2

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-5. 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,

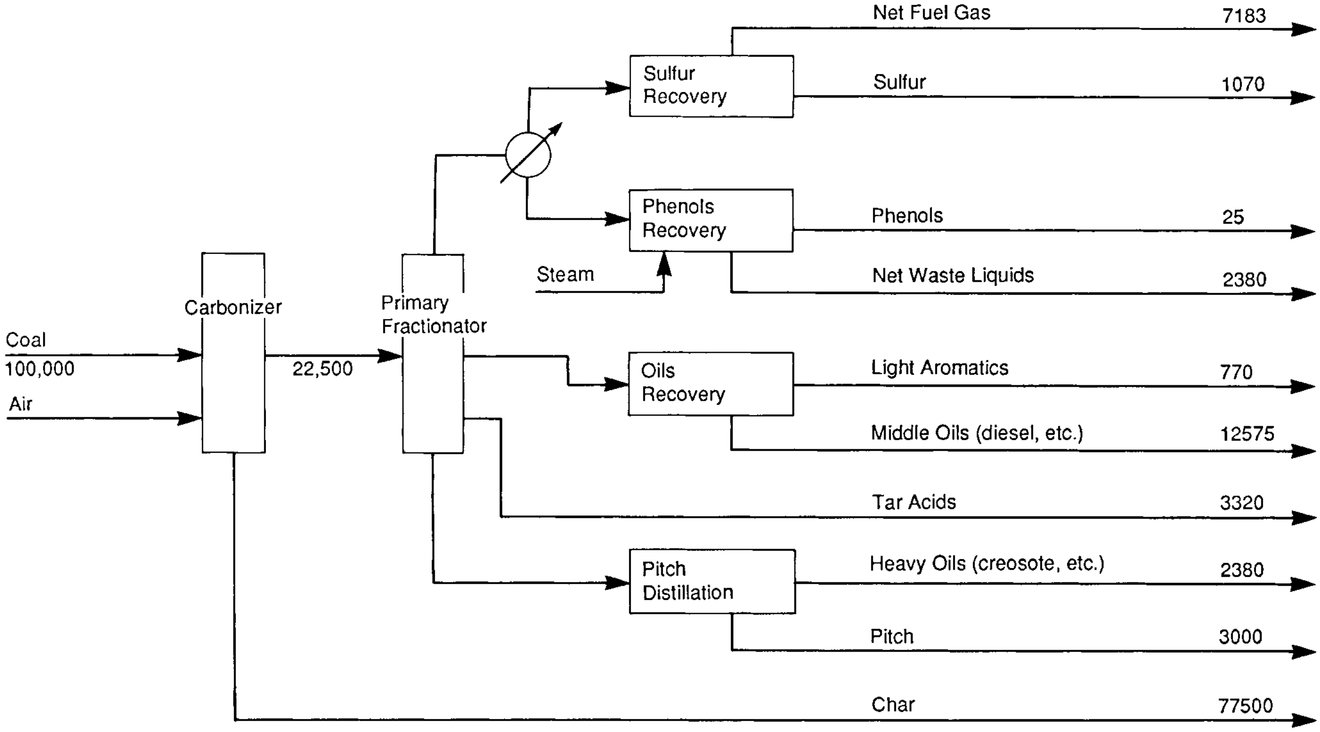


Figure 2.1. Coal carbonization block flowsheet. Quantities are in lb/hr.

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
8. Utilities requirements summary
9. Data included for particular equipment
   a. Compressors: SCFM (60°F, 14.7 psia); ΔP psi; 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), ΔP psi, 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

