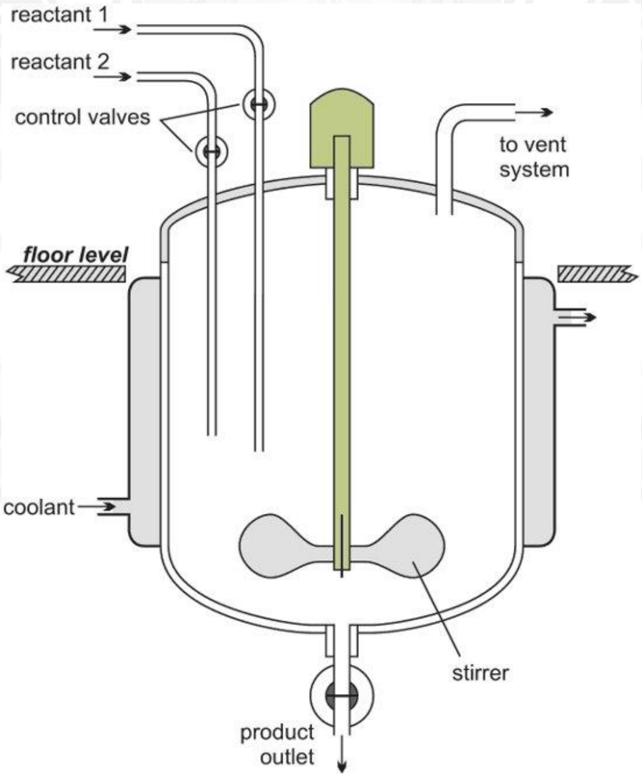
1.12 INDUSTRIAL PROCESS CONTROL

1.12.1 CHEMICAL REACTORS

The reactors, in which chemicals are made in industry, vary in size from a few cm^3 to the vast structures that are often depicted in photographs of industrial plants. For example, kilns that produce lime from limestone may be over 25 metres high and hold, at any one time, well over 400 tonnes of materials. The design of the reactor is determined by many factors but of particular importance are the thermodynamics and kinetics of the chemical reactions being carried out. The two main types of reactor are termed batch and continuous.

Batch reactors

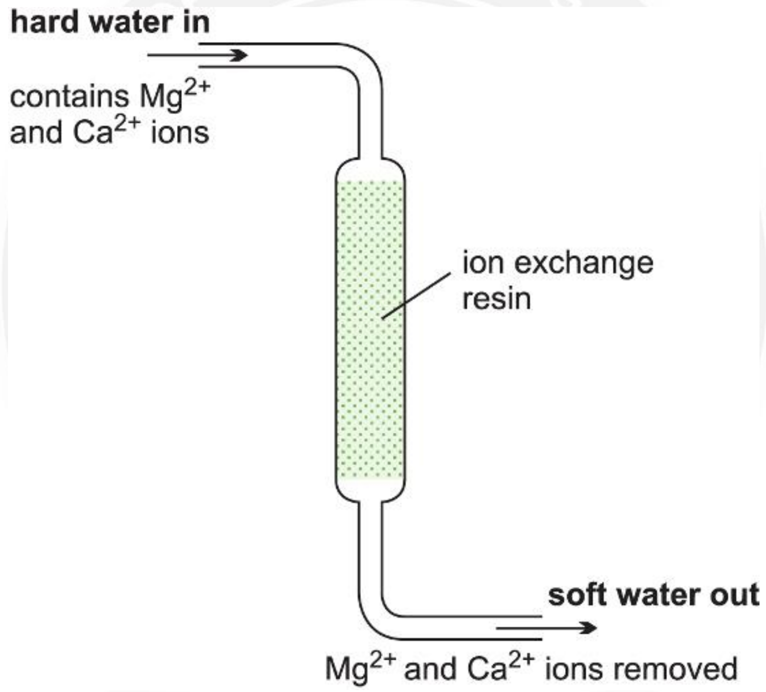
Batch reactors are used for most of the reactions carried out in a laboratory. The reactants are placed in a test-tube, flask or beaker. They are mixed together, often heated for the reaction to take place and are then cooled. The products are poured out and, if necessary, purified. This procedure is also carried out in industry, the key difference being one of size of reactor and the quantities of reactants.



