Dynamics of Stirred Tanks

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SAFETY IN THE USE OF EQUIPMENT SUPPLIED BY ARMFIELD

Before proceeding to install, commission or operate the equipment described in this instruction manual we wish to alert you to potential hazards so that they may be avoided.

Although designed for safe operation, any laboratory equipment may involve processes or procedures which are potentially hazardous. The major potential hazards associated with this particular equipment are listed below.

- INJURY THROUGH MISUSE
- INJURY FROM CORROSIVE LIQUIDS
- DAMAGE TO EYESIGHT
- DAMAGE TO CLOTHING
- RISK OF INFECTION THROUGH LACK OF CLEANLINESS

Accidents can be avoided provided that equipment is regularly maintained and staff and students are made aware of potential hazards. A list of general safety rules is included in this manual, to assist staff and students in this regard. The list is not intended to be fully comprehensive but for guidance only.

[redacted]

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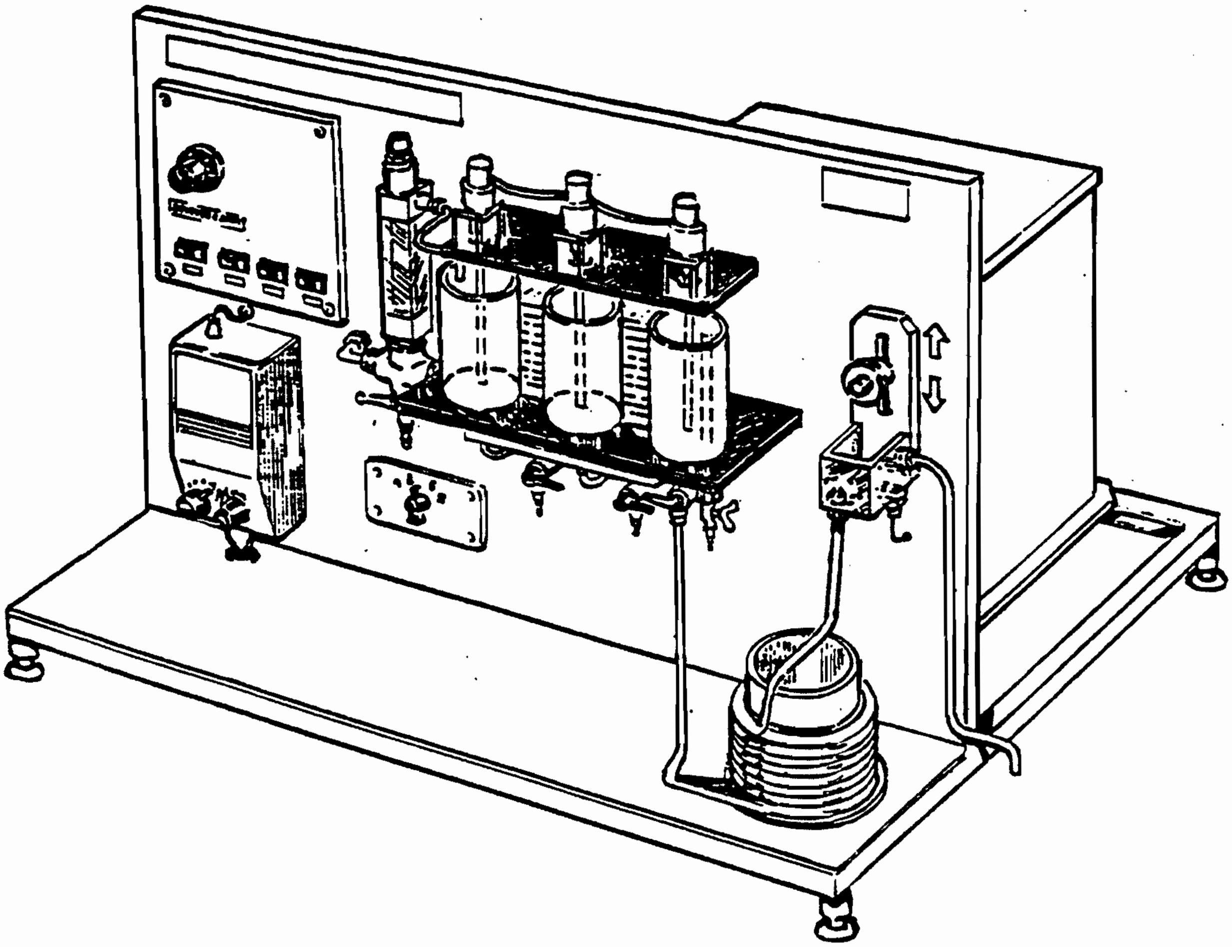

CEP DYNAMIC BEHAVIOUR OF STIRRED TANKS.

INTRODUCTION

Although all continuous industrial processes are designed to work at steady state conditions, it is inevitable that various disturbances occur in plant operation which (in the absence of control) would lead to time varying behaviour of the system. It is the purpose of automatic control equipment which, together with manual and/or computer supervision, to maintain the optimum steady state conditions of a manufacturing plant in a manner that compensates for unwanted disturbances and variations in the process conditions. In addition, many industrial processes are operated batch-wise which are inherently unsteady state systems.

For any personnel involved in plant design and operation, it is essential that an understanding of unsteady state conditions - in other words, the dynamic behaviour - of typical process units is gained during training. The Armfield Dynamics of Stirred Tanks Apparatus, described in this manual, is centred round the simplest industrial processing unit - the continuously operated stirred tank. Three such units are arranged in series, each of which operates at constant volume, and in each of which is installed a conductivity cell for measuring concentration changes produced by deliberately altering the inflow conditions in a predetermined manner. Provision is also made in the piping system for the inclusion of another typical industrial dynamic situation - 'dead time'.

The object of the apparatus is to compare experimentally determined responses of tank concentrations to an upset with those derived theoretically from simplified models.
The apparatus is essentially self-contained and is easily set up for student experimentation [redacted] Non-corroding materials are used throughout, and the equipment is capable of a number of different process configurations to allow maximum use to be made of the apparatus for both teaching and project exercises. Some knowledge of simple linear differential equations is required for analysis of the results, although it should be born in mind that the apparatus is in effect a visual example of such mathematics and can be used as such.

