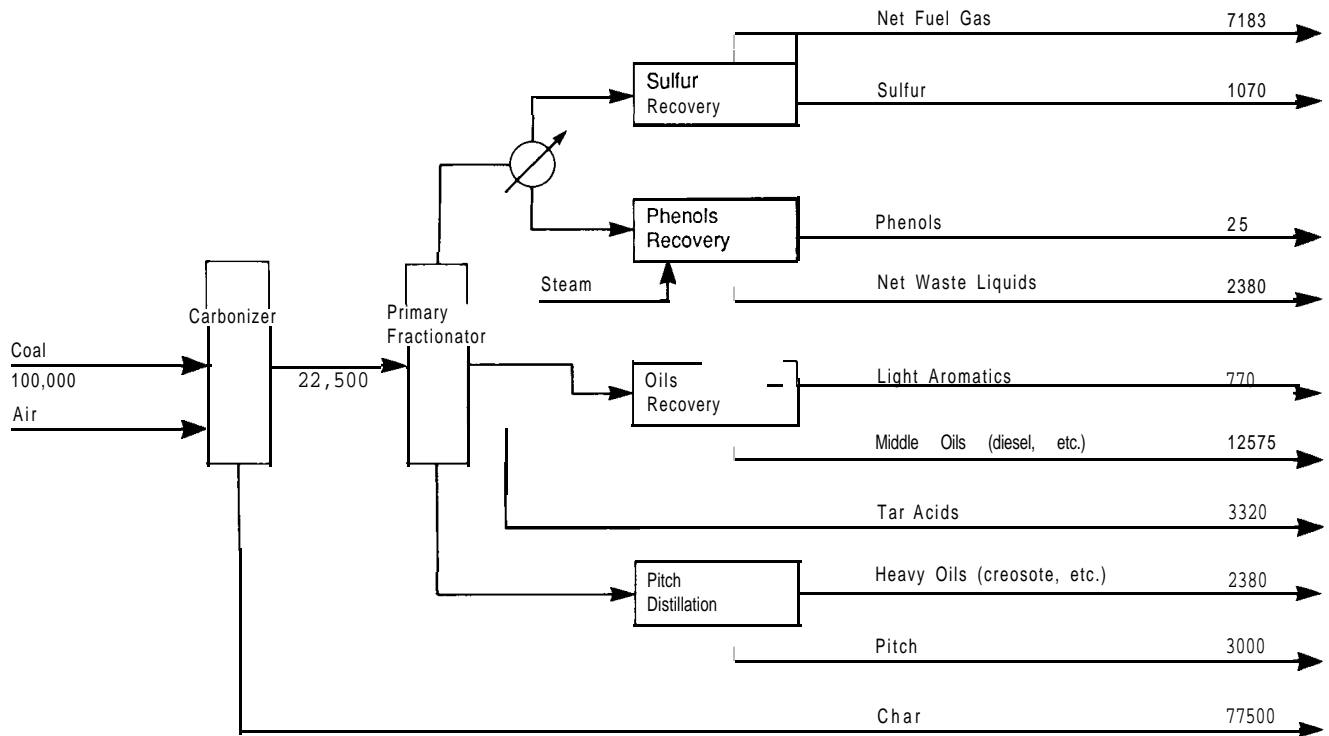


Figure 2.1. Coal carbonization block flowsheet. Quantities are in lb/hr.

compressed air, fuel, refrigerants, and inert blanketing gases, and how they are piped up to the process equipment. Connections for utility streams are shown on the mechanical flowsheet, and their conditions and flow quantities usually appear on the process flowsheet.

Since every detail of a plant design must be recorded on paper, many other kinds of drawings also are required: for example, electrical flow, piping isometrics, instrument lines, plans and elevations, and individual equipment drawings in all detail. Models and three-dimensional representations by computers also are now standard practice in many design offices.

2.5. DRAWING OF FLOWSHEETS

Flowsheets are intended to represent and explain processes. To make them easy to understand, they are constructed with a consistent set of symbols for equipment, piping, and operating conditions. At present there is no generally accepted industrywide body of drafting standards, although every large engineering office does have its internal standards. Some information appears in ANSI and British Standards publications, particularly of piping symbols. Much of this information is provided in the book by Austin (1979) along with symbols gleaned from the literature and some engineering firms. Useful compilations appear in some books on process design, for instance, those of Sinnott (1983) and Ulrich (1984). The many flowsheets that appear in periodicals such as *Chemical Engineering* or *Hydrocarbon Processing* employ fairly consistent sets of symbols that may be worth imitating.

Equipment symbols are a compromise between a schematic representation of the equipment and simplicity and ease of drawing. A selection for the more common kinds of equipment appears in Table 2.2. Less common equipment or any with especially intricate configuration often is represented simply by a circle or rectangle.

