# Journal of Applied Sciences

ISSN 1812-5654

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Journal of Applied Sciences 14 (14): 1570-1575, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.1570.1575

# Model Identification Comparison of Different Controllers for Humidity Process

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**Abstract:** Maintaining humidity at a desired value is of prime importance in several industries such as textile, food processing and pharmaceutics to achieve the product quality. In this study a laboratory scale humidity setup was developed. By introducing step change in inlet flow rate the response in terms of RH was recorded. From the data, a model for the humidity setup was identified. The model identified best fitted with first order plus dead time model. For the identified model, different control strategies such as Ziegler Nichols based Proportional Integral Controller (ZNPID), Skogestad based Internal Model Controller (SIMC) and Fuzzy based PID controller (FUZZYPID) were tested in MATLAB environment. The performance of the controllers based on time domain specifications like rise time, settling time and overshoot were studied. Among the developed controllers FUZZYPID outperformed the others.

**Key words:** Humidity, skogestad based internal model controller, fuzzy based PID

## INTRODUCTION

Humid air plays decisive role in human life activities. Humidity is the mixture of water content and other constituents of air. It is represented in terms of Relative Humidity (RH). RH is stated as relation between the quantity of water vapors content in air to the maximum amount of water the air can absorb, expressed as percentage (%) when air cannot absorb any more moisture, its relative humidity is 100%. The role humidity plays a very important role in industries and also in human life activities (Venkatesh and Sundaram, 2012a). The level of RH has to be maintained in many Industries like pharmaceuticals, textiles, sugar, tobacco, silicon wafer deposition industries to get a desired output of the product (Ballaney, 2002). It is very necessary for the researcher and industrialized people to revise the outcome of RH. Liau and Huang (2008) performed an experiment on photonic band gap film in silicon formation which result better performance of time and quality in this experiment gives accurate result if the desired RH value is achieved. Enshen (2005) conducted an experiment and concluded that the energy consumption was affected heavily by air humidity due to annual heating and cooling.

Many control technique for humidity is available in literature. The control methodology for humidity and temperature control was proposed by Guo *et al.* (2009) in intelligent industrial workshop. Control of nonlinear process by fuzzy based control was suggested by Misir *et al.* (1996). Fuzzy based process model which avoid the linguistic control rule was proposed by Michels (1997). Ziegler and Nichols (1993) developed a conventional and traditional tuning strategy. In this tuning methodology the integral and derivative gain of the process to be zero. The gain of the proportional controller is augmented from zero until it attains the ultimate gain. Whenever the marginal oscillatory response is obtained, the ultimate frequency will be evaluated (Coughnwar and Leblanc, 1991). The load disturbance rejection was improved by the modified SIMC method which was proposed by Skogested (2003). In this approach by increasing the time constant ($\tau$), the integral time for the process is reduced. The major intention of this study is to determine the model for a humidifying process and to develop different controllers for this process, comparing the results FUZZYPID, SIMC and ZNPID.

## MATERIALS AND METHODS

Figure 1 shows the Block diagram of experimental arrangement for the humidity process. The air compressor is used to supply air of desired pressure. The compressed air is passed into the humidity chamber through rotameter. The rotameter is a device that measures the compressed air flow rate coming out from air compressor. The compressed air flow rate that is introduced into the humidity chamber is manipulated using the hand valve. The humidity chamber is a closed container. The chamber is filled with water of desired level. The humidity chamber is having the dimensions of 140 mm length, 100 mm breadth and 175 mm height. Pressurized air is passed through the chamber, it forms air bubbles. As a result of

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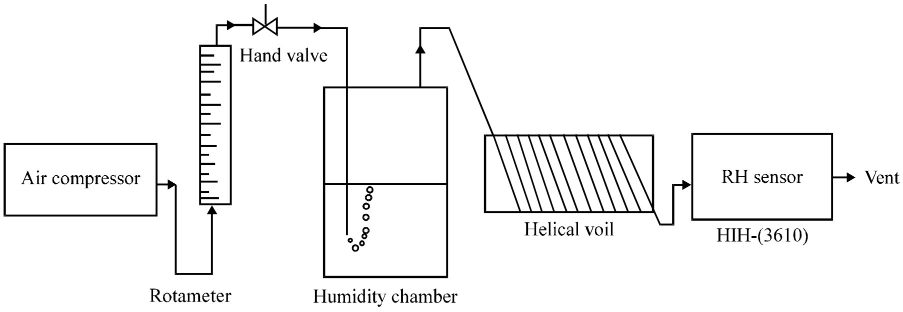

Fig. 1: Experimental set up for humidity process

this, humidified air is obtained which is made to pass through the helical coil. The coil produces time lag for the process. Honeywell make sensor HIH-3610 is used to measure the exit air Relative Humidity (RH) from the helical coil. A step magnitude of 0.1 L $\min^{-1}$ (LPM) in air flow rate is reduced into the humidity chamber. The exit air RH from the delay coil is measured and recorded with reverence to time.