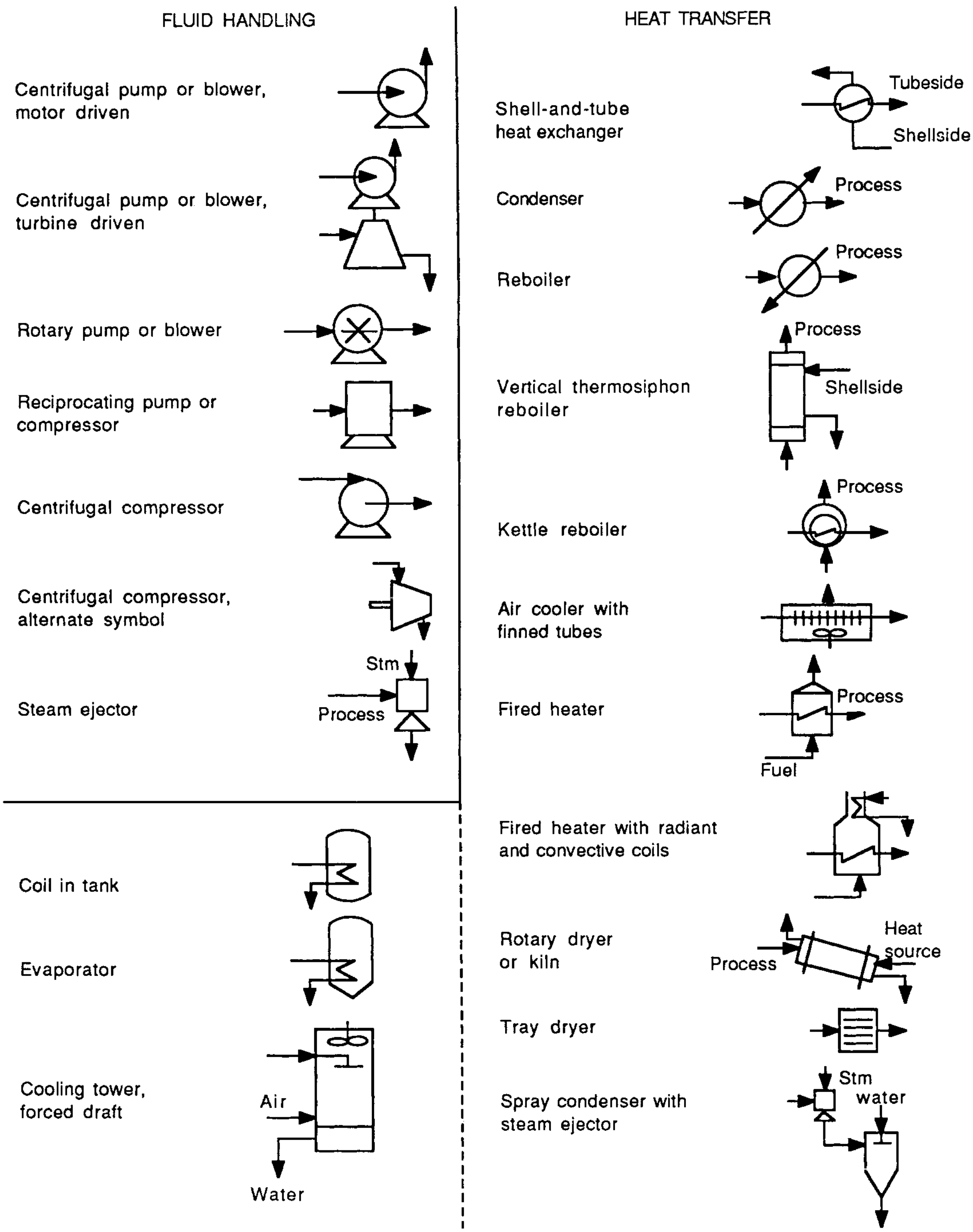
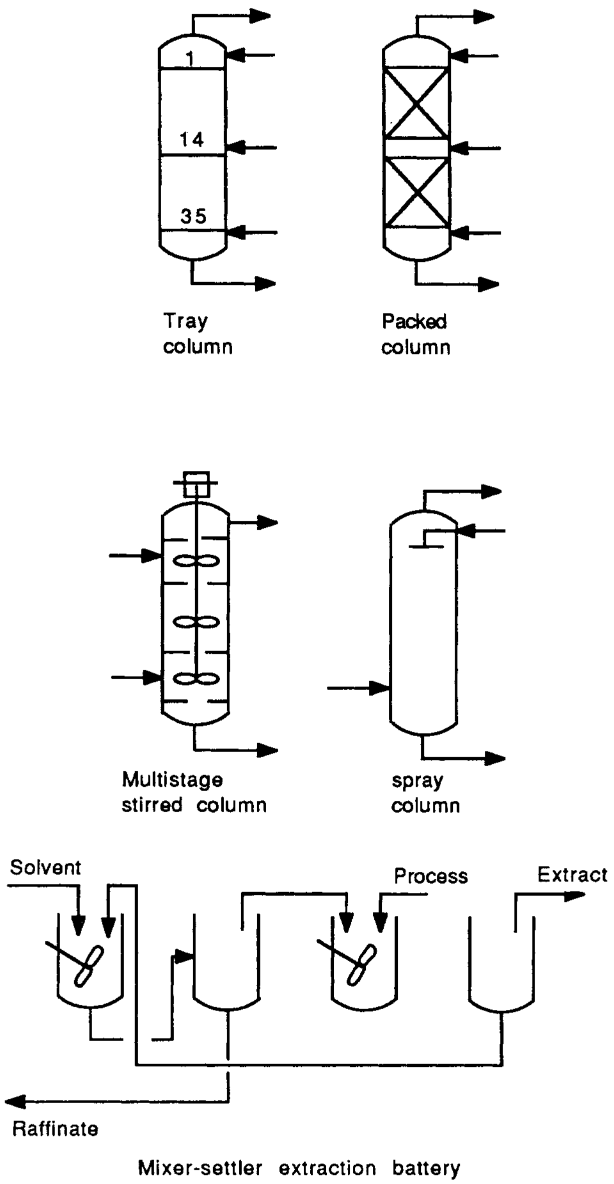


TABLE 2.2—(*continued*)