Since a symbol does not usually speak entirely for itself but also carries a name and a letter-number identification, the flowsheet can be made clear even with the roughest of equipment symbols. The

TABLE 2.1. Checklist of Data Normally Included on a Process Flowsheet

1. Process lines, but including only those bypasses essential to an understanding of the process
2. All process equipment. Spares are indicated by letter symbols or notes
3. Major instrumentation essential to process control and to understanding of the flowsheet
4. Valves essential to an understanding of the flowsheet
5. Design basis, including stream factor
6. Temperatures, pressures, flow quantities
7. Weight and/or mol balance, showing compositions, amounts, and other properties of the principal streams
6. Utilities requirements summary
9. Data included for particular equipment
 - a. Compressors: SCFM (60°F, 14.7 psia); APpsi; HHP; number of stages; details of stages if important
 - b. Drives: type; connected HP; utilities such as kW, lb steam/hr, or Btu/hr
 - c. Drums and tanks: ID or OD, seam to seam length, important internals
 - d. Exchangers: Sqft, kBtu/hr, temperatures, and flow quantities in and out; shell side and tube side indicated
 - e. Furnaces: kBtu/hr, temperatures in and out, fuel
 - f. Pumps: GPM (60°F), APpsi, HHP, type, drive
 - g. Towers: Number and type of plates or height and type of packing; identification of all plates at which streams enter or leave; ID or OD; seam to seam length; skirt height
 - h. Other equipment: Sufficient data for identification of duty and size

TABLE 2.2. Flowsheet Equipment Symbols

Fluid Handling	Heat Transfer
FLUID HANDLING	HEAT TRANSFER
Centrifugal pump or blower, motor driven	Shell-and-tube heat exchanger
Centrifugal pump or blower, turbine driven	Condenser
Rotary pump or blower	Reboiler
Reciprocating pump or compressor	Vertical thermosiphon reboiler
Centrifugal compressor	Kettle reboiler
Centrifugal compressor, alternate symbol	Air cooler with finned tubes
Steam ejector	Fired heater
Coil in tank	Fired heater with radiant and convective coils
Evaporator	Rotary dryer or kiln
Cooling tower, forced draft	Tray dryer
	Spray condenser with steam ejector

TABLE 2.2—(continued)

Mass Transfer	Vessels
MASS TRANSFER:	VESSELS
	Drum or tank
Tray column	
	Drum or tank
Packed column	
	Storage tank
Multistage stirred column	
	Open tank
spray column	
	Gas holder
Mixer-settler extraction battery	
	Jacketed vessel with agitator
	Vessel with heat transfer coil
	Bin for solids

letter-number designation consists of a letter or combination to designate the class of the equipment and a number to distinguish it from others of the same class, as two heat exchangers by E-112 and E-215. Table 2.4 is a typical set of letter designations.

Operating conditions such as flow rate, temperature, pressure,

enthalpy, heat transfer rate, and also stream numbers are identified with symbols called flags, of which Table 2.3 is a commonly used set. Particular units are identified on each flowsheet, as in Figure 2.3.

Letter designations and symbols for instrumentation have been


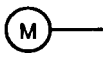
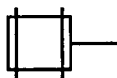
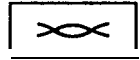




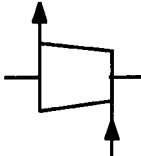

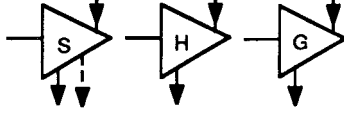

TABLE 2.2—(continued)

Conveyors and Feeders		Separators	
CONVEYORS & FEEDERS		SEPARATORS	
Conveyor		Plate-and-frame filter	
Belt conveyor		Rotary vacuum filter	
Screw conveyor		Sand filter	
Elevator		Dust collector	
Feeder		Cyclone separator	
Star feeder		Centrifuge	
Screw feeder		Mesh entrainment separator	
Weighing feeder		Liquid-liquid separator	
Tank car		Drum with water settling pot	
Freight car		Screen	
Conical settling tank			
Raked thickener			

thoroughly standardized by the Instrument Society of America (ISA). An abbreviated set that may be adequate for the usual flowsketch appears on Figure 3.4. The P&I diagram of Figure 2.6 affords many examples.

For clarity and for esthetic reasons, equipment should be represented with some indication of their relative sizes. True scale is not feasible because, for example, a flowsheet may need to depict both a tower 150ft high and a drum 2ft in diameter. Logarithmic

TABLE 2.2—(continued)

Mixing and Comminution		Drivers
MIXING & COMMINATION		DRIVERS
Liquid mixing impellers: basic, propeller, turbine, anchor		Motor  
Ribbon blender		DC motor 
Double cone blender		AC motor, 3-phase 
Crusher		Turbine 
Roll crusher		Turbines: steam, hydraulic, gas 
Pebble or rod mill		

scaling sometimes gives a pleasing effect; for example, if the 150 ft tower is drawn 6in. high and the 2ft drum 0.5 in., other sizes can be read off a straight line on log-log paper.

A good draftsman will arrange his flowsheet as artistically as possible, consistent with clarity, logic, and economy of space on the drawing. A fundamental rule is that there be no large gaps. Flow is predominantly from left to right. On a process flowsheet, distillation towers, furnaces, reactors, and large vertical vessels often are arranged at one level, condenser and accumulator drums on another level, reboilers on still another level, and pumps more or less on one level but sometimes near the equipment they serve in order to minimize excessive crossing of lines. Streams enter the flowsheet from the left edge and leave at the right edge. Stream numbers are assigned to key process lines. Stream compositions and other desired properties are gathered into a table that may be on a

separate sheet if it is especially elaborate. A listing of flags with the units is desirable on the flowsheet.

