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: (1) to use CHEMCAD to perform an optimized design and pricing of a section of pipeline, (2) to update the cost index in CHEMCAD, 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 process. The feed liquid temperature, pressure, and component flow rates are shown in Table 1 below, and this mixture is to be fed to a multi-component distillation column. That is, you will determine the size and cost of the pipeline needed to connect the feed pump to the column. You will also determine the power and price of the feed pump, 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 additional information 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 will *not* be designing the distillation column or column internals (trays, shell, condenser, reboiler). This has already been designed by another group.
- You are designing the pump and the pipe connecting the pump to the column.
- Additional piping constraints and specs:
  - Pipe sizing option in CHEMCAD is mode 1 (design for single-phase flow).
  - All pipe and fittings are Sch. 40 welded commercial (carbon) steel.
  - The length of the pipeline is 153 feet with a net elevation change of 19 feet.
  - The pipe material is from commercial steel and must be painted.

- The pipeline has twelve 90° standard elbows, two gate valves, three globe valves, and one sudden expansion where the fluid emerges into the distillation column. The diameter ratio for the expansion can be taken as 0.001.
- The feed must enter on the third tray from the top 33 feet above ground level at **298 K and 353.5 kPa**.
- Pipe and valve costs cannot be calculated in CHEMCAD. Pipe costs can be found in the PTW textbook or on the PTW web site. Any cost data taken from the textbook is referenced to 2002.
- Fittings costs are not in CHEMCAD and are not in 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 1979.
- Installed costs are 2.8 times the purchased equipment cost.

• Additional pump constraints and specs:

- The pump and motor costs are calculated in CHEMCAD. The pump is centrifugal, case steel and explosion proof, 1200 rpm, and is 79% efficient.
- CHEMCAD cost information must be updated by entering the current Chemical Engineering Plant Cost Indices. Values can be viewed in "Tools," then "Edit Cost Index."
- Installed costs are 2.8 times the purchased equipment cost.
- Energy cost is based on one year of operation (365d=1yr) at $0.0646 per kWh. (https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a)

Submission Requirements

1. 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.

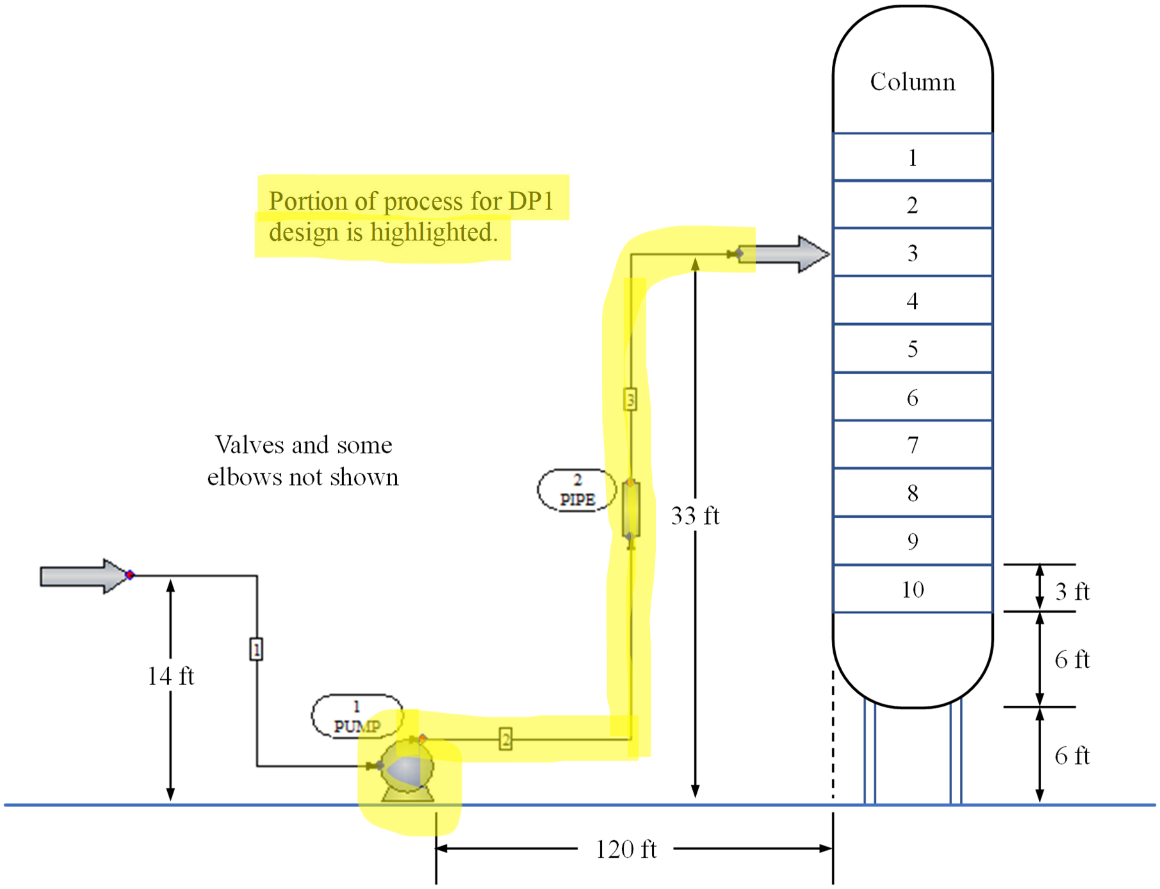
    d. Total cost of installed equipment and energy for one year of operation.

