Modernization of a cooling water control system for the production of plastic pipes using fuzzy logic

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Modernization of a Cooling Water Control System for the Production of Plastic Pipes Using Fuzzy Logic

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Abstract. Fuzzy logic is successfully used in the area of control systems where different problems are decided in flexible way leading to more efficient systems' performance. Such approach is suitable when the modeled system is complex and some parameters cannot be defined precisely. In this paper a fuzzy model of improved cooling water control system utilized in plastic pipes production is proposed. Its aim is more effective regulation of the freon compressor load to be achieved that influences on economy in energy consumption. The developed model is verified through simulation in FisPro environment where the knowledge base, fuzzy membership functions and inference engine are modeled.

INTRODUCTION

Fuzzy sets and fuzzy logic are theories applied in engineering applications and control systems as the main aim is their modeling and analysis when ambiguousness, uncertainty and ambiguity among the examined values exist [1]. Also, real world systems could easily be modeled when they are characterized with complexity and blurred boundaries. The purpose of such approach is to improve functions, to enhance processes or to facilitate events. Abdo-Allah et al. discuss design and analysis of fuzzy logic controller for heating, ventilation, and air conditioning system and they proved their research hypothesis concerning the improvement of the indoor temperatures control [2]. Isizoh et al. propose a fuzzy system for temperature control through regulation the heater and speed fan [3]. They conclude that fuzzy logic method is a further step in industrial automation and in control engineering of modern systems. Other authors Gao et al. present a fuzzy control system for temperature regulation and for industrial applications [4]. It deals with control problems when dynamics and time delay are with unknown values. The achieved results are positive – the designed system is with improved performance and stability. Oltean and Dulau present a fuzzy system for temperature control in a plasma ion nitriding process which is characterized with multi variability and nonlinearity and [5]. The authors after the performed simulations conclude that the developed fuzzy system possesses improved performance and characterizes with optimized cost.

It can be said that nowadays fuzzy logic techniques are successfully applied for better understanding, studying, and optimizing the systems that control of a wide variety of parameters.

In this work in the scope is a conventional cooling system that is reliable, but largely unprofitable in terms of energy consumption. This is due to the need for constant switching on and off of the freon compressor, and when it is switched on, it always operates at maximum power. This problem could be resolved through applying the theory of fuzzy logic that proposes flexible method for regulation the load of freon compressor and energy consumption taking into account the value of water temperature.

The aim of the paper is to present a model of improved control system for effective regulation of the load on the freon compressor and for flexible energy consumption. Theory of fuzzy logic is applied for construction the knowledge rule base and fuzzy inference system. The reliability of the fuzzy model is verified through simulation.

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COOLING WATER CONTROL SYSTEM

The process related to the production of plastic pipes requires a cooling water system which is responsible for water temperature control during pipes manufacturing. Figure 1 shows a schematic diagram of cooling water control system (taken from technical documentation of PipeLife Inc.) that consists of the following modules: (1) water tank which is divided to two parts - for warm and cold water, (2) water pump for circulation of water through a heat exchanger, (3) water pump for water circulation through a calibrator sleeve - the calibrator sleeve for the extruded material (polypropylene) is used to obtain a pipe by vacuum and water cooled to the desired temperature, (4) freon compressor and heat exchanger - the freon compressor, through an agent, cools the flowing water through the heat exchanger to the required temperature.

