MODELING OF THE EFFECTS OF THREEFOLD TYPE RHVT AND SIX CASCADE TYPE RHVT ON THE PERFORMANCE OF COUNTER FLOW RHVTS BY FUZZY LOGIC APPROACH

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Abstract—*In this study, performances of Ranque-Hilsch Vortex Tubes (RHVTs) were modeled under three different situations based on inlet pressure and the ratio of mass flow rate of the cold stream to the mass flow rate of the inlet stream (ξ) by fuzzy logic approach. 1st situation is the conventional RHVT. 2nd situation is the threefold cascade type RHVT. Here three RHVTs were used. 3rd situation deals with the six cascade type RHVT. In this case, six RHVTs were used. Input-output parameters were described by Rule Based Mamdani Type Fuzzy (RBMTF) with if-then rules. The performance parameters are the difference between the hot and cold stream temperatures (ΔT), the cold flow fraction (ξ), inlet pressure conditions. The comparison between experimental data and RBMTF is done by using statistical methods like absolute fraction of variance (R^2). The actual values and RBMTF results indicated that RBMTF can be successfully used for the analysis of performance RHVTs.*

KEYWORDS— **RANQUE-HILSCH, VORTEX TUBE, FUZZY LOGIC MODELLING**

1. Introduction

Vortex tube is a simple device, which can separate an incoming compressed gas stream of uniform temperature into two streams one warmer than the inlet stream and the other Colder than the inlet stream. Such separation of the gaseous ßuid stream into two different streams of higher and lower temperatures is referred to as temperature (energy) separation effect. Ranque invented the vortex tube and Þrst reported about energy separation. Later Hilsch published systematic experimental results of this effect. Since then, this phenomenon has attracted many scientists. Various theories have been proposed to explain this phenomenon from experimental, analytical and numerical studies. Hilsch suggested that the expansion of air from high pressure near the wall to low pressure near the axis generates a velocity gradient in radial direction, which results in transfer of kinetic energy by the viscous force from the inner ßuid layers to the outer ßuid layers [1].

Working principle of the counterflow RHVT can be defined as follows. Compressible fluid, which is tangentially introduced into the vortex tube from nozzles, starts to make a circular movement inside the vortex tube at high speeds, because of the cylindrical structure of the tube, depending on its inlet pressure and speed. Pressure difference occurs between tube wall and tube center because of the friction of the fluid circling at high speeds. Speed of the fluid near the tube wall is lower than the speed at the tube center, because of the effects of wall friction. As a result, fluid in the center region transfers energy to the fluid at the tube wall, depending on the geometric structure of the vortex tube. The cooled fluid leaves the vortex tube from the cold output side, by moving towards an opposite direction, compared to the main flow direction, after a stagnation point. Heated fluid leaves the tube in the main flow direction from the other endRHVTs are used, among others, for cooling, heating, drying and snow production [2]. In the existing literature, there have been many investigations [3-5] about RHVT performance.One of the methods to determine the effects of the parameters on RHVT performance is fuzzy logic method.

In this study, Ranque-Hilsch vortex tube (RHVT) was investigated experimentally for the best performance of 3 differentsituations. 1st situation is the conventional RHVT. 2nd situation is the threefold cascade type RHVT. Here three RHVTs were used. 3rd situation deals with the six cascade type RHVT. In this case, six RHVTs were used. When the entire test results under Pi = 360 kPa and Pi = 400 kPa pressure conditions are compared, it is found that the best performance occurs at the 3rd situation. Also in this study, Rule-based Mamdani-type fuzzy modeling used to evaluate performance of RHVT. Performance parameters are difference between the hot and cold stream temperatures (ΔT), the cold flow fraction (ξ), inlet pressure conditions (P_i). Study includes fuzzification of input variables, representation of fuzzy set with 9 linguistic variables, formation of rule basis and a comparison between output values obtained by experiments and by calculation based on generated rules and RBMTF technique.

2. Materials and Methods

The fuzzy subsets theory was introduced by Zadeh in 1965 as an extension of the set theory by the replacement of the characteristic function of a set by a membership function, whose values range from 0 to 1. RBMTF is basically a multi-valued logic that allows intermediate values to be defined between conventional evaluations like yes/no, true/false, black/white, large/small, etc [6].

Fuzzification is the initial process of a fuzzy model where fuzzy subsets of universal set of fuzzy variable are constructed. If there is no data, intuition and experience can be used in fuzzification process. By simply looking at the distribution of data of each variable the obvious clusters can be seen and fuzzified. If there is available data initially the dataset is portioned into two sets; calibration (training) and verification (testing). Calibration set is used for fuzzification and constructing the fuzzy rules. Verification set is used for testing the accuracy of the model set [7].

