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Meta-Heuristic and RSM Approach for Multi-Objective Optimization of Plain Flow Refrigerant Vapor Condensation Inside Tubes

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Abstract

Condensers are extensively used heat exchangers in automobiles and air conditioning systems. Optimization of heat transfer and pressure drop inside condensers is an important area of concern for the designers. In the present study, condensation characteristics inside smooth horizontal tubes is optimized using teaching-learning based optimization (TLBO) algorithm and response surface methodology (RSM). Refrigerant mass flux (G), vapor quality (x) and tube internal diameter (D_i) are taken as design parameters. Heat transfer coefficient (h) and pressure drop (ΔP) values of refrigerants calculated based on Shah and Friedel models respectively are served as objective functions for RSM. The same Shah and Friedel models are applied to formulate a multi-objective optimization problem with an aim to maximize heat transfer coefficient and minimize pressure drop and is solved using TLBO. Two different refrigerants have been considered to display the application of the approaches. TLBO algorithm seems to give better optimum results as compare to RSM method.

Keywords: *Condensation; heat transfer; pressure drop; TLBO; RSM.*

1. Introduction

Condensers are heat exchanging devices generally used in refrigeration and air conditioning, power plants and other thermal processing systems. The condensers transfer heat among process fluids at different temperatures.

Now a day the world is facing two major environmental problems named Ozone Layer Depletion and Global Warming. These problems are caused by the emission from the CFC refrigerants. During condensation, the refrigerant vapor coming from the compressor are cooled and condensed in condenser. In order to reduce discharge pressure and compressor power, the condenser is required to dissipate the heat at required rate. Increased size of condenser can enhance its effectiveness but it requires more maintenance and more refrigerant to be charged. Therefore, it is important to design a condenser that requires smaller amount of power and refrigerant volume.

Refrigerant vapor condensation inside plain tubes has been experimentally investigated by many researchers. Hossain et al. [1] investigated the effect of mass flux and saturation temperature on condensation heat transfer and pressure drop of refrigerants R-32, R-410A and R-1234ze. They compared their experimental data of R-410A with some well recognized available correlations of heat transfer coefficient and found that Dobson [4] predicts their experimental data within average deviation of 2.13%. Xing et al. [2] determined the effect of Froude number and inclination angle on condensation heat transfer of R-245fa. The experimental heat transfer coefficient data of horizontal tube were also compared with several well recognized correlations. The results showed that Shah [3] and Dobson et al. [4] correlations can predicted their experimental heat transfer coefficient data within an average deviation of 1.36% and 0.69% respectively. Shah [3] presented a generalized correlation of heat transfer coefficient during condensation of fluids in smooth tubes. The correlation presented was validated with the data of several fluids condensing in different flow conditions and tube orientations. Dobson [4] studied condensation of pure and azeotropic refrigerants over wide range of tube diameter and mass flux in plain horizontal tubes. They noticed that the heat transfer coefficient rises with increasing mass flux and quality of refrigerants. Dalkilic [5] in their review on in- tube condensation stated that the Friedel, Chisholm and, Lockhart and Martinelli correlations can be used to calculate the pressure drop in conventional passages. Khatua et al. [6] during study on the effect of coiled-wire inserts on condensation pressure drop of R-245fa inside horizontal tube reported that the pressure drop across the tube during plain flow increases with increasing mass flux and vapor quality of R-245fa. Zhang et al. [7] numerically studied condensation of R-410A inside smooth horizontal tube. Their outcomes indicated that the local heat transfer coefficient and pressure drop increased with increasing mass flux, vapor quality and with decreasing tube diameter and saturation temperature.

