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A Microcontroller based Furnace Oil Conditioning System for Improving Furnace Combustion in Industries.

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Abstract— Number-5 fuel oil is usually used as furnace fuel in industries due to its low cost. Conditioning of furnace oil including preheating and maintaining a fluctuation free continuous flow of oil to furnace is essential for better performance of the combustion control of a furnace. The developed system has two control loops; one is for pre-heating the fuel oil at 85±3 ˚C in tank-1 and the other is to maintain a constant fuel level at tank-2 for achieving a steady outflow from this tank to furnace without any fluctuation. Such fluctuation free fuel input to a combustion control system increases its efficiency. The system is modelled as two non-interactive level processes and derived transfer function of the system. Using this transfer function the system has been simulated using Simulink. The step response of the system is plotted and observed that there are no fluctuations at the output when the system is in steady state. The simulated system is practically implemented around a microcontroller. After tuning the control parameters, the constructed prototype system has been tested by giving a step change at the input. The response of the system is found fluctuation free when the system reaches in its steady state, which also validates the simulation result

Index Terms— automatic control, arduio microcontroller, Furnace oil, Fuel oil conditioning, level control, microcontroller based system, simulation.

1 INTRODUCTION

FURNACE oil, also known as Fuel oil or heavy oil or marine fuel is a fraction obtained from petroleum distillation either as a distillate or a residue. Fuel oil is a liquid fuel that is burned in a furnace of a boiler for generating steam or used in an engine for the generation of power. Furnace oil is made of long hydrocarbon chain, particularly alkenes, cycloalkenes and aromatics. Viscosity is one of the important characteristics of furnace oil specification. It influences the degree of pre-heat required for handling, storage and satisfactory atomization. On the basis of the boiling point and viscosity, fuel oil is nomenclatured as number-1, number-2 etc. up to number-6. Viscosity increases with increase of fuel number, but price usually decreases with increase of fuel number.

Number 5 fuel oil is a residual type requiring preheating to 77-104℃ [1] for reducing its viscosity so that pumping and atomization at the burner are possible. Number 6 fuel oil is a high viscosity residual oil requiring preheating to 104-127℃ Generally industries use Number 5 fuel oil for furnaces. This paper explains an automatic control system designed to handle Number 5 fuel oil which is preheated up to 85±3℃in tank-1 and then pumped to tank-2, where its level is maintained constant so that its outlet has constant flow without any fluctuation. Continuous fuel flow without any fluctuation to the furnace is one of the important conditions for furnace combustion control system to work efficiently [2].

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2 EXISTING SYSTEM

As mentioned above, most of the industries use number-5 furnace oil as fuel to their furnaces. In industries, fuel oil is pre-heated so that pumping and atomization at the burner is possible comfortably; but not maintained to have a fluctuation free fuel flow to furnace combustion control system. Optimum combustion in furnace is possible only if the fuel flow to the furnace is fluctuation free. An attempt has been made in this work to achieve fluctuation free fuel flow to the furnace.

3 PROPOSED SYSTEM

The block diagram of the proposed system is shown in figure 1. There are two control loops for the system. One is the temperature control loop of the storage tank-1 and the other is level control loop of fuel supply tank-2. After pre-heating, the oil is pumped through the pneumatic valve and reaches to tank-2. The fuel level of tank-2 is continuously controlled and kept at a constant level, so that the output of tank-2 will not fluctuate and has a steady flow to the furnace. Arduino Uno microcontroller is at the central processing unit, for monitoring and controlling the whole activity.

The level control system is modelled as two non-interactive level processes [3]. The level of tank-1 is maintained independent to the level of tank-2. The schematic of the level process is shown in figure 2. Tank-1 has a uniform cross section area A_1 is attached to a flow resistance R_1 due to pneumatic valve and pump in series. Assume that q be the volumetric flow of liquid into tank-1 and q_{o1} be the volumetric flow rate through the resistance R_1, which is related to the liquid head h_1 by the linear relation.

