Process flow diagram

From processdesign

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Introduction

The process flow diagram (PFD) is a critical component of process design. It is absolutely necessary that chemical engineers know how to read process flow diagrams because it is the primary method of detailing the process and design information. Additionally, the most effective way of relaying information about a process design is the use of process flow diagrams. The PFD shows the sequence of flow through a system through the various equipment (such as piping, instrumentation, and equipment design) and details the stream connections, stream flow rates and compositions and operating conditions through the plant layout. The PFD differs from a block flow diagram (BFD) in that the PFD is more detailed and conveys more information than the BFD, which only gives a general sense of flow of information.

Overview

On the process flow diagram, there are several pieces of information that must be included while there are some optional information that can be included to make the PFD more specific. Notable information that should be included should be major process equipment and followed by a short description. Additionally, each piece of equipment should be named and listed on a table along with a description of the name. For more details on how to name process equipment, see "Naming Equipment". On the process flow diagram, all streams should be labeled and identified with a number. A summary of the streams and their numbers should also be detailed on a separate table. All utility streams that supply energy to major equipment should be shown. In Table 1, other types of essential information to the process flow diagram as well as the optional information that could be supplied to further detail the process are listed.

Table 1: Information to Be Included in a Process Flow Diagram

Essential Information	Process vessels and equipment Process piping Process and Utility Flow Lines Full heat and material balances Composition, flow rate, pressure and temperature of every stream Stream enthalpy Location of every control valve Sizing of pumps and compressors Bypass and recycle streams
Optional Information	Molar percentage composition and/or molar flow rates Physical property data Mean values for stream Stream names

Categorization of Information In a Process Flow Diagram

The information that a process flow diagram conveys can be categorized into one of the following three groups. Each of the three aspects will be discussed in more details.

- "Process Topology"
- "Stream Information"
- "Equipment Information"

Process Topology

Process topology is defined as the interactions and locations of the different equipment and streams. It includes all of the connections between the equipment and how one stream is changed to another after it flows through a piece of equipment. On a separate table, following the process flow diagram, the equipment must be labeled (see "Naming Equipment") and followed by a short description so that the engineer who is trying to understand the process flow will have a easier time following. The following sections will describe how to catalog the necessary information for the equipment of the process topology.

Process Vessels and Equipment

One of the initial steps to creating a process flow diagram is to add all of the equipment that is in the plant. Not only is the major equipment, such as distillation columns, reactors, and tanks, necessary to be shown in a PFD, so is the equipment such as the heat exchangers, the pumps, reactors, mixers, etc). The following figures will display the most common symbols found in process flow diagrams.

Symbols for Process Technology

For process equipment, there are a few standard symbols that should be recognized by chemical engineers. Typically, these symbols correlate to the ones on the Microsoft Visio Engineering package that can be used to create process flow diagrams. In the next few sections, the figures will display various symbols that are used for the process flow diagrams. Figure 1 (Towler and Sinnott, 2013) displays typical process equipment - notables ones that should be recognized because they are relevant to this class are the symbols for the vertical and horizontal vessel, the packed column and the trayed column. For the typical information that follows the process equipment, refer to "Equipment Information".

