APPROVED SOLUTION

Design Problem 1 – Pump and Piping Design

1. Objectives
2. Problem statement.
3. Constraints and additional information.
4. Submission requirements.

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.

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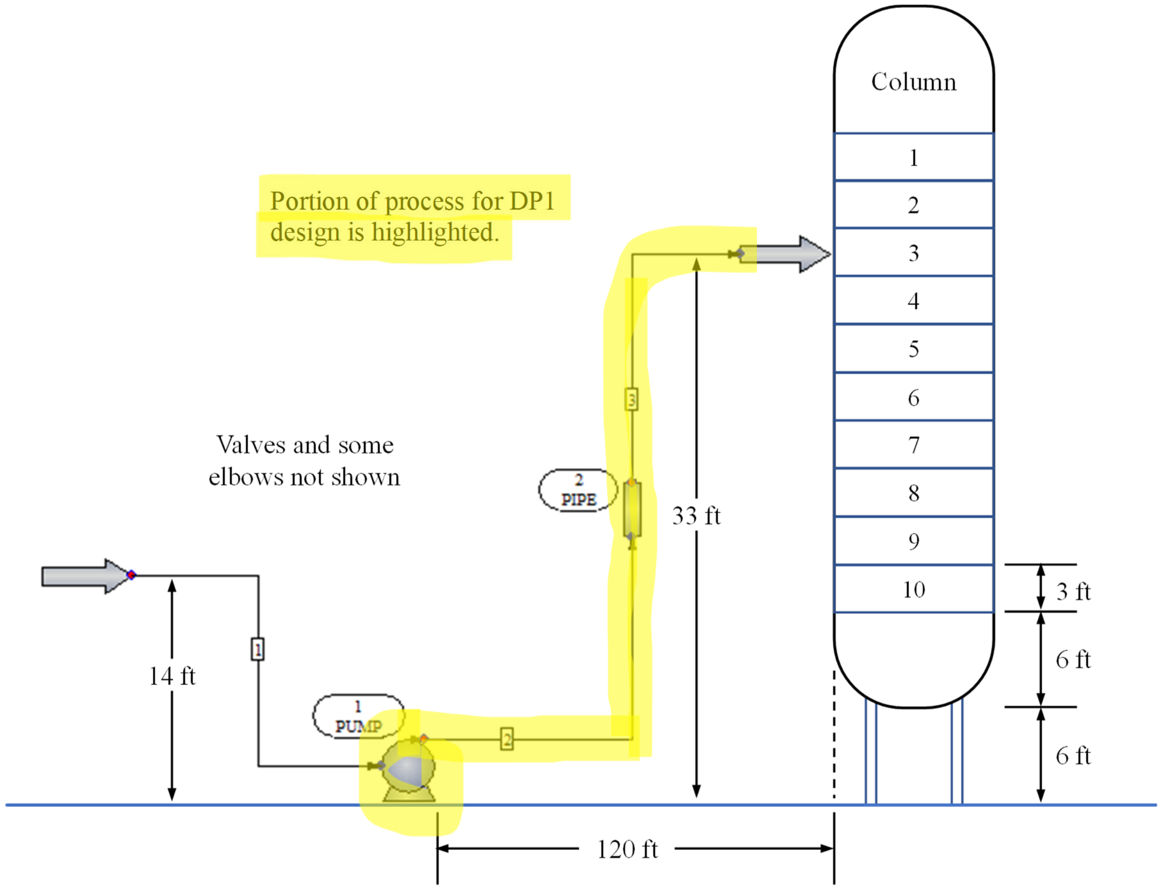
Addendum – Process Sketch

