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	114.38
Naphthalene	374.77
Biphenyl	3,945.70
Diphenylenemethane (Fluorene)	241.17
Phenanthrene	180.23
M-Terphenyl	449.77
Total	5,306.02

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 3600 rpm, and installed costs are 2.8 times the purchased equipment cost.
  - CHEMCAD cost information must be updated to January 2025 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)

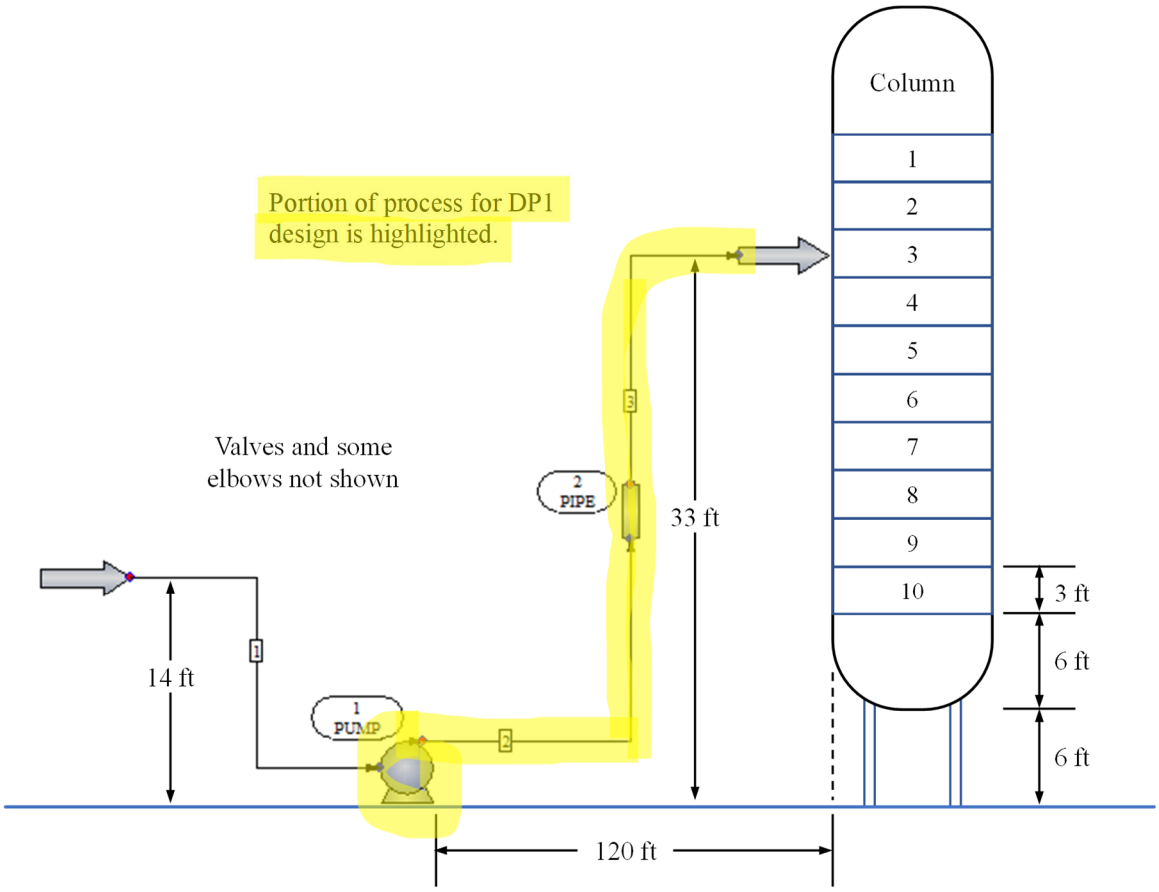
- Piping constraints and specs:
  - Pipe, valve, and fitting costs cannot be calculated in CHEMCAD. Pipe costs can be found in the PTW textbook. Any cost data taken from the textbook is referenced to January 2002.
  - Fittings costs are not in the 2002 edition of the textbook. They can be found in the "1979 Pipe & Fitting Prices" document found in CANVAS (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 2025 for pipe, elbows, valves, and paint.
   c. Purchased and installed cost of pump and motor in January 2025.
   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.