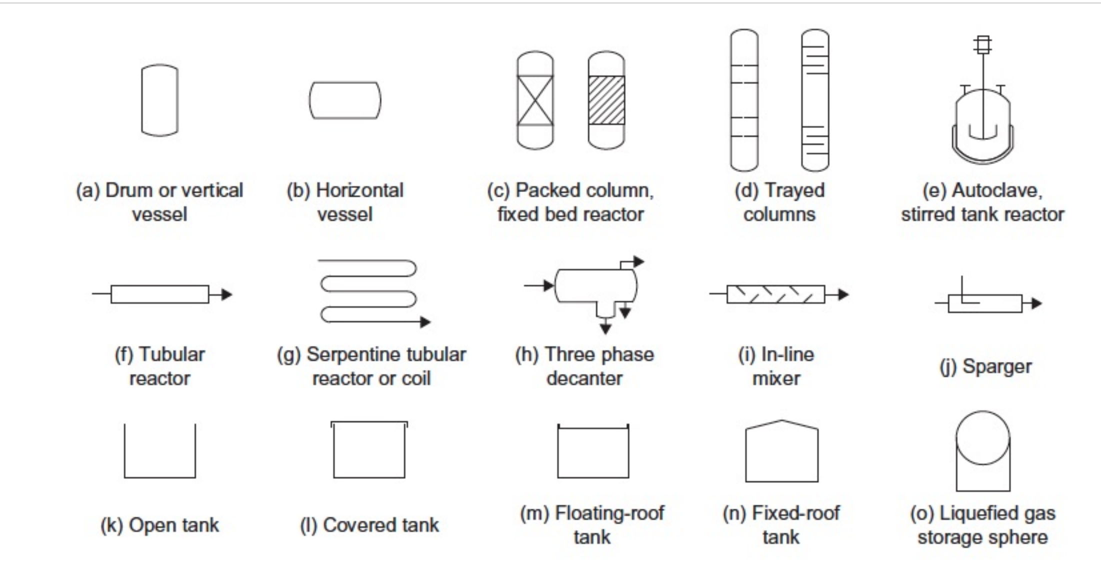


Figure 1: Various symbols for reactors, vessels and tanks (Towler and Sinnott, 2012)

Symbols for Heat Exchanger Equipment

In addition to the process equipment symbols, there will be heat exchanger equipment that are essential to process flow diagrams. Notable symbols that are relevant to this class include the basic heat exchanger symbols, the shell and tube exchangers, the kettle reboiler, the U-tube exchanger, and heating coils. Other heat exchanger equipment are listed in Figure 2. (Towler and Sinnott, 2013) Typical information that follows heat exchanger equipment are the utility streams that enter and exit the heat exchanger, the pressures, temperature, and the duties.

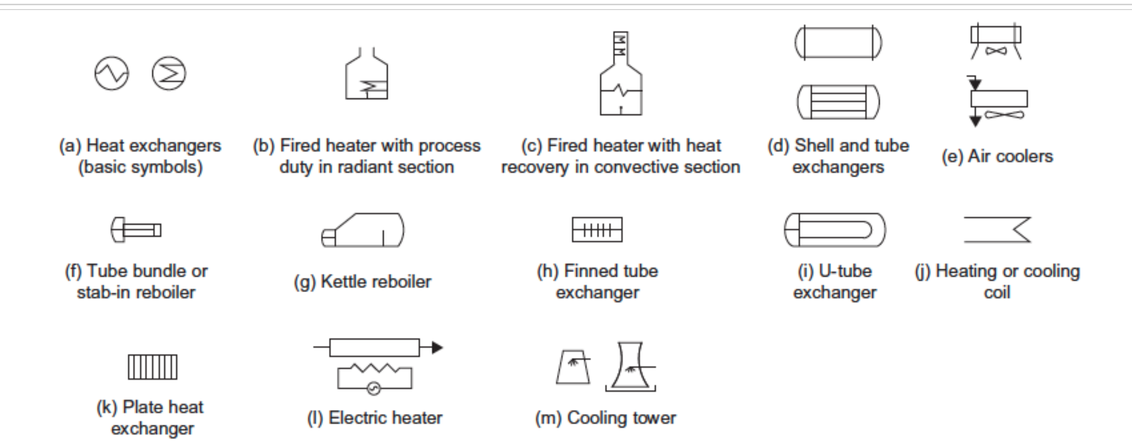


Figure 2: Various symbols for heat exchanger equipment (Towler and Sinnott, 2013)

Symbols for Fluid Handling Equipment

In a process, some streams may have difficulty moving from one process equipment to another. Therefore, the placement of fluid handling equipment in between streams can help facilitate this process. In Figure 3 (Towler and Sinnott, 2013), various symbols are displayed for fluid handling equipment. Notable equipment that we will use for this class include the centrifugal pumps, axial or centrifugal compressor, and the turbine. In addition to placing this equipment on the process flow diagrams, a separate table should list the name of this equipment, a description of the type of equipment, and the amount of power supplied to the machinery.