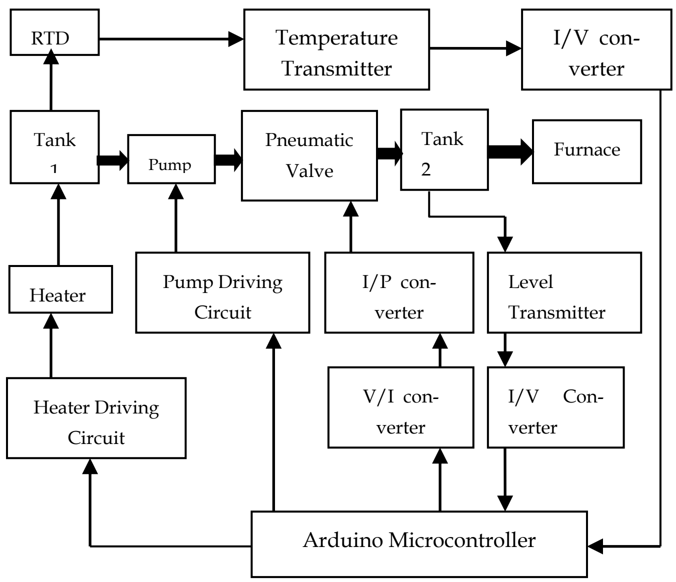

Fig1 The proposed Arduino microcontroller based system

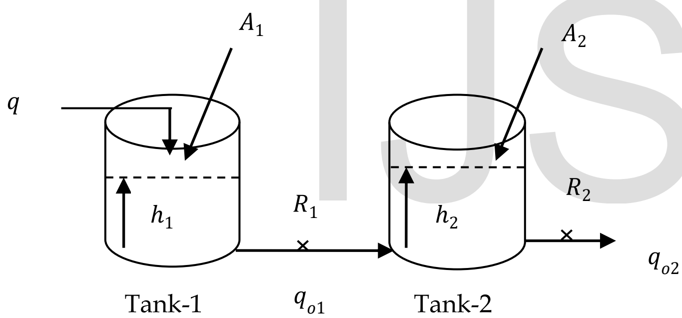

Fig 2 Schematic diagram of level process

$$q_{o1} = \frac{h_1}{R_1}$$

The temperature of the fuel oil in storage tank-1 is maintained at 85±3℃. Microcontroller gives command to switch ON the pump for pumping the oil to tank-2 only after taink-1 liquid temperature is reached within the range of 85±3℃. The system can be analyzed by writing a transient mass balance around tank-1 as

(Rate of mass flow in) – (Rate of mass flow out) = (Rate of accumulation of mass in tank-1)

In terms of the variables used, the mass balance equation becomes

$$q(t) - q_{o1}(t) = A_1 \frac{dh_1}{dt} \qquad (1)$$

It is assumed that the density ρ of the oil is constant within the range 85±3℃. Under steady state condition, equation (1) can be written as

$$q_s - q_{o1} = 0 \qquad (2)$$

where, q_s is the flow under steady state condition.

Subtracting equation (2) from equation (1) and introducing the deviation variables $Q_1 = q - q_s$ and $H_1 = h_1 - h_s$, gives

$$Q_1 = A_1 \frac{dH_1}{dt} \qquad (3)$$

Here, h_s is the liquid head at steady state.

Taking Laplace Transform on either side of equation (3) and solving for the transfer function of tank-1 as

$$\frac{H_1(s)}{Q_1(s)} = \frac{1}{A_1 s} \qquad (4)$$

The output of tank-1 level system is fed to tank-2. The level of tnak-2 is controlled using proportional controller and achieved a constant liquid head h_2 . Tank-2 has a uniform cross section area A_2 , which is connected to a pipe going to furnace whose resistance is R_2. In such a situation, the volumetric flow rate q_{o2} at the outlet of tank-2 can be written as

$$q_{o2} = \frac{h_2}{R_2} \qquad (5)$$

In terms of variables used in this analysis, the mass balance equation becomes

$$q_{o1}(t) - q_{o2}(t) = A_2 \frac{dh_2}{dt} \qquad (6)$$

Combining equations (5) and (6) to eliminate $q_{o2}(t)$ gives

$$q_{o1} - \frac{h_2}{R_2} = A_2 \frac{dh_2}{dt} \qquad (7)$$

It is assumed that the process is operating at steady state. Then, equation (7) becomes

$$q_{01s} - \frac{h_{2s}}{R_2} = A_2 \frac{dh_{2s}}{dt} \qquad (8)$$

Subtracting equation (8) from equation (7) becomes

$$q_{01} - q_{01s} = \frac{1}{R_2}(h_2 - h_{2s}) + A_2 \frac{d(h_2 - h_{2s})}{dt} \qquad (9)$$