Rather less freedom is allowed in the construction of mechanical flowsheets. The relative elevations and sizes of equipment are preserved as much as possible, but all pumps usually are shown at the same level near the bottom of the drawing. Tabulations of instrumentation symbols or of control valve sizes or of relief valve sizes also often appear on P&I diagrams. Engineering offices have elaborate checklists of information that should be included on the flowsheet, but such information is beyond the scope here.

Appendix 2.1 provides the reader with material for the construction of flowsheets with the symbols of this chapter and possibly with some reference to Chapter 3.

TABLE 2.3. Flowsheet Flags of Operating Conditions in
Typical Units

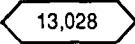
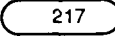
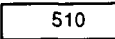

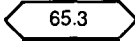
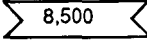
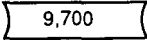
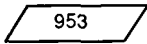
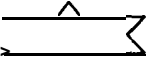
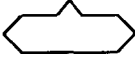
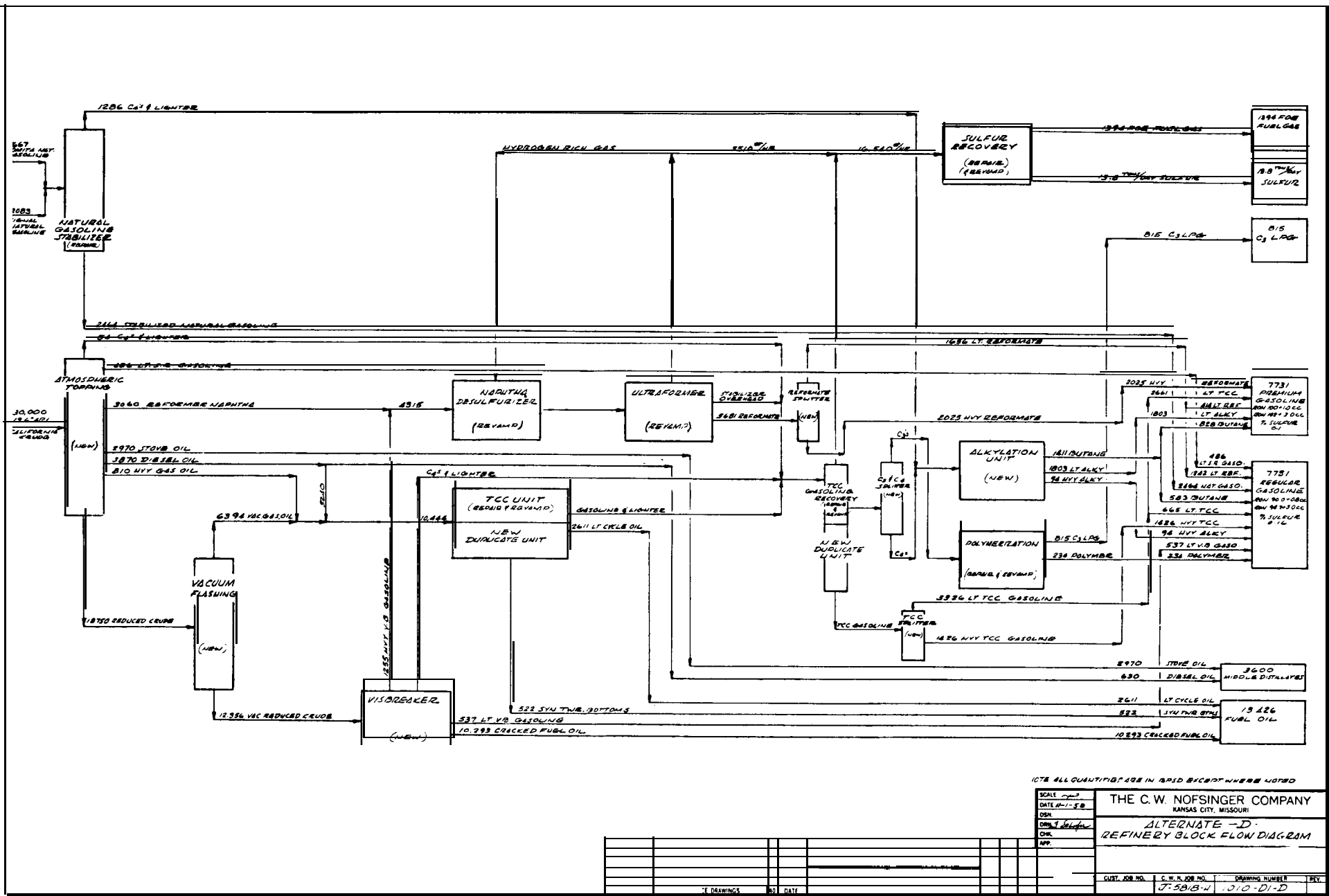
Mass flow rate, lbs/hr		13,028
Molal flow rate, lbmols/hr		217
Temperature, °F		510
Pressure, psig (or indicate if psia or Torr or bar)		155 psia
Volumetric liquid flow rate, gal/min.		65.3
Volumetric liquid flow rate, bbls/day		8,500
Kilo Btu/hr, at heat transfer equipment		9,700
Enthalpy, Btu/lb		953
Others		