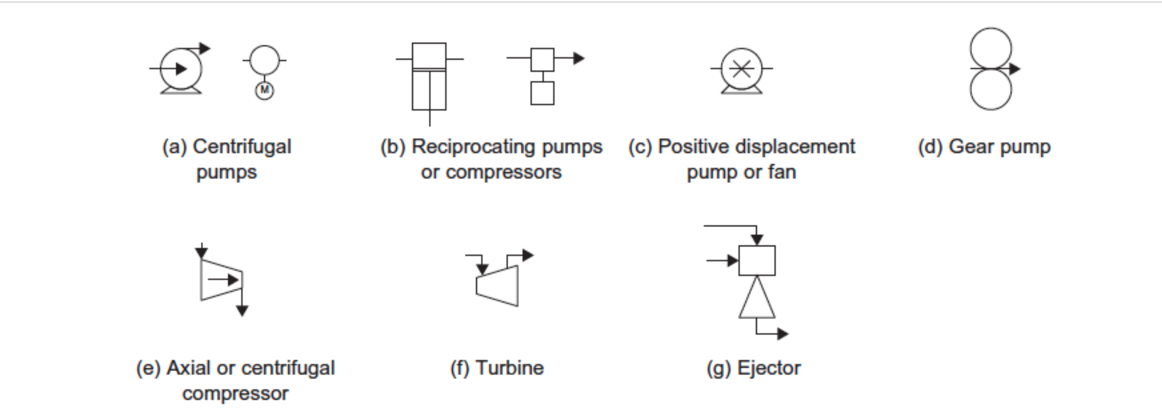


Figure 3: Various symbols for fluid handling equipment (Towler and Sinnott, 2013)

Utility Streams in Process Topology

Utilities are necessary for the plant to keep running. The purpose of the utilities is usually to add or remove heat to the equipment so that the temperature can be controlled. The type of utility for the duties should also be specified on a separate table following the process flow diagram. One way to find the type of utility that is supplied can be done in HYSYS where the process must first be modeled and then sent to the heat exchanger analyzer. The following bullet points are examples of the many different types of utilities that can service a plant:

- Electricity
- Compressed Air
- Cooling Water
- Refridgerated Water
- Steam
- Condensate Return
- Inert Gas
- Flares

The following table lists the initials that are typically found on a PFD followed by a description/definition of the initial.

Table 2: Utility Streams and Their Initials

Initials of the Utility Stream	Description of the Initial
lps	Low-Pressure Steam (3-5 barg)
mps	Medium-Pressure Steam (10-15 barg)
hps	High-Pressure steam (40-50 barg)
htm	Heat Transfer Media (Organic)
cw	Cooling Water
wr	River Water
rw	Refrigerated Water
rb	Refrigerated Brine
cs	Chemical Waste Water with high COD
ss	Sanitary Waste Water with high BOD
el	Electric heat
ng	Natural Gas
fg	Fuel Gas
fo	Fuel Oil
fw	Fire Water

Stream Information

Streams should be labeled so that they follow consecutively from left to right of the layout so that it is easier to follow along and locate numbers when you are trying to locate streams listed on the tables. For large processes, the designers of the flowsheet may have a system - for example, the streams in the 100 series may be named for the feed preparation section, the streams in 200 series may be for the reaction, in the 300 series, it may be used for separation and in the 400 series, it may be used for purification. This is especially useful when there is a lot of information and it can help the user of the process flow diagram locate the specific section faster.

In small PFDs, stream information, including flow rates, temperatures, pressures, and compositions, are shown directly next to the PFD on a table. The corresponding number on the stream will be translated onto the table. The following table shows a typical table that details stream information; it usually divided into two sections - one section for the essential information and one for the optional information.

Table 3: Example of Stream Information Table for a Small Process Flow Diagram

Essential Information	▪ Stream Number ▪ Temperature ▪ Pressure ▪ Vapor Fraction ▪ Total Mass Flow Rate ▪ Total Mole Flow Rate ▪ Individual Component Flow Rates
Optional Information	▪ Component Mole Fractions ▪ Component Mass Fractions ▪ Individual Component Flow Rates ▪ Volumetric Flow Rates ▪ Physical properties such as density and viscosity ▪ Thermodynamic Data such as heat capacity, stream enthalpy, and K-values

For a larger PFD, it is essential to list the stream name on the first row and the essential information about the stream on the first column. This table is usually located below the process flow diagram for easy access and reference.