In the last few decades, a number of optimization methods were developed and used by different researchers to optimize the design and performance of heat exchangers. Sanaye et al. [8] applied multi-objective genetic algorithm (GA) method to maximize the condenser heat transfer rate and minimize pressure drop. Patel et al. [9] implemented particle swarm optimization (PSO) technique to minimize cost of shell and tube heat exchanger. They presented optimized design parameters and effectiveness of PSO in design optimization of heat exchangers. The PSO results

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were found better as compared to predicted by genetic algorithm. Baadache et al. [10] demonstrated the use of genetic algorithm in cost optimization of shell and double concentric tube heat exchanger. Hajabdollahi et al. [11] applied genetic and particle swarm optimization algorithm for design optimization of a shell and tube heat exchanger. Rao et al. [12] presented optimized design of solar air heater using teaching-learning based optimization (TLBO) algorithm and evaluated the performance of the algorithm. The obtained results demonstrated that the TLBO algorithm is better or as good as other currently available optimization algorithm. Kumar et al. [13-14] implemented teaching-learning based optimization technique for single and multi-objective optimization of condensation characteristics during R-245fa condensation inside smooth horizontal tube. The results obtained using TLBO were compared with experimental data and found very closer to each other. Patel et al. [15] executed improved TLBO for multi-objective optimization of plate-fin heat exchanger design and displayed the effectiveness of the algorithm through two examples. The results stated that this algorithm can be used for the optimization of thermal systems. Safikhani et al. [16] modeled and optimized heat transfer coefficient and pressure drop of nanofluid flow in flat tubes with the help of CFD and response surface methodology (RSM). Shrivan et al. [17] implemented RSM for the optimization of heat transfer rate and pressure drop of a solar heat exchanger filled with nanofluid. Han et al. [18] computed the Nusselt number, friction pressure drop and overall heat transfer performance of double pipe heat exchanger using CFD. These evaluated values were used as objective functions to RSM. The optimal solution of design parameters were obtained using RSM. Subasi et al. [19] determined Pareto based optimal values of design factors to maximize Nusselt number and minimize friction factors using RSM. They formulated multi-objective optimization problem based on face centered central composite model.

From the literature study it could be inferred that a large number of experimental work have been performed on refrigerants condensation inside tubes. It was also observed that TLBO and RSM methods were successfully executed for the design optimization of heat exchangers. The aim of this paper was to find the optimum design parameters that give maximum heat transfer and minimum pressure drop of R-410A and R-245fa condensation inside tubes with the help of TLBO and RSM approaches.

2. Mathematical Models

2.1 Heat Transfer Coefficient (h)

Condensation heat transfer coefficient of R-410A and R-245fa inside smooth horizontal tubes was calculated using Shah's correlation which is as follow;

$$h = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}\left(\frac{\mu_f}{14\mu_g}\right)^{n}\left(\frac{k}{D_i}\right) \times\left[(1-x)+\frac{3.8\,x^{0.76}(1-x)^{0.04}}{\left(P_{sat}/P_{cri}\right)}\right] \tag{1}$$

where,

$$\mathrm{Re} = \left(\frac{G\times D_i}{\mu_f}\right) \tag{2}$$

$$n = 0.0058+0.557\times\frac{P_{sat}}{P_{cri}} \tag{3}$$

2.2 Pressure Drop (ΔP)

Frictional pressure drop during flow of R-245fa and R-410A inside horizontal tube was calculated based on the Friedel correlation which is as given below;

$$\Delta P = \Delta P_L\times{\phi_{fr}}^2 \tag{4}$$

where,

$$\Delta P_L = 4\times f_f\times G^2\times\left(\frac{1}{2\rho_f}\right)\left(\frac{L}{D_i}\right) \tag{5}$$

The liquid friction factor f_f and f_g are calculated by:

$$f_f = 0.079\left(\frac{GD_i}{\mu_f}\right)^{-0.25} \tag{6}$$

$$f_g = 0.079\left(\frac{GD_i}{\mu_g}\right)^{-0.25} \tag{7}$$

Friedel two phase multiplier, ϕ_{fr}^2, is computed by:

$$\phi_{fr}{}^2 = E+\frac{3.24\times F\times H}{Fr^{0.045}\times We^{0.035}} \tag{8}$$

