# SUPPORT VECTOR MACHINE FOR MODELLING AND SIMULATION OF HEAT EXCHANGERS

by

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*Manufacturing simulation is an encouraging field in every manufacturing industry. The manufacturing simulation facilitate to virtually analysis the performance of the product before manufacturing. So for most of the manufacturing activities are simulated effective and researchers have developed adequate tool for the simulation of various activities of manufacturing. Heat exchanger is one of the important devices used for the purposes including medical, food processing, air conditioning system, etc. Performance of these heat exchangers also important for achieving better performance in those fields. So simulation of heat exchanger gives more beneficial to the engineers to analysis its performance before manufacturing. Hence in this paper, a machine learning approach for the modelling and simulation of heat exchanger is proposed. The proposed technique uses support vector machine technique for the prediction of performance of the heat exchanger. The performance of the proposed technique is validated in terms of prediction accuracy. Ultimately the analysis proves that the proposed technique is more beneficial for the modelling of heat exchanger.*

Key words: *simulation in manufacturing, machine learning technique, heat exchanger, heat transfer rate prediction, support vector machine*

## Introduction

Heat exchangers are used in various filed to convert heat from one substance to another. The heat exchangers are normally contains tubes which allow fluid from one medium to another to transfer the heat [1]. These devices can either used to heat or cool down a substance. These exchangers contains containment vessels, which are used to cool or heat a liquid by transferring heat from one liquid to another. The heat exchangers are widely used in the fields such as oil and gas, food and beverage, paper and plumb, pharmaceuticals, refrigeration, power generation, and chemical [2]. The heat exchangers are in four main types, such as shell and

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tube, plate, double pipe and condensers, evaporators, and boilers. The first shell and tube type of heat exchangers are used in many applications. This type of heat exchangers are constructed with is a vessel or cylindrical pressure vessel using single or series of parallel tubes. These exchangers uses minimum of two fluids, in which one fluid is allowed to flow inside the tube and another fluid is flow outside the tube within the vessel [3].

Double pipe heat exchangers is also a variant of shell and tube type exchanger, in which the exchanger contains the cylindrical tube or pipe. The transfer of heat take place from the fuel in tube one to fuel in tube two. The plate type heat exchangers are constructed by bundling the corrugated plates together. In the bundle of plates each pair of plates form a channel to allow a fluid for the transfer of heat [4]. The last type of heat exchanger is condensers, evaporators, and boilers, this type of exchanger are used in the home appliances and automobile vehicular system. These type of heat exchangers mostly employ two phase heat transfer mechanism [5]. In the two phase heat transfer mechanism, the heat transfer occurred by converting a liquid to gas or gas to liquid. The condensers are used in air cooling system in which a hot gas or vapor is cooled to condensed to liquid state. Some other heat exchangers types are used in industries for the wide application especially air cooled and fan cooled heat exchangers are famous [6]. Heat exchangers having wide application, but design of these devices are complicated and expensive. Due to the usage of costly material and liquid [7]. Now a days every engineering process is analyzed to verify the performance before manufacturing it. Manufacturing simulation is a separate field emerged in industries to computationally analysis the behavior of mechanical component before manufacturing. Most of the manufacturing processes are simulated effectively and obtained very close result in real time simulation [8].

Simulation of heat exchanger become a complex task, so it is essential to develop a suitable simulator for the simulation of heat exchanger. In some research the authors have effectively used the neural network for the forecasting the internal computation engine performance [9]. But the prediction or forecasting of heat exchanger performance using machine learning technique is a challenging task. Hence in this paper, we are planned to propose a novel machine learning technique for the prediction of heat transfer rate of shell and tube heat exchanger. Wang *et al.* [10] have initiated this idea and presented a technique using ANN for the prediction of heat transfer rate. But the performance of ANN is not fulfilled due to the usage of normal back propagation algorithm for the learning purpose [11, 12]. Thus in this paper we are using a support vector machine (SVM) for the effective prediction of performance of heat exchanger by reducing the error. The proposed technique is tested using the experimental data used in [10].

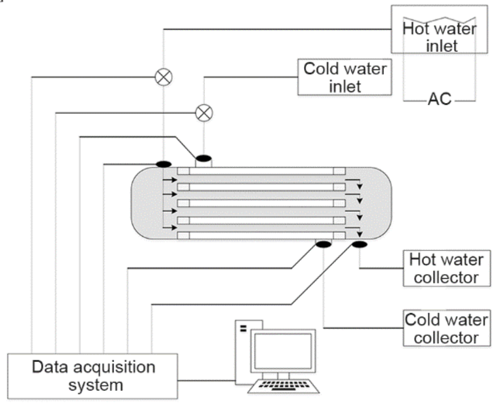


**Figure 1. Schematic of heat exchanger for data collection**

## Experimentation and data collection

In this work we used the data presented in [10]. In the referred paper, the authors described an experimentation, which is briefly described in this section. In the experimentation two heat exchangers which were named HX1 and HX2. The schematic of the heat exchanger for the data collection is shown in fig. 1 [9].