Table 4: Example of a Stream Information Table for a Large Process Flow Diagram

Stream Number	1	2	3	4	5	6	7	8
Temperature (Celsius)	30	49	88	23	143	222	133	300
Pressure (bar)	33	22	21	25	50	66	90	78
Vapor Fraction	0	1	0	0	1	1	1	0
Mass Flow (kg/hr)	10	16	20	22	38	45	33	22
Mole Flow (kmol/hr)	23	50	100	123	24	28	55	18
Hydrogen Mole Flow (kmol/hr)	0	25	25	23	2	4	50	6
Methane Mole Flow (kmol/hr)	23	25	25	50	20	12	5	6
Benzene Mole Flow (kmol/hr)	0	0	50	50	2	12	0	6

Equipment Information

In addition to the stream information, there should also be a table detailing equipment information. This table can be helpful for the economical analysis of the plant because it should provide the information necessary to estimate the cost of the equipment. The equipment information table should include a list of all of the equipment that is used in that particular flow diagram along with a description of size, height, number of trays, pressure, temperature, materials of construction, heat duty, area and other critical information.

Naming Equipment

Typical names for the equipment include a letter followed by a set of numbers. The letter usually corresponds to the first letter of the equipment. For example, the first pump in the PFD is typically labeled P-101. The following table displays the convention of naming the letters for process equipment:

Table 5: Initials for Various Equipment

Initials of the Equipment	Description of the Equipment
C	Compressor or Turbine
E	Heat Exchanger
P	Pump
R	Reactor
T	Tower
TK	Storage Tank
V	Vessel
Y	A Designated Area of the Plant
A/B	Identifies parallel units or backup units

Additionally, it should be noted that in a plant, certain equipment will need to be replaced. Typically, the new equipment will take the old equipment's name but an additional letter or number will be added onto the new equipment to indicate that there was a modification.

Examples of Equipment Summary Tables

In the following table, an equipment summary is provided for a toluene hydrodealkylation process flow diagram. Note that the equipment summary table is divided up into the respective type of equipment and the essential data that goes with each piece of equipment. For example, for the heat exchangers, duties, materials of constructions and area are types information that are essential because it can help with the economic evaluation. For vessels, reactors and towers, it is essential to include the size, materials of constructions, and temperature/pressures. For pumps, flow through it can help determine values for the economic evaluation.

Table 6: Example of an Equipment Information Table for Toluene Hydroealkylation Process Flow Diagram

Heat Exchangers	E-101	E-102	E-103	E-104
Type	Floating Head	Floating Heat	Multiple Double Pipe	Floating Heat
Area (m^2)	200	25	90	30
Duty (MJ/hr)	14,249	3,093	4,786	55
Shell				
Temperature (Celsius)	333	45	67	90
Pressure (bar)	35	140	45	120
Phase	Partially Condensed	Condensed	Vapor	Condensed
Materials of Construction	CS	CS	304SS	304SS
Tube				
Towers	**T-101**	**T-102**	**T-103**	**T-104**
Temperature (C)	24	267	300	345
Pressure (bar)	123	36	356	78
Orientation	Horizontal	Vertical	Horizontal	Vertical
Materials of Construction	316SS	CS	304SS	CS
Height (m)	4.5	5.9	10.6	4.9
Diameter (m)	5.5	6.4	2.3	3.3
Pumps	**P-101**	**P-102**	**P-103**	**P-104**
Flow (kg/hr)	1224	2226	3457	3488
Fluid Density (kg/m^3)	300	456	975	457
Power (kW)	456	7899	678	5678
Type	Centrifugal	Centrifugal	Explosion Proof Motor	Centrifugal
Material of Construction	CS	CS	CS	CS
Efficiency	.90	.55	.66	.88

Process Flow Diagram Example

Example 1: Polymer Production

Combining all of the information from the previous sections, we can now create and understand a full process flow diagram. In the following figure about polymer production (Towler and Sinnott, 2013), the PFD contains a few pieces of equipment so that the corresponding streams can be placed on the figure itself instead of on a separate table. Please note that all streams are labeled with the temperature, the flow rate and amount of each composition, and on a separate table, all of the equipment is clearly defined with their names. One improvement that can be made to this PFD is to be more detailed in the separate table and to include a description of the equipment.