Following reaction, the reactor is cleaned ready for another batch of reactants to be added. Batch reactors are usually used when a company wants to produce a range of products involving different reactants and reactor conditions. They can then use the same equipment for these reactions. Examples of processes that use batch reactors include the manufacture of colorants and margarine.

Continuous reactors

An alternative to a batch process is to feed the reactants continuously into the reactor at one point, allow the reaction to take place and withdraw the products at another point. There must be an equal flow rate of reactants and products. While continuous reactors are rarely used in the laboratory, a water-softener can beregarded as an example of a continuous process. Hard water from the mains is passed through a tube containing an ion-exchange resin. Reaction occurs down the tube and soft water pours out at the exit.



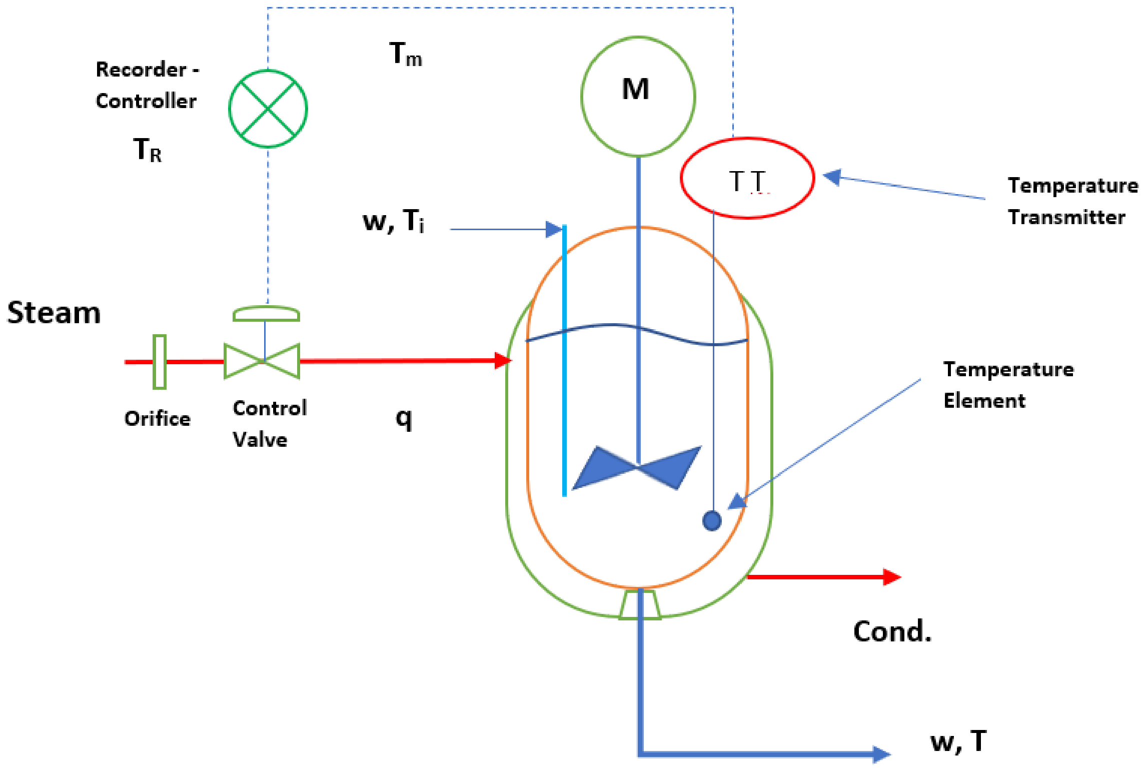
Continuous reactors are normally installed when large quantities of a chemical are being produced. It is important that the reactor can operate for several months without a shutdown. The residence time in the reactor is controlled by the feed rate of reactants to the reactor. For example, if a reactor has a volume of 20 m^3 and the feed rate of reactants is 40 m3 h-1 the residence time is 20 m3 /40 m3 h-1 = 0.5 h. It is simple to control accurately the flow rate of reactants. The volume is fixed and therefore the residence time in the reactor is also well controlled. The product tends to be of a more consistent quality from a continuous reactor because the reaction parameters (e.g. residence time, temperature and pressure) are better controlled than in batch operations. They also produce less waste and require much lower storage of both raw materials and products resulting in a more efficient operation. Capital costs per tonne of product produced are consequently lower. The main disadvantage is their lack of flexibility as once the reactor has been built it is only in rare cases that it can be used to perform a different chemical reaction.