TABLE 2.4. Letter Designations of Equipment

Equipment	Letters	Equipment	Letters
Agitator	M	Grinder	SR
Air filter	FG	Heat exchanger	E
Bin	I-r	Homogenizer	M
Blender	M	Kettle	R
Blower	JB	Kiln (rotary)	DD
Centrifuge	FF	Materials handling equipment	G
Classifying equipment	S	Miscellaneous*	L
Colloid mill	SR	Mixer	M
Compressor	JC	Motor	PM
Condenser	E	Oven	B
Conveyor	C	Packaging machinery	L
Cooling tower	TE	Precipitator (dust or mist)	FG
Crusher	SR	Prime mover	PM
Crystallizer	K	Pulverizer	SR
Cyclone separator (gas)	FG	Pump (liquid)	J
Cyclone separator (liquid)	F	Reboiler	E
Decanter	FL	Reactor	R
Disperser	M	Refrigeration system	G
Drum	D	Rotameter	RM
Dryer (thermal)	DE	Screen	S
Dust collector	FG	Separator (entrainment)	FG
Elevator	C	Shaker	M
Electrostatic separator	FG	Spray disk	SR
Engine	PM	Spray nozzle	SR
Evaporator	FE	Tank	I-r
Fan	JJ	Thickener	F
Feeder	C	Tower	T
Filter (liquid)	P	Vacuum equipment	VE
Furnace	B	Weigh scale	L

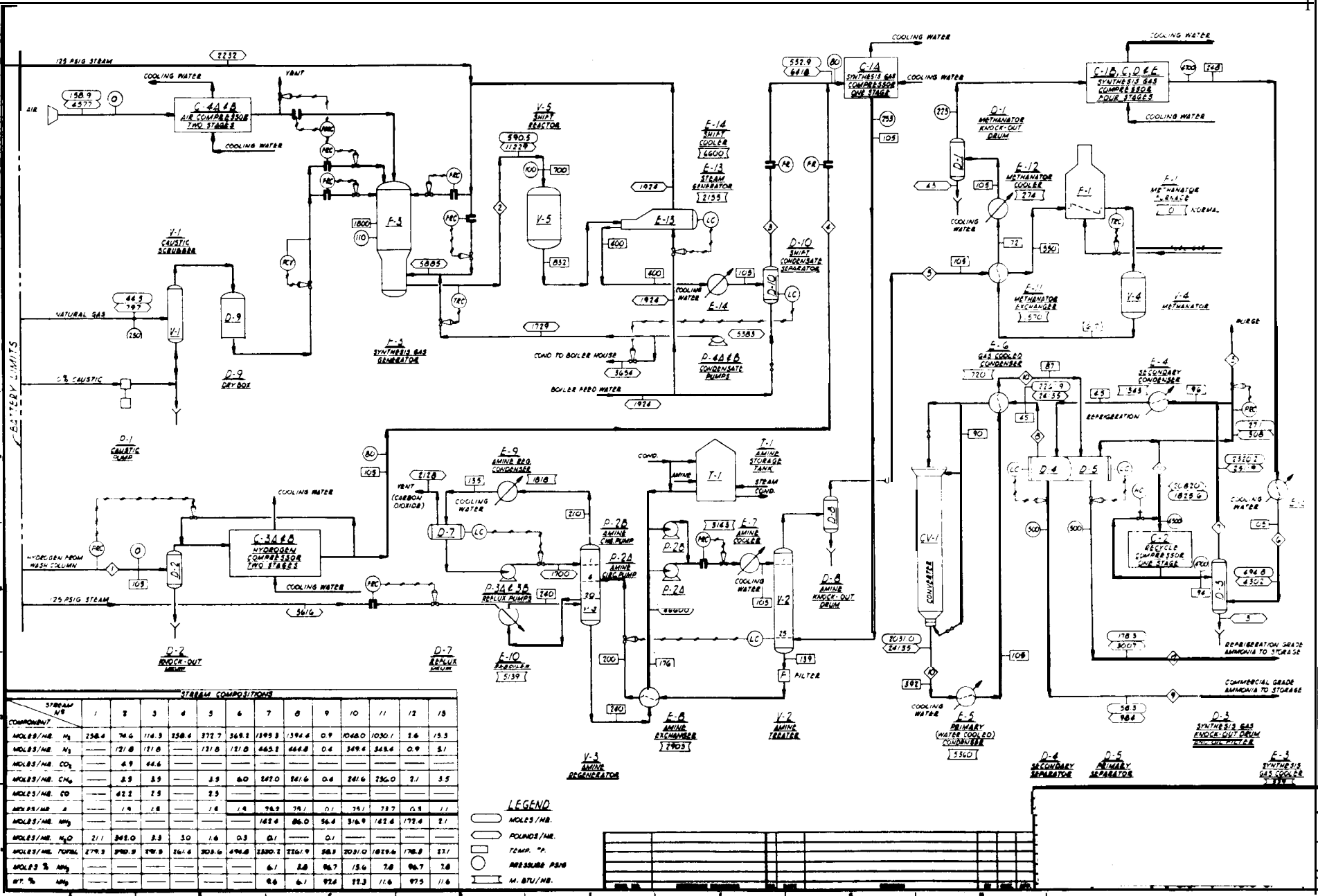
*Note: The letter L is used for unclassified equipment when only a few items are of this type; otherwise, individual letter designations are assigned.



