Design Problem 1 – Pump and Piping Design

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Objectives

The objectives of Design Problem 1 are to: (1) update the cost index in CHEMCAD, (2) use CHEMCAD to perform an optimized design and pricing of a section of pipeline, and (3) determine the purchased price and power requirements for a pump.

Problem Statement

Your assignment is to use CHEMCAD to design the piping and pump to deliver feed liquid to a distillation process. The feed temperature, pressure, and component flow rates are given in Table 1, and you will determine the size and cost of the pump and pipeline needed to deliver the feed to the column. You will also determine the size and cost of fittings and valves, the cost of paint for the pipe, and the energy requirements for one year of operation. Finally, this type of system must be *optimized* for peak economic efficiency, and you will discuss why your solution is considered to be optimized. Your design will be subject to the constraints and specifications described below.

Table 1. Feed Component Flow Rates (298 K and 202.650 kPa)

Component	Feed Rate, lb-mol/h
Toluene	91.50
Naphthalene	299.81
Biphenyl	3156.56
Diphenylenemethane (Fluorene)	192.94
Phenanthrene	144.19
M-Terphenyl	359.81
Total	4244.81

Constraints and Additional Information

- You are designing the pump and the pipe connecting the pump to the column. You will *not* be designing the distillation column or column internals (trays, shell, condenser, reboiler). This has already been designed by another group.

- Pump constraints and specs:

  – The pump and motor costs must be calculated in CHEMCAD. The pump is centrifugal, one stage, 3550 rpm vertical split casing (VSC), cast steel, and explosion proof, and the pump motor is 1200 rpm, and installed costs are 2.8 times the purchased equipment cost.

  – CHEMCAD cost information must be updated to January 2024 by entering the current Chemical Engineering Plant Cost Indices. Values can be viewed in "Tools," then "Edit Cost Index."

- – Energy cost based on one year of operation (365d=1yr) at $0.0646 per kWh and the pump is 79% efficient.
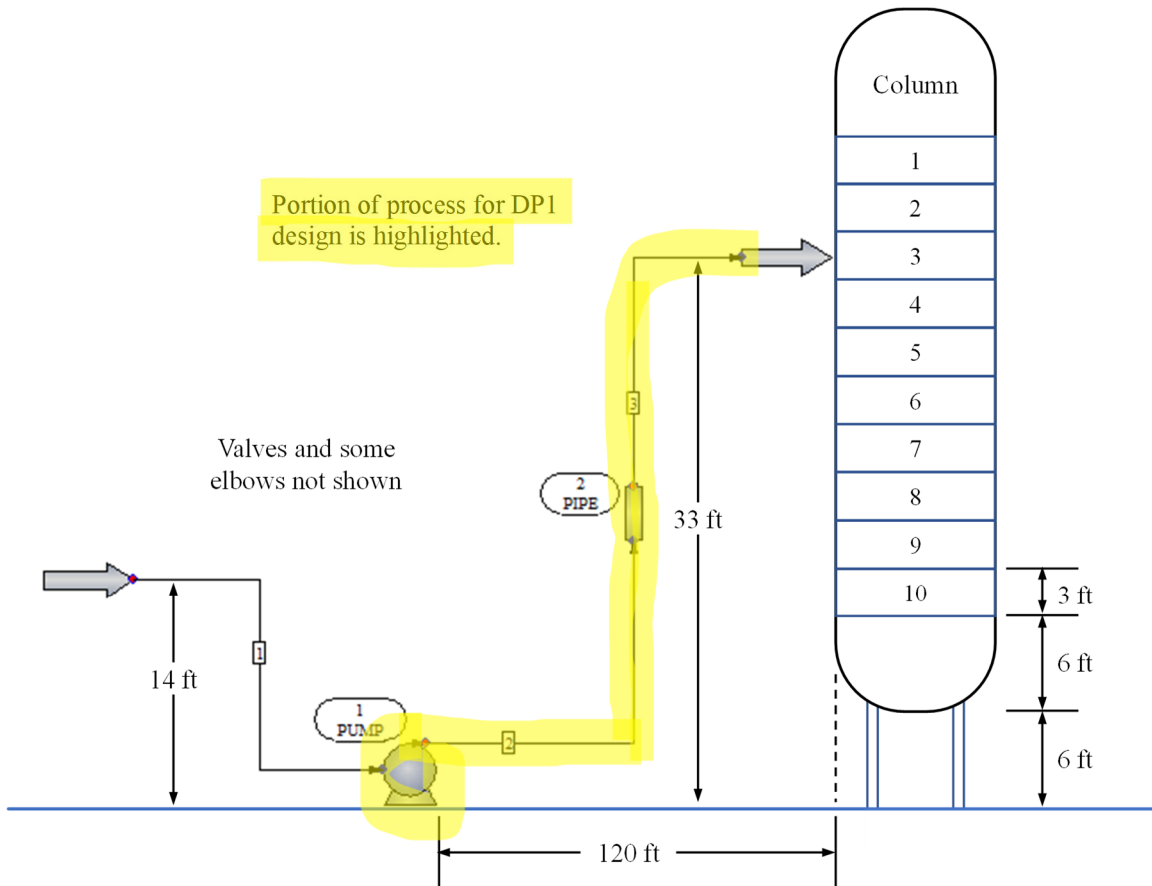 (energy costs found at https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a)