PROCESS CONTROL

In a chemical plant to achieve desired output with desired quality and capacity we need to control the process parameters. For each process parameter we have an operating range namely low value and high value. Apart from this we have one set point value also. Therefore, process control system continuously works to maintain the actual value of process parameter as much as close to the set point value. Moreover, in most of the plants, control of process parameters is very critical from safety and environment point of view.

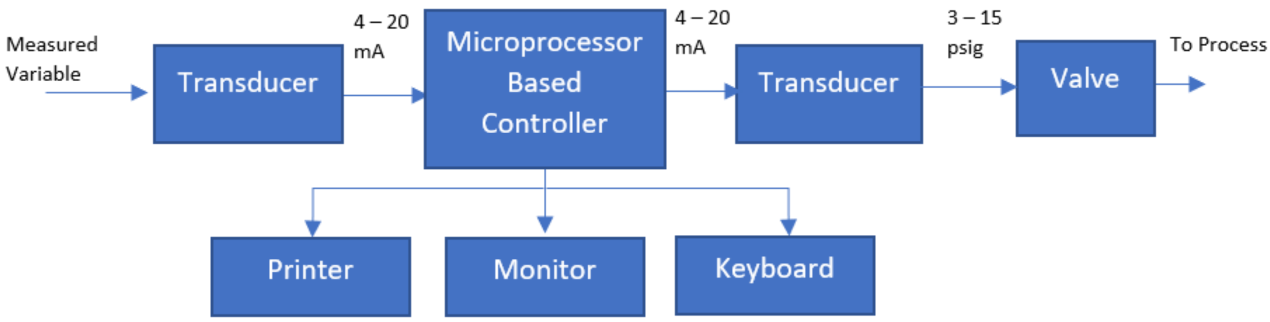
COMPONENTS OF A CONTROL SYSTEM

To design a control system for a process we need to develop a mathematical model first. This model enable us to understand the relationship between the process parameters. In below figure you can see different parts of a typical process control system.



MICROPROCESSOR-BASED CONTROLLER

In the 1970s first generation digital control hardware came into market. This was based on advanced microprocessor-based technology. This system was user friendly and easy to use for plant operators. Controller configuration was also very easy in this. The components of microprocessor-based controller can be seen in below figure.



A microprocessor-based controller works based on an algorithm. And, various features of this type of control system are below:

- Implement the control algorithms
- Provide display on the monitor (includes static & dynamic)
- Gives alarms for process variables
- Mathematical functions can be deployed
- We can store and retrieve data for process parameters

Microprocessor-based controller performs all above tasks with help of supporting software. And control system manufacturer supplies these software with the hardware.