The cooling water control system operates in the following way. The water tank is divided into two parts: warm and cold water. One pump draws water from the warm part of the tank. The water is passed through a heat exchanger where a refrigerant is circulating through a freon compressor that lowers the water temperature. After the water has cooled, it returns to the cold part of the tank. The other water pump draws water from the cold part of the tank, which cools the calibrator sleeve, after which the water returns to the warm part of the tank. In the cold part of the tank, there is a sensor for monitoring the temperature of the water, which sensor is connected to a controller. The controller sets the temperature to be maintained in the cold part of the tank. The control system is conventional and works with hysteresis ± 3 °C. The water pump that draws water from the warm part of the tank has a slightly higher flow rate than the pump that draws water from the cold part. In this way, there is always an overflow from the cold part of the water tank into the warm. This is necessary because even if the both pumps are selected at the same flow rate, or if any abnormality occurs - if the hot water is transferred to the cold part, it will cause imbalance and premature switching on of the freon compressor. For example, let the controller is set to 15°C, then the freon compressor turns on at full power and the water begins to cool. When the water temperature in the cold part of the tank reaches 12°C, the compressor stops working. The water begins to warm and when it reaches 18°C, the compressor switches on again at full power. This cycle is repeated.

What is the problem is such cooling water control system? Conventional cooling systems are reliable, but largely unprofitable in terms of energy consumption. This is due to the need for constant switching on and off of the freon compressor, and when it is switched on, it always operates at maximum power. Also, to replace a conventional cooling system with a modern inverter system, it takes quite a lot of investment - depending on the cooling capacity, the price ranges from 25,000€ to 50,000€.

One solution of this problem, proposed in the current work, is related to usage of fuzzy logic-based temperature monitoring and control system that allows more accurately regulation the load on the freon compressor. A frequency inverter must be connected to the freon compressor electric motor circuit to regulate its operation.

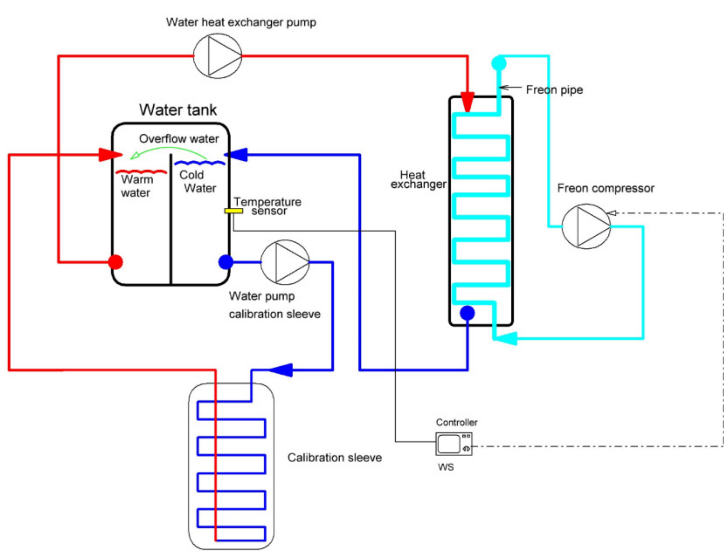


FIGURE 1. Schematic diagram of cooling water control system

IMPROVED COOLING WATER CONTROL SYSTEM THROUGH FUZZY LOGIC

The proposed solution for temperature monitoring and control system improvement is based on applying the principles of fuzzy logic that leads to more flexible regulation of the load on the freon compressor and thus an effective energy consumption could be achieved. The fuzzy-based control system modeling follows the developed research method that is presented on figure 2.

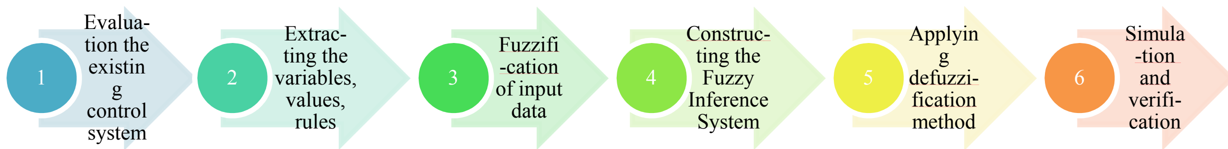


FIGURE 2. The used research method

During the first step the existing control system is studied and evaluated through two criteria: compressor load, % and energy power, %. It can be seen from Table 1 that the compressor load and energy consumption is on the 100% for temperature with middle value of 15°C and for temperature with high value 18°C. And the result is ineffective regulation of the compressor load and ineffective power consumption.