The dimension less factors E, F, H and Fr are calculated by:

$$E = (1-x)^2 + x^2\left(\frac{\rho_f}{\rho_g}\right)\left(\frac{f_g}{f_f}\right) \tag{9}$$

$$F = x^{0.78}(1-x)^{0.224} \tag{10}$$

$$H = \left(\frac{\rho_f}{\rho_g}\right)^{0.91}\left(\frac{\mu_g}{\mu_f}\right)^{0.19}\left(1-\frac{\mu_g}{\mu_f}\right)^{0.7} \tag{11}$$

$$\mathrm{Fr} = \frac{G^2}{gD_i{\rho_H}^2} \tag{12}$$

The Weber number 'We' and homogeneous density 'ρ_H' are defined as:

$$\mathrm{We} = \frac{G^2D_i}{\rho_H\sigma} \tag{13}$$

$$\rho = \left[\frac{x}{\rho}+\frac{1-x}{\rho}\right] \tag{14}$$

3. Teaching-Learning Based Optimization (TLBO) Algorithm

Teaching-learning based optimization is teaching learning procedure motivated algorithm [20]. In this optimization algorithm a group of learners reflect the population and subjects given them to study as design parameters. The marks secured by learners in a class reflects ''fitness'' value of the problem to be optimized. The teacher is the optimum solution among the whole population [21]. The constraints involved in the given optimization problem are the design variables and the optimum value of the objective function is ‘‘fitness’’ value. TLBO workings have been separated in two stages ‘‘Teacher phase’’ and ‘‘Learner phase’’. The Fig. 1 represents the flow chart of TLBO.

3.1 Teacher Phase

The teacher phase is the first stage of TLBO wherein the learners gain knowledge from the teacher. Teacher efforts his/her best to enhance the mean output of the class in the subject educated by him/her according to his/her intelligence. Let at any iteration i, mean of marks secured by learners in a particular subject be M_i. A teacher will try his/her best to enhance the outcome of the class towards his/her level, so new mean is called as M_{new}. The change between new mean and current mean is given by:

$$\text{Difference \_ Mean} = r_i (M_{\text{new}} - T_F M_i) \tag{15}$$

where, r_i is the random number between 0 and 1. T_F is teaching factor. The value of teaching factor is considered as 1.

In teacher phase current solution is updated as according below:

$$X_{\text{new, i}} = X_{\text{old, i}} + (\text{Difference - Mean})_i \tag{16}$$

Accept $X_{\text{new,i}}$, if it yields a better function value. All accepted values are retained at the end of teacher phase and used as input for the learner phase.

3.2 Learner Phase

The learner phase is the second stage of the teaching-learning based optimization algorithm. In this phase it is assumed that the learners randomly interact with each other and increase their knowledge. A learner gains somewhat different if other learner is more knowledgeable than him/her. The learners are modified as follows:

```
For i = 1: $P_n$
Arbitrarily select two learners $X_i$ and $X_j$ such that $i \neq j$
if $f(X_i) < f(X_j)$
$X_{\text{new, i}} = X_{\text{old, i}} + r_i (X_i - X_j)$
else
$X_{\text{new, i}} = X_{\text{old, i}} + r_i (X_j - X_i)$
end
Accept $X_{\text{new}}$ if it provides improved function value.
```

4. Objective Functions

The thermal performance of a condenser can be enhanced by improving heat transfer rate and decreasing pressure drop. From literature study it has been found that the heat transfer rate and pressure drop are proportional to mass flux and quality of refrigerant at any tube diameter. The tube diameter has also influence on the flow pattern changes. Hence tube diameter will affect the condensation characteristics. Therefore, in the current study, h and ΔP are taken as objective functions for optimization. Initially, the heat transfer coefficient and pressure drop are separately optimized using TLBO and RSM methods. Then, the same methods are used for the multi-objective optimization of heat transfer coefficient and pressure drop. The aim of multi-objective optimization is to increase the heat transfer and reduce the pressure drop simultaneously. Optimization problem can be explained as under:

Determine G, x, D_i
Calculate $h = f\{G, x, D_i\}$ and $\Delta P = f\{G, x, D_i\}$
Maximize $f_1 = h$ and $f_2 = -\Delta P$
Subject to:

$$100 \le G \le 300$$
$$0.1 \le x \le 0.9$$
$$7 \le D_i \le 15$$

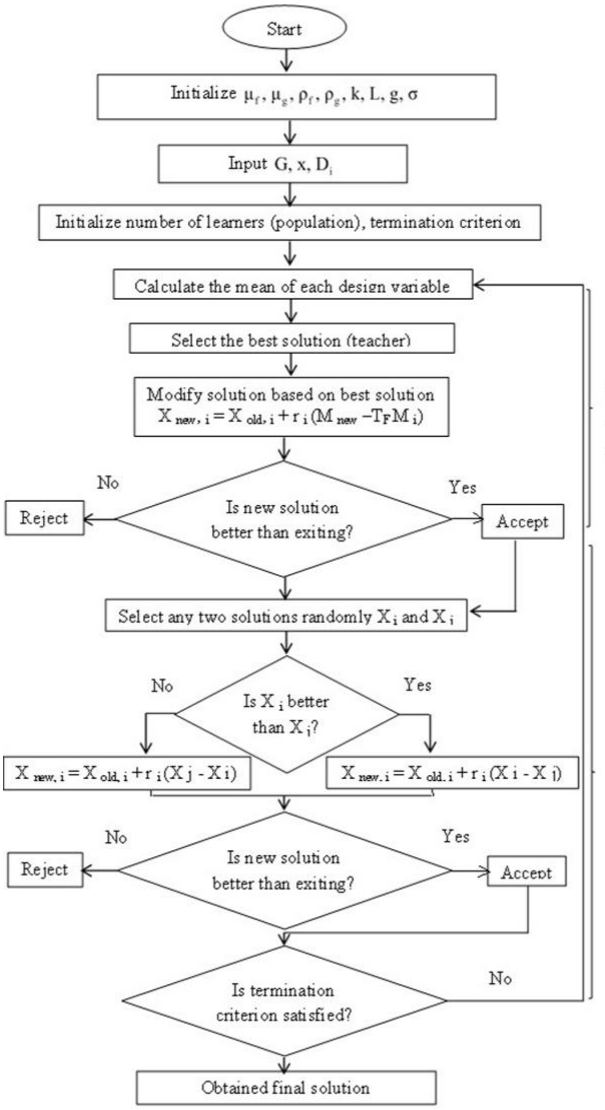


Figure 1. Flowchart of TLBO

The combined objective function prepared for TLBO is as given by Eq. 17.

$$\text{Maximize:} \quad \frac{w_1 f_1}{f_1^*} - \frac{(1-w_1)\, f_2}{f_2^*} \tag{17}$$

where, f_1^* and f_2^* are optimum values of functions f_1 and f_2 respectively and w_1 is the weight factor assigned to the first objective function. For the present cases w_1 values are 0.82 and 0.975 for R-410A and R-245fa respectively. To determine the w_1 value for a particular input parameter, at first its value was chosen 0.5 and evaluated the function value. Next time 0.05 added to earlier w_1 value and calculated the function value. This procedure was repeated for several times. A graph between w_1 and optimized value were plotted. And the value of w_1 was taken corresponding to optimum value of objective function.

The number of population size and number of iterations are determined by conducting several trials for the maximization of heat transfer coefficient and the minimization of pressure drop separately and also for the multi-objective optimization. The number of iterations and population size required for running the TLBO is decided by checking uniformity of the results. The number of population and iterations 10 and 20 respectively has been taken for the present study.

5. Response Surface Methodology (RSM)

Box and Wilson [22] firstly introduced the design of experiment approach like response surface methodology (RSM). It is mainly a scientific approach to efficiently plan and execute experiments through statistical analysis. It establishes relationship between input and output of any engineering system and also optimizes the systems are to be considered. RSM is a combination of mathematical and statistical approach to develop, improve and optimize any systems. It can solve those problems which involve large number of input parameters affecting the designing of systems. A second order polynomial equation is applied to establish the relationship between input parameters (factors) and output (response) of the process. The relationship between response variable '*Y*' and factors $X_1, X_2..., X_n$ can be expressed Eq. 18.

$$Y = f\,(X_1, X_2, ..., X_n) \qquad (18)$$

The RSM expresses relationship between responses and factors in the form of an approximate function through sequences of experimentation and statistical analysis. Most frequently model applied for function approximation is quadratic polynomial model. Quadratic polynomial model used for present investigation is written in Eq. 19.

$$Y = a_0 + \sum_{i=1}^{n}(a_i X_i) + \sum_{i=1}^{n}(a_{ii} X_i^2) + \sum_{i=1}^{n}(a_{ij} X_i X_j) \qquad (19)$$

where, X_i, X_i^2 and $X_i X_j$ are linear, square and interaction terms of factors respectively. The a_0, a_i, a_{ii} and a_{ij} are free term, coefficients of linear terms, quadratic terms and interaction terms respectively.