- Piping constraints and specs:

  - – Pipe, valve, and fitting costs cannot be calculated in CHEMCAD. Pipe costs can be found in the PTW textbook. Any cost data taken from the textbook is referenced to January 2002.

  - – Fittings costs are not in the 2002 edition of the textbook. They can be found in the "1979 Pipe & Fitting Prices" document found in your SharePoint (Fig. 13-4, PTW, 3rd ed., p. 529). This data is referenced to January 1979.

  - – Installed costs are 2.8 times the purchased equipment cost.

  - – The pipe diameter is determined in CHEMCAD. Fluid flow in the pipeline is single-phase, and the pipe sizing option in CHEMCAD is "1 Design, single-phase flow."

  - – All pipe and fittings are Sch. 40 welded commercial (carbon) steel and must be painted.

  - – The length of the pipeline is 153 feet with a net elevation change of 19 feet.

  - – The pipeline has 12 90° standard elbows, two gate valves, three globe valves, and one sudden expansion where the fluid emerges into the column. The diameter ratio for the expansion can be taken as 0.001.

  - – The feed must enter the column at **298 K and 353.5 kPa**.

Submission Requirements

1. Download, complete and upload the CHEMCAD template found in Canvas.

2. Download, complete and upload the Excel template found in Canvas, including:

   a. Diameter, purchased and installed costs in January 2024 for pipe, elbows, valves, and paint.

   c. Purchased and installed cost of pump and motor in January 2024.

   d. Pump NPSH, power, energy, and energy cost for 1 year of operation.

   d. Total cost of installed equipment and energy for one year of operation.

   e. Print the bordered areas from the Excel template as a pdf, attach a cover sheet, and submit the combined pdf to Canvas.

3. Discuss how the design has been *optimized*. Answer this question in the space provided in Excel.

4. All three electronic files (CHEMCAD, Excel, and PDF) must be uploaded to Canvas.

Addendum – Process Sketch

Column

1
2
3
4
5
6
7
8
9
10

Portion of process for DP1 design is highlighted.

Valves and some elbows not shown

2 PIPE

33 ft

1 PUMP

14 ft

3 ft

6 ft

6 ft

120 ft

Vertical split-case pump (VSC), https://www.statesupply.com/bell-and-gossett/pump/series-vsx. Casing split is perpendicular to motor shaft axis.

Horizontal split-case pump (HSC), https://www.ruhrpumpen.com/en/products/between-bearing-pumps/hsc-pump. Casing split is parallel to motor shaft axis.

Solution

The CHEMCAD flowsheet is shown below. Pump ΔP is adjusted until the pressure in stream 3 is on spec. The resulting stream and unit ops reports are shown on the following pages for 2.5-inch nominal pipe size. The calculation of the NPSH and the resulting value are shown in the unit ops report for the pump on page 5. The cost and optimization information are shown in the Excel spreadsheet on pages 7 and 8 of this document.

