**EXPERIMENT F1: Dynamic Process Characteristics of a Simple Holding Tank as a First Order System**

Objectives

The purpose of this experiment is to assess the process characteristics of a first order system using both static and dynamic measurement methods. The process in question is a simple holding tank system (see figure 1).

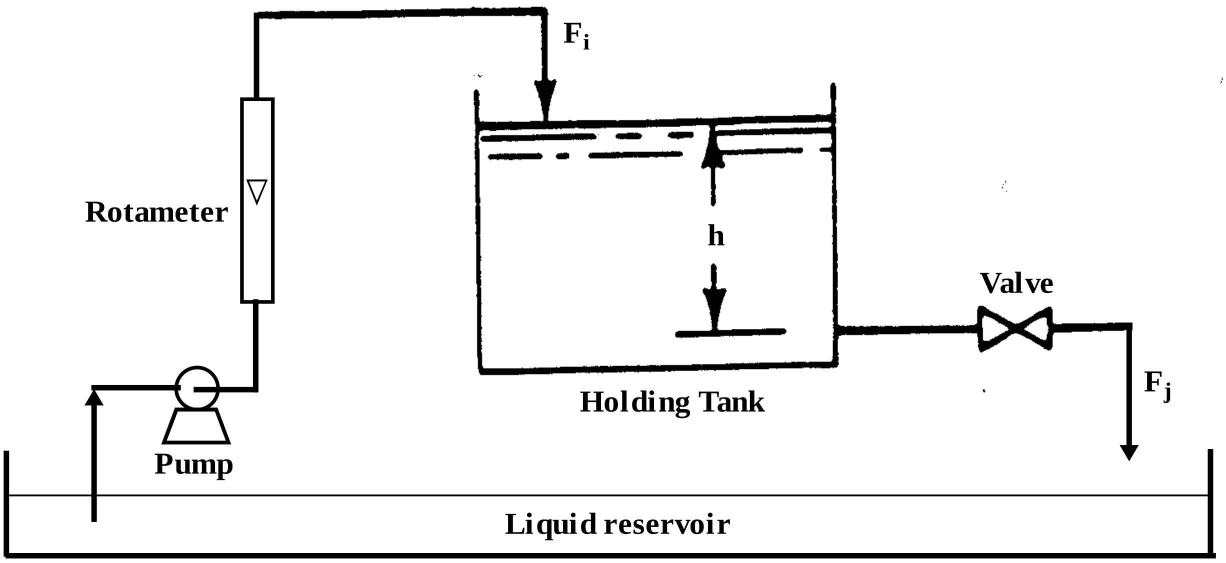


**Figure 1**

Background Theory

The dynamic behaviour (response to a time dependent disturbance) of many physical and chemical processes can be quantitatively modelled by appropriate differential equations. For example the response of the liquid level height,h, in a holding tank (shown in figure 1) to a sudden change in incoming liquid flow, $F_i$ ,can be represented by the following first order differential equation:

$$A.dh/dt = F_i - F_j \qquad (1)$$

where A = tank cross-sectional area
$F_j$ = flow rate out of tank
t = time

(This equation can be arrived at by performing a simple mass balance on the material entering and leaving the tank).

It is obvious that if equation (1) can be integrated, it is then possible to predict quantitatively the behaviour of the liquid level in the holding tank as a function of time, as a result of a given change in incoming liquid flow rate. Any system whose behaviour can be represented by a first order differential equation such as (1) is termed a first order process.

It is possible to have a more general form of the first order differential equation to represent any type of first order process:

$$\tau.dy/dt \;+\; y \;=\; K.x \qquad (2)$$

where $y$ = output (or dependent) variable = $h$ in the tank example
$x$ = input (or forcing) variable = $F_i$
$\tau$ = process time constant = $A.h/F_j$
$K$ = process gain constant = $h/F_j$

If the input variable change is a step function, i.e. in the tank process this would correspond to a sudden increase in inlet flow rate, then it is possible to show that the integrated form of (2) is:

$$y \;=\; K.\,B.(l-e^{-t/\tau}) \qquad (3)$$

where $B$ = the value of the step function = change in inlet flow rate

Thus it can be seen that the time dependent behaviour of the tank can be predicted using equation (3). It is obvious that mathematical models of the process dynamic response, such as equations (1) - (3), will be very useful in allowing the simulation of process behaviour in situations, for example, where it may be desirable to assess the effects of a new set of operating conditions without actually changing the existing conditions. Alternatively it may be desired to implement automatic control of a particular process, in which case it may be possible to combine the process model equation with a similar mathematical model of the control system and hence simulate the performance of the controlled process without having to actually set up and perform experiments on the process and control system.

From the foregoing discussion it should be apparent that in order to obtain a model for a given first order system it is necessary to determine the values of the characteristic process constants, namely the process gain, $K$, and time constant, $\tau$. There are two ways in which this can be done: under steady state conditions or in a dynamic experiment.

In the former method the system is operated at steady state conditions, and the values of $K$ and $\tau$ calculated from the observed steady state values of the input and output variables and other relevant physical properties of the process. Thus in the holding tank example:

$$K = h_s/F_s \qquad (4)$$

and

$$\tau = A.h_s/F_s \qquad (5)$$

where $h_s$ = liquid level in the tank at steady state, and
$F_s$ = flow rate at steady state.