NOTE ALL QUANTITIES ARE IN BBL/D BY EXCEPT WHERE NOTED

SCALE	DATE	THE C. W. NOFSINGER COMPANY KANSAS CITY, MISSOURI ALTERNATE - D - REFINERY BLOCK FLOW DIAGRAM	
DATE			
DESIGNER			
CHKD.			
APP.			
CUST. JOB NO.	C. W. N. JOB NO.	DRAWING NUMBER	REV.
	J-5818-4	1010-DI-D	

Fig 2.2. Block flowsheet of the revamp of a 30,000 Bbl/day refinery with supplementary light stocks (The C. W. Nofsinger Co.).



STREAM COMPOSITIONS

STREAM NO	1	2	3	4	5	6	7	8	9	10	11	12	13
COMPONENT													
MOLES/HR. H ₂	258.4	76.6	114.3	358.6	372.7	369.3	1899.3	1594.4	0.9	1048.0	1030.1	1.6	15.3
MOLES/HR. N ₂	171.8	171.8			131.8	131.8	463.3	464.8	0.4	349.4	348.4	0.9	5.1
MOLES/HR. CO ₂		4.9	48.6										
MOLES/HR. CH ₄		2.3	3.9		2.3	6.0	347.0	261.6	0.6	281.6	236.0	7.1	5.5
MOLES/HR. CO		42.3	2.5		2.5								
MOLES/HR. H ₂ O		1.4	1.8		1.4	1.4	94.9	74.1	0.1	74.1	73.7	0.1	1.1
MOLES/HR. NH ₃							182.4	86.0	36.4	316.9	182.4	172.4	2.1
MOLES/HR. H ₂ O	21.1	348.0	2.3	3.0	1.6	0.3	0.1	0.1					
MOLES/HR. TOTAL	279.3	390.9	97.9	261.6	303.6	494.8	1300.2	220.9	96.3	2091.0	1829.6	178.8	22.1
MOLES % NH ₃							6.7	2.8	96.7	15.6	7.8	96.7	7.8
WT. % NH ₃							8.6	6.1	92.4	22.3	11.6	97.9	11.6

LEGEND

- MOLES/HR.
- POUNDS/HR.
- TEMP. °F.
- PRESSURE PSIG.
- M. BTU/HR.

Figure 2.3. Process flowsheet of a plant making 47 tons/day of ammonia from available hydrogen and hydrogen made from natural gas (The C. W. Nofsinger Co.).

Figure 2.4. Process flowsheet of the manufacture of benzene by dealkylation of toluene (Wells, Safety in Process Design, George Godwin, London, 1980).