6. Design of Experiment

Shah's heat transfer coefficient and Friedel's frictional pressure drop correlations are used to generate the data for condensation heat transfer characteristics of R-245fa and R-410A inside a smooth horizontal tube of length 1000 mm [3, 5]. The data for the heat transfer coefficient and pressure drop are generated corresponding to 35^0C saturation temperate of each refrigerant and used for optimization in RSM. Taguchi's L_{25} orthogonal array is preferred as the experimental design in the present investigation. The parameters and their levels taken are as listed in Table 1. The L_{25} orthogonal array has total 25 numbers of runs. Refrigerant mass flux, vapor quality and tube diameter are assigned in first, second and third column respectively while responses are allocated in fourth and fifth column. Parameters and their corresponding responses are summarized in Table 2.

Table 1. Parameters and their levels of experimental design.

S/No.	Parameters	Levels				
		1	2	3	4	5
1	G (kg/m^2-s)	100	150	200	250	300
2	x	0.1	0.3	0.5	0.7	0.9
3	D_i (mm)	7	9	11	13	15

7. Results and Discussion

The effect of refrigerant mass velocity (*G*), quality (*x*) and tube diameter on condensation heat transfer coefficient (h) and pressure drop (ΔP) are studied in this paper. Multi-objective optimization is also performed using RSM and TLBO methods. The aim of optimization is to find the optimum values of parameters that will produce maximum heat transfer and minimum pressure drop.

Table 2. Parameters and their corresponding responses.

Test no.	Parameters			Responses			
				R-410A		R-245fa	
	G	x	D_i	h (W/m^2-K)	ΔP (Pa)	h (W/m^2-K)	ΔP (Pa)
1	100	0.1	7	696.69	88.59	717.76	414.05
2	100	0.3	9	1023.80	120.00	1233.20	632.43
3	100	0.5	11	1249.80	130.28	1603.20	723.00
4	100	0.7	13	1413.10	133.18	1684.40	766.00
5	100	0.9	15	1497.10	126.38	2059.90	752.00
6	150	0.1	9	916.40	125.57	943.93	580.63
7	150	0.3	11	1360.90	180.24	1638.60	947.90
8	150	0.5	13	1671.80	204.66	2144.90	1133.10
9	150	0.7	15	1988.40	216.69	2533.20	1250.10
10	150	0.9	7	2413.00	639.79	3318.40	3825.10
11	200	0.1	11	1108.20	156.49	1141.60	717.99
12	200	0.3	13	1656.10	233.37	1994.80	1225.40
13	200	0.5	15	2045.10	273.60	2623.60	1521.40
14	200	0.7	7	2784.0	896.26	3713.80	5183.60
15	200	0.9	9	2888.50	754.91	3972.30	4525.90
16	250	0.1	13	1281.20	183.07	1319.70	834.73
17	250	0.3	15	1923.90	280.46	2317.40	1470.90
18	250	0.5	7	2847.40	1014.0	3652.50	5644.90
19	250	0.7	9	3165.60	946.23	4222.00	5480.70
20	250	0.9	11	3317.20	852.54	4561.00	5119.80
21	300	0.1	15	1440.60	206.44	1483.90	936.44
22	300	0.3	7	2592.60	971.18	3122.80	5086.30
23	300	0.5	9	3133.00	999.03	4018.00	5563.00
24	300	0.7	11	3518.7	995.02	4692.80	5770.00
25	300	0.9	13	3712.00	938.19	5104.8	5642.00

7.1 ANOVA Results

The data presented in Table 2 are analyzed for condensation heat transfer coefficient and pressure drop of refrigerants inside smooth tubes. Analysis of variance (ANOVA) is applied to determine the factors (G, x, D_i) which significantly affect the responses (h and ΔP). This analysis was done for a significance level (α) of 0.05 (95% confidence level). The ANOVA contains a table comprising of degrees of freedom (DOF), sum of squares (SS), mean of

Table 3. ANOVA results of heat transfer coefficient.

