Mathematical Modeling And Analysis of Industrial Mixing Process

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Abstract- *This paper describes about modeling of Simple Continuous Stirred Tank Reactor (CSTR) using MATLAB Programming. CSTR is one of the common reactors in chemical process industries. All the industrial process requires a solution for specific concentrations of chemicals considered for analysis. In CSTR, one or more fluid reagents are introduced into the tank reactor equipped with an impeller. The impeller stirs the input reagent to ensure proper mixing. Simply dividing the volume of the tank by the average volumetric flow rate through the tank gives the resistance time. Using chemical kinetics, the reaction's expected percentage of completion can be calculated. Here simple CSTR model controlled by using PI and PID controller and output simulated through MATLAB.*

Keywords- PLC, stirred tank, DC motor, Level sensor, Relay

I. INTRODUCTION

A stirred tank mixer is a batch equipped with an impeller or other mixing device to provide efficient mixing. A continuous stirred tank runs at steady state with continuous flow of reactants and products; the feed assumes a uniform composition throughout reactor, exit stream has the same composition as in the tank. Stirred tank is widely used as means to convert reactants into valuable products in chemical industries. It is used regularly for liquid or suspension reaction. On the basis of end-use industry, continuous stirred tank mixer market can be segmented as, Chemical industry, Pharmaceutical industry, Bio-fuel industry, Food industry, Paint industry etc.

Mostly embedded system programming is employed for enabling the rotation of the continuous tank stirrer using dc motor. In an automated system a PLC controller is usually the major part of a process control system. With the execution of a program stored in program memory, PLC continuously monitors status of the system through signals from the input devices. Based on the logic implemented in the program, PLC determines which action to be executed with output coils. According to that the speed of the motor is varied and the liquid is mixed properly.

II. LITERATURE REVIEW

A. Existing method

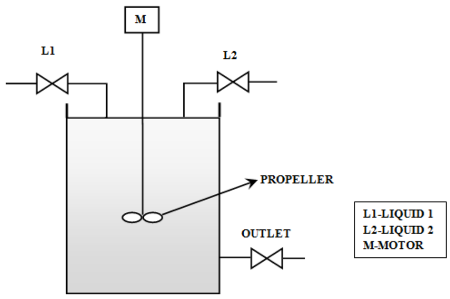

Fig.1 Existing Stirred Tank Model

In continuous stirred tanks, the stirrer runs at steady speed with the continuous flow of reactants and products, the feed assumes a uniform composition throughout the reactor, exit stream has the same composition as in the tank but it results in improper proportion in order to achieve the accurate proportion the stirrer speed is to be varied. As shown in the Fig.1, the experimental setup consists of two inlets, liquid1 and liquid 2 and motor M, that runs at steady speed which is connected to the stirrer through propeller.

B. Disadvantages of Existing Method

1) Time Dependent Rpm

- Using time dependent rpm, the mixing process was enhanced in the stirrer vessels.
- But the proportion was not maintained because the level is not taken into account.

2)Flow Visualization

- Using flow visualization, the proportionate mixture was obtained in the continuous stirred tanks.
- But flow visualization is not possible in large scale industries.

C. Proposed Prototype

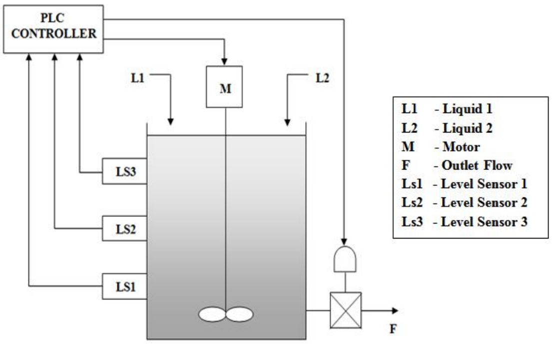

Fig. 2 Proposed Prototype

In Fig. 2, L1 and L2 represents two liquids to be mixed in the tank. Three level sensor LS1, LS2, LS3. Here the solenoid valve F is placed in order to control the outlet flow. PLC Controller will vary the speed of themotor according level sensors input to it. The stirrer and propeller speed varied by motor, whose input is from PLC Controller according to the level present in the mixing tank.