If we define the deviation variable as $Q_2 = q_{o1} - q_{o1s}$ and $H_2 = h_2 - h_{2s}$

Then equation (9) can be written as

$$Q_2 = \frac{1}{R_2} H_2 + A_2 \frac{dH_2}{dt} \qquad (10)$$

Laplace transform of equation (10) gives

$$Q_2(s) = \frac{1}{R_2} H_2(s) + A_2 s H_2(s) \qquad (11)$$

Equation (11) can be rearranged into standard form of the first order lag gives

$$\frac{H_2(s)}{Q_2(s)} = \frac{R_2}{\tau s+1} \quad ; \text{Where; } \tau = A_2R_2 \qquad (12)$$

Thus the overall transfer function of the furnace oil conditioning system is

$$\left(\frac{H_1(s)}{Q_1(s)}\right)\left(\frac{H_2(s)}{Q_2(s)}\right) = \left(\frac{1}{sA_1}\right)\left(\frac{R_2}{\tau s+1}\right)$$
$$= \frac{R_2}{sA_1(\tau s+1)}$$
$$= \frac{1}{sA_1(\tau s+1)}$$; when R_2 is assumed as 1

Proportional Control is enough for maintaining a constant liquid level in tank-2. The error due to the offset of proportional control is not a problem here, because we are interested in a constant fuel level in tank-2 such that the fuel flow through its outlet will be fluctuation free.

The system is simulated using Simulink. The dimension of tank-1 is chosen as length L_1 = 30 cm, width W_1 = 30 cm and height H_1 = 30 cm. The dimension of tank-2 is chosen as length L_2 = 20 cm. width W_2 = 20 cm and height H_2 = 30 cm. Thus the transfer function of tank-1 is $\frac{1}{900s}$ and the transfer function of tank-2 is $\frac{1}{400s+1}$. The simulink diagram is shown in figure 3.

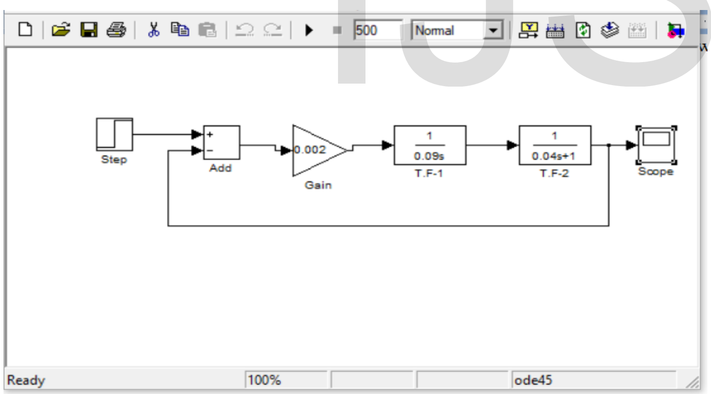

Fig 3 Simulink diagram of the proposed system

The final value of step input is chosen as 20 units. The simulated output of the system corresponds to the step input is shown in figure 4. The output response of the system is fluctuation free under steady state.

4. Practical Implementation Of The Proposed System

A prototype of the system is designed around Arduino Uno microcontroller. Tank-1 is constructed with the dimension of length = 30 cm, width = 30 cm and hight = 30 cm and Tank-2 is construted with the dimension of length = 20 cm, width = 20 cm and hight = 30 cm. The heater is connected at the bottom of the tank-1 and its temperature is controlled by the software embedded in Arduino UNO microcontroller. Temperature control loop adopts ON-OFF control strategy [4]. As the temperature range is not high, an industrial grade RTD (Resistance Temperature Detector) [5] is used for sensing the temperature. RTD temperature transmitter (OMEGA STX 70) [6] is used to convert RTD output into 4 – 20 mA standard signal. This signal is converted into standard voltage range (1-5V) using a current to voltage converter and fed to Arduino UNO microcontroller board [7].