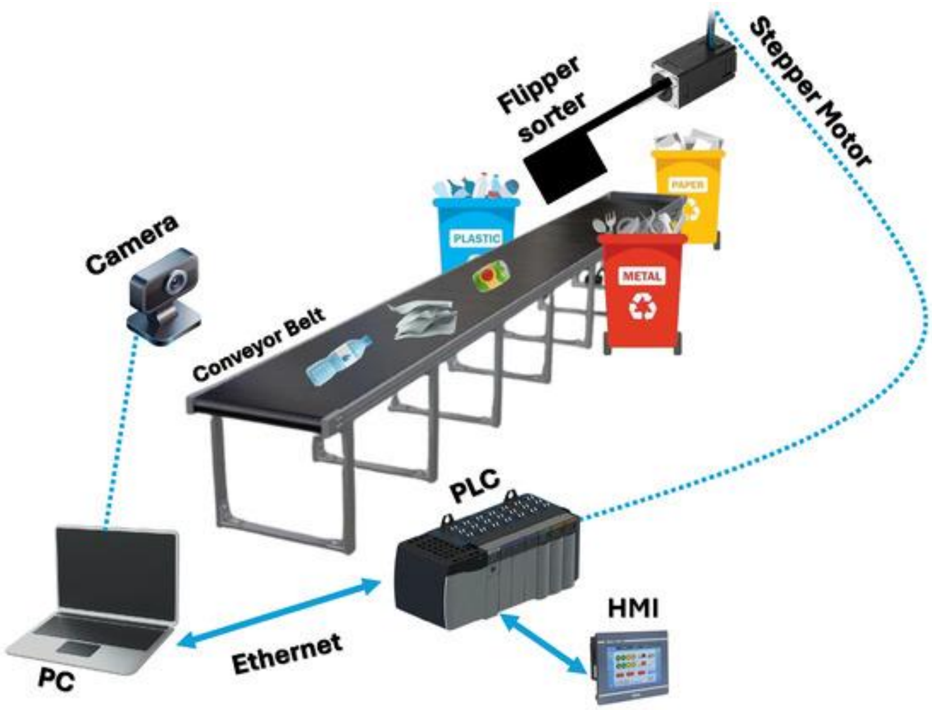
1.12.2 CONVEYOR BELTS

Conveyor belts are continuous loops of material, often rubber or PVC that move items or bulk materials between points, powered by pulleys and used across industries like manufacturing, mining, and logistics for efficient, automated transport from point A to B. They consist of a belt, pulleys (drive and idler), rollers, and a frame, with variations like flat, cleated, or modular belts designed for different materials and inclines, moving goods like packages, grain, or ore.

COMMON TYPES & USES:

a) Flat Belts: General purpose for packages, totes, and irregular items.
b) Cleated Belts: Have dividers (cleats) to carry bulk materials or items up inclines without rollback.
c) Modular Belts: Plastic links, durable, easy to clean (food industry), and replaceable sections.

d) Applications: Manufacturing lines, airport baggage, mining (coal, ore), warehouses, food processing, and logistics.



Conveyor belt control involves using automation systems, PLCs, sensors, and drives to manage movement, speed, and tracking, ranging from simple start/stop buttons to complex HMI interfaces for precise material flow, energy efficiency, and automated processes in manufacturing, logistics, and mining. Key controls include Variable Frequency Drives (VFDs) for speed, sensors (proximity, optical, limit switches) for object detection, and PLCs (Programmable Logic Controllers) as the central brain, often with an HMI (Human-Machine Interface) for operator control, ensuring safety, optimizing performance, and synchronizing with other machinery.

CORE CONTROL COMPONENTS:

- ❖ Motors & VFDs: Motors provide power, while VFDs adjust motor speed and torque, crucial for smooth starts, stops, and variable material flow, saving energy and reducing wear.
- ❖ Sensors: Detect material presence (proximity, photoelectric), position, or belt edge (optical, pneumatic) to trigger actions like starting, stopping, or diverting.
- ❖ PLCs: The central controller, receiving sensor inputs and sending commands to motors, lights, and other actuators based on programmed logic (e.g., ladder logic).

- HMIs: Touch screens or panels for operators to monitor status, adjust settings, and intervene, making systems user-friendly.

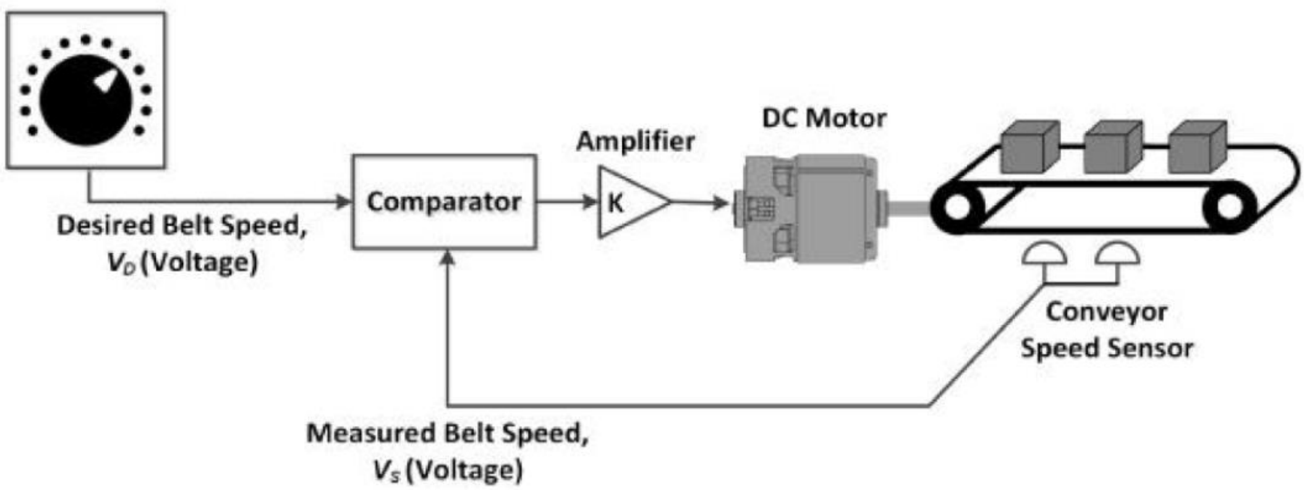
TYPES OF CONTROL APPLICATIONS:

- Basic Start/Stop: Simple circuits with buttons and contactors for manual operation.
- Automated Sequencing: PLC-controlled systems that automatically start, stop, and count items as they pass sensors.
- Belt Tracking: Automatic systems that use edge sensors to pivot pulleys, correcting belt misalignment (tracking) to prevent damage and contamination.
- Process Integration: Controlling conveyor flow to synchronize with filling, packaging, or sorting machines.

WORKING:

1. Start: Operator presses 'Start', powering the control circuit.
2. Material Detection: A sensor detects an item at the start, activating the motor.
3. Movement: The VFD controls motor speed to move the item.
4. End Detection: Another sensor at the end detects the item, signalling the PLC.
5. Stop/Cycle: The PLC stops the motor, waits for the item to clear, then resets for the next cycle.

AUTOMATED CONVEYOR BELT CONTROL SYSTEM



The figure illustrates an automatic conveyor belt speed control system.

(i) Conveyor Speed Sensor senses the measured or actual belt speed.

(ii) Comparator compares measured belt speed with desired belt speed to find the error between them.

(iii) A DC motor is used to drive the belt together with DC Motor Amplifier so that the error is rectified.

PROGRAMMING THE ABOVE MODEL USING MATLAB:

A. Construct the block diagram of the control system based on the components and variables described in Figure 1.1 and Table 1 (transfer functions are not required). [2 marks]

B. The DC motor used in ***Figure 1*** can be modelled as a first order system:

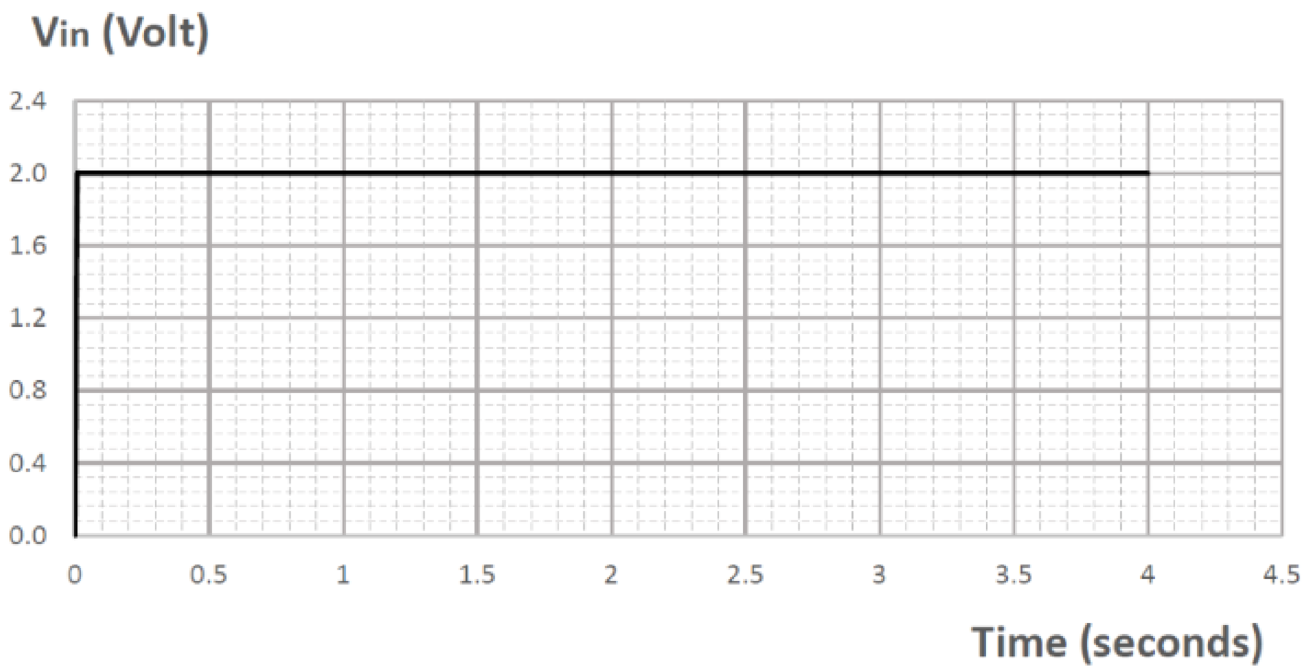
$$\frac{\omega(s)}{V_{in}(s)} = \frac{K_m}{T_m s+1}$$