CHEMCAD pipe tool is set to Method 2 (Single Phase Flow) and Sizing option 1 (Design, Single phase flow).
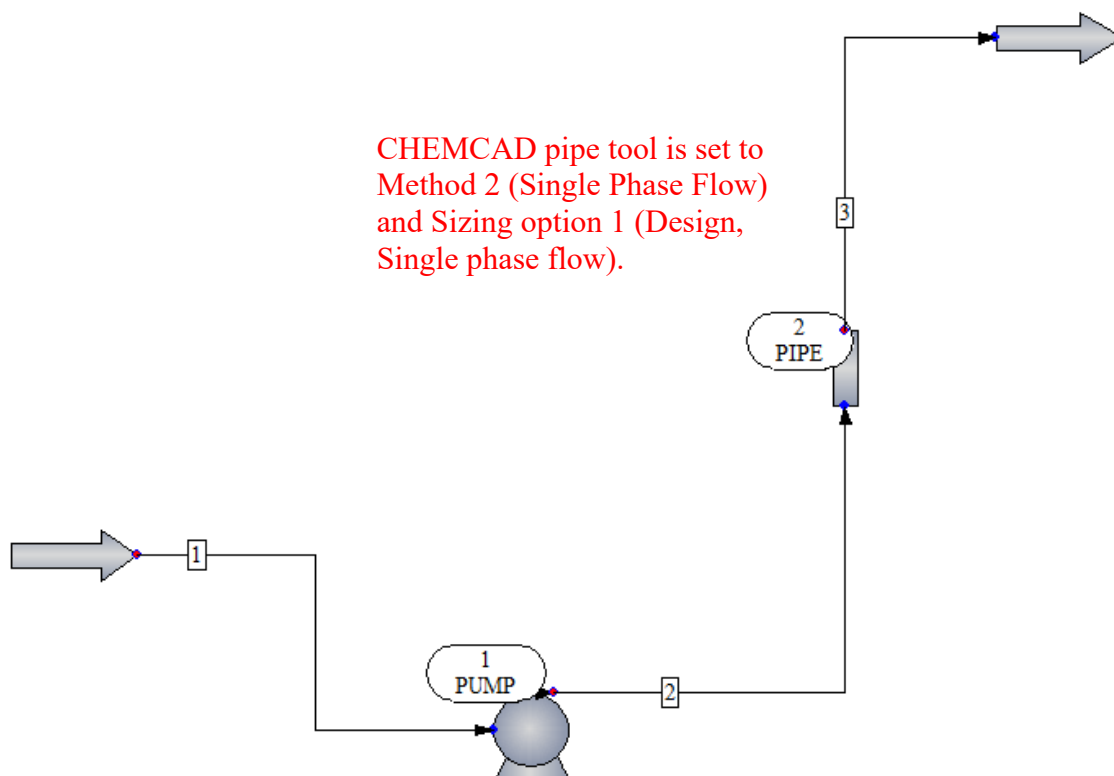
CHEMCAD pump is set to "Specify pressure increase" mode. A value of 296.18 kPa puts stream 3 on spec.