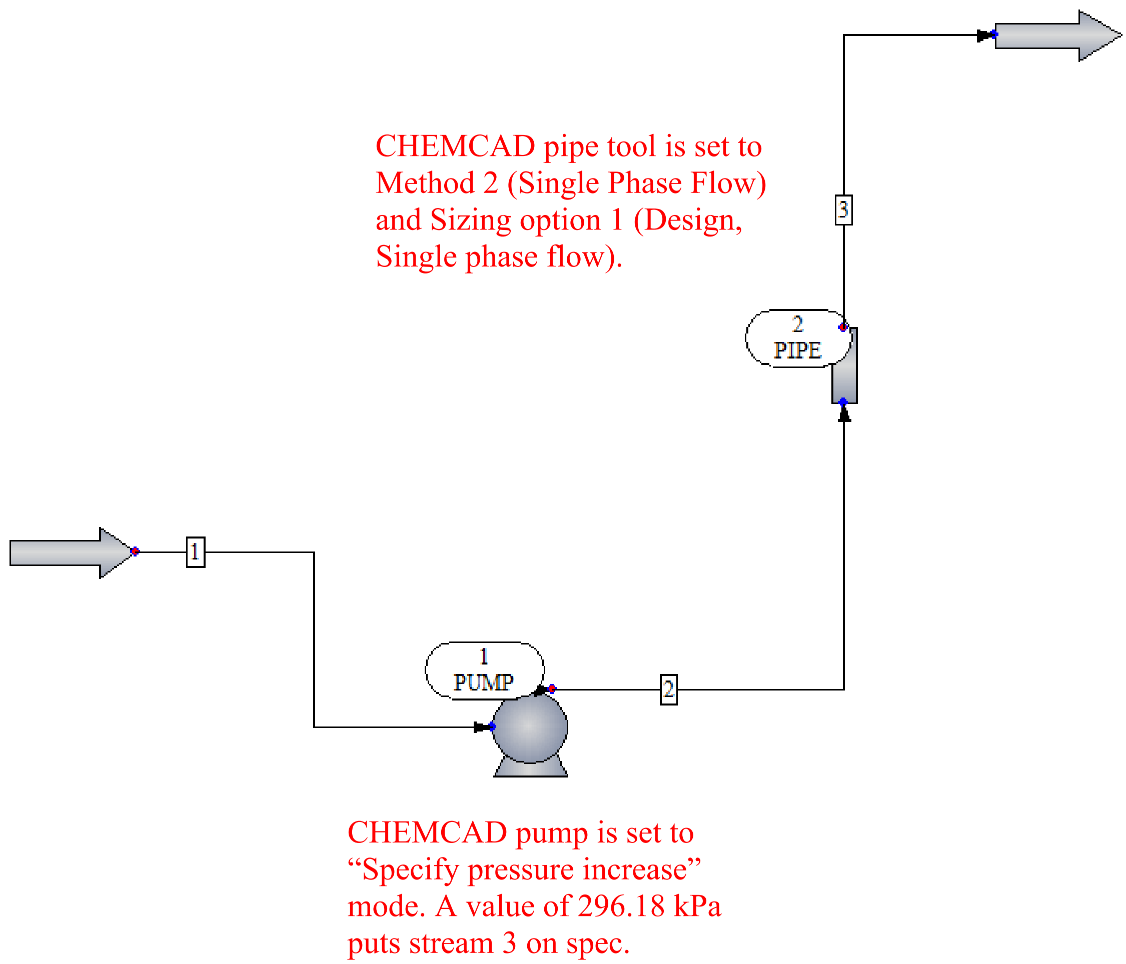


Vertical split-case pump (VSC), https://www.statesupply.com/bell-and-gossett/pump/series-vsx. Casing split is perpendicular to motor shaft axis.

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.



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Pump Summary from CHEMCAD

Pressure increase kPa	296.1800
Efficiency	0.7900
Calculated power kJ/sec	30.5755
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
Basic pump cost $	18139.73
Basic motor cost $	9849.54
Total purchase cost $	27989.28
Total installed cost $	78369.97

Pump spec set by cadets. Pressure increase is iterated, and efficiency was given.

Given in problem statement.

Pump costs carried forward to spreadsheet.

Pipe / Line Sizing Summary from CHEMCAD

Method	2
Pipe schedule	40
Nominal size DN mm	200
Nominal size NPS in	8
Calculated ID m	0.2027
Wall thickness m	0.0082
Pipe length m	46.6344
Roughness factor m	4.5720e-005
Elevation change m	5.7912
Sizing option	1
Pressure drop kPa	145.3295
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
DP/100ft, psi	1.2993
Liquid flow lb/sec	187.2978
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

Calculated by CHEMCAD using design mode (optimal economic pipe diameter.

Total length of pipe = 153 feet

Must subtract feed pipe height from pipe outlet height at column:
33 ft - 14 ft = 19 ft = 5.7912 m

Constraint. System must deliver this pressure to column.

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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.

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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 diameter using optimium diameter equations discussed in Lesson 1 in "How to find the Pipe Diameter."