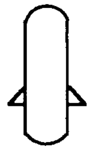
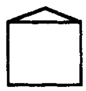
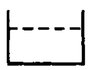
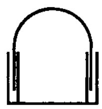
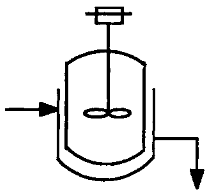
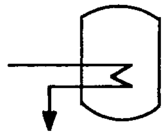
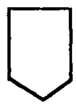
Mass Transfer

MASS TRANSFER



Vessels

VESSELS

Drum or tank	
Drum or tank	
Storage tank	
Open tank	
Gas holder	
Jacketed vessel with agitator	
Vessel with heat transfer coil	
Bin for solids	

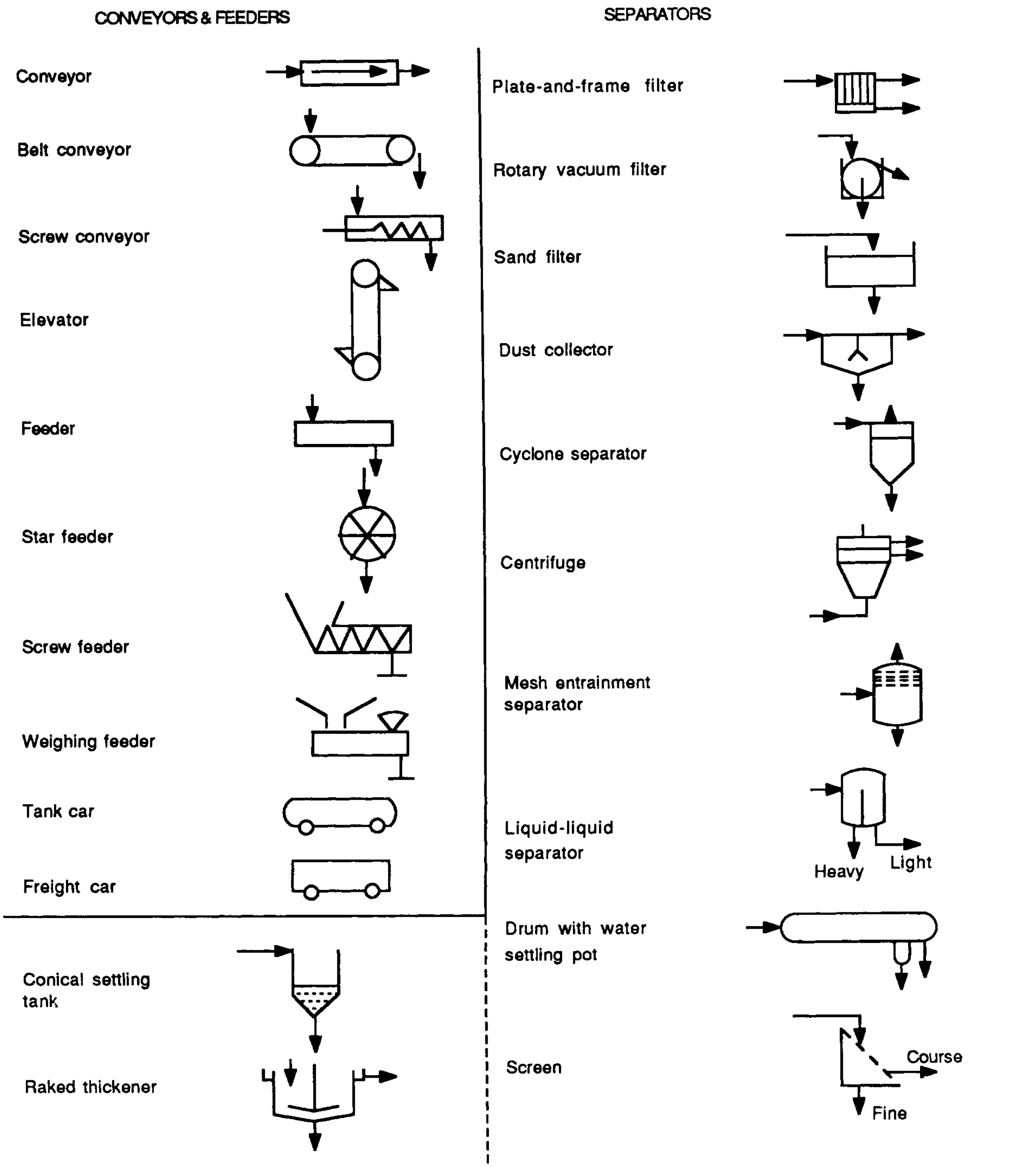
letter-number designation consists of a letter or combination to designate the class of the equipment and a number to distinguish it from others of the same class, as two heat exchangers by E-112 and E-215. Table 2.4 is a typical set of letter designations.

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



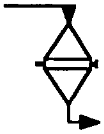
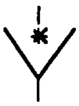
thoroughly standardized by the Instrument Society of America (ISA). An abbreviated set that may be adequate for the usual flowsketch appears on Figure 3.4. The P&I diagram of Figure 2.6 affords many examples.