**System identification:** The model parameters were acquired as recommended by Sundaresan and Krishnaswamy (1978). They proposed a method where two points were selected from the graph corresponding to the time taken for the response to reach 35.3 and 85.3% of the ultimate value that is $t_1$ and $t_2$, respectively. The following equations are used to estimate the time delay ($\theta$) and time constant ($\tau$) (Nithya *et al*., 2008):

$$\theta = 1.3t_1-0.29t_2$$

$$\tau = 0.67(t_1-t_2)$$

The gain K is found using the ratio of change in output to change in input. The model obtained is given as:

$$G(S) = \frac{184.64e^{-0.75s}}{5035S+1} \tag{1}$$

The obtained model was validated with the experimental data as shown in Fig. 2 which shows minimum error between experimental and theoretical model. Based on the correlation of many data, the values of $\theta$ and $\tau$ approximately minimize the difference between measured response and the model. It is a step response based method which avoids the use of point of inflection on the process step response to estimate the time delay (Seborg *et al*., 1989).

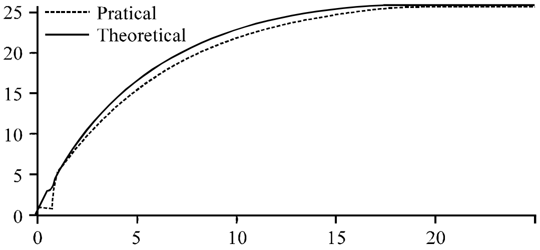

Fig. 2: Theoretical and practical step response curves

**Controller design:** The model obtained perfectly describes the plant. The obtained model was used to simulate different control schemes since it is mandatory to maintain the RH to a specific value to achieve the product quality.

**Zn based pid controller (ZNPID):** Many methods have been suggested in literature for designing a controller of a plant. A Z-N tuning rule is a closed-loop tuning method proposed by Ziegler and Nichols (1993) which is still used today in one form or another. The Z-N rules are considered only as approximate settings for satisfactory control (Coughnwar and Leblanc, 1991). The time-honored Z-N tuning rule serves as the basis for an upcoming generation in PID technology. With Z-N tuning rules, engineers had a systematic and practical way of tuning PID loops for improved performance. The Z-N rule serves as an aid for learning PID tuning rule which produces better values for the three PID controller gain constrains.

$K_c$: Gain
$\tau_I$: Integral time constant
$\tau_D$: Derivative time constant

Using the values of ultimate gain $K_u$ and ultimate period $P_u$, Z-N prescribes the value $K_c$, $\tau_I$ and $\tau_D$

depending on the type of controller used. The Tuning of this controller is shown in the Table 1.

$$K_u = \frac{1}{A} \text{ –ultimate gain}$$

$$P_u = \frac{2\pi}{\omega_{co}} = \frac{\frac{\text{radians}}{\text{cycle}}}{\frac{\text{radians}}{\text{sec}}} = \frac{\text{sec}}{\text{cycle}} \text{ –ultimate period}$$

Ziegler and Nichols (1993) proposed two methods namely frequency response and step response. Investigating step response method and in- depth gives deep intuitive understanding to new tuning rules (Astrom and Hagglund, 2004; Hagglund and Astrom 2004). Analysis of Z-N frequency response for tuning PI controllers have severe limitations which could be avoided by a simple modification for the process where the time delay is estimated (Astrom and Hagglund, 2004; Hagglund and Astrom 2004). The drawbacks of Z-N ultimate gain method are small stability margin and it is a trial and error process (Haugen, 2010).

Coefficient Diagram Method (CDM-PI) for a nonlinear pH neutralization system was proposed by Meenakshipriya *et al.* (2012). In this study, the set point tracking performance for a pH neutralization is compared with Ziegler Nichlos in terms of Performance indices like Integral Absolute Error (IAE), Integral Squared Error (ISE), Time domain specification like rise time ($t_1$r, settling time $t_s$, peak overshoot (%Mp) which results CDM-PI gives better performance when compared with ZN-PI.

