Final Project - Reservoir Flow

CIVL13 and MATH 20

Objective

The objective of this project is for students to develop the equations and assumptions required to construct an Excel workbook that will complete a quasi-steady state analysis, also referred to as an extended period simulation (EPS). The system being analyzed is a reservoir draining through a pipeline into another reservoir. The workbook is required to calculate a series of steady state simulations over multiple time steps where variables, such as tank level and flow, are updated after each time step. The concept explored is the basic method applied by hydraulic modelling software used to analyze and evaluate municipal water distribution systems.

Submission

CIVL13

- 1 Excel file submitted on Blackboard worth 20% (Completed in pairs)
  - File Name: `LastNameFirstInitial1_FinalProject.xlsx`
- 1 Demonstration of excel file (10-15 minutes) worth 40% (Completed in pairs)
- 1 Blackboard Quiz worth 40% (Completed individually)

MATH20

- 1 Demonstration of excel file (10-15 minutes) worth 70% (Completed in pairs)
- 1 Derivation of the truncated cone volume worth 30% (Completed in pairs)

Excel Requirements

- Use the Excel template provided to prepare your Excel sheet.
- Use the diagram provided as the initial configuration for your system.
- A PDF of a solution is provided; you can use this solution/system to check that your sheet is completing the calculations correctly.
- Bernoulli's equation is to form the basis of your calculations.
- Apply the Darcy equation for pipe friction.
- Apply the minor loss equation for fittings and valves.
- Calculation variables are required to be easily adjustable.

The Excel sheet must include:

- Adjustable variables: pipe length, pipe diameter, friction factor, K coefficient, duration of time step, initial liquid level, and change in elevation of piping.
- A summary table with all system variables easily adjustable.
- Calculations for 100 timesteps with adjustable duration.
- A single plot displaying reservoir level and flow rate vs. time, updating with changes in parameters.

Derivation Requirements

- Disk Method: Calculate the infinitesimal volume of the horizontal cross-section of the truncated conical reservoir in terms of its radius (x) at a fluid level, shown in figure 1. Use the slope (a) and y-intercept (b) to express the infinitesimal volume. Then integrate the total volume of the truncated cone to the fluid height (h).
- Verify your answer by using the Shell Method.
- Shell Method: Calculate the infinitesimal volume of a shell within the truncated conical reservoir in terms of its radius (x) to a fluid level (h). Use the slope (a) and y-intercept (b) to express the infinitesimal volume. Then integrate the total volume of the truncated cone to the fluid height (h).

General Procedure

1. Calculate the infinitesimal volume of the horizontal cross-section of the truncated conical reservoir in terms of its radius (x) at a fluid level, shown in figure 1. Use the slope (a) and y-intercept (b) to express the infinitesimal volume. Then integrate the total volume of the truncated cone to the fluid height (h).
2. Express the volume of the truncated cone as a function of the fluid height (h):

   $$V_1(h) = f(h, a, b)$$

   where h is the fluid height, a and b are the slope of the truncated cones side wall and the y-intercept, respectively.
3. Correlate the a and b parameters of the truncated cone to the physical parameters, such as, the radius of the top opening R, the radius of the bottom opening r and the total height of the truncated cone H, as labeled in figure 1.
4. For the cylindrical reservoir, express its volume as a function of the fluid height (z_1):

   $$V_2(h) = \pi R_2^2 h$$

   where h is the fluid height and R_2 is the radius of the cylinder.
5. Apply Bernoulli's equation for the flow between the two reservoirs. Derive the fluid velocity in the pipe connecting the truncated cone and the cylinder based on fluid properties, pipe parameters, and the fluid heights in both reservoirs.
6. Perform a numerical simulation using time steps (Δt) to iteratively update the variables. Track the decreasing fluid height (z_1) in the truncated cone and the increasing fluid height (z_2) in the cylinder over time.
7. Differentiate the volumes of the two reservoirs, $V_1(z_1)$ and $V_2(z_2)$ with respect to time, to compute the volumetric flow rate through the connecting pipe. Use the volumetric flow rate to solve for changes in fluid height ($\Delta z_1, \Delta z_2$) over each time step.

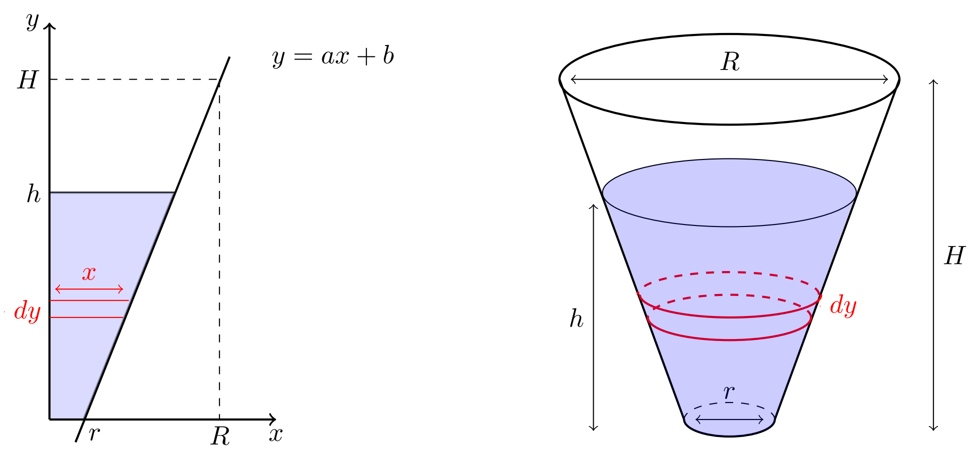

Figure 1: Dimensioned Truncated Conical Reservoir

System to be Modeled and Initial Set Points

Constants

- Gravitational constant, g: $9.81\,\mathrm{m/s^2}$
- Fluid density, ρ: $1000\,\mathrm{kg/m^3}$

Fluid Reservoir Properties

- Reservoir length, L: 17 m
- Reservoir height, H: 12 m
- Reservoir top half width, W: 3 m
- Reservoir bottom half width, w: 2 m

Numerical Approximation Variables

- Initial time, t_0: 0 s
- Time step, Δt: 30 s
- Initial fluid height, h_0: 4.4 m
- Initial volume, V_0: $326.63\,\mathrm{m^3}$

Pipe System Properties

- Pipe height, b: 2 m
- Pipe diameter, D: 0.2 m
- Total length of pipe, L: 3 m
- Friction factor, λ: 0.040
- Minor loss: 1x entrance loss, 1x exit loss, 2x 90° elbows, 1x gate valve.

Interview / Demonstration

During the interview you need to be prepared to:

- Outline the assumptions incorporated into your Excel sheet and their justification.
- Specify where individual calculations are performed within your sheet and provide a general explanation of its functionality.
- Modify your sheet to accommodate changes in the system, such as reservoir level, pipe diameter, number of fittings, friction factor, elevation difference, or pipe length.
- Determine the reservoir level, system flow rate, or velocity at a specific time.
- Calculate how long it will take for the reservoir to reach a specified level or to fully drain.
- Alter the time interval and describe how this adjustment affects the results generated by your Excel sheet.
- Discuss the implications of using longer versus shorter time steps in hydraulic simulations and their impact on the model's accuracy and efficiency.

Blackboard Quiz

Answer questions that interpret data from your model.