The geometric parameters considered in this work are total tube number, $N_t$, baffle pitch, $S_b$, total baffle number, $N_b$, and center diameter,

$D_c$. The mentioned experiments were executed as per the Reynolds number in the shell side from 300 to 7000. Then in the tube side the Reynolds number was considered in the range of 3000 to 4000. Then the heat transfer rate was varied from 20 kW to 50 kW. Totally 39 sets of experimental data were collected for the training of proposed machine learning technique. The geometric parameter and the Reynolds number of the training data are given in the tab. 1 [13].

The collected data in tabs. 1 and 2 are used for the modelling of machine learning algorithm, which is explained in the subsequent sections. Table 2 gives the test data for the heat transfer rate prediction.

**Table 1. Training data**

| Type | $N_b$ | $S_b$ | $N_t$ | $D_c$ | $Re_o$ |
|---|---|---|---|---|---|
| HX1 | 9 | 48 | 158 | 48 | 1148, 1413, 3121, 4365, 4979, 5669, 5843, 6702, 6996 |
| HX2 | 7 | 70 | 176 | 0 | 296, 525, 697, 821, 1102, 1253, 1399, 1486, 1693, 1825 |
| HX3 | 9 | 48 | 158 | 48 | 571, 745, 981, 1950, 2591, 2565, 3045, 3507, 4949, 5536, 7018 |

**Table 2. Test data**

| $Re_o$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 378[a] | 912[a] | 1371[c] | 1978[b] | 2610[b] | 3480[b] | 4251[c] | 5761[c] | 6625[c] |

a – Test data for mathematical modeling, b – test data for ANN, c – test data for SVM model

## Modelling of SVM for heat exchanger

The SVM is one of the well performing machine learning algorithm used for the classification purpose [3]. It is one of the learn model technique for the regression or classification of unknown data. In this technique the data are plotted on *n* dimensional space, the data acts as the point in plotting. While plotting the data based on its class gathered as group in the graph. The SVM technique includes two phases, such as training phase and testing phase.

The training phase perform training process by creating a model based on the training data set or known data obtained from the experimentation. The testing phase perform classification of unknown data based on the training model. Then the testing phase find the appropriate class based on the coordinate range. The flowchart for the SVM technique is given in fig 2.

The proposed SVM model has four input and one output, the inputs are $N_b$, $S_b$, $N_t$ and $D_c$ and the output as heat transfer rate $Re_o$.

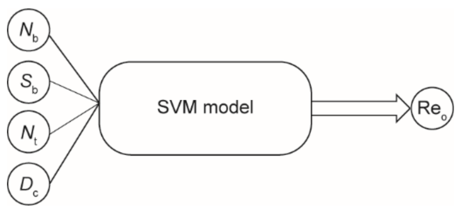


**Figure 2. SVM technique for the prediction of heat exchanger performance**

## Performance analysis

Performance of the proposed SVM based heat exchanger modelling is tested using the shell and tube exchanger data collected from [10]. Then the analysis is executed in MATLAB and its performance is compared with the conventional ANN with back-propagation training. The performance is compared based on the confusion matrix and precision, recall and accuracy. Figure 3 given below shows the performance comparison chart.

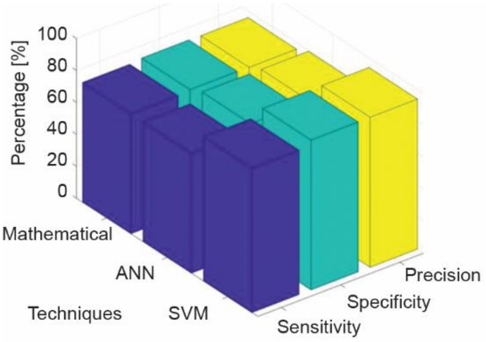


**Figure 3. Comparison of sensitivity, specificity, and precision**

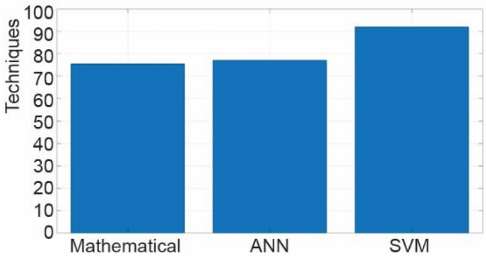


**Figure 4. Accuracy of prediction**

Figure 3 gives the classifier comparison in terms of sensitivity, specificity and precision. The comparison chart clear shows that the performance of the SVM is better in terms all the metrics. Thus the SVM has an advantage for the modelling of heat exchanger. Figure 4 gives the accuracy of prediction. The chart show the accuracy of SVM is more than 90% but all other techniques provided less accuracy. Thus from the comparison, it proves that the SVM is more suitable for the prediction of heat transfer rate and for the modelling of heat exchanger.

## Conclusion

The heat exchanger is modelled analyzed using machine learning technique. Hence the SVM technique is proposed for the prediction of heat transfer rate of shell and tube type heat exchanger. The proposed technique is analyzed using an experimental data obtained from literature. Then the performance of the proposed technique is analyzed in terms of sensitivity, specificity, precision and prediction accuracy. The performance of the proposed technique is compared with the ANN and other mathematical technique. The overall performance analysis shows the SVM outperforms all other technique.

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