Norges Teknisk-Naturvitenskapelige Universitet

TPK4186 - Advanced Tools for Performance Engineering
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Assignment 1: Pumping Circuits

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Contents

1 Introduction

1.1 Presentation of the Problem

The objective of this assignment is to design a Python script to assess the energy consumption of seawater pumping circuits such as those used in fish farms. Figure 1 shows such a circuit.

This circuit is made of the following elements:

– The source tank S in which the seawater is pumped and the target tank T.
– The horizontal pipe sections P1, P2, and P4.
– The vertical pipe section P3.
– The 90 degrees bends B1, B2 and B3.
– The motor pump MP.

Later on, we shall introduce additional elements such as valves and filters.

Roughly speaking (we shall make a number of simplifying assumptions), the energy required by the motor pump depends on:

– The volume of seawater that flows through the circuit per unit of time.

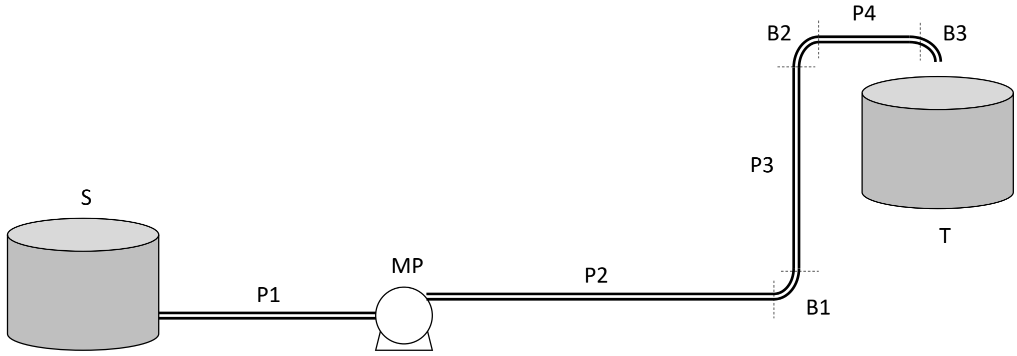

Figure 1: A simple pumping circuit

- The efficiency of the pump.
- The height at which the seawater must be lifted up.
- The losses of pressure due to frictions in the circuit.

We shall give the mathematical formulas to calculate that, and it will be up to you to implement them in Python.

1.2 Requirements

The objective of this assignment is not only, nor even primarily, to assess the energy consumption of pumping circuits, but rather to show your Pythonic skills.

Here follows a number of requirements.

1. You must provide your program together with a small document explaining how it is organized, what it is doing (which functionalities are implemented) and reporting experiments you have performed with it. You may also provide additional files such as those you use to test your program and to perform experiments.
2. Assuming your name is Jack Sparrow, all of the above files must be included in a zip archive named:

   `TPK4186 - 2020 - Assignment1 - Sparrow Jack.zip`

   The deliverable of the assignment is this zip archive.
3. The assignment must be made invidually.
4. You must program in an object-oriented style, preferably splitting your program into modules.
5. Recall that the quality of a program can be judge along three criteria: its completness, its correctness and its maintainability:
   - A program is complete if it provides all functionalities demanded by the client. Some functionalities are however more important than other. You must first concentrate on the main functionalities, then develop the "nice-to-have" ones.
   - A program is correct if it is bug free. To ensure that your program is correct, you must test it extensively. Design tesst before writing the first line of code. There is no such a thing than a program or a functionality that works "most of the time". Either it works, or not. If you are not able to make a functionality work, do not deliver it.
   - A program is maintainable if it is well presented, if the identifiers are significant, and so on. But before all, a program is maintainable if it well organized and as modular as possible. Separate the concerns.
6. You will be asked to develop several interfaces for circuit descriptions. These interfaces will be tested with several circuit descriptions to which you will not have access. This

to say that you must be very careful in developing these interfaces and obey strictly the syntax which will be given later in this document.

2 Pumping Circuits

2.1 Circuit Elements

The circuits we shall design are sequences of elements. Each element has a name, a type and a number of characteristics that depend on its type. The different types of elements are the following.

Tanks Tanks have just a name.

Pipes Pipes have a name, an inside diameter, a length and an angle. To simplify, we whall assume that circuits are made only of horizontal and vertical pipes, i.e. that the angle of a pipe is either 0 or 90 degrees. To simplify, we shall assume that inside diameters and lengths of pipes are measured in meters.

Bends Bends make it possible to pass from horizontal to vertical pipes and vice-versa. They have a name and an inside diameter. As we consider only horizontal and vertical pipes, all bends have a 90 degrees angle. To simplify, we shall assume that inside diameters of bends are measured in meters.

Pumps Pumps have a name and an efficiency. The latter varies between 0.7 and 0.9 depending on the pump and motor configuration.

Valves Valves have a name and can be more or less open, which has indeed an influence on frictions and therefore pressure losses. To simplify, we shall assume that valves are either fully or half open.