TABLE 1. Criteria for evaluation the conventional control system

Water temperature in the tank, °C	12°C	15°C	18°C
Compressor load in %	0%	100%	100%
Energy power in %	0%	100%	100%

The second step is related to extraction the variables, their values and rules that connect them, taking into account the operational functionality and the purpose of the cooling water control system.

The first important input variable is the water temperature in the tank (**WT**) that changes from 12°C to 18°C in the conventional control system taking just three values: 12°C, 15°C and 18°C. Our proposition is this variable **WT** to be controlled more precisely and this could be achieved if the **WT** takes values: 12°C, 13°C, 14°C, 15°C, 16°C, 17°C and 18°C.

The second input variable is the temperature change (**TC**) that is proposed to be: big negative change (**BN**) with -2°C, negative change (**N**) with -1°C, no change (**NC**) with 0°C change, change in positive direction (**P**) with +1°C and big positive change (**BP**) with +2°C.

The output variable is freon compressor load (**FCL**) that in the conventional control system takes two values: 0% and 100% that leads to ineffectively functioning. We propose flexible change of the compressor load according to the water temperature: 0%, 10%, 50%, 90% and 100%.

Then, the rules that manage the flexible and effective control system are in the form:

IF Water temperature in the tank is **WT AND** Temperature change is **TC THEN** Freon Compressor load is **FCL**.

The proposed linguistic variables and their values are summarized in Table 2.

TABLE 2. The proposed linguistic variables and their values

Level of compliance	Extremely low	Very low temperature	Low temperature	Normal	High temperature	Very high temperature	Extremely high
Input variable 1 Water temperature in the tank (°C)	12°C	13°C	14°C	15°C	16°C	17°C	18°C
Input variable 2 Temperature change, (°C)	BN N NC P BP	BN N NC P BP	BN N NC P BP	BN N NC P BP	BN N NC P BP	BN N NC P BP	BN N NC P BP

TABLE 2 (Continued). The proposed linguistic variables and their values

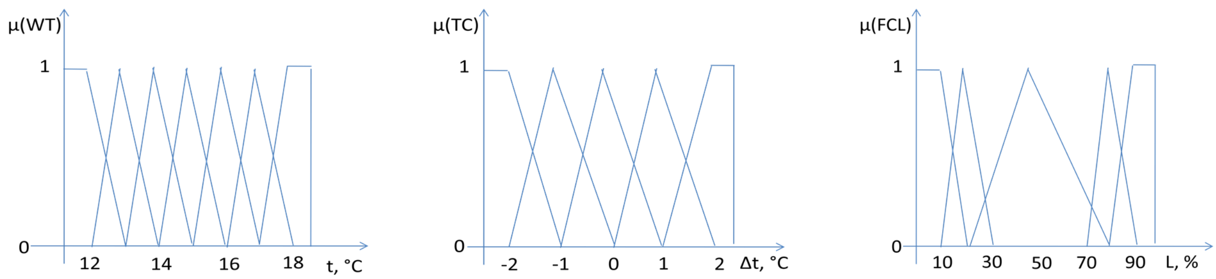
Level of compliance	Extremely low	Very low temperature	Low temperature	Normal	High temperature	Very high temperature	Extremely high
Output variable Freon compressor load (%)	0%	10%	50%	50%	50%	90%	100%

During the third step the linguistic variables are fuzzified through applying regular grids in the range, typical for each variable (figure 3). The fuzzy membership functions are chosen to be trapezoidal at the grid end:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, x < a, x > b \\ \dfrac{x-a}{b-a}, a \le x < b \\ \dfrac{c-x}{c-b}, b \le x \le c \end{cases} \quad (1)$$

and triangular in the middle:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, x < a, x > d \\ \dfrac{x-a}{b-a}, a \le x < b \\ 1, b \le x < c \\ \dfrac{d-x}{d-c}, c \le x \le d \end{cases} \quad (2).$$



a) *b)* *c)*

FIGURE 3. Fuzzy membership functions of input and output variables

The fourth step includes construction of the fuzzy inference system (FIS). For this purpose a fuzzy associative memory is created (Table 3). It presents associations and patterns among the linguistic variables.