where K_m and T_m are the motor voltage constant and time constant, respectively. During an experiment, it is found that the DC motor has the output response as shown in ***Figure 1.2*** to step voltage input with amplitude of 2.

Calculate the model parameters K_m and T_m based on the time response data given in ***Figure 1.2***. [2 marks]

C. Derive the closed-loop transfer function, given the following information:

- One rotation of DC motor shaft translates to 0.5 meter of belt motion
- The belt speed sensor is calibrated to produce an output of 1V per 1m/s of belt speed
- The amplifier has a gain of K = 5



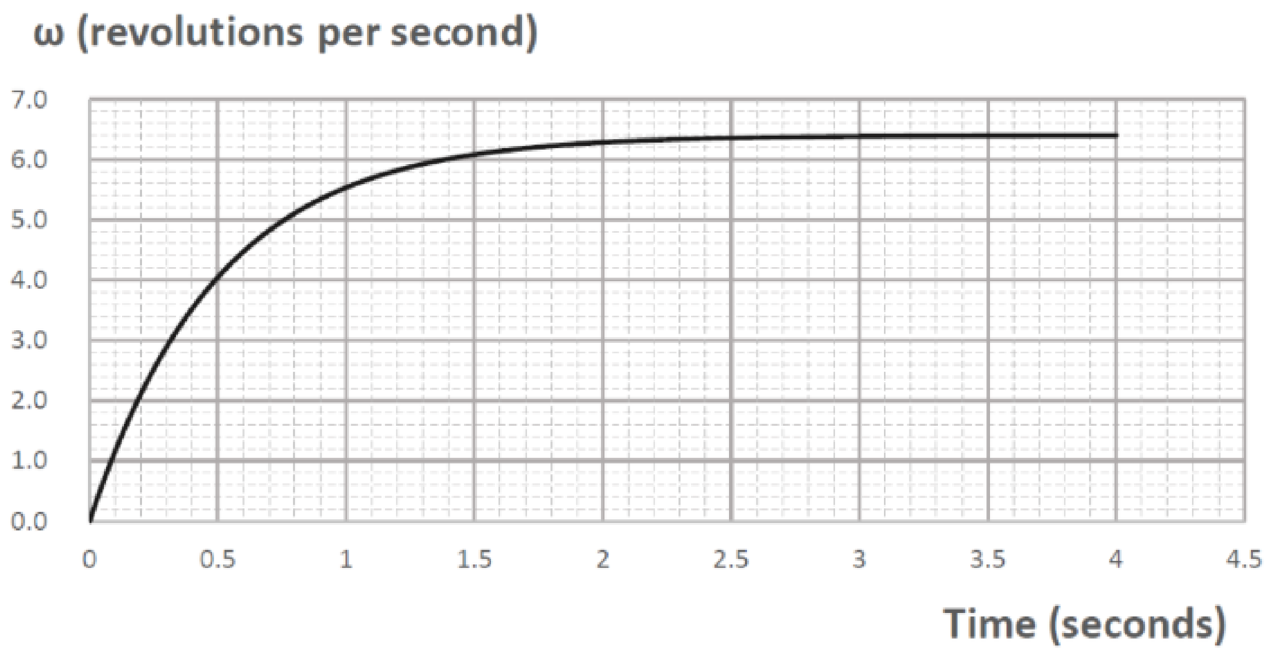

ω (revolutions per second)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (seconds)

Figure 1.2