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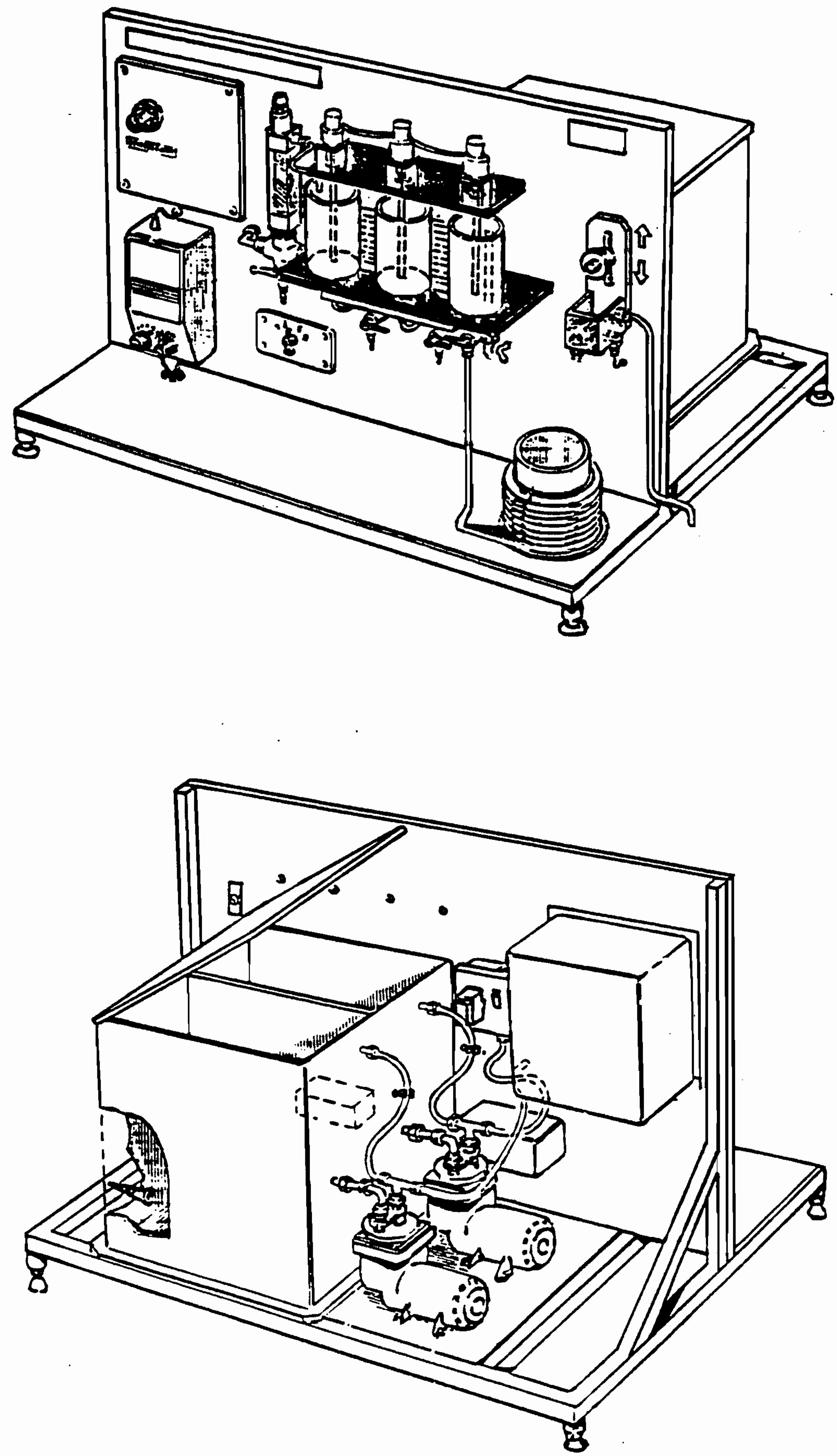
DESCRIPTION

The apparatus consists of a bench mounted main frame carrying a PVC tank divided into two sections fitted with drain taps. Two positive displacement diaphragm pumps each draw from one side of the tank and supply feed liquid to a gapmeter mounted on the front panel. Excess feed liquid is returned to the tanks through fixed orifice return lines.

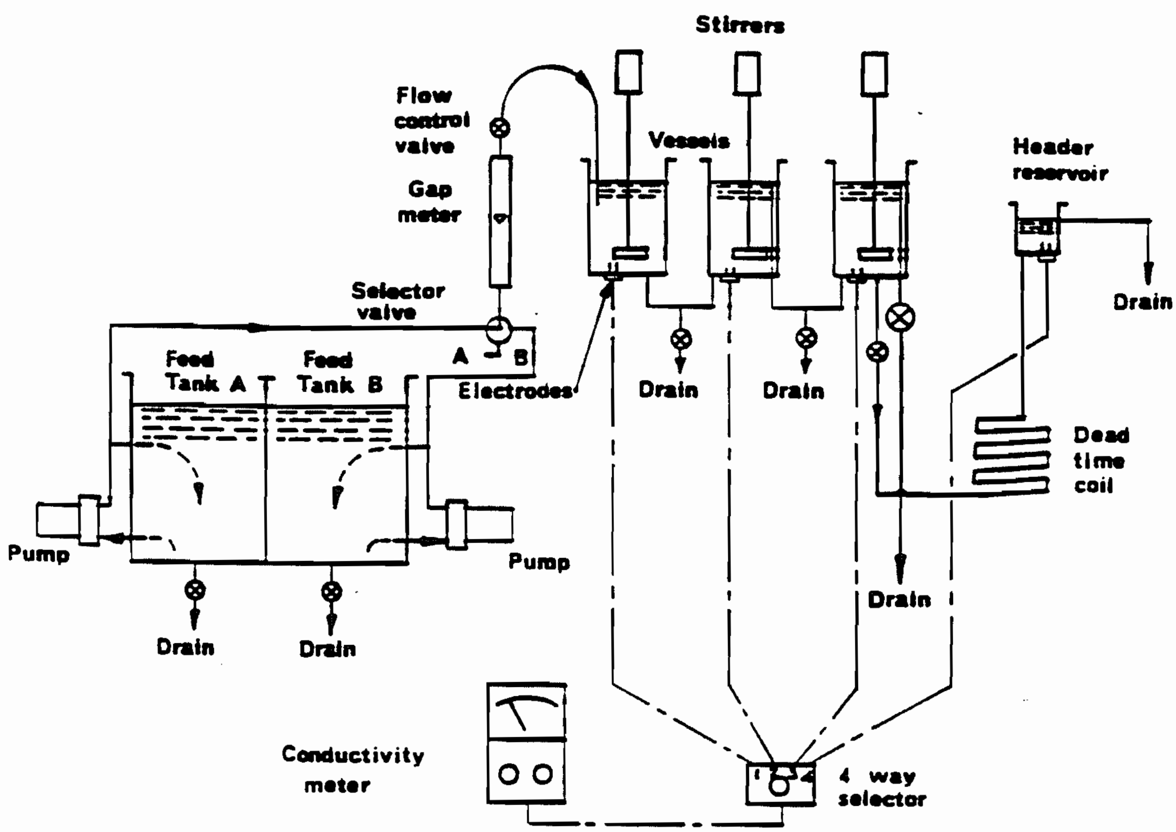
A 3-way valve below the gapmeter facilitates selection of liquid from either feed tank whilst a valve above the gapmeter controls the flow delivered to three transparent inter-connected vessels mounted on a sub-frame. Liquid passes through each vessel in series and the levels are controlled by an overflow connected to a drain tube. The levels can be measured on scales fitted between each vessel whilst two drain taps below the vessels facilitate emptying of the contents when required. Each vessel contains a motor driven stirrer to provide agitation of the contents and an electrode assembly for measurement of liquid conductivity.

An alternative discharge from the third vessel is controlled by a valve and connects a fourth vessel in series through a coiled tube wound around a former. The fourth vessel comprises a header reservoir whose height can be adjusted relative to the liquid level in the third vessel. Liquid passes from the header reservoir to drain whilst a separate electrode assembly in the reservoir is used for measurement of conductivity.
All electrodes are connected through a 4-way selector switch to a conductivity meter mounted on the front panel. The ranges extend from 10^{-1} mho to 10^{-5} mho full scale and the meter is supplied from a 7.5V DC supply.

A control unit mounted on the front panel carries the pump starter push buttons along with the stirrer starter and speed control.