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Pump Summary from CHEMCAD
Pressure increase   kPa          296.1800    ⟵   Pump spec set by cadets. Pressure
Efficiency                         0.7900         increase is iterated, and efficiency
Calculated power   kJ/sec         30.5755         was given.
Calculated Pout   kPa            498.8300
Head   m                          28.9756
Vol. flow rate   m3/h            293.4264
Mass flow rate   lb/sec          187.2978
NPSH available   m                19.8175
Cost estimation flag                    1
Material                                1
Motor type                              2
Motor RPM                               2
Install factor                    2.8000    ⟵   Given in problem statement.
Basic pump cost   $             18139.73    ⟵
Basic motor cost   $             9849.54    ⟵   Pump costs carried forward to
Total purchase cost   $         27989.28        spreadsheet.
Total installed cost $          78369.97
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Pipe / Line Sizing Summary from CHEMCAD
Method                                  2
Pipe schedule                          40
Nominal size DN mm                    200        Calculated by CHEMCAD using
Nominal size NPS in                     8    ⟵   design mode (optimal economic pipe
Calculated ID   m                 0.2027         diameter.
Wall thickness   m                0.0082
Pipe length   m                  46.6344    ⟵   Total length of pipe = 153 feet
Roughness factor   m          4.5720e-005
Elevation change   m              5.7912    ⟵   Must subtract feed pipe height from
Sizing option                           1        pipe outlet height at column:
Pressure drop   kPa             145.3295        33 ft - 14 ft = 19 ft = 5.7912 m
Reynolds # liq               152945.4219
Fric factor liq                   0.0179
Avg density   kg/m3            1042.3170
Calc. velocity   m/sec            2.5254
Min. velocity   m/sec             0.9847
DP friction   kPa                86.1339
DP elevation   kPa               59.1954
Output press. kPa               353.5005    ⟵   Constraint. System must
DP/100ft, psi                     1.2993         deliver this pressure to
Liquid flow   lb/sec            187.2978         column.
Liquid density   kg/m3         1042.3170
Liq viscosity   N-s/m2            0.0035
Surface tension   N/m             0.0418
EL. fittings   m                246.4270
Total ELength   m               293.0614
Gate valve                              2
Glb seat flatBevelPlug                  3
Standard elbow 90 deg. 12
Friction fac. model                     1
Incl. expansion fac.                    1
Pipe wall cond. W/m-K            51.2818
Inclination angle                 7.1336
```

nominal size	in	8"	200 mm
pipe inside diameter, actual	m	0.2027	ID, inches, page 962
pipe length	m	46.63	
pipe price per length, 2002	$/m	49	Fig 12-4, page 503
pipe price, total, 2002	$	2285	
pipe price, total, JAN 2024	$	5257	
pipe installed price	$	*14719*	
number of elbows		12	
elbow price each, 1979	$ each	40	See "1979 Pipe & Fitting Prices"
elbow price, total, 1979	$	480	Found in Lesson 2 on Website
elbow price, total, JAN 2024	$	2044	Fig 13-4, PTW 3rd Ed., p. 529
elbow installed price	$	*5723*	
number of gate valves		2	
gate valve price each, 2002	$ each	700	Fig 12-8, page 505
gate valve price, total, 2002	$	1400	
gate valve price, total, JAN 2024	$	3221	
gate valve installed price	$	*9019*	
number of globe valves		3	
globe valve price, each, 2002	$ each	900	Fig 12-8, page 505
globe valve price, total, 2002	$	2700	
globe valve price, total, JAN 2024	$	6212	
globe valve installed price		*17393*	
paint price, 2002	$/m	1.6	Fig 12-12, page 507
paint price, total, 2002	$	75	
paint, total, JAN 2024	$	*172*	
pump NPSH	m	19.82	
pump ΔP	kPa	296.18	
pump cost, JAN 2024	$	18140	CHEMCAD
motor cost, JAN 2024	$	9850	CHEMCAD
total price, pump+motor	$	27990	
pump+motor installed price	$	*78372*	
Electrical Power			
pump efficiency	0.79		
pump input power	kW	22.019	CHEMCAD
operating time	h	8760	