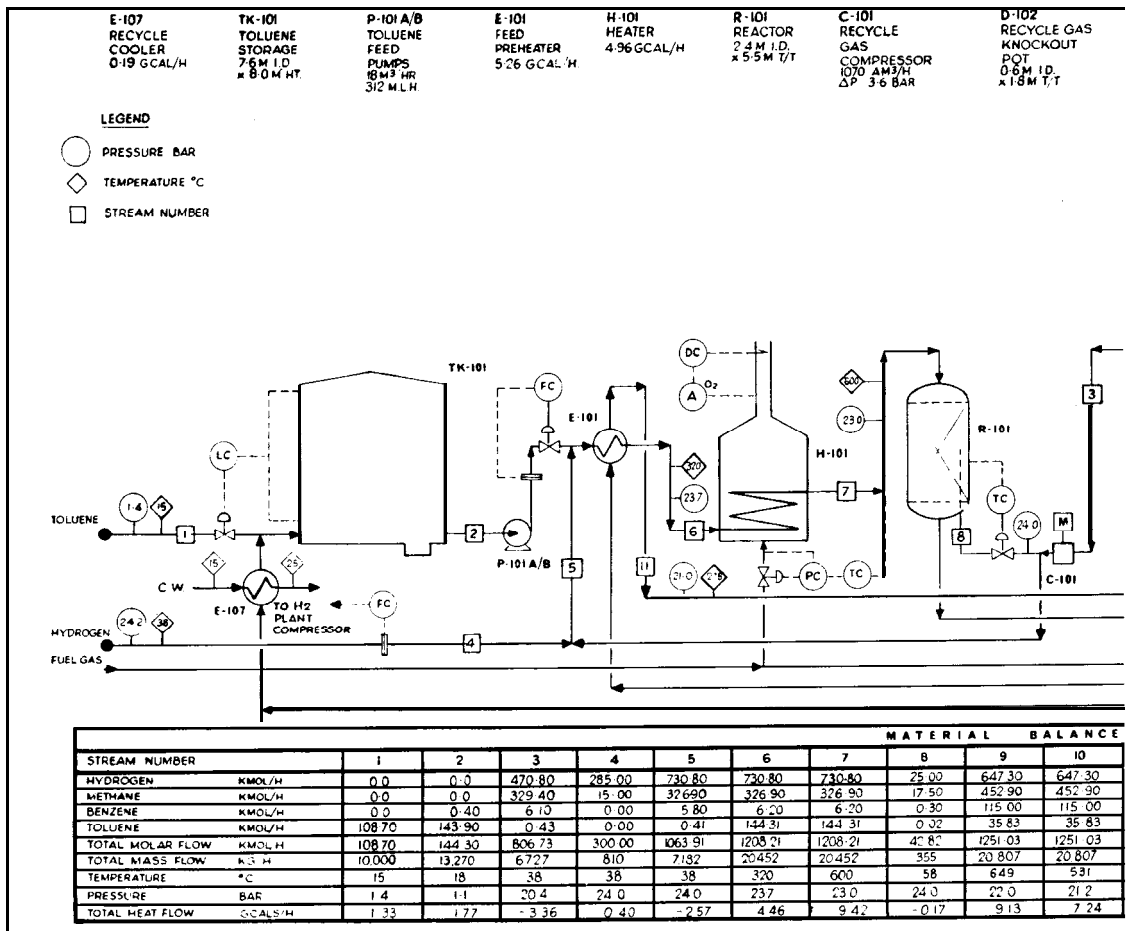
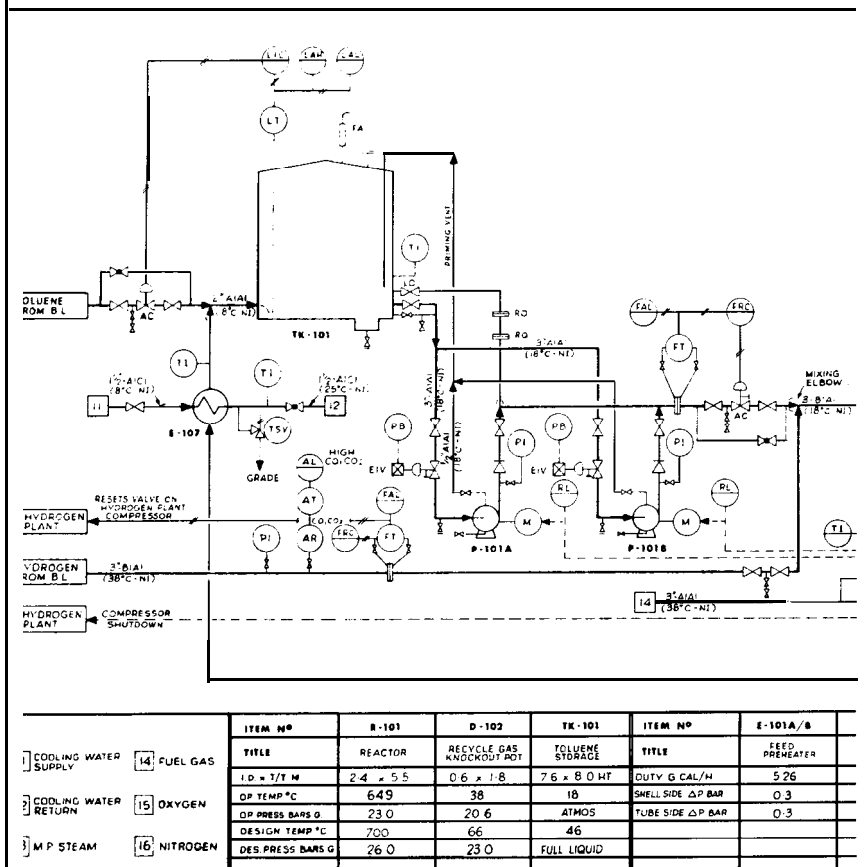
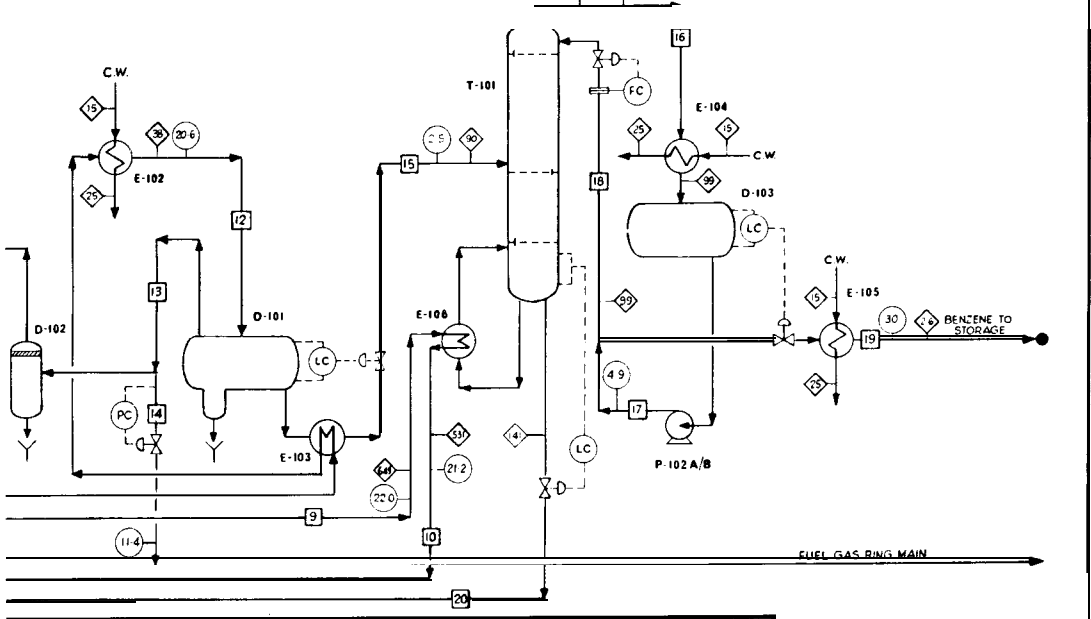


Figure 2.5. Engineering (P&I) flowsheet of the reaction section of plant for dealkylation of benzene (Wells, Safety in Process Design, George Godwin, London, 1980).