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

2. Complete and upload the CHEMCAD template found in 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.

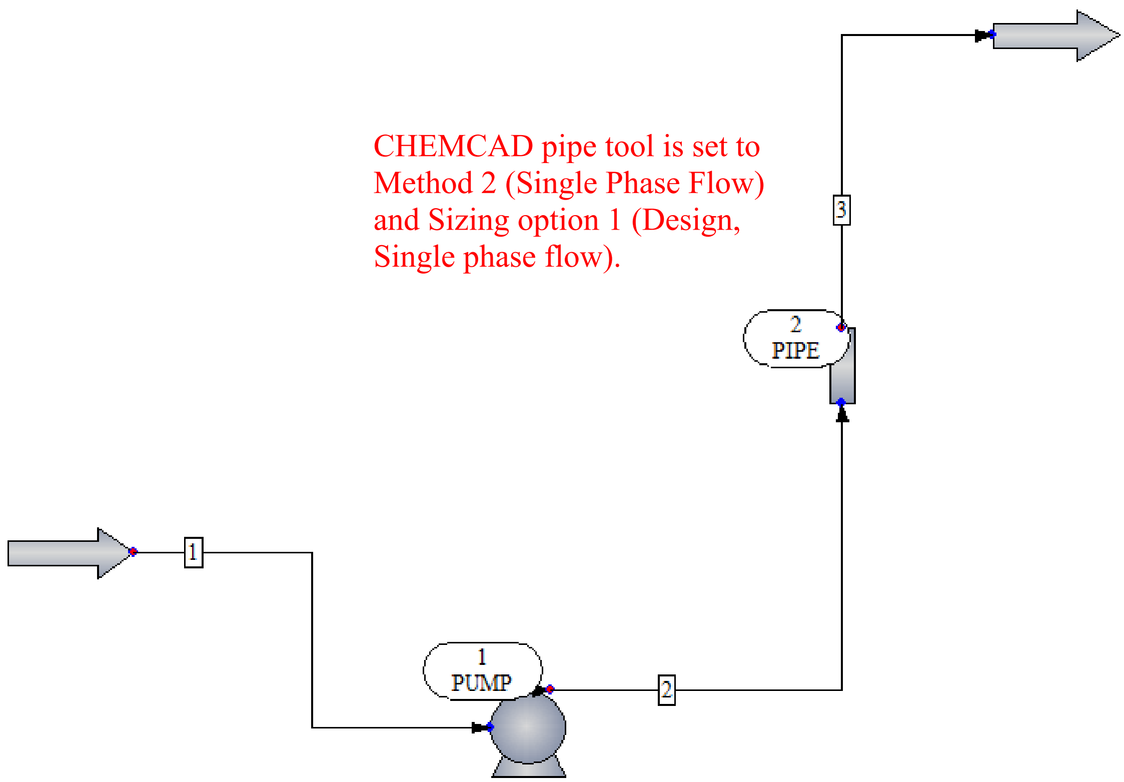
APPROVED SOLUTION

Addendum – Process Sketch



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 pump is set to "Specify pressure increase" mode. A value of 296.18 kPa puts stream 3 on spec.

APPROVED SOLUTION

Pump Summary from CHEMCAD

Pressure increase kPa	296.1800	Pump spec set by cadets. Pressure increase is iterated, and efficiency was given.
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	Given in problem statement.
Basic pump cost $	18139.73	Pump costs carried forward to spreadsheet.
Basic motor cost $	9849.54	
Total purchase cost $	27989.28	
Total installed cost $	78369.97	

Pipe / Line Sizing Summary from CHEMCAD

Method	2	
Pipe schedule	40	
Nominal size DN mm	200	
Nominal size NPS in	8	Calculated by CHEMCAD using design mode (optimal economic pipe diameter.
Calculated ID m	0.2027	
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 pipe outlet height at column: 33 ft - 14 ft = 19 ft = 5.7912 m
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	Constraint. System must deliver this pressure to column.
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	

APPROVED SOLUTION

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.

APPROVED SOLUTION

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."