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 150 ft high and a drum 2 ft in diameter. Logarithmic

TABLE 2.2—*(continued)*

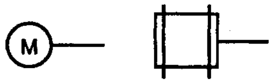
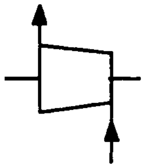
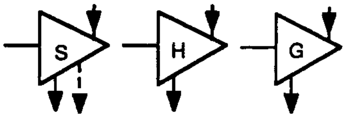
Mixing and Comminution

MIXING & COMMINUTION

Liquid mixing impellers: basic, propeller, turbine, anchor	
Ribbon blender	
Double cone blender	
Crusher	
Roll crusher	
Pebble or rod mill	

Drivers

DRIVERS

Motor	
DC motor	
AC motor, 3-phase	
Turbine	
Turbines: steam, hydraulic, gas	

scaling sometimes gives a pleasing effect; for example, if the 150 ft tower is drawn 6 in. high and the 2 ft 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	TT	Homogenizer	M
Blender	M	Kettle	R
Blower	JB	Kiln (rotary)	DD
Centrifuge	FF	Materials handling equipment	G
Classifying equipment	S	Miscellaneous[a]	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	TT
Fan	JJ	Thickener	F
Feeder	C	Tower	T
Filter (liquid)	P	Vacuum equipment	VE
Furnace	B	Weigh scale	L