TABLE 3. Fuzzy associative memory

Temperature t, °C/ Temperature change Δt, °C	BN	N	NC	P	BP
Extremely low - EL	0%	0%	0%	10%	50%
Very low temperature - VL	0%	0%	10%	50%	50%
Low temperature - L	0%	10%	50%	50%	50%
Normal temperature - N	10%	50%	50%	50%	90%
High temperature - H	50%	50%	50%	90%	100%
Very High temperature -VH	50%	50%	90%	100%	100%
Extremely high - EH	50%	90%	100%	100%	100%

The Mamdani fuzzy inference system for two rules is presented on figure 4. If the first rule is WT is very low and TC is BP then FCL is 50% and the second rule is if WT is EL and TC is P then FCL is 10% then a fuzzy inference is obtained according to the Mamdani implication.

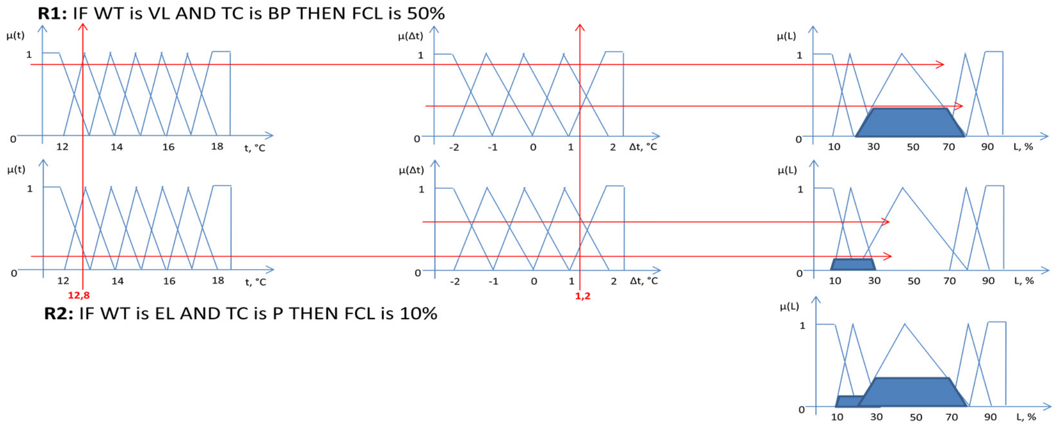
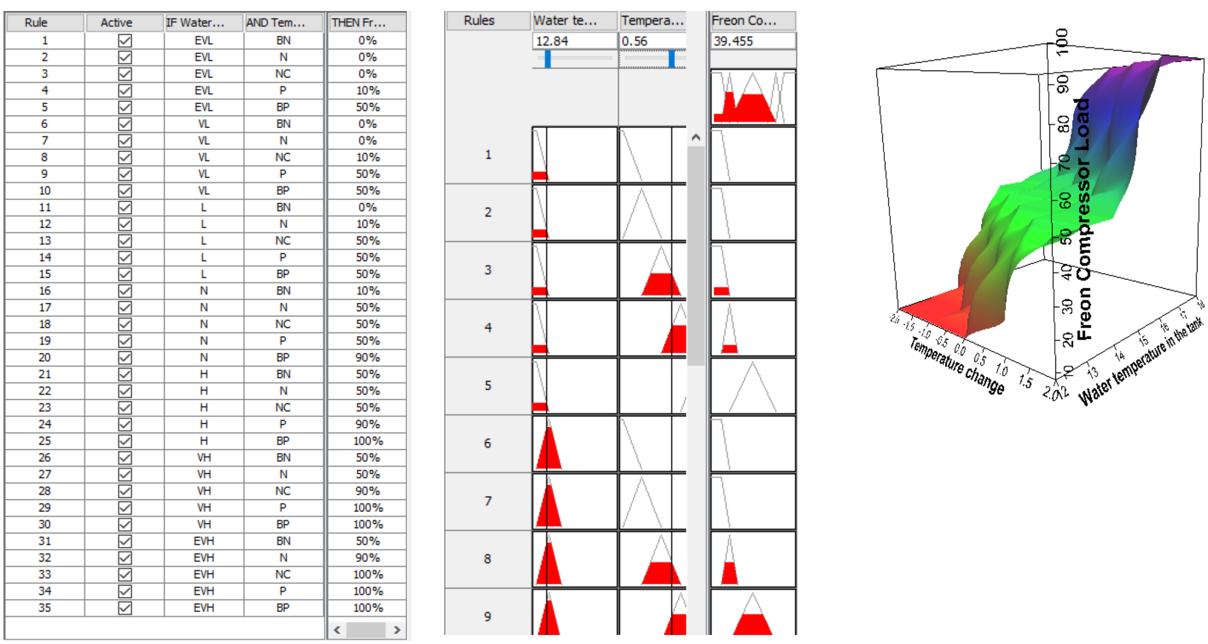