The general structure of the fuzzy logic modeling consists of four components: fuzzification, fuzzy rule base, fuzzy output engine, and defuzzification. Fuzzification converts each piece of input data to degrees of membership by lookup in one or more several membership functions The central fuzzy rule base is the concept of the fuzzy If-Then rule, which is a mathematical interpretation of the linguistic If-Then rule. Membership functions are used to retranslate the fuzzy output into a crisp value. This technique is known as defuzzification and can be performed using several methods. There are many defuzzification methods such as centre of gravity or centroid, bisector area, mean of maxima, leftmost maximum, rightmost maximum, etc [8]. In this study, we applied the most widely used centre of gravity technique.

The aim of this study is tomodel RHVT performance for 3 different situations by using fuzzy logic. 1st situation is the conventional RHVT: the RHVT in the literature, in this situation classical RHVT is taken into account. One RHVT was used in the classic RHVT. Inlet pressure selected was 360 kPa and 400 kPa. 2nd situation is the threefold cascade type RHVT. Here three RHVT were used. The inlet pressure values of the first RHVT were 360 kPa and 400 kPa.3rd situation deals with the six cascade type of RHVT. In this case, six RHVTs were used. All of the RHVTs, the inlet pressures (P_i) were 360 kPa and 400 kPa [9]. With the aid of experimental data, RHVT performances at different situations in terms of difference between the hot and cold stream temperatures (ΔT), the cold flow fraction (ξ) were modeled with Rule-Based Mamdani-Type Fuzzy (RBMTF) modeling technique. RBMTF was designed using MATLAB fuzzy logic toolbox. In the developed RBMTF system, output parameter difference between the hot and cold stream temperatures (ΔT)was determined using inlet parameters the cold flow fraction (ξ) and inlet pressure conditions. Hereafter the rules, which are used to detect the behavior of the fuzzy logic controller and the relationship between system's input and output, are determined. As a result of these rules, every value obtained from the experimental study is also determined by fuzzy logic too.

3. Results and Discussion

Vortex tubes are classified into two groups according to their flow characteristics: counter flow RHVT and parallel flow RHVT. The efficiency of parallel flow RHVT is low. For this reason, in this study the counter flow RHVT was used. The cold flow fraction (ξ) is an important parameter in the counter flow RHVT. The cold flow fraction is defined as the ratio of the mass flow rate of the cold stream to the mass flow rate of the inlet stream [9]. The aim of this study with the aid of experimental data, RHVT performances in terms of difference between the hot and cold stream temperatures (ΔT), the cold flow fraction (ξ) were modeled with fuzzy logic modeling technique. In the developed RBMTF system, output parameters ΔT was determined using inlet parameters ξ and P_i.

Figs. 1-2 show comparison of experimental data with RBMTF for the variation of cold flow fraction with inlet pressure of difference between the hot and cold stream temperatures (P_i = 360-400 kPa; ξ = 0.1-0.9). From a comparison of the experimental results with the results of the fuzzy logic study, one can see that the results are quite compatible (Figs. 1-2).

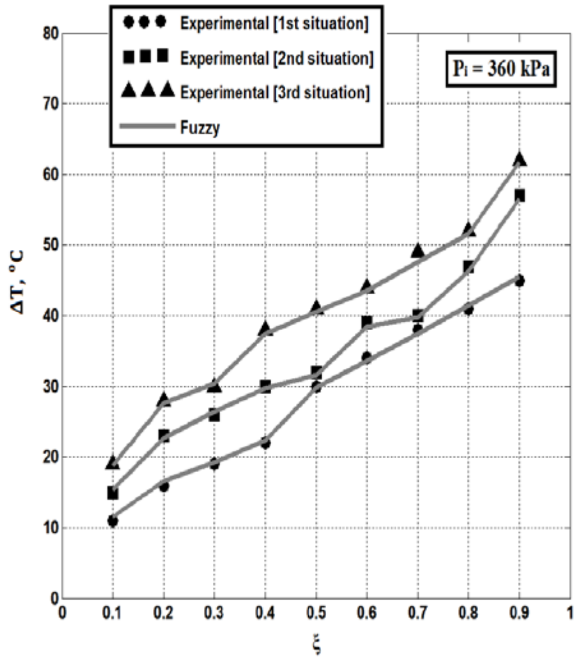

Fig. 1 *Comparison of experimental data with RBMTF in terms of performances of classic RHVT (1st situation), threefold cascade type RHVT (2nd situation) and six cascade type RHVT (3rd situation) under 360 kPa inlet pressure operating conditions.*