CEP DYNAMIC BEHAVIOUR OF STIRRED TANKS.



CEP SYSTEM DIAGRAM

CEP - DYNAMIC BEHAVIOUR OF STIRRED TANKS APPARATUS

FACT SHEET

TEST SOLUTIONS AND CONDUCTIVITY MEASUREMENTS

The most convenient and accurately measured method of finding the responses of the various inter-vessel assemblies is to monitor the concentration changes of a salt solution by conductimetric methods. Potassium chloride solutions in distilled or deionised water are the best documented on conductance - concentration information. Two feed solutions (A or B as referred to in the experiments) should be M/1000 and M/10 KCl i.e. 0.0745g per litre and 7.45g per litre of solution respectively. The water used for making up these solutions must have a conductance of less than 1×10^{-4} mho s and preferably of 1×10^{-5} mho s.

For each experiment, sufficient solution should be made up to give 1-2 hours running time of each liquid.

The relationship between conductance of a solution (G) as measured by a conductivity meter and the concentration (C) of the dissolved salt is given by:

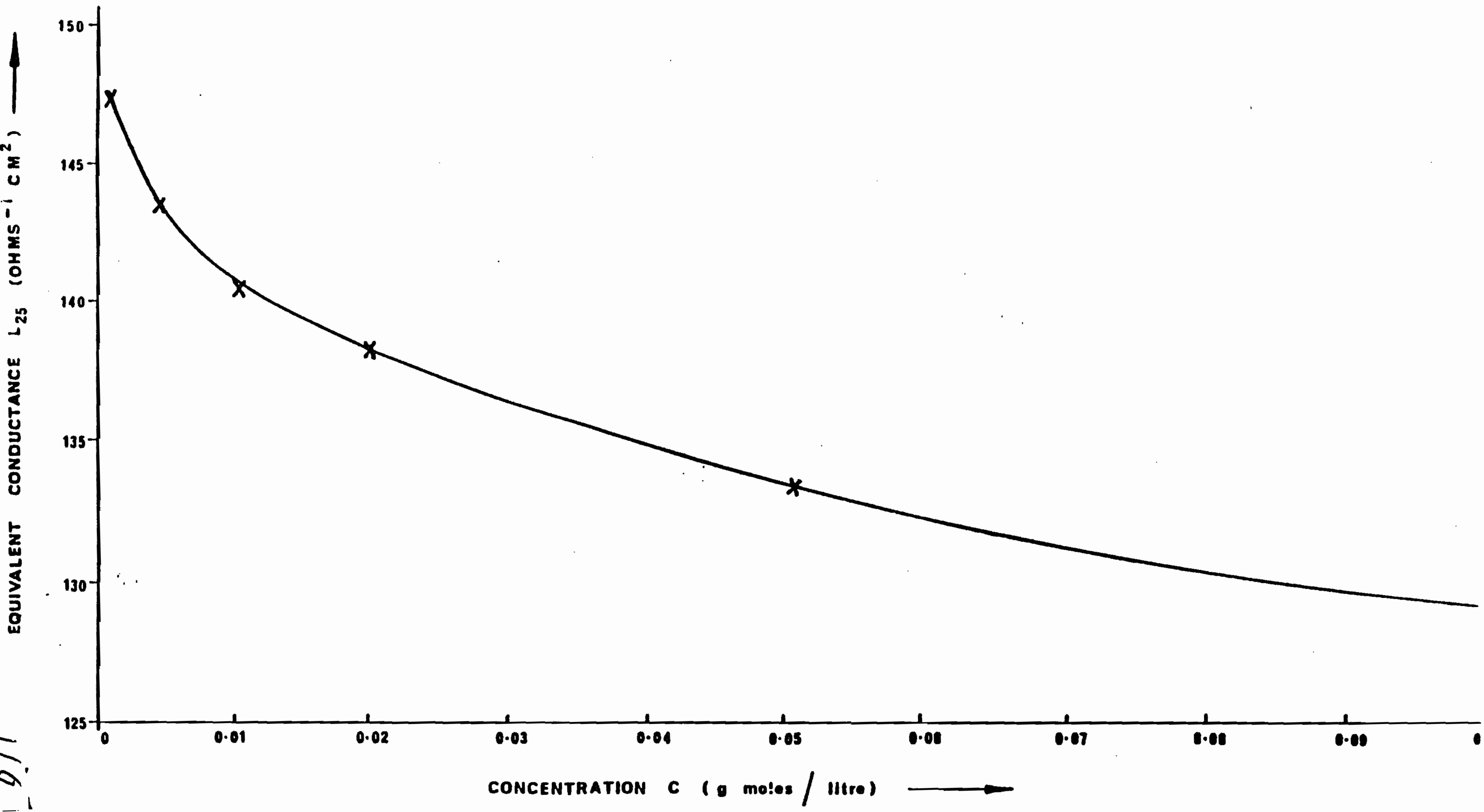
$$C = \frac{1000kg}{L} \quad KG \qquad \text{.........(1)}$$

where C is expressed in moles/litre, G is measured on the meter in mho s, K is the conductivity cell constant and L is the equivalent conductance (cm^{2}mho/mole) at T°C. The temperature effect on L (which is a standard conductance at 25°C) for potassium chloride is given approximately by:

$$L = L_{25} + 2.4\,(T - 25) \qquad \text{..........(2)}$$

Values of L_{25} are given in the graph over page from which it is clear that a trial and error solution is necessary to evaluate C from L and G. The value of K for all cells is 0.3.

The conductivity meter and cells should be used to check that the equations (1) and (2) above are accurate for the two standard solutions of M/10 and M/1000 potassium chloride solution. Separate clean beakers should be used for these standardisation checks before the experiments on dynamics are commenced.


150
145
140
135
130
125
EQUIVALENT CONDUCTANCE L_{25} (OHMS^{-1} CM^2)
0
0·01
0·02
0·03
0·04
0·05
0·06
0·07
0·08
0·09
CONCENTRATION C (g moles / litre)