Filters Filters have a name and can be more or less dirty, which has indeed an influence on frictions and therefore pressure losses. To simplify, we shall assume that filters are either new (clean) or used (dirty).

To simplify, we shall assume that vertical pipes are only used to lift-up water, i.e. that the circuit never goes down.

2.2 Well-Designed Circuits

As already said, a circuit is essentially a sequence of elements. For the circuit to be well-designed, this sequence must obey the following rules.

1. The circuit must start and end with a tank. These two tanks must be the only ones of the circuit.
2. The second element of the circuit must be a horizontal pipe.
3. The circuit must contain one and only one pump.
4. All pipes and bends of the circuit must have the same inside diameter.
5. If a pipe follows another pipe, then the two pipes must have the same angle.
6. Bends make pass from a horizontal pipe to a vertical pipe or vice-versa (except before the target tank).
7. Pumps and filters must be preceded and followed by horizontal pipes.
8. Valves must be preceded and followed by pipes with the same angles.

Circuits that are not well designed must be rejected.

2.3 Calculations

The actual energy P_a (in KW) needed can be calculated using the following formula.

$$P_a = \frac{P_t}{\eta}\,[kW] \tag{1}$$

Where:

– P_t denotes the theoretical energy required to pump the seawater.
– η denotes the efficiency of the pump (recall that this efficiency is comprised between 0.7 and 0.9).

The theoretical energy P_t can be calculated in turn by means of the following formula.

$$P_t = \frac{(\Delta_h + \Delta_f) \times Q}{1000}\,[kW] \tag{2}$$

Where:

– Δ_h denotes the pressure losses due the height the seawater has to be lifted-up.
– Δ_f denotes the pressure losses due to frictions.
– Q denotes the flow of seawater that circulates in the circuit.

The flow Q is calculated by means of the following formula.

$$Q = A \times v\,[m^3/s] \tag{3}$$

Where:

– A denotes the inside cross sectional area of the pipes. A is the same all over the circuit as all pipes and bends are assumed to have the same inside diameter d.
– v denotes the velocity of the seawater (in m/s) circulating in the circuit. Due to cavitation and turbulences, v should be lower than 5 m/s.

The area A (in m^2) is simply calculated as follows.

$$A = \frac{\pi \times d^2}{4}\,[m^2] \tag{4}$$

Given our assumptions, Δ_h is calculated has follows.

$$\Delta_h = h \times g \times \rho\,[N/m^2] \tag{5}$$

Where:

– h denotes the sum (in m) of the lengths of vertical pipes.
– $g = 9.81$ denotes the gravity (in m/s^2).
– ρ denotes the density of the seawater, namely $1025\,kg/m^3$.

Recall that $1N = 1kg \cdot m \cdot s^{-2}$.

It remains thus to define how to calculate the loss of pressure due to each individual circuit element, which depends indeed of the type of the element.

Losses of pressure due to tanks It is null.

Losses of pressure due to pipes The loss of pressure Δ_{pipe} (in N/m^2) due to frictions in a pipe can be estimated by means of the following formula.

$$\Delta_{pipe} = \lambda \times \frac{l}{d} \times \frac{\rho}{2} \times v^2\,[N/m^2] \tag{6}$$

Where:

– λ is a coefficient that depends on the flow.
– d denotes as previously the inside diameter of the pipe (in m).

- ρ denotes as previously the density of the seawater (in kg/m^3).
- v denotes as previously the velocity of the seawater (in m/s) circulating in the circuit.

λ is calculated with different equations depending on whether the flow is laminar or turbulent, which in turns depends on the velocity v of the seawater, once fixed the dimension of the pipe. To know whether the flow is laminar or turbulent, one has first to calculate the Reynolds number Re, which is defined by the following formula.

$$Re = \frac{v \times d}{\kappa} \tag{7}$$

- v denotes as previously the velocity of the seawater (in m/s) circulating in the circuit.
- d denotes as previously the inside diameter of the pipe (in m).
- κ denotes the kinematic viscosity of the seawater, which is equal to $1.35 \times 10^{-6}\, m^2/s$).

Note that the Reynold number has no unit.

Now, the flow is laminar if $Re < 2300$ and turbulent otherwise.

For laminar flow, the coefficient λ is calculated as follows.

$$\lambda = \frac{64}{Re} \tag{8}$$

For turbulent flow (at least while $Re < 10^5$), it is calculated as follows.

$$\lambda = \frac{0.316}{\sqrt[4]{Re}} \tag{9}$$

Losses of pressure due to bends The loss of pressure Δ_{bend} due to a bend can be calculated by the following equation.

$$\Delta_{bend} = \zeta_{bend} \times \frac{\rho}{2} \times v^2\, [N/m^2] \tag{10}$$

Where:
- $\zeta_{bend} = 0.1 \times \sin(\pi/2)$ for a 90 degrees bend.
- ρ denotes as previously the density of the seawater (in kg/m^3).
- v denotes as previously the velocity of the seawater (in m/s) circulating in the circuit.