The determination of process characteristics using a dynamic technique involves the measurement of the system response to a step change in input variable in conjunction with equation (3). This method has an added advantage over the steady state method in that if (3) is linearised it is possible to confirm that the system is actually behaving as a first order process ( the process order may not be known in many cases).

## Experimental Procedure

*The apparatus*

Figure 1 shows the basic experimental set-up: the process consists of two perspex tanks which are interconnected by a number of orifices. In the present experiment all of the orifices are opened and the tanks essentially behave as a single large tank. Water is pumped into the tank from the underlying reservoir by means of a variable speed pump. The inlet water flow rate can be measured on the rotameter by taking the reading corresponding to the **bottom of the float**.

Water leaves the tank system via the manually adjustable exit valve. The water level in the tank can be accurately measured using either manually from the depth scale on the tank or by the depth sensor (these is the black strip located at the rear of the tank). The output from the depth sensor is a dc voltage of 0 - 10V, measured using a digital voltmeter (not shown) and fed into the computer via LabView the interface box. It is necessary to calibrate the depth sensor used at the end of the experiment.

An instrumentation box allows manual adjustment of the pump speed as well as providing signal processing for the depth sensors.

*Commencing data logging*

Commence computer data logging as follows: on the computer, ensure that ‘Experiment F1 Datalogger’ is highlighted in the Configuration menu on the left hand side of the screen.
Click on both the ‘Run task’ icon and the ‘Start/stop Plotting’ traffic light button. The latter is located immediately below the ‘Run task’ icon. The traffic light button should turn green to indicate that data plotting has commenced. Wait for the real time data (level sensor voltage signal versus time) to start appearing in the black graphical window.

When data logging has commenced you will see a new file appear below the ‘Experiment F1 Datalogger’ item in the Configuration menu. This file will have the current date and time, and will contain the accumulated data from your experiment. You can view the contents of this file at any time by clicking on it, and you will see all of your data logged to date in the graphical window. It is possible to zoom in or out to look at particular parts of your data, by using the + and – zoom controls above the graphical display.

*Steady state measurements*

Close the outlet valve fully. Check that the water level in the reservoir covers the pump inlet. If it does not, inform the demonstrator (the pump can be permanently damaged by allowing it to pump air). Fill the tank to a level of approximately 80mm using the manual pump control. Open the outlet valve fully and quickly set the inlet flow rate to 200 ml/min. Now partially close off the outlet valve until the liquid level in the tank remains constant at around 70-1l0 mm. Check the level sensor output voltage at l min. intervals until two consecutive readings are the same in order to ensure this. Record the level sensor voltage at steady state.

*Dynamic response measurements*

Having achieved steady state conditions, quickly change the inlet flow rate to a value of 500ml/min and run the system until the liquid level reaches a new steady state value. **Notes: 1) You must not adjust the outlet valve during this part of the experiment. 2) Make sure that the liquid level has reached a new steady state before stopping the experiment.** This is best done by observing the datalogger voltage plot on the computer.

*Additional measurements and depth sensor calibration*

Measure the total cross-sectional area, A, of the tanks using a ruler. Calibrate the depth sensor as follows. Fully close off outlet valve and allow the tank to fill up to a level approximately 10mm above the maximum observed the dynamic part of the experiment. Stop the pump. Record the liquid level from the scale on the tank and the corresponding sensor voltage. Open the outlet valve and allow the liquid level to drop by approximately 20mm, again recording the voltage at that level. Repeat until you have calibrated the depth sensor over the range of measurements observed in the experiment.

At the end of the experiment, stop data logging by clicking on the 'Stop Task' icon.

*Saving your logged data*

Highlight your data file in the Configuration menu. **Use the 'Zoom out (-)' button to make sure that all of your data is displayed on the screen. This is very important since only the data that is displayed on the screen will be saved.** Right click on your data file in the Configuration menu. Select 'Rename' and give your file a name that you will recognise. Again right click on your data file and select 'Export Data'. Note the output file address so that you can find it later. Click on OK. This will save your data file in text format.

Open Excel and choose File, Open. Select the following address where your text file of results is located: MyDocuments\VI logger data\My VI logger Task 1. In the box 'Files of type as', choose 'All files'. Select your results file. Click on Next until Finish. View your results in Excel and Save As an Excel workbook file.

<u>Results and Discussion</u>

Construct a sensor calibration plot of liquid level versus voltage and use this to convert your experimental voltage measurements into liquid level values. Note that liquid levels mentioned in the theoretical section refer to the level above the outlet valve. Since the outlet valve itself is 27mm above the tank bottom, it is necessary to subtract this value from each of the level values measured.

Calculate K and $\tau$ from your steady state measurements.

Plot y versus time for your dynamic measurements. Note that it is onventional to make $y = 0$ at the start of the dynamic experiment, i.e. it is necessary to subtract the initial steady state level value from each of the levels observed in this part of the experiment. Determine the values of K and $\tau$ from your plot.

Do the values of K and $\tau$ obtained by the two methods show good agreement? If not, give an explanation.

Derive a linearised form of equation (3) for this process and use it to illustrate graphically that the process can indeed by represented by a first order model.

Can you see any shortcomings in the representation of this process as first order? (Hint: consider the validity of equations (2) and (3). Are there any parameters in these which are given as constants but which may in fact vary during the dynamic experiment? Determine the importance of these shortcomings from your experimental results and suggest an explanation for your findings.