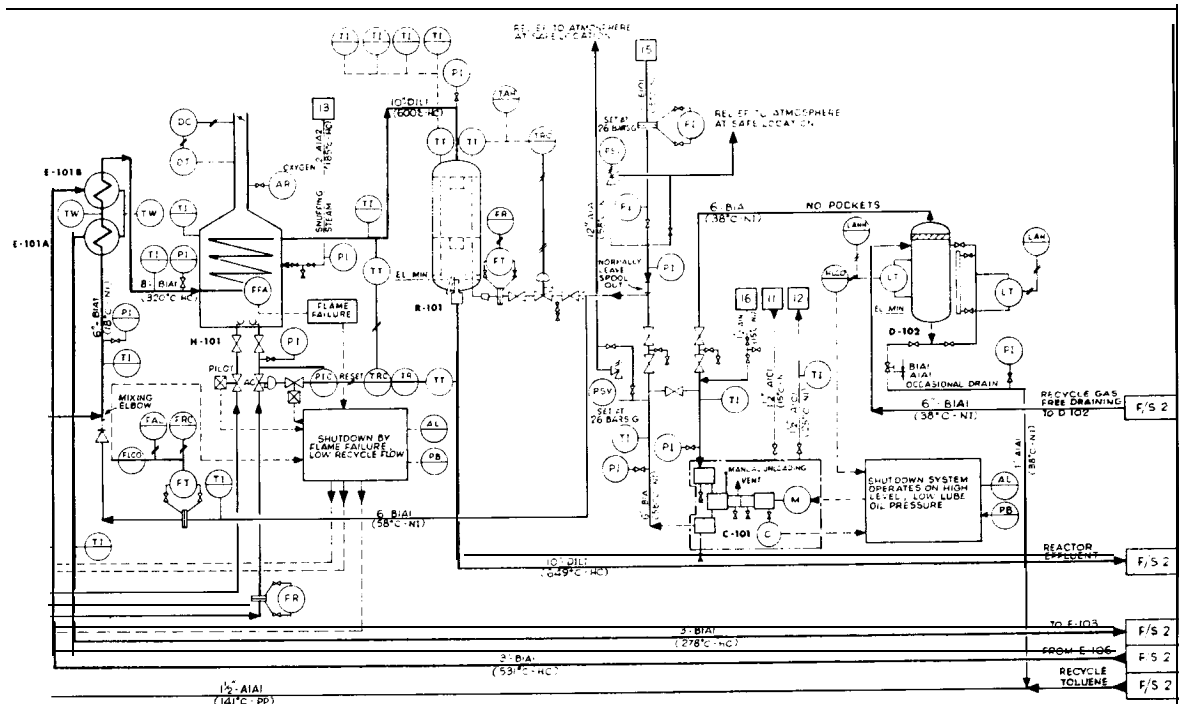


E-102 REACTOR EFFLUENT CONDENSER 3.74 GCAL/H
 D-101 HIGH PRESSURE KNOCKOUT POT 2.3 M I.D. x 6.7 M T/T
 E-103 BENZENE COLUMN REHEATER 0.18 GCAL/H
 T-101 BENZENE COLUMN 1.5 M I.D. x 20.0 M T/T
 E-104 OVERHEAD CONDENSER 1.83 GCAL/H
 D-103 REFLUX ACCUMULATOR 1.0 M I.D. x 2.5 M T/T
 P-102 A/B REFLUX PUMPS 27 M³/H x 35 M.L.H.
 E-105 PRODUCT COOLER 0.26 GCAL/H
 E-106 BENZENE REBOILER 2.07 GCAL/H



11	12	13	14	15	16	17	18	19	20
647.30	647.30	647.30	176.50	0.00	0.00	0.00	0.00	0.00	0.00
452.90	452.90	452.90	123.50	0.00	0.00	0.00	0.00	0.00	0.00
115.00	115.00	8.40	2.30	106.60	245.70	245.70	139.50	106.20	0.40
35.83	35.83	0.59	0.16	35.24	0.09	0.09	0.05	0.04	35.20
1251.03	1251.03	1109.10	302.46	141.84	245.79	245.70	139.65	106.21	35.60
20.807	20.807	9.250	2.523	11.557	19.173	19.173	10.886	8.267	3.270
278	38	38	38	99	99	99	99	30	141
21.0	20.6	20.6	20.6	2.5	2.0	2.9	2.9	2.6	2.3
1.98	-1.94	-4.62	-1.26	2.86	7.18	5.39	3.06	2.06	0.63