Losses of pressure due to valves The loss of pressure Δ_{valve} due to a valve can be calculated by the following equation.

$$\Delta_{valve} = \zeta_{valve} \times \frac{\rho}{2} \times v^2\, [N/m^2] \tag{11}$$

Where:
- The value of ζ_{valve} is determined from tables, e.g.
  - 0.2 for a fully open valve.
  - 4 for a half open valve.

  For openings in between 0.5 (half open valve) and 1.0 (fully open valve), the value of ζ_{valve} is obtained by a linear interpolation. Other values are considered as impossible.
- ρ denotes as previously the density of the seawater (in kg/m^3).
- v denotes as previously the velocity of the seawater (in m/s) circulating in the circuit.

Losses of pressure due to filters The loss of pressure Δ_{filter} due to a filter can be calculated by the following equation.

$$\Delta_{filter} = \zeta_{filter} \times \frac{\rho}{2} \times v^2 \, [N/m^2] \quad (12)$$

Where:
- The value of ζ_{filter} is determined experimentally, e.g.
  - 0.5 for a clean filter.
  - 5 for a dirty filter.

  For cleanliness in between 1.0 (clean filter) and 0.0 (dirty filter), the value of ζ_{filter} is obtained by a linear interpolation. Other values are considered as impossible.
- ρ denotes as previously the density of the seawater (in kg/m^3).
- v denotes as previously the velocity of the seawater (in m/s) circulating in the circuit.

3 Tasks

Here follows the series of tasks that you are asked to complete.

3.1 Core Module

Design a Python module to represent circuit elements (tanks, pipes, bends, valves and filters) and circuits themselves.

3.2 Tools

Design a Python module that implements two classes:
- A class to check that a circuit is well-designed.
- A class to calculate the energy consumption of a circuit.

3.3 TSV Interface

Design a Python module that implements a TSV interface for your program. The syntax of TSV files is examplified by the file `circuit.tsv`.

3.4 XML Interface

Design a Python module that implements a XML interface for your program. The syntax of XML files is examplified by the files `circuit.xml`.

3.5 Calculations

Using the modules developed in the previous questions, you shall now study the pumping circuit pictured in Figure 2. The diameter of pipes and bends is 80mm.

This study aims at determining the influence of different factors on the energy consumption. It should be published in form of a web page (HTML page), automatically generated by your Python script (so that the same script could be applied to a different circuit). Curves should be drawn with `matplotlib`.

1. Study the relationship between the energy consumption and pump efficiency. Consider also the velocity given to seawater in your study.
2. Study the influence of the diameter of pipes and bends on the energy consumption. Consider also the velocity given to seawater in your study.

Code	Length (in m)
P1	2.00
P2	2.00
P3	2.50
P4	2.50
P5	1.50
P6	3.50
P7	1.50

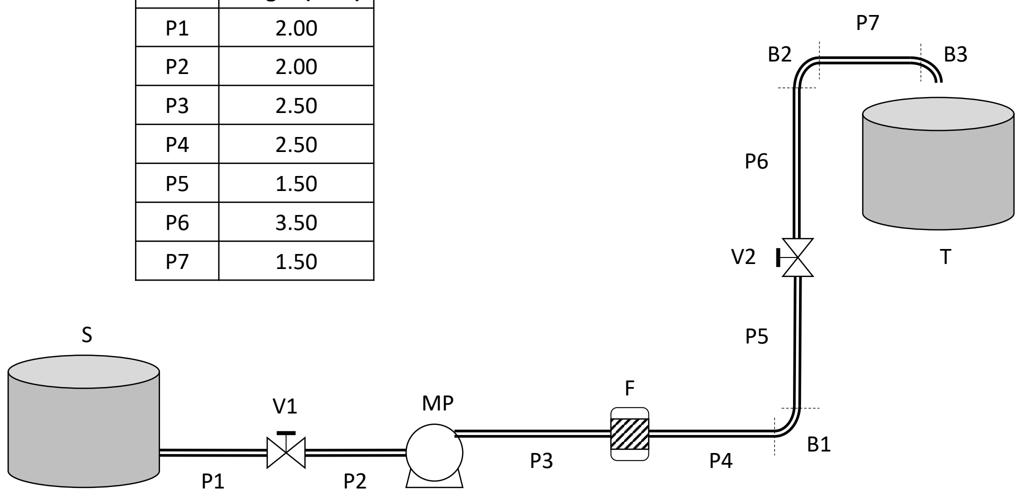

Figure 2: The pumping circuit under study

3. Study the influence of valves, i.e. their opening, and filters, i.e. their cleanliness, on the energy consumption. Consider also the velocity given to seawater in your study.
4. Study the influence of the height of the target tank in your study. Consider also the velocity given to seawater in your study.