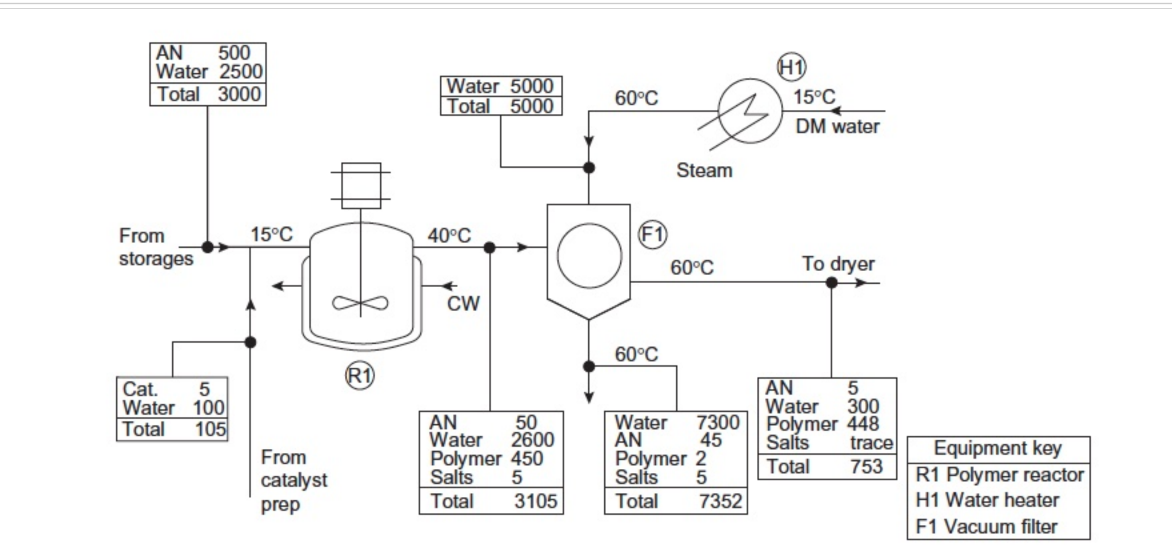


Figure 4: Process Flow Diagram Documenting Polymer Production (small process) (Towler and Sinnott, 2013)

A new process flow diagram was created in order to avoid the clutter of this first process flow diagram. Note that the streams that are labeled are just the numbers, with their stream information detailed in a separate table (Table 7).