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

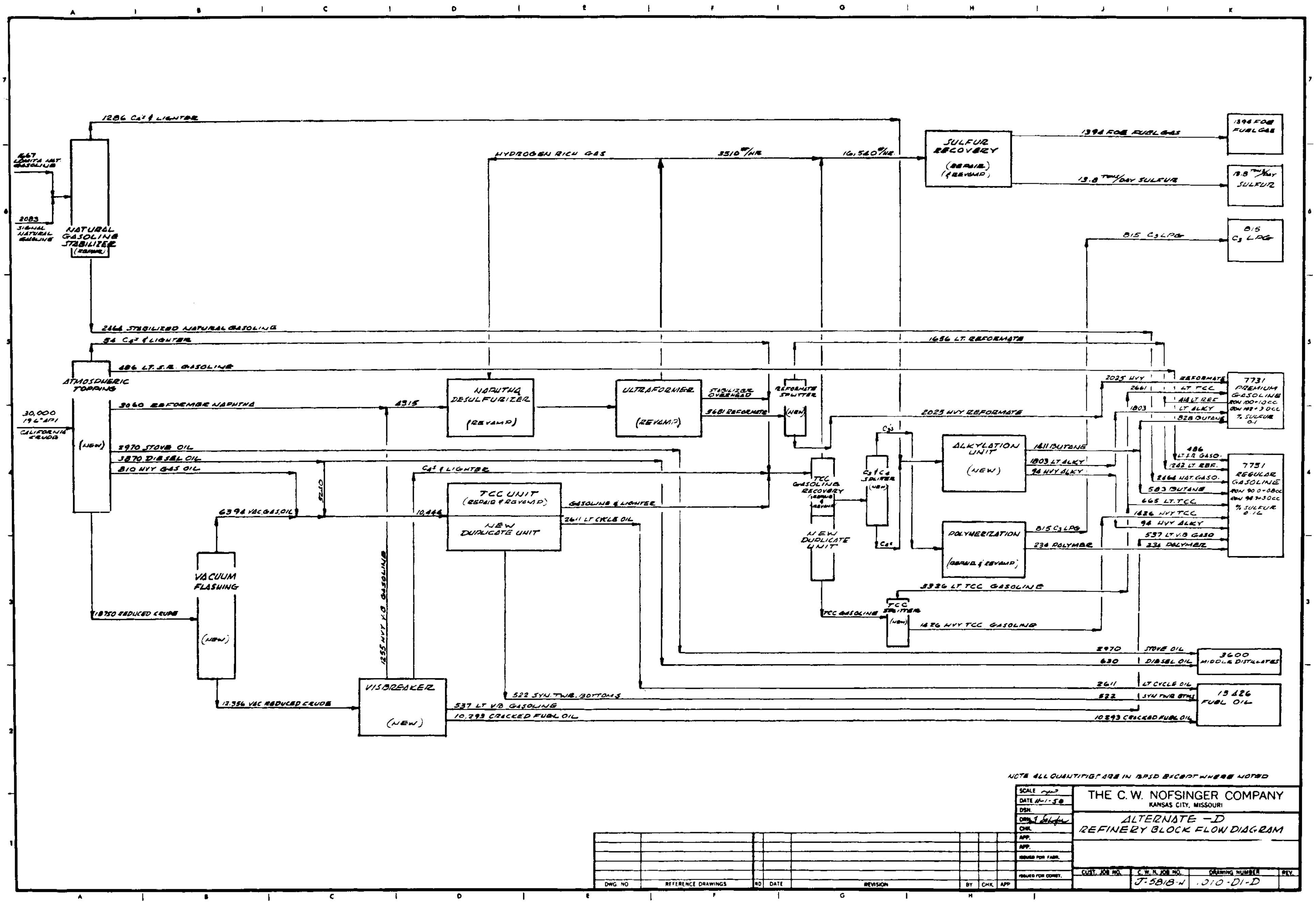
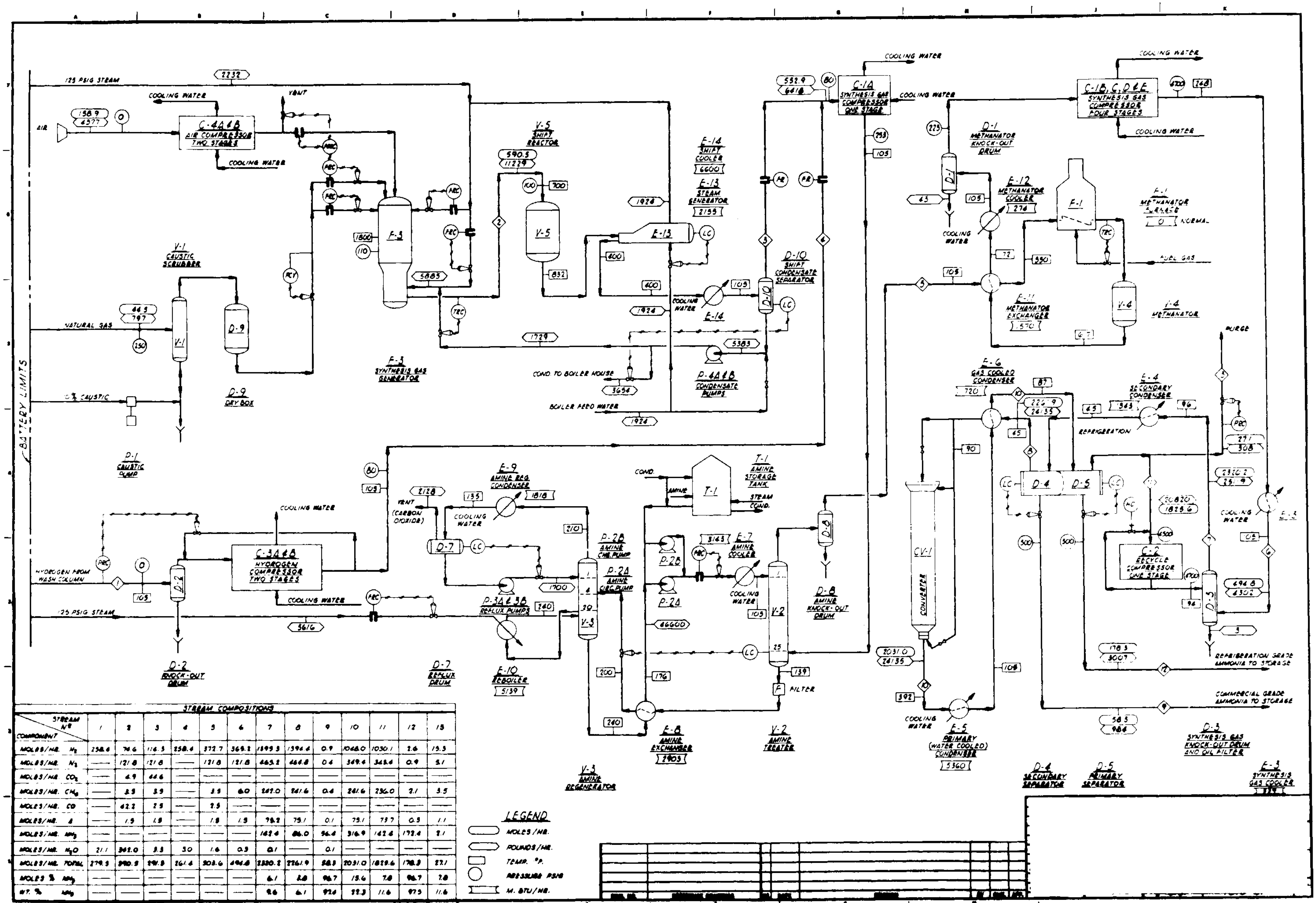


Figure 2.2. Block flowsheet of the revamp of a 30,000 Bbl/day refinery with supplementary light stocks (*The C. W. Nofsinger Co.*).