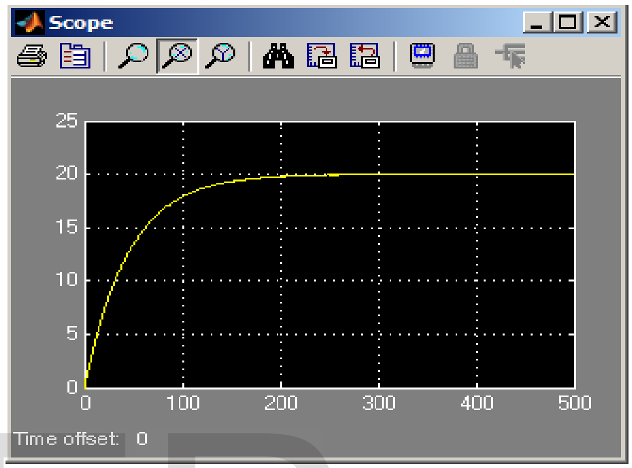

Fig 4. Simulation result (System response) of the proposed system

To start the process, microcontroller sends logic one through pin-7 which energises the power relay [8] and makes the heater connected to 230 V_{ac} which heats the fuel oil in tank-1. Microcontroller continuously monitors RTD output and the ON-OFF temperature control loop of tank-1maintains the temperature at 85±3℃ When the temperature reaches above 82℃ microcontroller sends logic-1 (5V) through its pin-6 which energizes another power relay for switching ON the pump. Pneumatic valve is controlled through Pin-9 of the microcontroller. The output of pin-9 is connected to a voltage to current converter, which converts voltage output (1-5V) of the microcontroller to standard current signal (4-20 ma) and fed to current to pressure converter (Omega Engineering make IP 210) [9]. Current to pressure converter converts current 4 - 20 mA into standard pressure signal 3 – 15psi. Thus controller output in voltage form has been converted into pressure signal and the motion of pneumatic valve is adjusted. At the beginning pneumatic valve is fully opened and the fuel oil is rushed to tank-2. The level of tank-2 is monitored by a level transmitter working with the principle of differential pressure (Yokogawa EJX 120A) [10]. High pressure end of the transmitter is connected at the bottom of the tank and the low pressure end is opened to atmosphere. The output of the level transmitter is connected to a current to voltage converter and its output is read by microcontroller. The level control loop (proportional control) takes this reading and error is calculated by subtracting this value from set point. In the constructed prototype set-point of fuel level in tank-2 is kept as 21 cm and the gain of the controller is set to 1. The complete flow chart of the software is given in figure 5. The software has been written in C language.