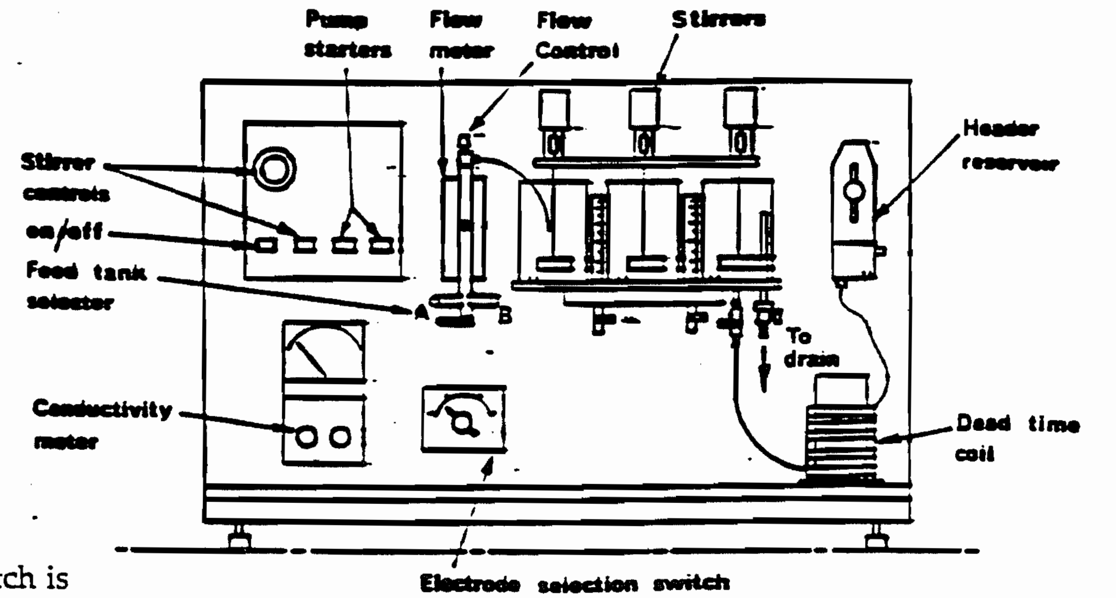
CEP DYNAMIC BEHAVIOUR OF STIRRED TANKS APPARATUS

EXPERIMENT A

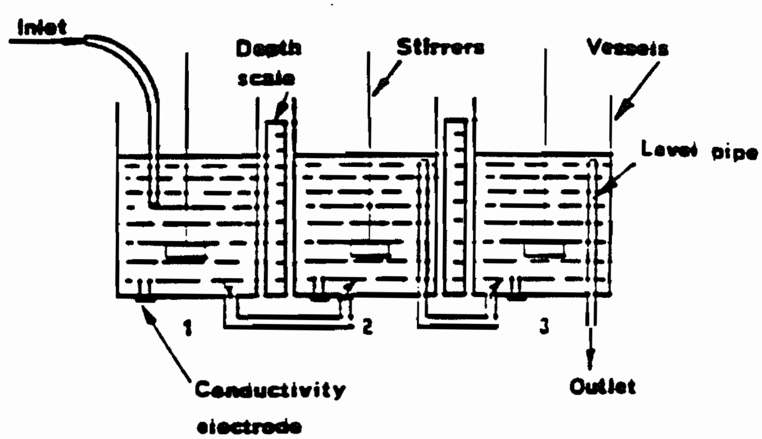
OBJECT OF EXPERIMENT:

To determine the response of tank concentrations to a step change in the input concentration for a system comprising three tanks.

EQUIPMENT SET-UP:



Note:
1. A stop watch is required for this experiment.
2. For salt solution use 7.45g of potassium chloride per litre of deionised water.



SUMMARY OF THEORY:

The response of a first order system consisting of three tanks in series to a step change in input isan exponential curve from the first tank followed by S-shaped curves from the remaining tanks. These tanks respond sluggishly after introduction of the step change because of the transfer lag but eventually reach the new input level.

If A = Concentration in tank at time t after the input step change

and E = Concentration of the input $e^{-t/T}$

then $A = E\,(1 - e{-}t/^{-t/T})$ where T = Time constant

and $\dfrac{dA}{dt} = \dfrac{E}{T}\, e^{-t/T}$ $\qquad = \dfrac{E}{T}$ at $t = 0$

Hence T may be found graphically as shown above.

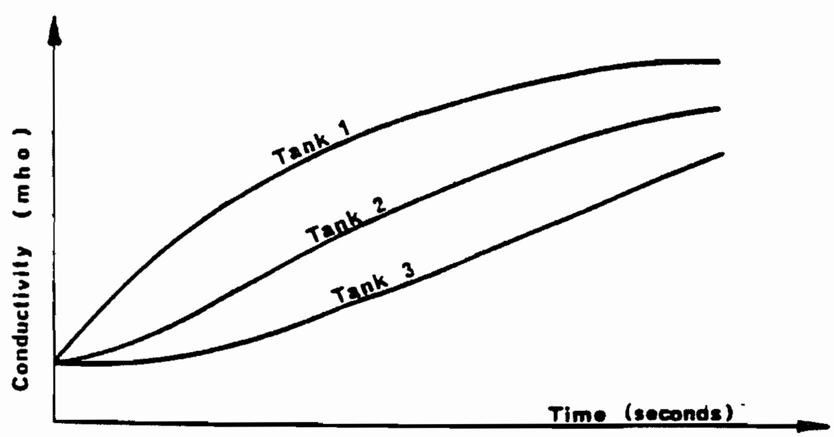
READINGS TO BE TAKEN:

Fill tank A with deionised water and tank B with salt solution. Flush and fill the system with the deionised water from tank A at a selected flow rate with the stirrers providing adequate agitation within the vessels. Switch over to tank B using the selector valve below the flowmeter to pump salt solution into the system. Using the meter and selector switch, monitor the conductivity of the liquid in each vessel at selected time intervals.

RESULTS:

Flow rate through tanks = _________ ml/min

Time	Conductivity (mho)		
(seconds)	Tank 1	Tank 2	Tank 3
0			



Plot a set of curves relating the conductivity of the liquid in each of the three tanks to the time from the step change in the input and explain their shape.

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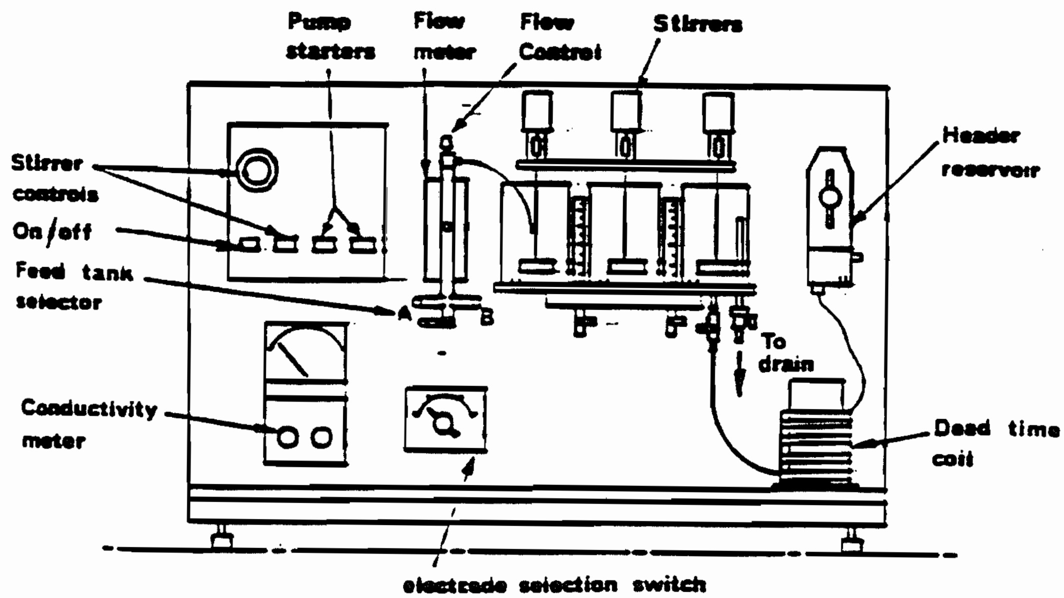
CEP DYNAMIC BEHAVIOUR OF STIRRED TANKS APPARATUS

EXPERIMENT B

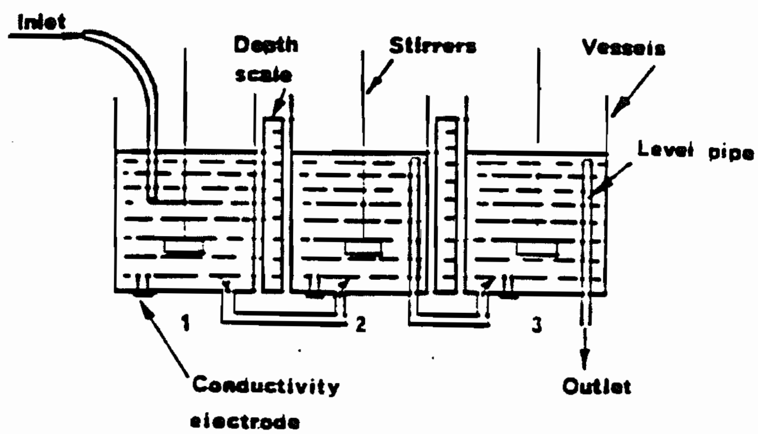
OBJECT OF EXPERIMENT:

To determine the response of tank concentrations to an impulse change in the input concentration for a system comprising three tanks in series.