Table 1: Ziegler Nichols based tuning parameters

| Type of controller | $G_c(S)$ | kc | $\tau_i$ | $\tau_d$ |
|---|---|---|---|---|
| Proportional | $k_c$ | 0.5 $k_u$ | - | - |
| Proportional integral | $kc\left(1+\frac{1}{\tau_i(S)}\right)$ | 0.45 $k_u$ | pu/1.2 | - |
| Proportional integral derivative | $k_c\left(1+\frac{1}{\tau_i(S)}+\tau_d(s)\right)$ | 0.6 $k_u$ | pu/2 | pu/8 |

## SKOGESTAD BASED INTERNAL MODEL CONTROL (SIMC)

Skogestad (2003) has suggested control technique in which tuning is expressed as a function of the process model parameter (Haugen, 2009). The transfer function of the process model is assumed to be a continuous (Haugen, 2010).

$C_{ref}(S)$ = Set point
$G_c(S)$ = Controller
$U(S)$ = Control variable
$V_d$ = Equivalent process disturbance
$G_{psf}(s)$ = Process with sensor and measurement filter
$C_{act}(S)$ = Filtered process measurement

Block diagram of control system in PID tuning with SIMC method is shown in the Fig. 3, in which transfer function $G_{psf}(s)$ is a combined transfer function of the process, sensor and the measurement low pass filter $G_{psf}(s)$ which represent all the dynamics of the controller (Haugen, 2010). It is a combined transfer function which also represents a process transfer function of the process. Process transfer function can determined from a simple step response experiment with the process. The disturbance on the process is shown in the block diagram. The information about this disturbance is not present in the tuning but if it is tested with the process disturbance, it is required to add a disturbance at the point indicated in the block diagram. In most process the dominating disturbance influence the process as the control variable. This disturbance is called Input disturbance. The control system tracking transfer function T(s) which is the transfer function from the set point or the reference to the (filtered) process measurement (Haugen, 2009), is specified with a time constant with time-delay transfer function (Haugen, 2010):

(C↓act(s))/(C↓ref (s)) = T(s) = 1/((↓CS+1) (2)

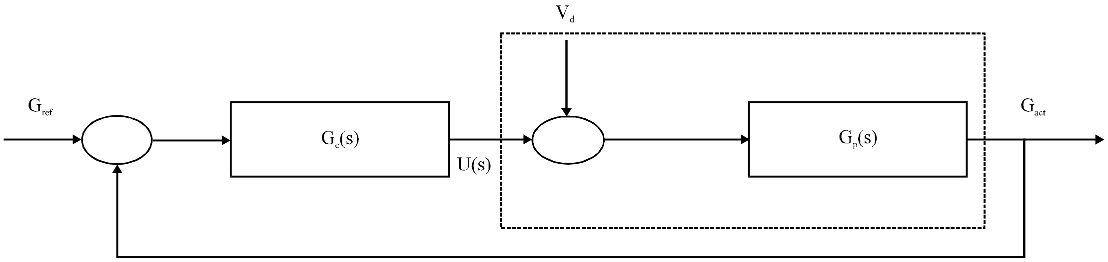

Fig. 3: Functional diagram of SIMC tuning method

Table 2: Controller tuning parameter for SIMC method

| Process type | $G_{psr}(S)$ | $k_p$ | $\tau_i$ | $\tau_d$ |
|---|---|---|---|---|
| Integrator+delay | $\frac{k}{s}e^{-\tau s}$ | $\frac{1}{k(\tau c+\tau)}$ | $c(\tau c+\tau)$ | 0 |
| Time constant+delay | $\frac{k}{\tau s+1}e^{-\tau s}$ | $\frac{T}{k(\tau s+\tau)}$ | $\min[T, c(\tau c+\tau)]$ | 0 |
| Integrator+time constant+delay | $\frac{k}{\tau s+1}e^{-\tau s}$ | $\frac{1}{k(\tau c+\tau)}$ | $c(\tau c+\tau)$ | T |
| Two time constant+delay | $\frac{k}{(\tau_1 s+1)(\tau_2 s+1)}e^{-\tau s}$ | $\frac{T_1}{k(\tau c+\tau)}$ | $\min[T_1, c(\tau c+\tau)]$ | $T_2$ |
| Double integrator+delay | $\frac{k}{s^2}e^{-\tau s}$ | $\frac{1}{4(\tau c+\tau)^2}$ | $4(\tau_c+\tau)$ | $4(\tau_c+\tau)$ |