APPROVED SOLUTION

Addendum – Process Sketch



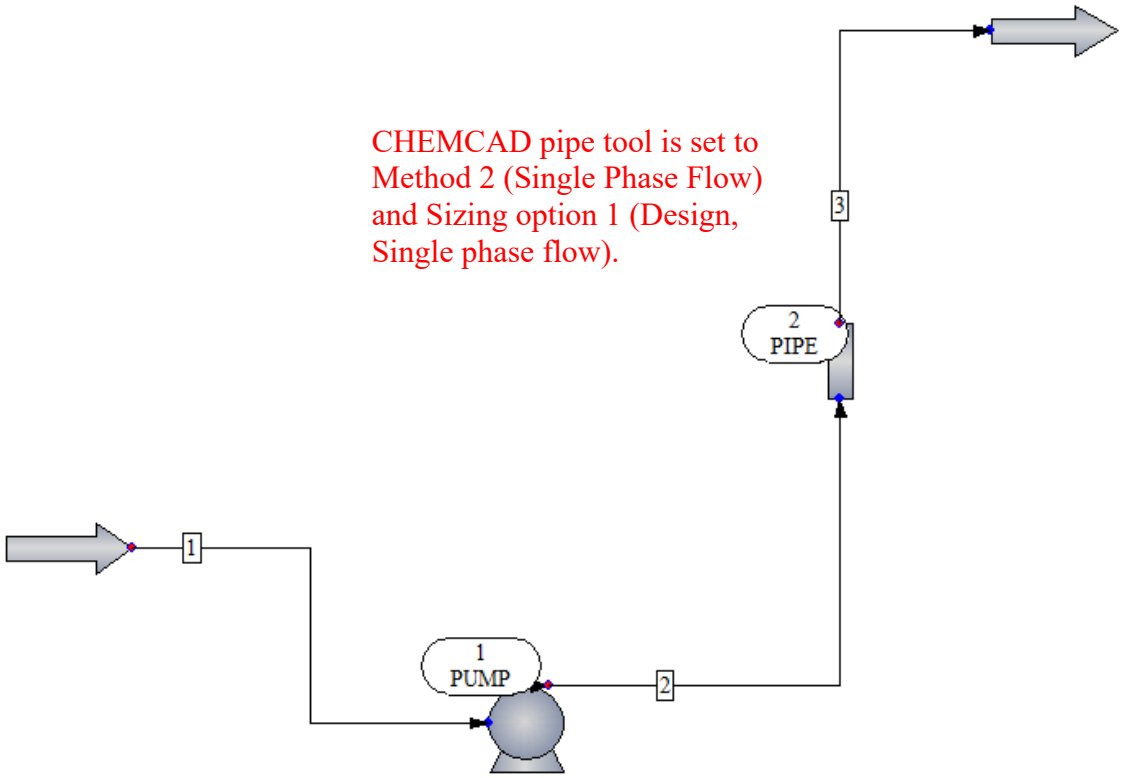
The photographs below illustrate vertical and horizontal split pump cases. These designs show up in CHEMCAD in the pump unit "cost estimation" tab, as VSC and HSC in the "Centrifugal pumps" dropdown.

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 8-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.



APPROVED SOLUTION

Pump Summary from CHEMCAD

Pressure increase kPa	343.8300
Efficiency	0.7900
Calculated power kJ/sec	44.3682
Calculated Pout kPa	546.4800
Head m	33.6373
Vol. flow rate m3/h	366.7834
Mass flow rate lb/sec	234.1225
NPSH available m	19.8176
Cost estimation flag	1
Material	1
Motor type	2
Install factor	2.8000
Basic pump cost $	21137.91
Basic motor cost $	11013.05
Total purchase cost $	32150.97
Total installed cost $	90022.71

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	192.9788
Reynolds # liq	152945.4219
Fric factor liq	0.0174
Avg density kg/m3	1042.2915
Calc. velocity m/sec	3.1568
Min. velocity m/sec	0.9848
DP friction kPa	133.7846
DP elevation kPa	59.1941
Output press. kPa	353.5013
DP/100ft, psi	1.9701
Liquid flow lb/sec	234.1225
Liquid density kg/m3	1042.2915
Liq viscosity N-s/m2	0.0035
Surface tension N/m	0.0418
EL. fittings m	253.5709
Total ELength m	300.2053
Gate valve	2
Glb seat flatBevelPlug	3
Standard elbow 90 deg.	12
Sudden expansion	1
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.