III. SYSTEM DESIGN

A. Block Diagram

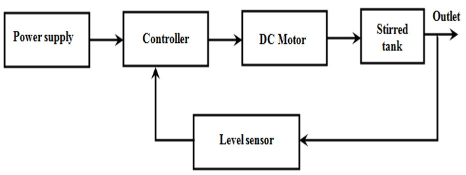

Fig. 3 Block Diagram of the Process

B. Methodology

In the proposed methodology, the Level sensor senses the liquid level in the tank. Three level sensors are positioned in the tank. The output from these sensors is given as an input to the PLC controller, according to the level in the tank, the speed of the motor will be varied. This results in proper mixing proportion of two liquids. In the existing method, the motor attached to the continuous stirrer rotates at a constant speed. As a result, proportion of a mixing liquid will be varied. This causes wide variation in the resultant product. So, in order to avoid this problem, as in the Fig. 2, the speed of the stirrer is varied which is connected to the shaft of the motor, according to the level in the mixing tank.

C. Hardware Design

1) Level Sensor

A float switch is a device for determining the level or amount of fluids, liquids or other substances that flow in an open or closed system. There are two types of level measurements, namely, continuous level and point level measurements. In Continuous level measurement, level is measured within a specified range and determine the exact amount of substance in a certain place, while in point-level measurement only indicate whether the substances are above or below the sensing point.

When a permanent magnet sealed inside a float rises or falls to the actuation level, switching occurs with magnetically actuated float switch. With a mechanically actuated float switch, switching occurs as a result of the movement of a float against a micro switch. The choice of float material is also influenced by its temperature-induced changes in specific gravity and viscosity – changes that directly affect buoyancy.

Here the magnetic float switch is employed and is of normally closed type. It is of light weight, easy to use and shock proof because it does not require any electrical contact with water. The magnetic float switch is made up of plastic and hence it is corrosion free and rust free device. Advanced magnetic technology is employed in this magnetic float switch.

Ideal operation rating of this float switch:

- Voltage : 2V to 12V
- DC Current : 5mA to 50mA

Fig. 4 Level Switch

Features:

- Choice of normal open or normal close
- No standby power requirement.
- Customer can define activated distance, cable length and connector.
- Hermetically sealed, suit to tough environment and long life.

2) DC Motor

A DC motor is an electrical machine that converts dc electrical energy into mechanical energy. It mainly depends on that "if a current carrying conductor is placed in a magnetic field, it will experience a mechanical force". The direction of DC motor's force is given by Fleming's Left Hand Rule.

The most common types are based on the forces produced by magnetic fields. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic in order to change periodically the direction of current flow in part of the motor.

A Dc motor's speed can be controlled over a wide range by using either a variable supply voltage or by changing the strength of current in its field windings. Small DC motors are majorly used in tools, toys and appliances. Larger DC motors are mostly used in propulsion of electric vehicles, elevator and hoists or in drives for steel rolling mills.

Specifications:

- Speed: 100rpm
- Operating Voltage: 4 to 12 volt
- Rated torque: 2.9 kg-cm
- Stall torque: 11.4 kg-cm

The motor is fixed on the top of the continuous stirred tank, which continuously rotates according to the input given from the PLC controller. Speed of the stirrer and propeller is varied, according to the control action provided by the PLC controller to the DC motor in order to obtain accurate proportion of the product to be obtained.

3) Relay

A relay is an electrically operated switch. When a current flowing through the coil of the relay creates a magnetic field which attracts a lever and changes the switch contacts. The coil current be ON or OFF so the relays have two switch positions and they are double throw (change over) switches. Relays use an electromagnet to mechanically operated switch, but other operating principles are also used, such as solid-state relays. Relays are used to control a circuit by a separate low-power signal, or several circuits must be controlled by one signal.

When an electric current is passed through the coil it generates a magnetic field that will activate the armature, and the consequent movement of the movable contact either makes or break a connection with a fixed contact. If the set of contacts was closed or when the relay was de-energized, then the movement opens the contacts and breaks the connection, and happens vice versa if the contacts were open. When the current to the coil is switched off, the armature is returns back by a force, approximately half as strong as the magnetic force applied to its relaxed position. Usually, this force is provided by the spring, but gravity is also used majorly in industrial motor starters. Most relays are manufactured to operate safely as well as quickly. In a low – voltage application this reduces noise as well as in high voltage or current applications it reduces arcing.

4) Controller

PLC's can range from small "building brick" devices with tens of inputs and outputs (I/O), in a housing integral with the processor, to large rack-mounted modular devices with a count of thousands of I/O. They can be designed for multiple arrangements for both digital and analog I/O modules, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are stored in battery-backed-up or non-volatile memory (EPROM). Programs were exclusively stored on cassette tape cartridges.