$\tau_c$: Time constant of the process, define by the user
$\tau$: Delay time of the process, given by the process model

The tracking transfer function for the block diagram is as follows:

$$\frac{G_{ref}(S)G_{psf}(s)}{1+G_{ref}(S)G_{psf}(s)=T(S)} \tag{3}$$

$G_c(S)$ is an unknown parameter in the transfer function. By assume some simplifying approximation to the time delay term, the controller become PID controller or PI controller. Skogestad (2003) defines the parameter c which gives good set point tracking. But the disturbance compensation becomes sluggish (Haugen, 2010). The disturbance compensation is the most important task for the controller, to obtain faster response for the disturbance compensation parameter c is chosen as c = 1.5. This value causes larger overshoot in the set point step response and reduces the stability of the control loop. Table 2 shows the tuning rules used in SIMC method for different controllers.

**Fuzzy logic based controller (FUZZYPID):** Fuzzy logic plays a vital role in humidity control process (Dorrah *et al*., 2010). Fuzzy PID is a combination of conventional PID and Fuzzy based controller (Zulfatman and Rahmat, 2009). Fuzzy Logic Controller (FLC) is the collection of fuzzy rule base, fuzzification interface, fuzzy inference machine and defuzzification interface (Wang *et al*., 2012). Input variable of the process is given to the fuzzy interface, where the input variable is converted into linguistic variable which is in the form of if then else. Fuzzy rule is also known as knowledge base. Information about the linguistic control rule are presented in the data base with the help of linguistic control rule and the control policy is characterized by rule base. Fuzzy interface machine plays a vital role in FLC. Defuzzification is used to convert the fuzzy data into crisp data (Venkatesh and Sundaram, 2012b). Fuzzy logic is used for controlling nonlinear as well as conventional control (Wang *et al*., 2012).

Fuzzy logic have many distinct advantages compared to other methods in designing a controller: It is a user friendly and easy computation control, in which many output and input variables are handled simultaneously. Fuzzy logic expresses uncertainty information. Incomplete information about some plant can be done with some fuzzy tools. FLC can be incorporate with conventional controller and it gives fine tune to a nonlinearity plant. It is possible to combine FLC with conventional controllers using ‘zooming’ feature. PID controller combines with a fuzzy controller to improve the over or undershoot behavior. The extent to which fuzzy controller donate to the joint output of mutual parallel controllers is also determined by itself. Its computational model can be used in many paradigms. If the control action is not satisfied for a particular combination of system inputs, then the active rules controller will act immediately and corrections can be made, without disturbing the behavior of the controller.

Two Process control System using FLC was implemented by Shaharurrizal *et al.* (2002) in which conventional simulation is created and can able to model the particular control system by the application of fuzzy logic technology. The performance Fuzzy Logic Controller (FLC) is compared with Conventional Propotional Interal and Derivative Controller (PID) which result FLC outperformed well when compared with PID. Controlling the temperature of the process using Neuro Fuzzy Inference Network (NFIN) has been studied by Jha *et al.* (2011). NFIN is a modified form of fuzzy rule based system, in which the hybrid learning algorithm is used as a learning algorithm. Hybrid learning algorithm is a mixture of least square and gradient descent algorithm. In this study the performance of the temperature process with NFIN is combined with FLC and PID. NFIN gives better performance when compared with PID and FLC. Neuro and fuzzy technique for a robot manipulator is implemented by Arbaoui *et al.* (2006). In which the advantage over Neuro and Fuzzy Controller for identification and tracking the multivariable nonlinear robot manipulator system.