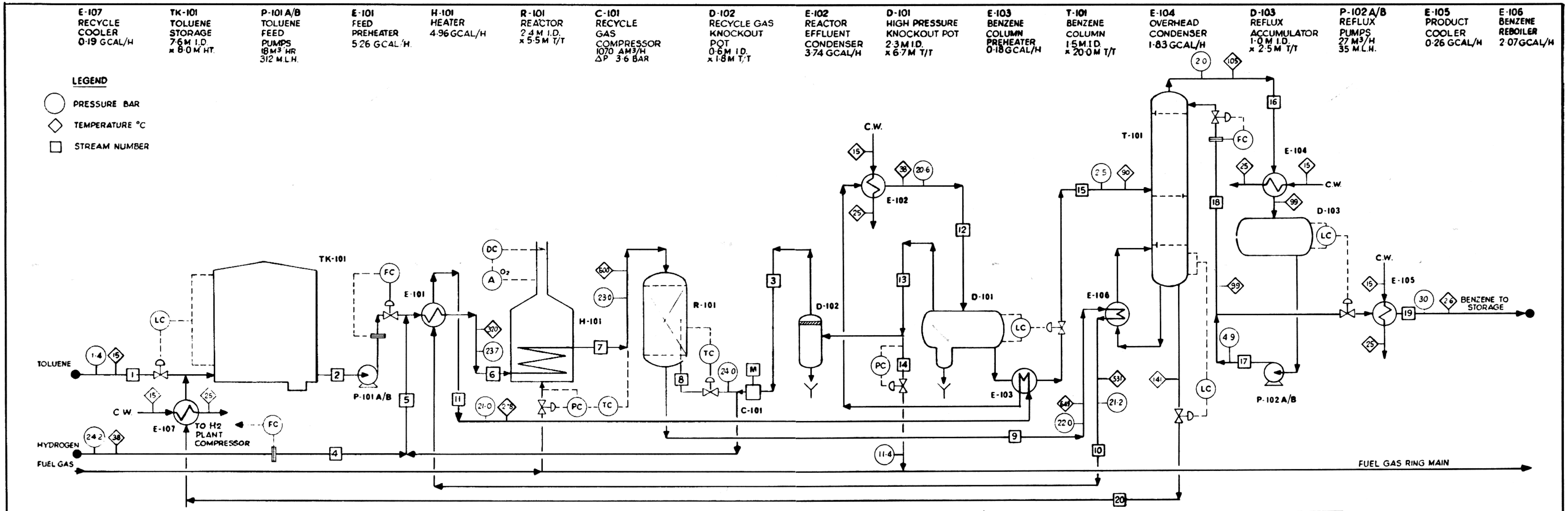


STREAM COMPOSITIONS

COMPONENT \ STREAM Nº	1	2	3	4	5	6	7	8	9	10	11	12	13
MOLES/HR. H_2	258.4	74.6	116.3	258.4	372.7	369.2	1899.3	1394.4	0.9	1048.0	1030.1	2.6	15.3
MOLES/HR. N_2	—	121.8	121.8	—	121.8	121.8	465.2	464.8	0.4	349.4	348.4	0.9	5.1
MOLES/HR. CO_2	—	4.9	44.6	—	—	—	—	—	—	—	—	—	—
MOLES/HR. CH_4	—	3.5	3.9	—	3.5	6.0	242.0	241.6	0.4	241.6	236.0	2.1	3.5
MOLES/HR. CO	—	42.2	2.5	—	2.5	—	—	—	—	—	—	—	—
MOLES/HR. A	—	1.5	1.5	—	1.5	1.5	79.2	79.1	0.1	79.1	73.7	0.5	1.1
MOLES/HR. NH_3	—	—	—	—	—	—	142.4	86.0	56.4	316.9	142.6	172.4	2.1
MOLES/HR. H_2O	21.1	342.0	3.3	3.0	1.6	0.3	0.1	—	0.1	—	—	—	—
MOLES/HR. TOTAL	279.5	590.5	291.3	261.4	503.6	494.4	2330.2	2261.9	58.3	2031.0	1829.6	178.3	27.1
MOLES % NH_3	—	—	—	—	—	—	6.1	3.8	96.7	15.6	7.8	96.7	7.8
WT. % NH_3	—	—	—	—	—	—	9.6	6.1	97.4	22.3	11.6	97.5	11.6

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*).