FIGURE 4. Mamdani fuzzy inference

The next step is related to the process defuzzification and receiving a crisp value for the output variable. Several methods for defuzzifications exist and in this work the method: center of gravity is chosen:

$$z = \frac{\sum_{i=1}^{n} c_i \min\{\mu(t_i), \mu(\Delta t_i)\}}{\sum_{i=1}^{n} \min\{\mu(t_i), \mu(\Delta t_i)\}} \tag{3}$$

Finally, the simulation and verification of the proposed fuzzy model is performed in the environment of the software FisPro (figure 5).



Rule	Active	IF Water...	AND Tem...	THEN Fr...
1	☑	EVL	BN	0%
2	☑	EVL	N	0%
3	☑	EVL	NC	0%
4	☑	EVL	P	10%
5	☑	EVL	BP	50%
6	☑	VL	BN	0%
7	☑	VL	N	0%
8	☑	VL	NC	10%
9	☑	VL	P	50%
10	☑	VL	BP	50%
11	☑	L	BN	0%
12	☑	L	N	10%
13	☑	L	NC	50%
14	☑	L	P	50%
15	☑	L	BP	50%
16	☑	N	BN	10%
17	☑	N	N	50%
18	☑	N	NC	50%
19	☑	N	P	50%
20	☑	N	BP	90%
21	☑	H	BN	50%
22	☑	H	N	50%
23	☑	H	NC	50%
24	☑	H	P	90%
25	☑	H	BP	100%
26	☑	VH	BN	50%
27	☑	VH	N	50%
28	☑	VH	NC	90%
29	☑	VH	P	100%
30	☑	VH	BP	100%
31	☑	EVH	BN	50%
32	☑	EVH	N	90%
33	☑	EVH	NC	100%
34	☑	EVH	P	100%
35	☑	EVH	BP	100%

FIGURE 5. The fuzzy model simulation: a) knowledge base; b) inference visualization; c) control surface

CONCLUSIONS

In this paper a model of a cooling water control system for the production of plastic pipes is presented. It is developed through usage of the theories of fuzzy sets and fuzzy logic. The provided simulations point out that:

- the effective regulation of the freon compressor load could be achieved and

- the flexible energy consumption from the compressor could be obtained.

The proposed approach allows smoothly switching the freon compressor when the water temperature is changed and precisely loading of the freon compressor according to the temperature value. This leads to the minimization the power consumption and energy economy realization as well as the flexible loading of the compressor.

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