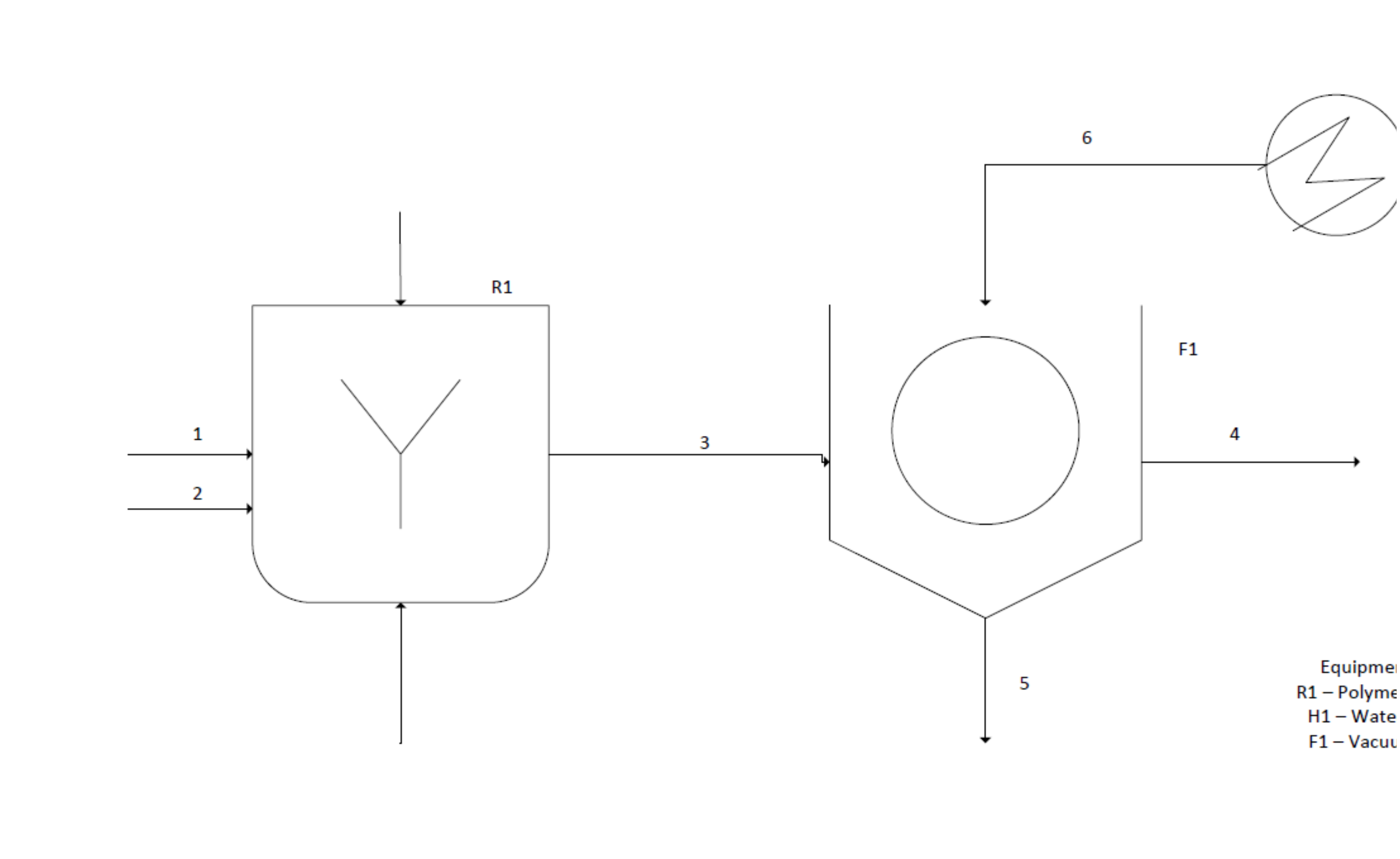


Figure 5: Revised Process Flow Diagram Documenting Polymer Production (Towler and Sinnott, 2013)

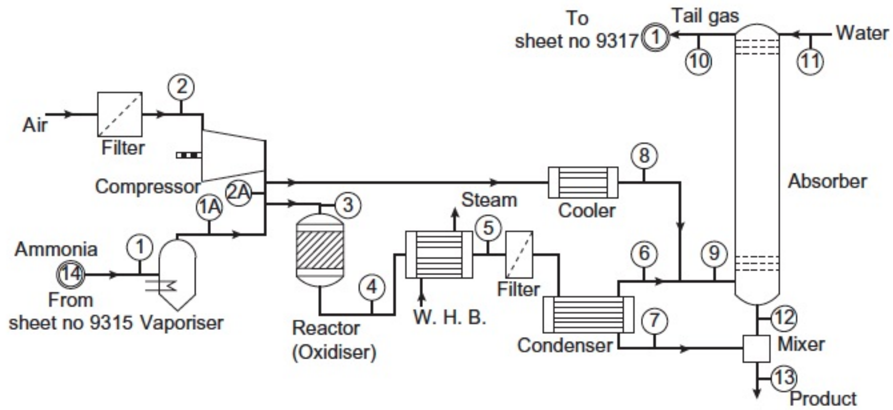
Table 7: Stream Information Table (Revised PFD)