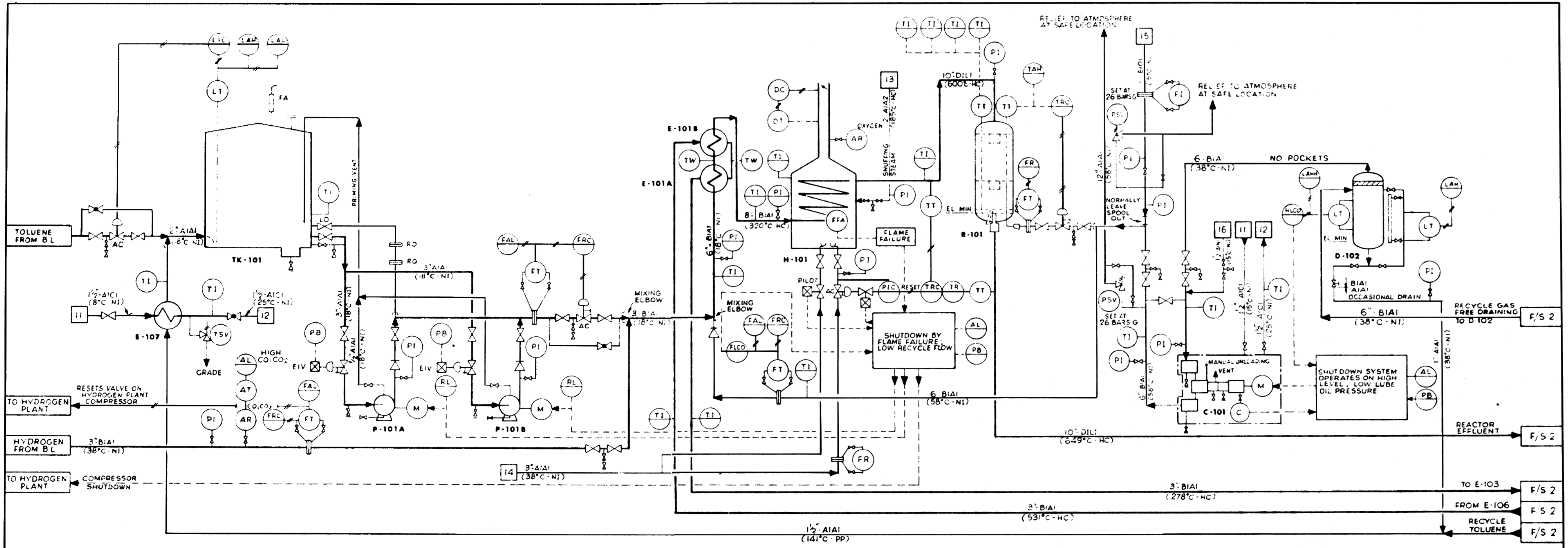


MATERIAL BALANCE

STREAM NUMBER		1	2	3	4	5	6	7	8	9	10
HYDROGEN	KMOL/H	0·0	0·0	470·80	285·00	730·80	730·80	730·80	25·00	647·30	647·30
METHANE	KMOL/H	0·0	0·0	329·40	15·00	326·90	326·90	326·90	17·50	452·90	452·90
BENZENE	KMOL/H	0·0	0·40	6·10	0·00	5·80	6·20	6·20	0·30	115·00	115·00
TOLUENE	KMOL/H	108·70	143·90	0·43	0·00	0·41	144·31	144·31	0·02	35·83	35·83
TOTAL MOLAR FLOW	KMOL/H	108·70	144·30	806·73	300·00	1063·91	1208·21	1208·21	42·82	1251·03	1251·03
TOTAL MASS FLOW	KG/H	10,000	13,270	6727	810	7,182	20452	20452	355	20 807	20 807
TEMPERATURE	°C	15	18	38	38	38	320	600	58	649	531
PRESSURE	BAR	1·4	1·1	20·4	24·0	24·0	23·7	23·0	24·0	22·0	21·2
TOTAL HEAT FLOW	GCALS/H	1·33	1·77	-3·36	0·40	-2·57	4·46	9·42	-0·17	9·13	7·24

STREAM NUMBER		11	12	13	14	15	16	17	18	19	20
HYDROGEN	KMOL/H	647·30	647·30	647·30	176·50	0·00	0·00	0·00	0·00	0·00	0·00
METHANE	KMOL/H	452·90	452·90	452·90	123·50	0·00	0·00	0·00	0·00	0·00	0·00
BENZENE	KMOL/H	115·00	115·00	8·40	2·30	106·60	245·70	245·70	139·50	106·20	0·40
TOLUENE	KMOL/H	35·83	35·83	0·59	0·16	35·24	0·09	0·09	0·05	0·04	35·20
TOTAL MOLAR FLOW	KMOL/H	1251·03	1251·03	1109·19	302·46	141·84	245·79	245·79	139·55	106·24	35·60
TOTAL MASS FLOW	KG/H	20,807	20,807	9,250	2523	11,557	19,173	19173	10,886	8,287	3,270
TEMPERATURE	°C	278	38	38	38	90	105	99	99	30	141
PRESSURE	BAR	21·0	20·6	20·6	20·6	2·5	2·0	2·9	2·9	2·6	2·3
TOTAL HEAT FLOW	GCALS/H	1·98	-1·94	-4·62	-1·26	2·86	7·18	5·39	3·06	2·06	0·63

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*).



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

11 COOLING WATER SUPPLY	14 FUEL GAS
12 COOLING WATER RETURN	15 OXYGEN
13 M P STEAM	16 NITROGEN

ITEM No	R-101	D-102	TK-101
TITLE	REACTOR	RECYCLE GAS KNOCKOUT POT	TOLUENE STORAGE
I.D. × T/T M	2·4 × 5 5	0·6 × 1·8	7·6 × 8 0 HT
OP TEMP °C	649	38	18
OP PRESS. BARS G.	23 0	20 6	ATMOS
DESIGN TEMP °C	700	66	46
DES. PRESS. BARS G	26 0	23 0	FULL LIQUID

ITEM No	E-101A/B	E-107	H-101
TITLE	FEED PREHEATER	RECYCLE COOLER	HEATER
DUTY G CAL/H	5 26	0 19	4·96
SHELL SIDE △P BAR	0 3	0 35	-
TUBE SIDE △P BAR	0·3	0·7	0 7

ITEM No	P-101A	P-101B
TITLE	TOLUENE FEED PUMP	SPARE FOR P 101A
CAPACITY M³/H	18	18
HEAD M L.C	3!2	312
PUMPING TEMP °C	18	18
S G. AT P.T.	0·87	0 87

ITEM No	C-101
TITLE	RECYCLE GAS COMPRESSOR
CAPACITY AM³/H	1070
△ PRESS BAR	3 6

XYZ ENGINEERING LTD.