pump power	kWh	267841	
power cost per unit	$/kWh	0.0646	
power cost	$	*17303*	
Total cost	$	**$142,699**	

Calculations are embedded in the spreadsheet. The optimization of the pipeline diameter was conducted using the "Sizing" tool in CHEMCAD, resulting in 8-inch nominal pipe.

CE Plant Cost Indices	
Pipe, Valves, and Fittings, 1979	300.3
Pipe, Valves, and Fittings, 2002	555.8
Pipe, Valves, and Fittings, JAN 2024	1278.7
Pipes, Valves and Fittings, 2002 to JAN 2024	2.301
Pipes, Valves and Fittings, 1979 to JAN 2024	4.258
Installation Factors	
Install factor for pumps	2.8
Install factor for pipes, valves, and fittings	2.8

CE Plant Cost Index values are found in the "CE Plant Cost Index" linked to the main course web page and are used in the spreadsheet to update prices from 1979 or 2002 to 2024.

How has the design been optimized? (Answer in the space below.
CHEMCAD computes pipe diamter using optimum diamter equations discussed in Lesson 1 in "How to Find the Pipe Diameter." The pipe diamter can be changed in CHEMCAD to prove this. For example, the total cost of the system for 6-inch pipe is $157,393, for 8-inch it is $142,697, and for 10-inch it is $167,074, showing a minimum at 8 inches. Additional results are shown below.

nominal size	in	6"	200 mm
pipe inside diameter, actual	m	0.1541	ID, inches, page 962
pipe length	m	46.63	
pipe price per length, 2002	$/m	32	Fig 12-4, page 503
pipe price, total, 2002	$	1492	
pipe price, total, JAN 2024	$	3433	
pipe installed price	$	*9612*	
number of elbows		12	
elbow price each, 1979	$ each	24	See "1979 Pipe & Fitting Prices"
elbow price, total, 1979	$	288	Found in Lesson 2 on Website
elbow price, total, JAN 2024	$	1226	Fig 13-4, PTW 3rd Ed., p. 529
elbow installed price	$	*3434*	
number of gate valves		2	
gate valve price each, 2002	$ each	420	Fig 12-8, page 505
gate valve price, total, 2002	$	840	
gate valve price, total, JAN 2024	$	1933	
gate valve installed price	$	*5411*	
number of globe valves		3	
globe valve price, each, 2002	$ each	550	Fig 12-8, page 505
globe valve price, total, 2002	$	1650	
globe valve price, total, JAN 2024	$	3796	
globe valve installed price		*10629*	
paint price, 2002	$/m	1.5	Fig 12-12, page 507
paint price, total, 2002	$	70	
paint, total, JAN 2024	$	*161*	
pump NPSH	m	19.82	
pump ΔP	kPa	492.58	
pump cost, JAN 2024	$	20038	CHEMCAD
motor cost, JAN 2024	$	15451	CHEMCAD
total price, pump+motor	$	35489	
pump+motor installed price	$	*99369*	
Electrical Power			
pump efficiency	0.79		
pump input power	kW	50.850	CHEMCAD
operating time	h	8760	
pump power	kWh	445446	
power cost per unit	$/kWh	0.0646	
power cost	$	*28776*	
Total cost	**$**	**$157,392**	

nominal size	in	**10"**	200 mm
pipe inside diameter, actual	m	0.2545	ID, inches, page 962
pipe length	m	46.63	
pipe price per length, 2002	$/m	65	Fig 12-4, page 503
pipe price, total, 2002	$	3031	
pipe price, total, JAN 2024	$	6973	
pipe installed price	$	*19525*	
number of elbows		12	
elbow price each, 1979	$ each	70	See "1979 Pipe & Fitting Prices"
elbow price, total, 1979	$	840	Found in Lesson 2 on Website
elbow price, total, JAN 2024	$	3577	Fig 13-4, PTW 3rd Ed., p. 529
elbow installed price	$	*10015*	
number of gate valves		2	
gate valve price each, 2002	$ each	1100	Fig 12-8, page 505
gate valve price, total, 2002	$	2200	
gate valve price, total, JAN 2024	$	5061	
gate valve installed price	$	*14172*	
number of globe valves		3	
globe valve price, each, 2002	$ each	1900	Fig 12-8, page 505
globe valve price, total, 2002	$	5700	
globe valve price, total, JAN 2024	$	13114	
globe valve installed price		*36718*	
paint price, 2002	$/m	1.8	Fig 12-12, page 507
paint price, total, 2002	$	84	
paint, total, JAN 2024	$	*193*	
pump NPSH	m	19.82	
pump ΔP	kPa	242.56	
pump cost, JAN 2024	$	17477	CHEMCAD
motor cost, JAN 2024	$	8338	CHEMCAD
total price, pump+motor	$	25815	
pump+motor installed price	$	*72282*	
Electrical Power			
pump efficiency	0.79		
pump input power	kW	25.040	CHEMCAD
operating time	h	8760	
pump power	kWh	219350	
power cost per unit	$/kWh	0.0646	
power cost	$	*14170*	
Total cost	$	**$167,075**	