Stream Number	1	2	3	4	5	6	7
Temperature (Celsius)	15	15	40	60	60	60	15
Total Flow	3000	105	3105	753	7352	5000	5000
AN Mole Flow	500	0	50	5	45	0	0
Water Mole Flow	2500	100	2600	300	7300	5000	5000
Polymer Mole Flow	0	0	450	448	2	0	0
Salt Mole Flow	0	0	5	0	5	0	0
Cat Mole Flow	0	5	0	0	0	0	0

However, not all process flow diagrams are as simple as the previous example. In fact, many are complicated processes that may span multiple pages. Therefore, a better example would be the following one.

Example 2: Simplified Nitric Acid Process

In Figure 5 (Towler and Sinnott, 2013), air enters a filter while ammonia enters a vaporiser to eventually combine in a reactor and form nitric acid. Each stream is labeled with a number and the compositions of the streams are labeled in a separate table. Additionally, in the separate table that follows directly below the PFD (standard convention), the pressures and temperatures of the streams are also listed. The one improvement on this PFD that can be made is to name the equipment with the nomenclature detailed in "Naming Equipment" and define those names on a separate table instead of writing the name of the equipment on the PFD. This way, there is less clutter on the PFD and it may be easier to follow along when all the names of the equipment are placed on the same table.



Flows kg/h pressures nominal

Line no. Stream component	1 Ammonia feed	1A Ammonia vapor	2 Filtered air	2A Oxidiser air	3 Oxidiser feed	4 Oxidiser outlet	5 W.H.B. outlet	6 Condenser gas	7 Condenser acid	8 Secondary air	9 Absorber feed	10 Tail(2) gas	11 Water feed	12 Absorber acid	13 Product acid	C & R Construction Inc
NH_3	731.0	731.0	—	—	731.0	Nil	—	—	—	—	—	—	—	—	—	Nitric acid 60 percent
O_2	—	—	3036.9	2628.2	2628.2	935.7	(935.7)(1)	275.2	Trace	408.7	683.9	371.5	—	Trace	Trace	100,000 t/y
N_2	—	—	9990.8	8644.7	8644.7	8668.8	8668.8	8668.8	Trace	1346.1	10,014.7	10,014.7	—	Trace	Trace	Client BOP chemicals
NO	—	—	—	—	—	1238.4	(1238.4)(1)	202.5	—	—	202.5	21.9	—	Trace	Trace	SLIGO
NO_2	—	—	—	—	—	Trace	(?)(1)	967.2	—	—	967.2	(Trace)(1)	—	Trace	Trace	Sheet no. 9316
HNO_3	—	—	—	—	—	Nil	Nil	—	850.6	—	—	—	—	1704.0	2554.6	
H_2O	—	—	Trace	—	—	1161.0	1161.0	29.4	1010.1	—	29.4	26.3	1376.9	1136.0	2146.0	
Total	731.0	731.0	13,027.7	11,272.9	12,003.9	12,003.9	12,003.9	10,143.1	1860.7	1754.8	11,897.7	10,434.4	1376.9	2840.0	4700.6	
Press bar	8	8	1	8	8	8	8	8	1	8	8	1	8	1	1	Dwg by Date
Temp. °C	15	20	15	230	204	907	234	40	40	40	40	25	25	40	43	Checked 25/7/1980

Figure 6: Process Flow Diagram Detailing the Nitric Acid Process (Towler and Sinnott, 2013)

Conclusion

The process flow diagram is an essential part of chemical engineering. It conveys a process and the path of its individual components - therefore, it is essential to learn how to read and create one. The process flow diagram is divided into three sections: process topology, stream information, and equipment information. The more detailed these three sections are, the easier it is for a user of the process flow diagram to follow along and understand.

Sources

1. Towler G, Sinnott R. Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design. 2nd ed. Boston: Elsevier; 2013.
2. Turton R, Bailie RC, Whiting WB, Shaeiwitz JA. Analysis, Synthesis, and Design of Chemical Processes. 2nd ed. New Jersey: Prentice Hall; 2003.