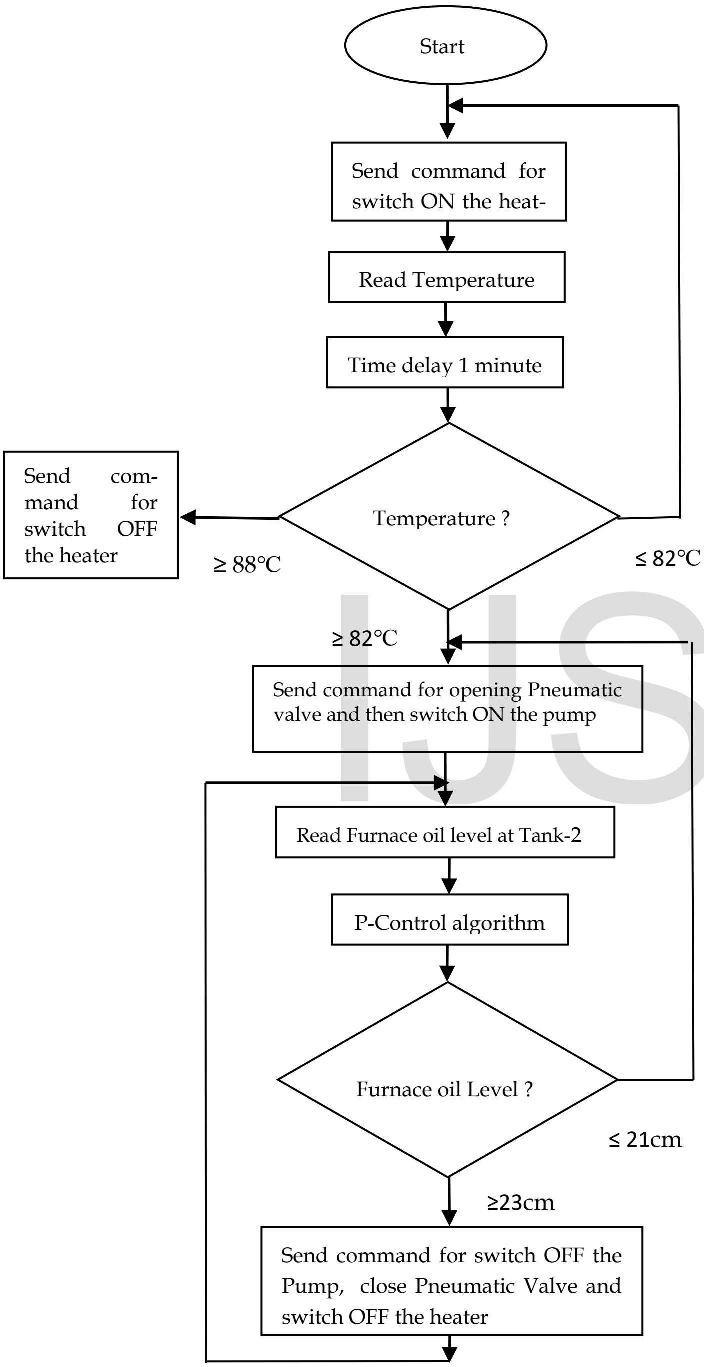

Fig 5 Flow chart of the software of the system

5. TESTING OF THE PROTOTYPE OF THE SYSTEM

The constructed prototype of the system is shown in figure 6. Tank-1 is at the left side and tank-2 is at the right side. In a real industrial system output of the second tank goes to furnace; but in the prototype, the output is taken back to tank-1 for continuous operation. Microcontroller, Power supplies, Differential pressure transmitter and associated electronics circuits are mounted behind the board. Due to safety reason (to avoid fire) instead of furnace oil, pure water is used for conducting the experiment. The proportional control element of the system is tuned by keeping the system in operational. After the system was tuned satisfactorily, it was tested continuously for hours and its performance has been evaluated. The output response of the level controller for a step input is shown in figure 7. Set point of the level control is kept at 21cm. The obtained response of the level controller of tank-2 reveals that its level is fluctuation free at 20 cm when the system attains steady state. During this steady state condition, the flow of fuel through the outlet of tank-2 is found fluctuation free which enables combustion control of furnace to work efficiently.

Fig 6 Constructed Prototype of the system

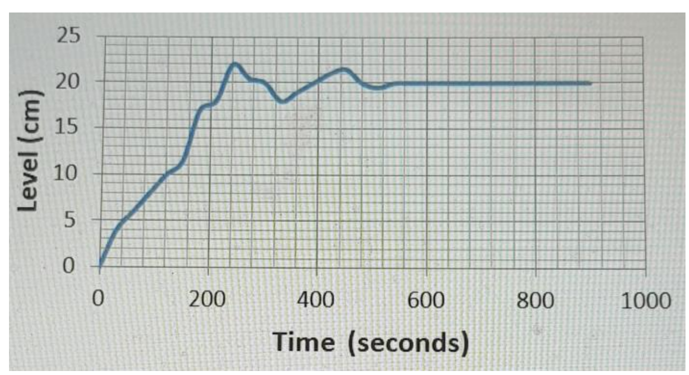

Fig 7 Response of level controller of tank-2 for a step input.

6. CONCLUSION

Mathematical modelling of furnace oil conditioning system is done and simulated using simulink. Practical design of the system is done and a prototype has been constructed around Arduino Uno microcontroller. The system preheats the furnace oil and pumped to tank-2, where its level has been maintained constant so that the outlet of tank-2 going to furnace will be fluctuation free. The performance of the system has been tested continuously for a long time and the obtained result was encouraging. The result of the practically implemented system is identical to the simulation result which also validates the mathematical model of the system.

The temperature of the oil tank-1 is tried to maintain at 85±3℃ but possible to control only at 85±5˚C due to process delay. Though the constructed system was tested using water due to safety reasons (to avoid fire as the system was testing in laboratory), all the requirements have been kept intact to replace the water with Number-5 furnace oil. The system can be modified by incorporating a level switch at tank-2, to switch OFF the system for avoiding overflow in case the automatic control system fails. Provide a stand-by pump for pumping the fuel oil will increase the reliability of the system operation.

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