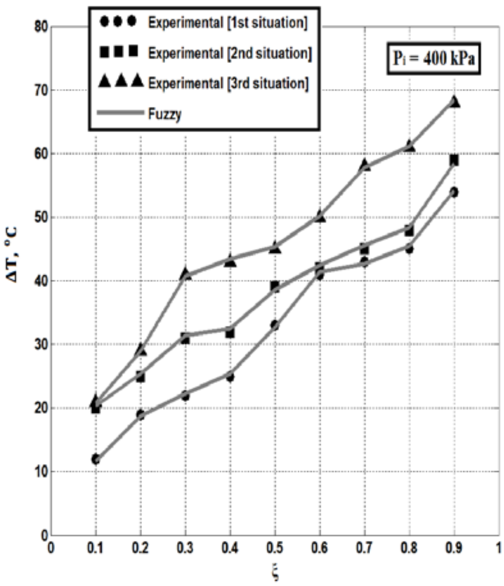

Fig. 2 *Comparison of experimental data with RBMTF in terms of performances of classic RHVT (1st situation), threefold cascade type RHVT (2nd situation) and six cascade type RHVT (3rd situation) under 400 kPa inlet pressure operating conditions.*

These figures present that;

- The performances of the classic RHVT, the performances of threefold type RHVT and the performances of six cascade type RHVT increase with the ratio ξ.
- When the entire test results under P_i = 360 kPa and P_i = 400 kPa pressure conditions are compared, it is found that the best performance occurs at the 3rd situation. Moreover, the performance of the 3rd situation at P_i = 400 kPa pressure is higher than that at P_i = 360 kPa (Figs 1-2).

In this study, fuzzy logic is also used for prediction. The 48 cold flow fraction values between 0.15-0.85 which are not obtained from experimental work for difference between the hot and cold stream temperatures are predicted by fuzzy logic method. Figs. 3-4 show the comparison of experimental data with fuzzy prediction for the variation of cold flow fraction with inlet pressure conditions of difference between the hot and cold stream temperatures.

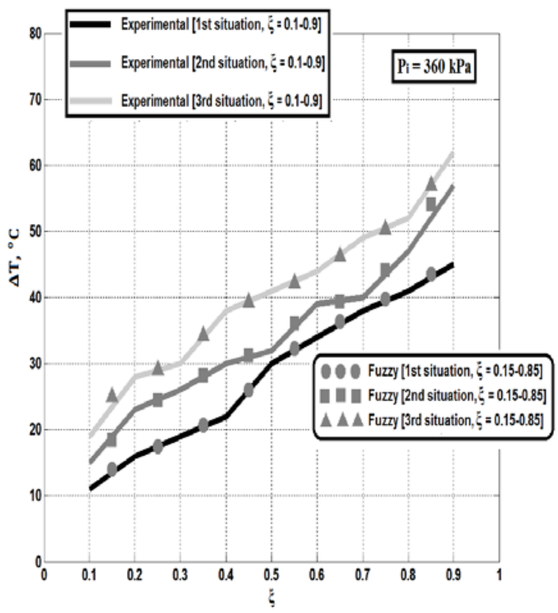

Fig. 3*Comparison of experimental data with fuzzy predict for different cold flow fraction (ξ) values under 360 kPa inlet pressure operating conditions.*

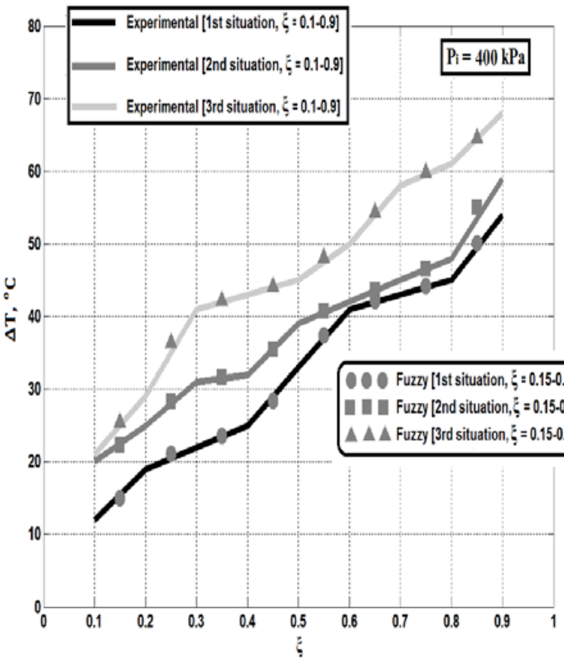

Fig. 4*Comparison of experimental data with fuzzy predict for different cold flow fraction (ξ) values under 400 kPa inlet pressure operating conditions.*

These figures present that;

- The difference between the hot and cold stream temperature value predicted by RBMTF for 2nd situation and the cold flow fraction = 0.75 is higher than the temperature value from the results of the experimental work for 2nd situation and the cold flow fraction = 0.7, but less than the temperature value from the results of the experimental work for the 2nd situation and the cold flow fraction = 0.8

- The difference between the hot and cold stream temperature value predicted by RBMTF for 3rd situation and the cold flow fraction = 0.25 is higher than the temperature value from the results of the experimental work for 3rd situation and the cold flow fraction = 0.2, but less than the temperature value from the results of the experimental work for the 3rdsituation and the cold flow fraction = 0.3 (Figs. 3-4).