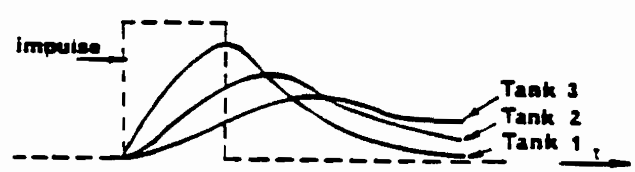
EQUIPMENT SET-UP:



Note:
1. A stop watch is required for this experiment.
2. For salt solution use 7.45g of potassium chloride per litre of deionised water.



SUMMARY OF THEORY:



The response of a first order system consisting of three tanks in series to an impulse change in input is an exponential curve from the first tank for the duration of the impulse followed by an exponential decay back to the restored input level after the impulse is over. The other tanks show a sluggish moderated response delayed by their respective transfer lags but ultimately return to the restored input level.

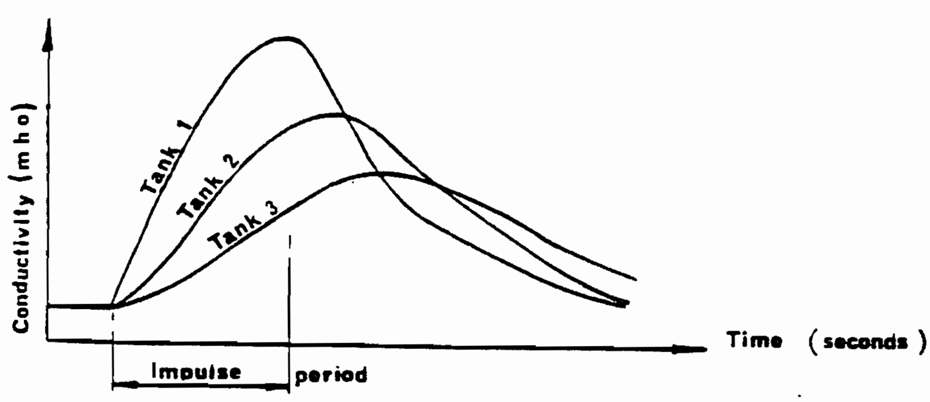
READINGS TO BE TAKEN:

Fill tank A with deionised water and tank B with salt solution. Flush and fill the system with the deionised water from tank A at a selected flow rate with the stirrers providing adequate agitation within the vessels. Switch over to tank B using the selector valve below the flowmeter and continue to pump salt solution into the system for about 5 minutes before switching back to tank A once again. Using the meter and selector switch, monitor the conductivity of the liquid in each vessel at selected time intervals throughout the experiment.

RESULTS:

Flow rate from tank A = ________ ml/min
Flow rate from tank B = ________ ml/min from ____ sec. to ____ sec.

Time (seconds)	Conductivity (mho)		
	Tank 1	Tank 2	Tank 3
0			



Plot a set of curves showing the conductivity of the liquid in each of the three tanks before, during and after the impulse change in the input. Comment on the shape of the resulting curves and account practically for them by reasoning from physical principles.

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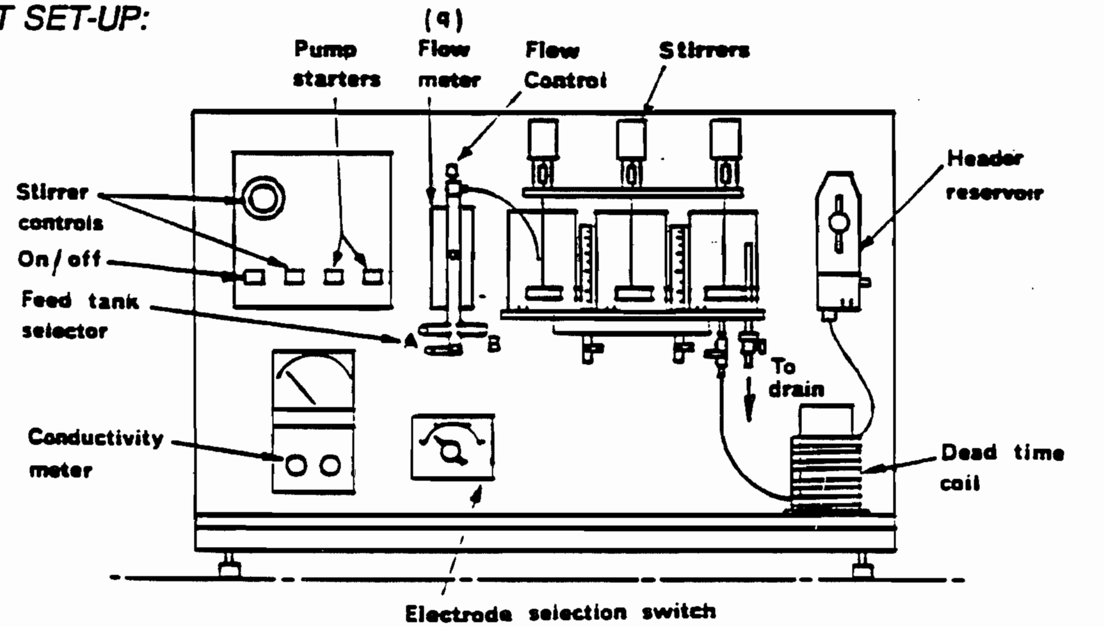
CEP DYNAMIC BEHAVIOUR OF STIRRED TANKS APPARATUS

EXPERIMENT C

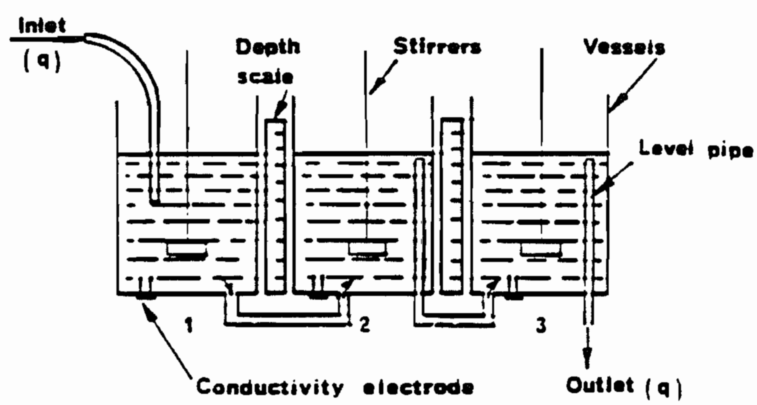
OBJECT OF EXPERIMENT:

To determine the influence of flow rate on the response of a system comprising three tanks in series following a step change in input concentration level.