TITLE: ENGINEERING LINE DIAGRAM (Sheet 1 of 2) REACTION STAGE BENZENE PLANT

REV | Drawn By F.T.T. | Date 25.9.76 | DRG No B-1001 | No 8

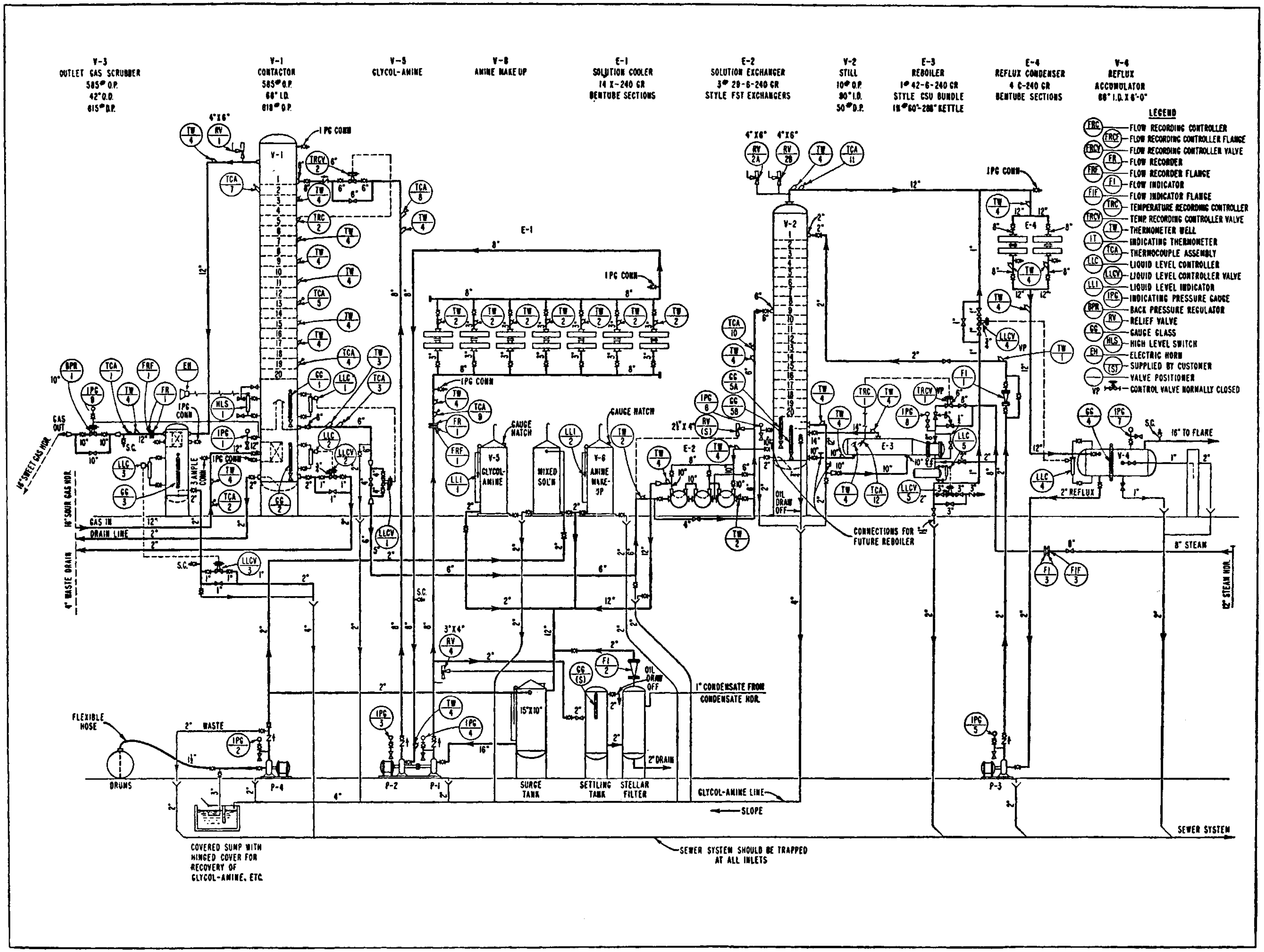


Figure 2.6. Engineering flowsheet of a gas treating plant. Note the tabulation of instrumentation flags at upper right (*Fluor Engineers, by way of Rase and Barrow,* Project Engineering of Process Plants, *Wiley, New York, 1957*).

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