The comparison between experimental data and fuzzy logic is done using statistical methods such as the coefficient of multiple determination (R^2) are defined as follows, where n is the number of data patterns, $y_{p,m}$ indicates the predicted, $t_{m,m}$ is the actual value of one data point m, and $\bar{t}_{m,m}$is the mean value of all actual data points [6]. When Table 1 is observed, it is found that actual values and the values from fuzzy technique are very close to each other.

$$R^2 = 1 - \frac{\sum_{m=1}^{n}(t_{m,m} - y_{p,m})^2}{\sum_{m=1}^{n}(t_{m,m} - \bar{t}_{m,m})^2} \quad (1)$$

Table 1. *Comparison of the actual and RBMTF results for difference between the hot and cold stream temperatures (ΔT)*

INLET PRESSURE	ΔT, °C
	R^2
360 kPa	98.05%
400 kPa	97.89%

4. Conclusions

In this study, RHVT performances at different situations in terms of difference between the hot and cold stream temperatures (ΔT) were experimentally investigated. With this study, it has been found that when the performance of the cascade type RHVT is compared with that of the classic RHVT, the performance of the cascade type RHVT becomes higher than that of its classic counterpart. The best performance obtained at six cascade type RHVT (3rd situation). With the aid of experimental data, RHVT performances at different situations in terms of difference between the hot and cold stream temperatures (ΔT), the cold flow fraction (ξ) were modeled fuzzy logic technique. In the developed RBMTF system, output parameters ΔT was determined using inlet parameters ξ and P_i. Every value obtained from the experimental study is also determined by fuzzy logic too. The comparison between fuzzy logic and experimental data is done using statistical methods. R^2 is calculated under 360 kPa-400 kPa inlet pressure operating conditions 98.05% and 97.89% respectively. The actual values and RBMTF results indicated that RBMTF can be successfully used for the specification RHVT performances at different situations.

5. References

[1] Yılmaz, Y., Berber, A., Dincer, K., Özen, D.N., Baskaya, Ş. “”Rule-Based Mamdani Type Fuzzy Modeling of Exergy Analysis Performances of Counter Flow Ranque-Hilsch Vortex Tubes With Different Geometric Constructions For Aluminum”, Academic Journal of Science, 1(3), 75-88, 2012.

[2] Dincer, K., Tasdemir, S., Baskaya, S., Uysal, B.Z. “Modeling of the effects of length to diameter ratio and nozzle number on the performance of counterflow Ranque–Hilsch vortex tubes using artificial neural networks”, Applied Thermal Engineering, 28, 2380-2390, 2008.

[3] Niknam, P.H., Mortaheb, H.R., Mokhtarani, B. “Numerical Investigation of a Ranque–Hilsch Vortex Tube Using a Three-Equation Turbulence Model”, Chemical Engineering Communications, DOI: 10.1080/00986445.2016.1155989, 2016.

[4] Dincer, K., Baskaya, S., Uysal, B.Z., Ucgul, I., “Experimental investigation of the performance of a Ranque–Hilsch vortex tube with regard to a plug located at the hot outlet”, International Journal of Refrigeration, 32, 87-94, 2009.

[5] Behera, U., Paul, P.J., Dinesh, K., Jacob, S. “Numerical investigations on flow behaviour and energy separation in Ranque–Hilsch vortex tube”, International Journal of Heat and Mass Transfer, 51, 6077-6089, 2008.

[6] Onal, G., Dincer, K., Yayla, S., Yılmaz, Y., Ersoyoğlu, A.S. “Pt/C Coating for Proton Exchange Membrane Fuel Cell (PEMFC) and Rule-Based Mamdani-Type Fuzzy Modeling of PEMFC Performance,” International Journal of Mining, Metallurgy & Mechanical Engineering, 3(3), 122-128, 2015.

[7] Selvi, Ö. “Traffic Accident Prediction Based On Fuzzy Logic Approach For Safer Urban Environment, Case Study: İzmir Metropolitan Area”, PhD Thesis, İzmir Instıtute of Technology, İzmir, 2009.

[8] Bozokalfa, G. “Artificial Neural Networks and Fuzzy Logic Models For Cooling Load Prediction”, MSc Thesis, İzmir Instıtute of Technology, İzmir, 2005.

[9] Dincer, K., “Experimental investigation of the effects of threefold type Ranque-Hilsch vortex tube and six cascade type Ranque-Hilsch vortex tube on the performance of counter flow Ranque-Hilsch vortex tubes”, International Journal of Refrigeration, 34, 1366-1371, 2011.