RESEARCH ARTICLE

STUDY OF THE APPLICATION OF A PID CONTROLLER FOR PH CONTROL OF WASTE WATER IN WASTE-WATER TREATMENT PLANT

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ARTICLE INFO	ABSTRACT
	Theoretical studies have been carried out to find the performance of a waste –water treatment plant where PID controller is applied for PH control of waste water. Steady state errors of the system have been determined for application of different types of input signal, such as unit step, unit ramp and unit parabolic. A programming using 'C' language has also been developed to find overall gain of the system and hence to find the frequency response of the same. Some numerical calculations have been made. Results have been tabulated, shown graphically and discussed.

INTRODUCTION

Applications of control system, in various fields, have been given due importance for the last many years due to the following facts (Kuo, 1995; Nagrath and Madan Gopal, 2005; Sreyasree Mandal and Mandal, 2014)

- They help in conserving materials, manpower and electrical energy, etc.
- They help in saving the time of operation.
- They also contribute in increasing the reliability and the stability of the system.

Waste-water treatment plant has a significant role for production of potable water. For this waste water is treated chemically to remove impurities and unwanted materials to maintain a standard PH of the purified water (Mark, 1981). In this paper, an attempt has made to present the results of the investigation carried out for a typical waste water treatment plant where a PID controller has been used to maintain the PH of purified water. Some numerical calculations have made. The results have been tabulated, graphically shown and discussed.

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INSTRUMENTATION SYSTEM AND METHODS

Waste water treatment system with PID controller

Fig 1 shows the physical model of a waste-water purification system with a PID controller. The PID controller continuously monitors the output PH of the treated water with the help of a PH meter located at the exit and compares it with the desired PH. The controller manipulates the valve stem position according to the linear law. The influent is acidic and has a fixed PH. It flows into continuous stirred tank reactor with a fixed flow rate. The PH of the effluent has to maintained at a set point in the range of 4 to 7 pH. This is accomplished by controlling the flow rate of the basic reagent with the help of a valve. The opening of the valve is controlled by the PID controller (Sreyasree Mandal and Mandal, 2014). Fig 2 depicts a Block diagram model of a waste water treatment plant with PID controller.

Analysis

The analysis of the system has been done to find:

- The overall transfer function of the system,
- The overall gain of the system,
- The steady state errors of the system, and
- To develop a programme using 'C' language to find the frequency response of the system.
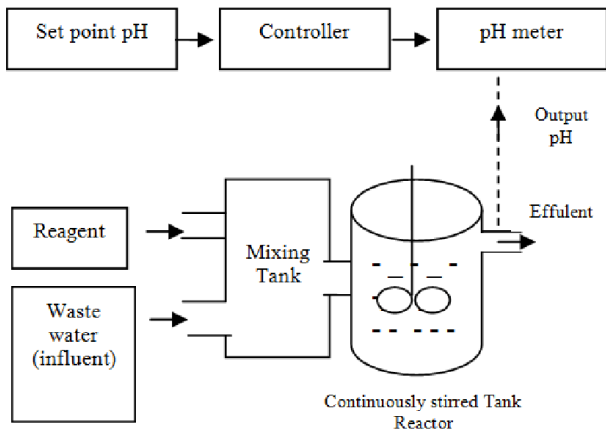
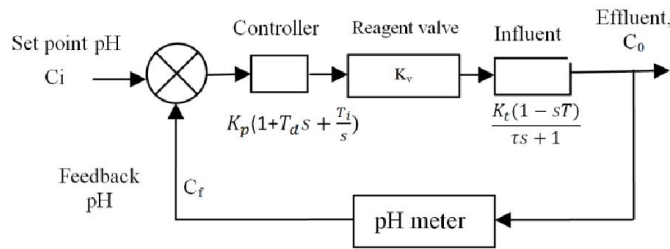**Fig. 1. Physical model of waste water treatment system with PID controller**

Fig. 2. Block diagram model of waste water treatment plant with PID controller

Determination overall transfer function of the system

To determine the transfer function of the whole system, let us consider the Block diagram model as shown in Fig. 2. Using this block diagram model, we can get closed loop transfer function with PID controller

$$A(s) = \frac{K[-T.T_ds^3 + s^2(T_d - T) + s(1 - TT_i) + T_i]}{-kK_mT\,T_ds^3 + s^2[KK_m(T_d - T) + \tau] + s[(1 - TT_i)KK_m + 1] + KK_mT_i} \qquad \text{................... (1)}$$

Where $K = K_pK_vK_t$ .... (2)

C_i = Set point pH = Input signal
C_o = pH of Effuent = output signal
C_f – Feedback pH
K_p = Proportional controller constant
K_v = Reagent valve constant
K_t = Tank-reactor constant
K_m = pH meter constant
T = Delay time
τ = Overall time constant of control factor
T_d = Deferential control factor
T_i = Integral control factor

Determination of the overall gain of the system

At   s = jω the equation (1) can be expressed as

$$A(j\omega) = \frac{Co\,(j\omega)}{Ci\,(j\omega)} = \frac{K(A + jB)}{c + jD} \qquad \text{................... (3)}$$

Where, = $A = T_i + \omega^2(T - T_d)$ .... (4)

$B = TT_d\omega^3 + \omega(1 - TT_i)$ .... (5)

$C = KK_mTi - \omega^2[(T_d - T)KK_m + \tau]$ .... (6)
$D = KK_mTT_d\omega^3 + \omega[(1 - TT_i)kk_m + 1]$ .... (7)

The overall gain of the system in dB can be written as

$$\left| A(j\omega) \right| = 20 \log \frac{K\sqrt{A^2 + B^2}}{\sqrt{C^2 + D^2}} \qquad \text{................ (8)}$$

At different values of ω, the equation (8) can be used to find the frequency response of the system. A programme has been developed using 'C' language for the same and it is given in section 2.2.4.

