Flowing Fine: Moving Fluids on an Industrial Scale

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Part I – Which Design to Choose?

Vince had a problem. Clicking his pen meditatively, he stared at the scribbled calculations that covered several pages spread over his desk. *I don't think I'm doing this right,* he thought with a worried frown. *I can't possibly have to buy a pump this big, not for the setup we've got in the pilot plant. None of the other pumps down there are this big.*

"Hey Vince, I'm starving. Want to grab lunch?" Vince looked up to see Tom, a process engineer who had been working in the pilot plant for more than five years.

"Tom, you're always hungry. What time is it, anyway?" asked Vince, glancing up at the wall clock as he spoke. "Geez, it's 1:17. I've been trying to figure out this pump stuff for over two hours! It just won't come out right! Look at these numbers; there's no way we need a pump this big."

"Lemme see, maybe I can help," said Tom. "Wait, why do you have four different diagrams?"

"Because I've come up with four different options to run the line around the filtration unit that's between the milk holding tank and the spray dryer," said Vince. "Look, here's my list."

Tom looked at the list. "Why are the pipe diameters all different here?"

"Well, I was trying to get the length of straight pipe as short as possible, and it turns out the smaller pipes can fit in areas the bigger ones can't, so they don't have to be as long. Oh, and the valves depend on the pipe diameter too. I can't find flanged elbows for an inch diameter pipe in the right material; the manufacturer would have to custom-make them. And the elbows… well, long story short, these four setups will cost us the least amount in capital. You know how the higher-ups are with capital costs."

"Yeah, well, you get what you pay for," said Tom with a smile. "Remember the ultrafiltration membrane fiasco last year? And the thermocouples we got for the jacketed mixing tank?"

"Ugh, don't remind me about the membranes," groaned Vince, who had had to install and replace them. "Wrecked a lot of good product and I had to work overtime for a month to get back on schedule. Anyway, I don't want to be the guy who was responsible for the pump in the floor, like in the juice plant I interned at."

"You had to put a pump in the floor?" Tom started laughing. "What, did you size it too big?"

"Not *me*, it was some new guy with a fancy degree and no sense," huffed Vince. "Putting the pump in the floor is what I'm trying *not* to do, so stop laughing and help me out here!"

"Okay, sorry," Tom chuckled. "Okay, you've got to get the milk from the holding tank to the spray dryer, right? And the inlet to the spray dryer is 2.6 m above the level of milk in the holding tank. And the pressure in the spray dryer is 150 bar… you know that's gauge pressure?" Vince nodded.

"Okay, cool," said Tom. "And the holding tank is vented, and we always keep the level in the tank constant. How much milk are you trying to move?"

"Ten thousand liters of milk per hour, max," said Vince. "The spray dryer can't handle any more than that."

"Gotcha," said Tom. "Okay, so now you just have to figure out how much power your pump needs."

"Yeah, but this dang energy balance won't come out right," said Vince. "And I don't know which piping system I want. One of these systems probably loses less energy to friction, but I don't know which one!"

"Well, I want lunch," said Tom. "Just write out the general balance for a fluid transport system and bring it with you. We can debate over lunch."

Vince's four piping options:

- 1.5-inch diameter stainless steel pipes ($\varepsilon = 1.5 \times 10^{-5}$ m) with five 90 degree flanged elbows ($C_{ff} = 0.35$) and two gate valves ($C_{ff} = 0.2$). Total length of straight pipe = 360 m
- 1.5-inch diameter stainless steel pipes ($\varepsilon = 1.5 \times 10^{-5}$ m) with three 90 degree flanged elbows ($C_{ff} = 0.35$) and two gate valves ($C_{ff} = 0.2$). Total length of straight pipe = 390 m
- 1.0-inch diameter stainless steel pipes ($\varepsilon = 1.5 \times 10^{-5}$ m) with four 90 degree threaded elbows ($C_{ff} = 1.55$) and two gate valves ($C_{ff} = 0.14$). Total length of straight pipe = 240 m
- 1.0-inch diameter stainless steel pipes ($\varepsilon = 1.5 \times 10^{-5}$ m) with two 90 degree threaded elbows ($C_{ff} = 1.55$) and two ball valves ($C_{ff} = 0.06$). Total length of straight pipe = 270 m

Questions

1. Write the general energy balance for a fluid system. What terms can be excluded from the balance for Vince's system, regardless of what piping option he chooses? Justify your reasoning.
2. Which of the four options for the fluid transport system do you think will require the least amount of pump energy? Explain why you chose that option.

Part II – Size That Pump and Check Your Units

"Much better," said Tom, finishing up the last few bites of his brownie. "So you know what piping option you want now, right?"

"Yeah, and thanks for the tips," said Vince. "Back to work on the pump, I guess. I wish I could get the numbers to come out to something reasonable."

"You're using mass flowrates, right? It won't work if you don't—hey, are you throwing out those chips?"

"Here, you can have them." Vince tossed the bag over to Tom. "I have no idea where you put it all."

"Hollow leg," said Tom, tearing open the bag and grabbing a chip. "Oh, and check your units. I had a ChemE prof that was always on my case about units and dimensional analysis. Grumpy as anything, but right; half of the stuff I missed on his tests was because I messed up units."

"Hmm, good idea," said Vince, frowning. "Actually, I think that's where I might be going wrong—that and mass flowrates. Thanks, man! I'll rerun the numbers and see if I can't get this off my desk by the end of today. Oh, and if you check my work, I'll buy you a Snickers out of the vending machine."

"I'd do it for nothing," said Tom, crunching busily through the chips, "but since you offered, it's a deal."

Vince shook his head and smiled, figuring he had enough loose change rattling around in his desk that he could scrape enough together for a candy bar. After getting back to his desk, he shuffled through the papers on it until he found the sketches he had originally made of the piping system. *Okay, time to go through the equations again,* he thought. As he checked the equations against the data he had, he realized that he was missing some information. *Well, no wonder the pump size was so weird. I was doing this wrong the whole time. But I'm missing some info I need to size the pump right. Hey, maybe Tom knows where to find this stuff. Or at least he'd know who to ask.* Feeling rather sleepy after lunch, he decided to send Tom an IM rather than walk over to his desk:

"**Hey Tom, missing some info I need for eqns, know where I can find it?**"

Questions

1. What would Vince's diagrams look like? Draw a diagram of the fluid transport system with the piping option selected in Part I and label it appropriately. You only need to draw the diagram for your chosen system.
2. Write the energy balance for your chosen system in terms of variables only.
3. Are you missing any information needed to solve the energy balance? As Tom, what would your response be to Vince about where you might find missing information? If you are missing information, use this advice to find values. State your source of information and any assumptions you make.
4. Calculate each term in the energy balance.
5. Calculate the energy required from the pump.
6. What is the largest source of energy loss in the system? Discuss ways to reduce energy losses, considering equipment location and materials, flowrates, and fluid properties in your suggestions.
7. If the pump you select is 90% efficient, what is the brake power needed for the pump?
8. Discuss how Vince could select a pump from pump curves based on your calculated results for brake power.