EQUIPMENT SET-UP:



Note:
1. A stop watch is required for this experiment.
2. For salt solution use 7.45g of potassium chloride per litre of deionised water.

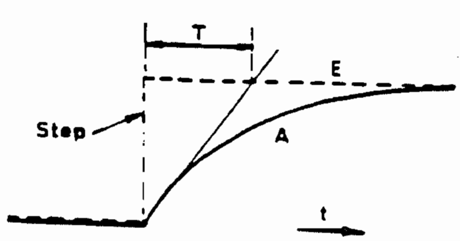


SUMMARY OF THEORY:

If the input concentration is changed step-wise, an exponential change in concentration is observed in the first tank given by

$A = E(1 - e^{-t/T})$ where T is the time constant.

$T = \frac{V}{q}$



The time constant $T = \frac{v}{q}$ where:

v = volume of tank
q = flow rate

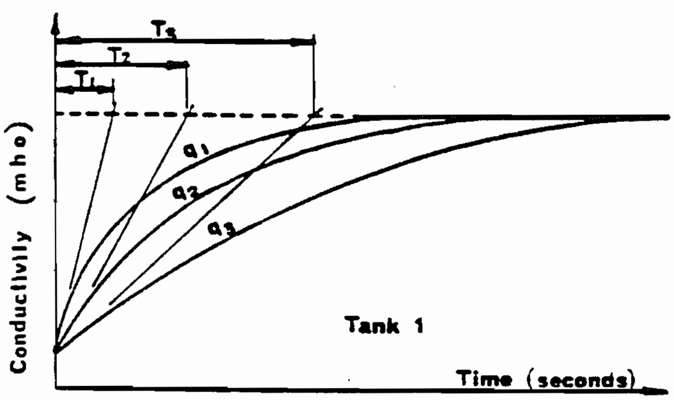
i.e. for a fixed tank volume (v) the time constant is inversely proportional to the flow rate (q).

READINGS TO BE TAKEN:

Fill tank A with deionised water and tank B with salt solution. Flush and fill the system with the deionised water from tank A at a nominal flow rate with the stirrers providing adequate agitation within the vessels. Switch over to tank B using the selector valve below the flowmeter and pump salt solution into the system. Using the meter and selector switch, monitor the conductivity of the liquid in each vessel at selected time intervals. Flush and refill the system with deionised water before repeating the experiment at other flow rates (q).

RESULTS AND CALCULATIONS:

Flow (ml/min)	Time (seconds)	Conductivity (mho)		
		Tank 1	Tank 2	Tank 3
	0 etc			
	0 etc			
	0 etc			



$$\frac{dA}{dt} = \frac{E}{T} e^{-t/T}$$

$$\therefore \quad \frac{dA}{dt} = \frac{E}{T}$$

at $t = 0$

Plot a set of curves for the various flow rates tested (q_1 q_2 q_3 etc.) to show the relationship between conductivity and time within the first tank. Tangents drawn to these curves at $t = 0$ will intersect the step input conductivity line at the time constant for each flow rate. Determine the time constants and verify that they are inversely proportional to the respective flow rates. Comment on the results and explain any observed deviation from the theoretical relationship.

The influence of flow rate on the conductivity excursions within the second and third tanks should be investigated. Sets of curves may be drawn and the results explained.

Note: By utilising a range of solution concentrations of known molarity, it would also be possible to investigate the influence of this factor on the system responses.

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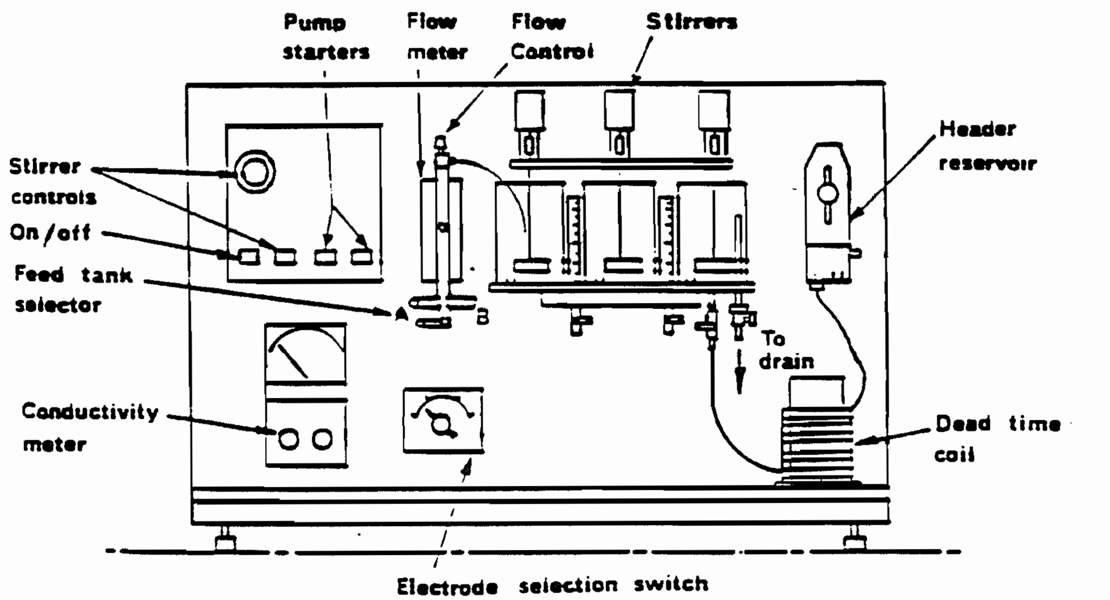
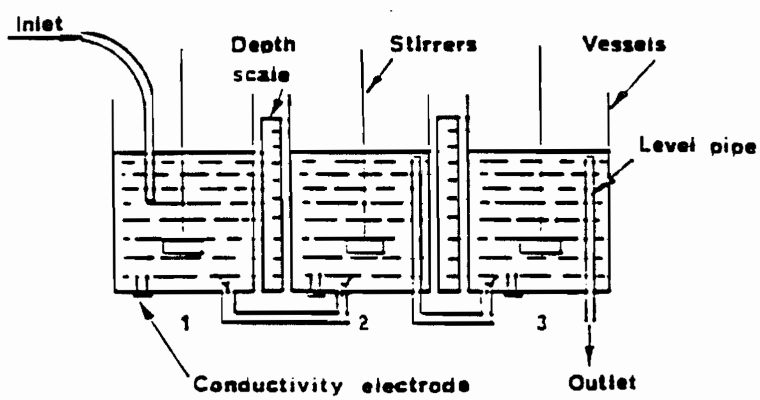
EXPERIMENT D

OBJECT OF EXPERIMENT:

To determine the effect of stirring on the response of tank concentrations to a step change in the input concentration for a system comprising three tanks in series.

EQUIPMENT SET-UP:





Note:
1. A stop watch is required for this experiment.
2. For salt solution use 7.45g of potassium chloride per litre of deionised water.

SUMMARY OF THEORY:

Tanks which contain substances having different concentrations are normally stirred to ensure a homogeneous mixture of the components. Unstirred tanks may give rise to stratified layering of the component substances due to density differences. Similarly streaming of one liquid through the other along the direct inlet to outlet path may occur. Such factors will upset the response of a system following an input variation.