XYZ ENGINEERING LTD.
 TITLE: PROCESS FLOW DIAGRAM
 BENZENE PLANT
 Project No. Date: / / Rev. No. A-1001 1/8



(N.B. LINE & INSTRUMENT NOS OMITTED FOR CLARITY)

E-107	H-101	ITEM NO	P-101A	P-101B	ITEM NO	C-101
RECYCLE COOLER	HEATER	TITLE	TOLUENE FIELD PUMP	SPARE FOR P-101A	TITLE	RECYCLE GAS COMPRESSOR
0.19	4.96	CAPACITY M ³ /H	.18	.18	CAPACITY AM ³ /H	1070
0.35	-	HEAD M.L.C.	3.2	3.2	Δ PRESS BAR	3.6
0.7	0.7	PUMPING TEMP °C	.18	.18		
		S.G. AT P.T.	0.87	0.87		

XYZ ENGINEERING LTD.
 TITLE: ENGINEERING LINE DIAGRAM
 (Sheet 1 of 2)
 REACTION STAGE
 BENZENE PLANT
 Project No. Date: / / Rev. No. B-1001 1/8

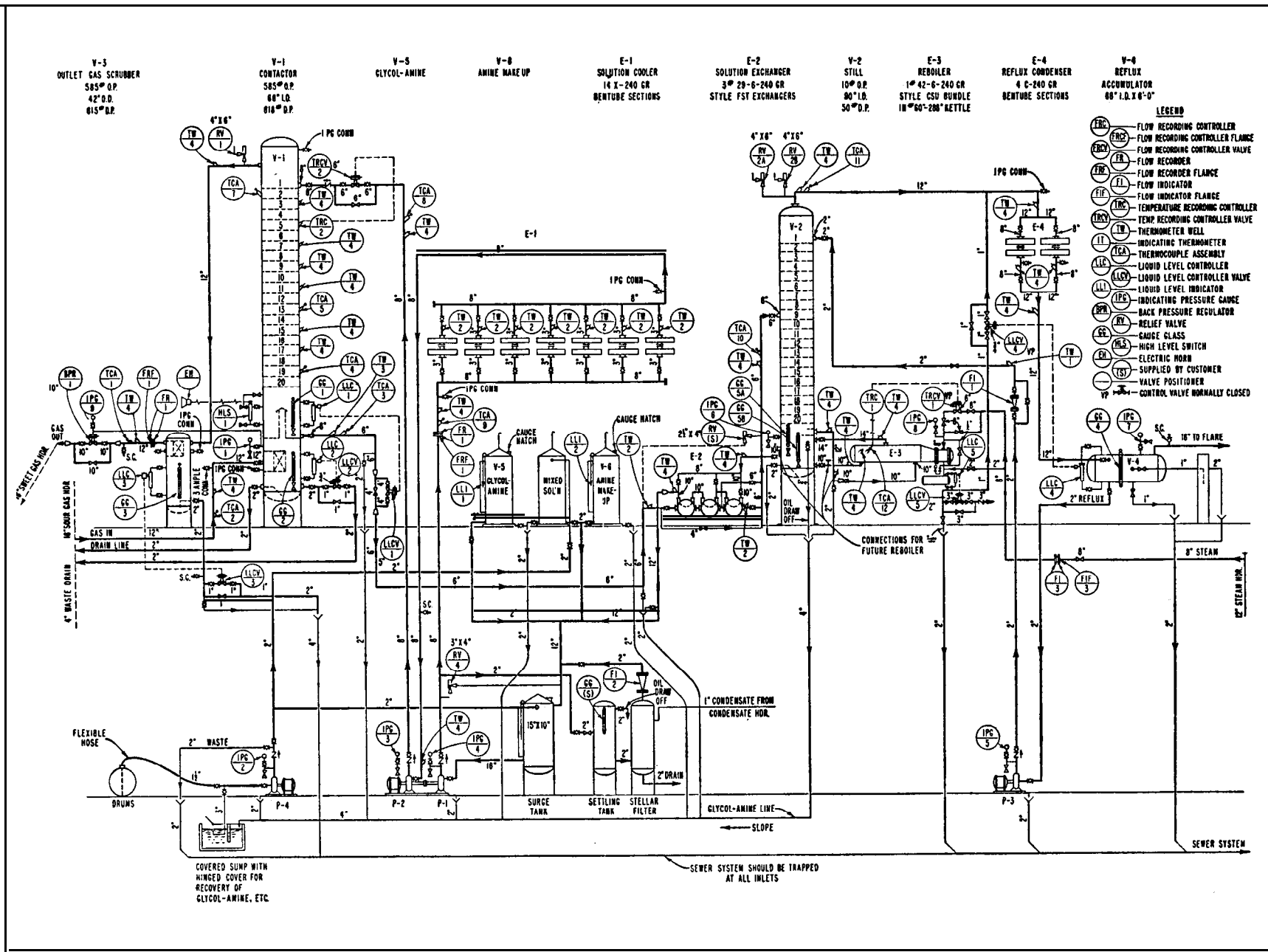


Figure 2.6. Engineering flowsheet of a gas treating plant. Note the tabulation of instrumentation flags at upper right (*Fluor Engineers, by way of Ruse and Barrow, Project Engineering of Process Plants, Wiley, New York, 1957*).

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