Here the output from the three level sensors is given to the PLC controller. The PLC is programmed with the help of RS Logix software in order to control the speed of the motor. The output from the PLC is 24 Volt and the voltage is varied with the help of the relays and the motor is driven according to the corresponding speeds.

PLCs are recently programmed using application software on personal computers, which now representing the logic in graphic form instead of character symbols. The computer is mostly connected to the PLC via USB, Ethernet, RS-232, RS-485or RS-422 cabling. The programming software for PLC allows entry and editing of the ladder-style logic. In some software packages, it may also possible to view and edit the program in function block diagrams, sequence flow charts and structured text. The software generally provide functions for debugging and troubleshooting the PLC software, for example, by highlighting portions of the logic to show current status during operation or via simulation. The software will upload and download the PLC program and also for backup and restoration purposes. In some models of programmable controller, the program is majorly transferred from a personal computer to the PLC through a programming board which writes the program into a removable chip such as an EPROM .

5) Stirrer and Propeller

Stirrer and propeller are used for suspensions and homogenization. Homogenization is a process used mainly to make a mixture of two mutually non-soluble liquids the same throughout. It is ideal for stirring liquids with medium to high viscosity. They commonly create local shearing forces and axial flow in the vessel. These propeller and stirrer are used at low to high speeds.

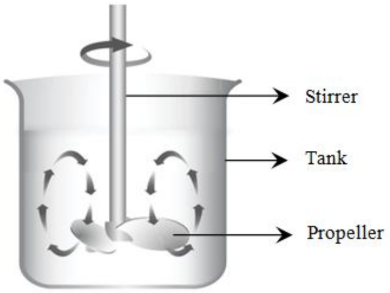

Fig. 5 Tank Stirrer and Propeller Setup

The stirrer is connected to the shaft of the motor as shown in the Fig. 8, it will rotate according to the speed of the motor. For the proper mixing of the liquids, the stirrer and propeller will rotate according to the level in the tank. The speed of the stirrer and propeller is maximum for high level, moderate for medium level and minimum for low level in the tank; this will enhance the mixing process. The mixing of two liquids continuously in a tank will results in corrosion, in order to avoid this stirrer and propeller used in the industrial mixing process should be good corrosion resistance.

IV. RESULT

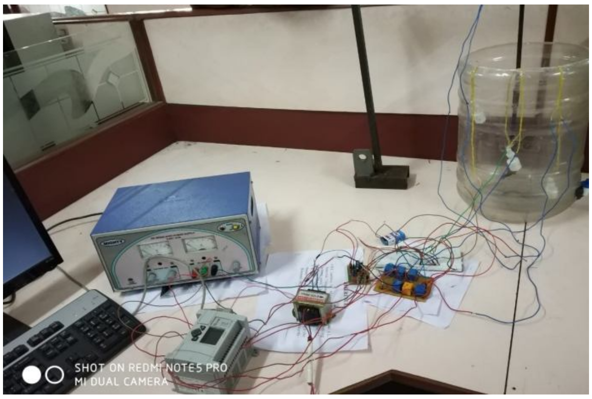

Fig.6 Model Setup

Here the input from level sensors are connected to the relays and from that the corresponding inputs are sensed and sent to the PLC and using ladder logic the speed of the motor is varied according to the input from the level sensor.

Tab. 1 Observation of Results

VOLTAGE	MOTOR SPEED
5V	60 RPM
9V	200 RPM
12V	800 RPM

V. CONCLUSION

The speed of the dc motor is controlled using PLC controller with the help of the corresponding outputs from the level sensors placed in the stirred tank.

Thus the simple CSTR connected in series was PI and PID controller simulated using MATLAB programming, the result graph shown in figure 10 and 11.