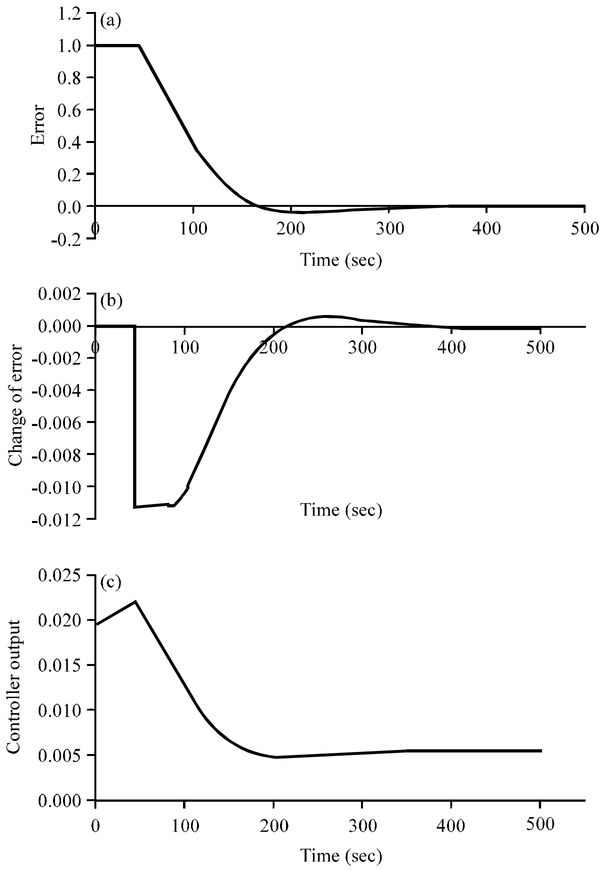

Fig. 4(a-c): Different input variables for fuzzy logic controller varying with time. (a) Variation of error with time, (b) Variation of change in error with time and (c) Variation of controller output with time

Table 3: Fuzzy rule set used for FUZZZYPID controller

| Rate of change of error | | | |
|---|---|---|---|
| Neg | Neg | Zero | Pos |
| Neg | Neg | Zero | Pos |
| Zero | Zero | Pos | Neg |
| Pos | Pos | Neg | Neg |

For the plan of Fuzzy based PID controller (FUZZYPID), error and rate of change of error are taken as the two input parameters. Figure 4a and b show the graphs for error and rate of change of error. The rule base is written taking four membership functions namely negative (Neg), Zero (Zero) and Positive (Pos). As a whole 16 rules were written that is shown in Table 3. The controller output obtained for this rule base is shown in Fig. 4c.

## RESULTS AND DISCUSSION

The model was recognized for the humidity process via SK method which resulted with minimum error between the plant and model. Since it is desirable for the industries like textile, tobacco, food processing and pharmaceutics, different control schemes were designed and tested for this process and compared for time domain specification. The normalized RH was taken for unit step response for the sake of simplicity. Figure 5 shows the comparison of different control schemes for the humidity process. It clearly indicates that FUZZYPID shows better performance like no overshoot and oscillations whereas the other controllers SKOGESTAD and ZNPID resulted with poor performance in terms of oscillations and overshoot.

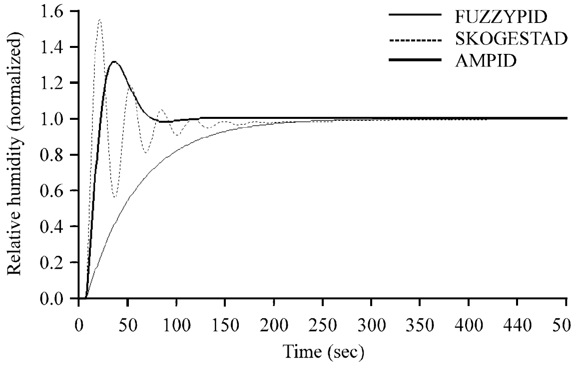

Fig. 5: Step response for different controllers

Table 4: Time domain specifications for different controllers

| Specifications | ZNPID | SIMC | FUZZYPID |
|---|---|---|---|
| Rise time (min) | 1.29 | 2.8094 | 0.68 |
| Overshoot (%) | 68.00 | 4.0800 | 1.50 |
| Settling time (min) | 11.55 | 5.8300 | 1.20 |

From Table 4 it is evident that though lesser settling time and rise time is reported in ZNPID, it resulted with huge overshoot which is not recommended. FUZZYPID is showing the best concert in terms of Settling time, Overshoot and Rise Time compared with the other two controllers ZNPID and SIMC. Hence it can be concluded that FUZZYPID controller is best suited for the humidity process.

## CONCLUSION

Experimental study on humidification and control of the same were done in laboratory scale. The model was identified and fitted to a first order process with time lag. Three different controllers like ZNPID, SIMC and FUZZYPID were tested for the process in MATLAB. It can be concluded that out of these controllers FUZZYPID showed better performance compared with the other two controllers in terms of Settling time, Overshoot and Rise Time As a future work, to implement all these controllers in the real time process.

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