READINGS TO BE TAKEN:

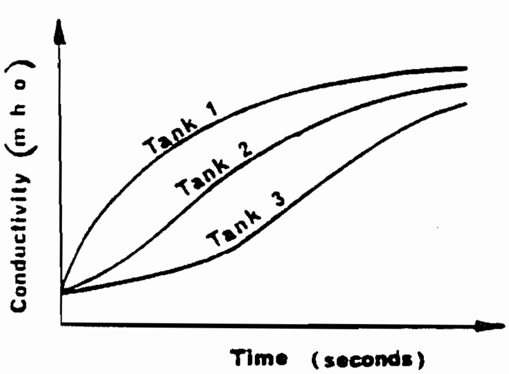
Fill tank A with deionised water and tank B with salt solution. Flush and fill the system with the deionised water from tank A at a selected flow rate with the stirrers providing adequate agitation within the vessels. Switch over to tank B using the selector valve below the flowmeter and continue to pump salt solution into the system. Using the meter and selector switch, monitor the conductivity of the liquid in each vessel at selected time intervals.

Flush and refill the system with deionised water from tank A using the same flow rate. Repeat the experiment as above but keeping all stirrers stationary throughout the test.

RESULTS AND OBSERVATIONS:

Flow rate from tanks = __________ ml/min

TIME	WITH STIRRING			WITHOUT STIRRING		
	CONDUCTIVITY (mho)			CONDUCTIVITY (mho)		
(seconds)	TANK 1	TANK 2	TANK 3	TANK 1	TANK 2	TANK 3



Plot a set of curves relating the conductivity of the liquid in each of the three tanks to the time from the step change in the input for the situation in which the tanks were stirred. On the same graph a similar set of curves for the situation in which the tanks were unstirred. Compare the results commenting upon the observed differences and explaining how these differences may have been caused. How important is it to ensure that tanks are adequately stirred in practical industrial processes?

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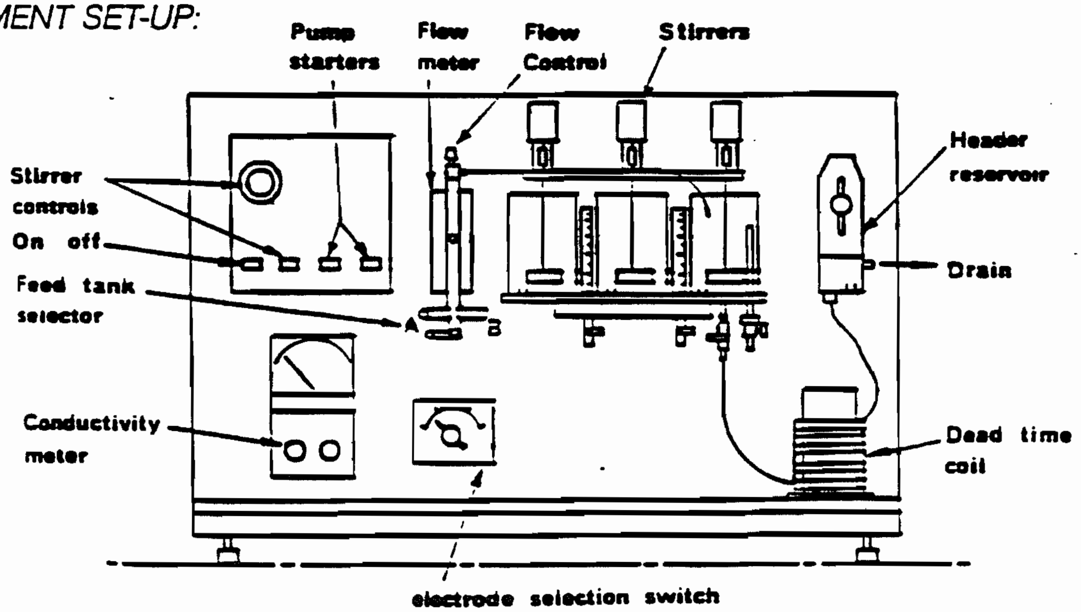
CEP DYNAMIC BEHAVIOUR OF STIRRED TANKS APPARATUS

EXPERIMENT E

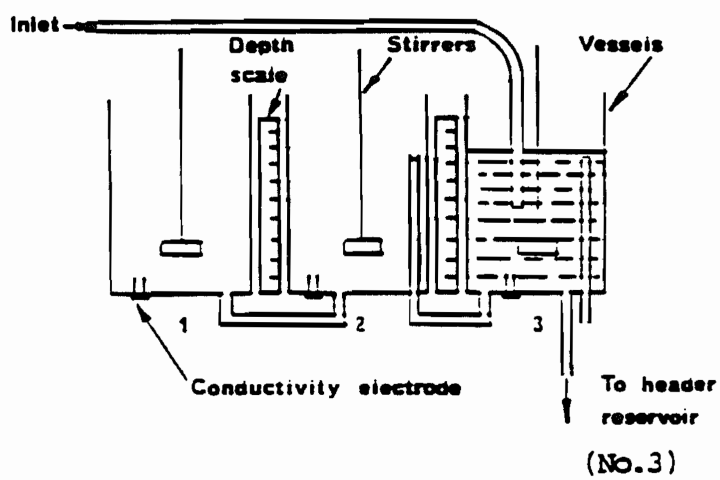
OBJECT OF EXPERIMENT:

To determine the response to a step change in input concentration of a system comprising one stirred vessel and the dead time unit.

EQUIPMENT SET-UP:



Note:
A stop watch and thermometer are required for this experiment.



SUMMARY OF THEORY:

The transient response of a system comprising one tank (No.3) followed by dead time (the coil and No.4) is given by:

$$\exp\left(-\frac{t-T_4}{T_3}\right) \quad \text{for } t > T_4$$

$$C_4(t) = [C_B - C_A]\left(1 - e^{-\left(\frac{(t-T_4)}{T3}\right)}\right) + C_A$$

where:

$C_4(t)$ = concentration in tank (4) at time (t sec) - g moles/litre

C_A, C_B = concentration of feed liquids in tanks (A), (B) - g moles/litre

T_3 = time constant for tank (3) - sec

T_4 = time constant for dead time coil and tank (4) - sec.

Prepare feed solutions (A) and (B) of M/10 and M/1000 potassium chloride as described in "Fact Sheet - Test Solutions and Conductivity Measurements".

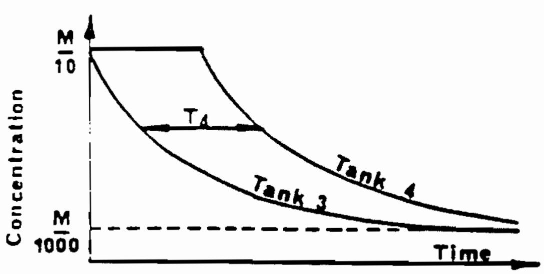
READINGS TO BE TAKEN:

Fill tank No. 3, the dead time coil and header reservoir (tank No.4) with M/10 solution and establish a steady flow of approximately 200 ml/min through to drain with the stirrers providing adequate agitation. Once the conductivity reading in tank (4) has stabilised, use the feed tank selector valve below the flowmeter to switch over and allow the M/1000 solution to flow into he system at the same rate. Monitor the conductivity changes in tanks (3) and (4) at regular time intervals after the changeover until a new steady value of conductivity reading (corresponding to the M/1000 solution concentration) has been achieved in tank (4). This should be after approximately six volume changes in the system. Note the temperature of the solutions.