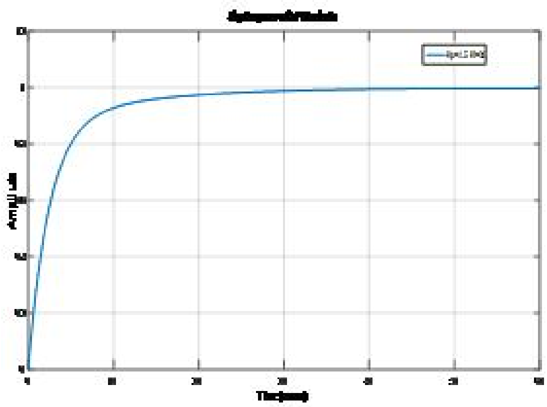

Fig .7 Step response with PI Controller

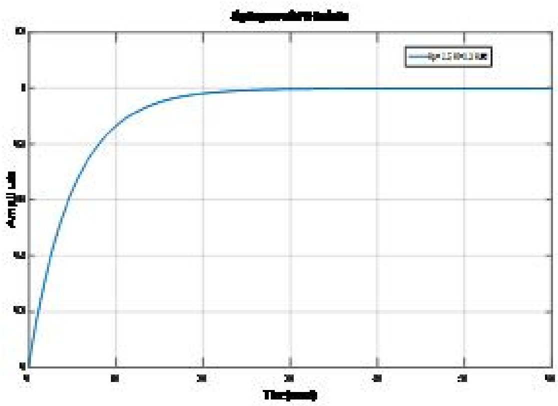

Fig.8 Step response with PID Controller

Simulation is carriedout in MATLAB platform with the parameter values as given below. Flow rate F=0.085 m3/min, Volume of the tank V=1.05 m3, Reaction rate k=0.04 min-1, calculated constant parameters t=8.25 and kp=0.669. PI and PID controllers are tuned by using trial and error basis through manually final controller parameters indicated Table-1.

Table-1: PI and PID Controller Parameters

Type	Kp	Ki	Kd
PI	4.5	0.4	-
PID	2.5	0.3	0.1

From the simulation results shown the performance of PID controller are better than PI controller proved from the results settling time and overshoot very less in PID controller comparatively to the PI controlle

VI. MATHEMATICAL MODELING

Consider simple CSTR with the constant inlet (F) and outlet flow rate is constant, Volume of the tank is V, inlet concentration is Cin, Outlet concentration is Cout and k is reaction rate Figure shown below.

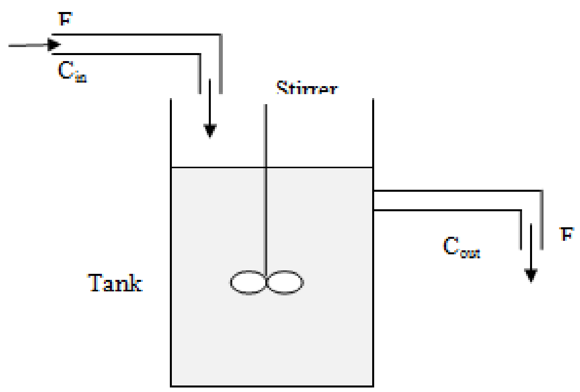

Fig.9 CSTR model

Let us consider mass balance equation for simple cstr equation in S domain is shown below

V Cout s + F Cout +V Cout k = F Cin (1)

s + (F + Vk)/V = FCin /V Cout (2)

Simplify the equation and introduce with constant t and kp.

Cout (s + 1/t) = F Cin/V (3)

Where t = V/ (F+Vk)

Cout (1 + t s) = F Cin / (F + V k) (4)

Cout / Cin = kp / (1 + t s) (5)

Where kp = F / (F+Vk)

Finally the above dynamic equation is simulated using MATLAB and controlled using PI and PID controller simulation results shown below.

VII. FUTURE SCOPE

The inlet and outlet flow is not yet controlled in this setup, if the inlet flow of the two different liquids is controlled according to the outlet flow of the mixture, the resultant mixture obtained will be in accurate in proportion

REFERENCES

[1] D.J. Lamberto, F.J. Muzzio, P.D. Swanson and A.L. Tonkovich, “Using time-dependent rpm to enhance mixing in stirred vessels,” Chemical Engineering Science, vol. 51, 1996, pp. 733–741.

[2] N. Harnby, M.F. Edwards and A.W. Nienow, Mixing in the Process Industries, 2nd ed., Oxford: Butterworth-Heinemann, 1992, pp. 1–2.

[3] F. Raynal and J.N. Gence, “Energy saving in chaotic laminar mixing,”Journal of Heat and Mass Transfer, vol. 40, 1997, pp. 3267–3273

[4] M.M. Alvarez-Hernández, T. Shinbrot, J. Zalc and F.J. Muzzio,“Practical chaotic mixing,” Chemical Engineering Science, vol. 57,2002, pp. 3749–3753.

[5] J.H. Chen, K.T. Chau and C.C. Chan, “Analysis of chaos in currentmode controlled dc drive systems,” IEEE Transactions on Industrial Electronics, vol. 47, 2000, pp. 67–76.