Determination of steady state error

The examination of Block diagram model as shown in Fig. 2, gives the open loop transfer function with PID controller as

$$G(s) = K_cK_vK_t(1 - sT)(T_ds^2 + s + T_i) \qquad \text{................. (9)}$$

The steady state error of the system can be expressed as

$$e_{ss} = \underset{s \to 0}{Lt} \frac{s^2 c_i}{s + K_cK_vK + (1 - sT)(T_ds^2 + s + T_i)} \qquad \text{................. (10)}$$

The test signals that can be used for calculation of steady state errors are:

i) Unit step signal, $C_i(s) = 1/s$ .... (11)
ii) Unit Ramp signal, $C_i(s) = 1/s_2$ .... (12)
iii) Unit parabolic signal, $C_i(s) = 1/s^3$ .... (13)

For the each signal input, the steady state error can be determined using equation (10)

Table 1. Calculation of Steady state error

Type of controller	Type of input signal used	Steady state error (e_{ss})
	Unit step	Zero
PID	Unit ramp	$1/(K_vK_tK_pT_i)$
	Unit parabolic	Infinity

Computer programming using 'C' for determination of the overall gain of the system

```
≠ include < stdio.h>
≠ include <math.h>
int main ( )
{
float A;
char ch;
int Kp, Kv, Kt, Km, T, τ, ω, x, y, z, r;
Print f ("Enter the values of Km, Kv, Kt, Kp, T, τk);
scan f ("%d, %d, %d, %d %d, %d of Km, Kv, Kt Kp, T, τ &
f");
get char ( );
print f ("Do you want to enter the values of ω (Y/N)?:");
ch = get char ( );
while (ch = 'y')
{
print f ("Enter the values of ω:");
scan f (:%d", & ω);
x = poω ((Ti + w*w (T–Td)2);
```

```
y = poω (((T*Td*w*w*w+w (1-T*Ti))2);
z = poω (((K*Km*Ti – w*w*K*Km (1-T*Ti)+τ)2);
r = poω (((K*Km*T*Td*w*w*w+w(K*Km(1-T*Ti)+1)2);
A = K*sqrt (x + y) / (z+r);
get char ( );
print f  ("the gain of the system is % f/x," A);
print f ("Do you want to enter another value of ω (Y/N)?:";
ch = get char ( );
}
return  0;
}
```

RESULTS AND DISCUSSION

The data obtained, after the analysis of the system of waste water treatment plant where PID controller is used to control the pH of the purified water, can be used to study its performance. For this, calculations of steady state errors and the gain of the system at different values of frequency have been done using typical values of the following parameters:

$K_p = 1$, $T_d = 10$, $T_i = 40$, T = 20 sec

$\tau = 2$ sec., $K_v = 6$ ml/s/rad, $K_t = 0.9$, $K_m = 0.9$

Table-I shows the steady state errors for PID control action with various types of input signals. From this table it can be seen that for application of unit-step input signal, the steady state error of the system is zero. Theoretically, this is an ideal case. The real system will have always some error. Again, for unit-ramp input signal, the system's steady state error depends on the values of K_p, K_v, K_t and T_i. So, for this type of signal, the steady state error of the system is adjustable. For the application of unit parabolic input signal, the steady state error of the system is infinite. So, this type of signal cannot be used to operate the system.
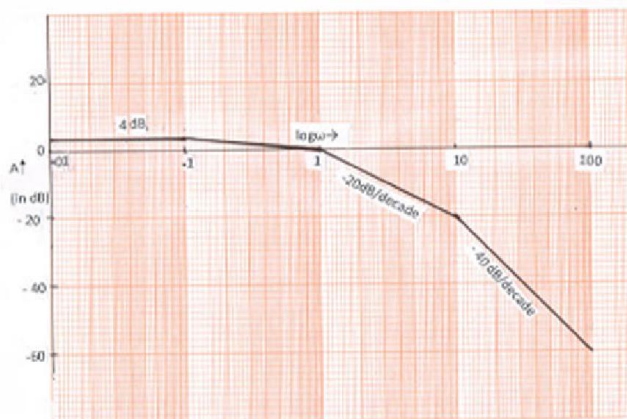

Fig 3. Frequency response of the waste water treatment plant with PID controller

The Fig. 3 depicts the frequency response of the system over a frequency range of 0.01 rad/sec to 100 rad/sec. It can be observed from the same figure that the gain of the system is constant of 4 dB for the frequency range of 0.01 to 0.1rad/s. Then it falls to 0 dB gradually from 0.1 to 1rad/s. Again, the gain of the system changes for the frequency range of 1 to 10 rad/s with a slope of -20dB/decade and for the frequency range of 10 to 100 rad/s with a slope of -40 dB/decade. It may be due to the fact that the system response at slower rate at lower frequencies, but it responds at faster rate.

Conclusion

In this investigation, we have studied theoretically the performances of a typical waste water treatment plant with PID controller. The actual performance can be obtained by designing such type of practical system and conducting some experiments on it. The performance of this system will also vary if we consider other types of controller, such as proportional, derivative, integral or combination of them instead PID controller and other values of the system parameters.

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