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 2025	$	5410		
pipe installed price	$	*15147*		
number of elbows		12		
elbow price each, 1979	$ each	43		See "1979 Pipe & Fitting Prices"
elbow price, total, 1979	$	516		Found in Lesson 2 on Website
elbow price, total, JAN 2025	$	2261		Fig 13-4, PTW 3rd Ed., p. 529
elbow installed price	$	6331		
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 2025	$	3315		
gate valve installed price	$	*9281*		
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 2025	$	6392		
globe valve installed price		*17899*		
paint price, 2002	$/m	1.6		Fig 12-12, page 507
paint price, total, 2002	$	75		
paint, total, JAN 2025	$	177		
pump NPSH	m	19.82		
pump ΔP	kPa	343.83		
pump cost, JAN 2025	$	21138		CHEMCAD
motor cost, JAN 2025	$	11013		CHEMCAD
total price, pump+motor	$	32151		
pump+motor installed price	$	*90023*		
Electrical Power				
pump efficiency	0.79			
pump input power	kW	44.368		CHEMCAD
operating time	h	8760		
pump power	kWh	388665		
power cost per unit	$/kWh	0.0646		
power cost	$	25108		
Total cost	**$**	**$163,965**		

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 2025	1315.9
Pipes, Valves and Fittings, 2002 to JAN 2025	*2.368*
Pipes, Valves and Fittings, 1979 to JAN 2025	*4.382*
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 course web page, and are used in the spreadsheet to update prices from 1979 or 2002 to 2025.

How has the design been optimized? (Answer in the space below.
CHEMCAD computes pipe diameter using optimum diameter equations discussed in Lesson 1 in "How to Find the Pipe Diameter." The pipe diameter can be changed in CHEMCAD to prove this. For example, the total cost of the system for 6-inch pipe is $205,982, for 8-inch it is $163,965, and for 10-inch it is $180,600, showing a minimum at 8 inches. The additional results are shown in the 6" and 10" spreadsheets.

APPROVED SOLUTION

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 2025	$	3533		
pipe installed price	$	*9892*		
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 2025	$	1262		Fig 13-4, PTW 3rd Ed., p. 529
elbow installed price	$	3534		
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 2025	$	1989		
gate valve installed price	$	*5569*		
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 2025	$	3907		
globe valve installed price		*10938*		
paint price, 2002	$/m	1.5		Fig 12-12, page 507
paint price, total, 2002	$	70		
paint, total, JAN 2025	$	166		
pump NPSH	m	19.82		
pump ΔP	kPa	649.15		
pump cost, JAN 2025	$	24198		CHEMCAD
motor cost, JAN 2025	$	21688		CHEMCAD
total price, pump+motor	$	45886		
pump+motor installed price	$	*128481*		
Electrical Power				
pump efficiency	0.79			
pump input power	kW	83.766		CHEMCAD
operating time	h	8760		
pump power	kWh	733794		
power cost per unit	$/kWh	0.0646		
power cost	$	47403		
Total cost	**$**	**$205,982**		

APPROVED SOLUTION

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	$	7176		
pipe installed price	$	*20093*		
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	$	3681		Fig 13-4, PTW 3rd Ed., p. 529
elbow installed price	$	10306		
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	$	5209		
gate valve installed price	$	*14584*		
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	$	13495		
globe valve installed price		*37787*		
paint price, 2002	$/m	1.8		Fig 12-12, page 507
paint price, total, 2002	$	84		
paint, total, JAN 2024	$	199		
pump NPSH	m	19.82		
pump ΔP	kPa	242.56		
pump cost, JAN 2024	$	19946		CHEMCAD
motor cost, JAN 2024	$	8205		CHEMCAD
total price, pump+motor	$	28152		
pump+motor installed price	$	*78825*		
Electrical Power				
pump efficiency	0.79			
pump input power	kW	33.232		CHEMCAD
operating time	h	8760		
pump power	kWh	291112		
power cost per unit	$/kWh	0.0646		
power cost	$	18806		
Total cost	**$**	**$180,600**		

APPROVED SOLUTION

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**		

APPROVED SOLUTION

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**		