READINGS AND CALCULATIONS:

Flow rate from tanks = ____________ ml/min
Temperature of solutions = ____________ °C

Time (seconds)										
Conductivity (Tank 3) (mho)										
Conductivity (Tank 4) (mho)										
Concentration (Tank 3) (g moles/litre)										
Concentration (Tank 4) (g moles/litre)										



From the experimental results plot curves relating concentration level and time for each tank. Note the effect of transportation lag. Plot the curve showing the theoretical response for tank (4) and compare the results obtained. Account for any significant differences. Does the mathematical model accurately predict the actual response?

Notes:

1. This experiment examines the response of a one vessel system with dead time. However, it is equally possible to repeat the test for systems consisting of two or three vessels in series with dead time. Equations can be derived to predict the response of such systems and the results compared to those from the mathematical model.
2. This experiment examines the response to a step input only. However, by applying the input disturbance for a specific period only, it is possible to simulate an impulse function. The responses may be experimentally determined and compared to theoretical predictions.

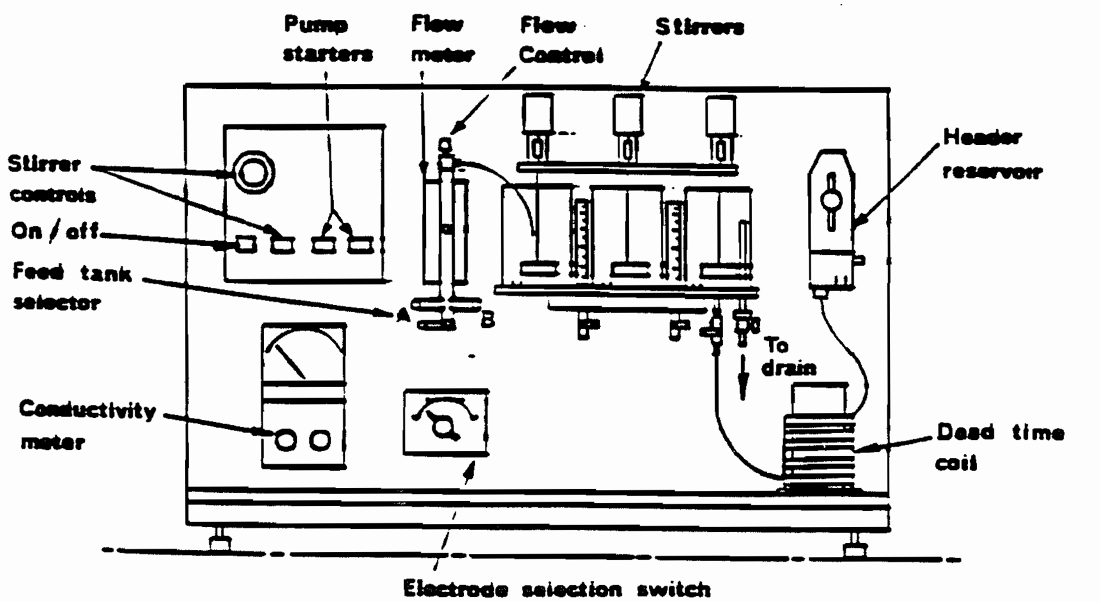
CEP DYNAMIC BEHAVIOUR OF STIRRED TANKS APPARATUS

EXPERIMENT F

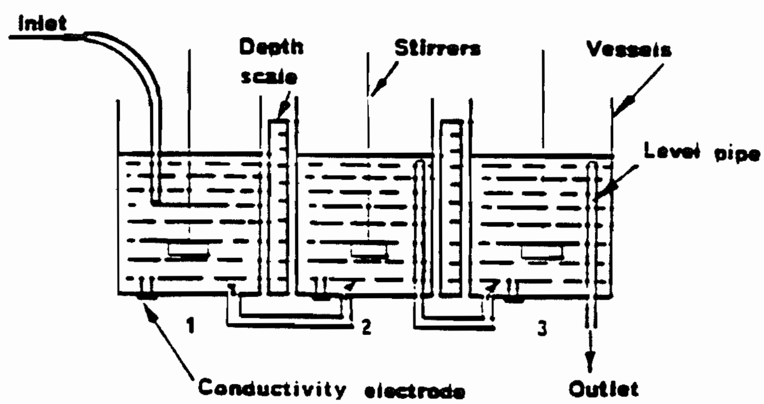
OBJECT OF EXPERIMENT:

To determine the response of a system comprising one stirred vessel to a step change in input concentration.

EQUIPMENT SET-UP:



Note:
A stop watch and thermometer are required for this experiment.



SUMMARY OF THEORY:

The transient response of a one tank system to a step input function is given by:

$$C_1(t) = (C_B - C_A)(1 - e^{-t/T1}) + C_A$$

where: $C_1(t)$ = concentration level in tank (1) at time (t sec) - g moles/litre
C_A, C_B = concentration of feed liquids in tanks (A) (B) - g moles/litre
T_1 = time constant for tank (1) - sec.

INITIAL VALUES OF VARIABLES TO BE USED:

Prepare feed solutions (A) and (B) of M/10 and M/1000 potassium chloride as described in "Fact Sheet - Test Solutions and Conductivity Measurements".

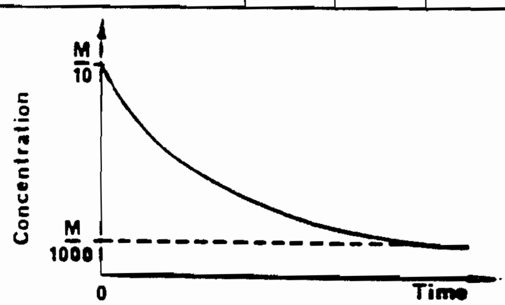
READINGS TO BE TAKEN:

Fill the system with M/10 solution at approximately 200ml/min and establish a constant level in tank (1) with the stirrers operating at a speed to provide adequate agitation. Once the conductivity reading in tank (1) has stabilised, use the feed tank selector valve below the flowmeter to switch over and allow the M/1000 solution to flow into the system at the same rate. Monitor the conductivity changes in tank (1) at regular time intervals after the changeover until a new steady value of conductivity reading (corresponding to the M/1000 solution concentration) has been achieved. This should be after approximately six volume changes in tank (1). Note the temperature of the solutions.

READINGS AND CALCULATIONS:

Flow rate from tanks = ____________ ml/min
Temperature of solutions = ____________ °C

Time (seconds)										
Conductivity (mho)										
Concentration (g moles/litre)										



From the experimental results plot a curve relating concentration and time. Alongside this curve, plot the theoretical response as calculated from the equation for transient response. Compare the results obtained and account for any significant differences.

Does the mathematical model accurately produce the actual response?.

Notes:

1. This experiment examines the response of a one vessel system only. However, it is equally possible to repeat the test for systems consisting of two or three vessels in series. Equations can be derived to predict the response of such systems and the results compared to those from the mathematical model.
2. This experiment examines the response to a step input only. However, by applying the input disturbance for a specific period only, it is possible to simulate an impulse function. The responses may be experimentally determined and compared to theoretical predictions.