		R-410A				R-245fa			
Source	DOF	Adj SS	Adj MS	F Value	P	Adj SS	Adj MS	F Value	P Value
Model	8	19416219	2427027	4023.33	<0.000	40954046	5119256	1534.04	<0.000
Linear	3	16193884	5937961	8950.53	<0.000	33395745	11131915	3353.80	<0.000
G	1	9079441	9079441	11601.11	<0.000	15392183	15392183	4612.43	<0.000
X	1	6996496	6996496	15054.91	<0.000	1786030	1786030	5350.75	<0.000
D_i	1	355429	355429	589.35	<0.000	621939	621939	186.37	<0.000
Square	3	250822	83607	138.63	<0.000	472878	157626	47.23	<0.000
G*G	1	20813	20813	34.51	<0.000	63137	63137	18.92	<0.000
x*x	1	210858	210858	349.36	<0.000	364709	364709	109.29	<0.000
D_i * D_i	1	6385	6385	10.59	0.005	18240	18240	5.47	0.033
Interaction	2	314295	157147	260.57	<0.000	939514	469757	140.77	<0.000
G*x	1	259835	259835	430.84	<0.000	731235	731235	219.12	<0.000
G* D_i	1	2785	2785	4.62	0.047	1045	1045	0.31	0.583
Residual	16	9649	603			53394	3337		
Total	24	19425869				41007440			
R^2 = 99.95%, R^2 (Pred.) = 99.80%, R^2 (Adj.) = 99.93%						R^2 = 99.87%, R^2 (Pred.) =99.50%, R^2 (Adj.) = 99.80%			

Table 4. ANOVA results of pressure drop.

		R-410A				R-245fa			
Source	DOF	Adj SS	Adj MS	F Value	P	Adj SS	Adj MS	F Value	P Value
Model	8	3310819	413852	775.94	<0.000	113160793	14145099	637.20	<0.000
Linear	3	2640332	880111	1650.13	<0.000	90021190	30007063	1351.74	<0.000
G	1	1595845	1595845	2992.08	<0.000	50462505	50462505	2273.21	<0.000
X	1	598825	598825	1122.75	<0.000	26099327	26099327	1175.71	<0.000
D_i	1	545964	545964	1023.64	<0.000	17163843	17163843	773.19	<0.000
Square	3	34503	11501	21.56	<0.000	899576	299859	13.51	<0.000
G*G	1	295	295	0.55	0.468	66	66	0.00	0.957
x*x	1	23760	23760	44.55	<0.000	682992	682992	30.77	<0.000
D_i * D_i	1	6748	6748	12.65	<0.000	128423	128423	5.79	0.029
Interaction	2	21271	10636	19.94	<0.000	771460	385730	17.38	<0.000
G*x	1	17211	17211	32.32	<0.000	769301	769301	34.66	<0.000
G* D_i	1	14587	14587	27.35	<0.000	229234	229234	10.33	0.005
Residual	16	8534	533			355181	22199		
Total	24	3319353				113515974			
R^2 = 99.74%, R^2 (Pred.) = 98.96%, R^2 (Adj.) = 99.61%						R^2 = 99.69%, R^2 (Pred.) = 98.71 %, R^2 (Adj.) = 99.53%			

squares (MS), F-values (F), probability (P) values and percentage of contributions. Statistical significance of factors to the responses (heat transfer coefficient and pressure drop) is assessed by P-values and F-values of ANOVA. The sources with P-value less than 0.5 (or 95% confidence) and F-value larger than F-table are treated to have a statistically significant to the responses. The ANOVA results of heat transfer coefficient and pressure drop of R-410A and R-245fa have been displayed in Tables 3 and 4.

As can be observed from Tables 3 and 4, greater value of R^2 for h and ΔP indicate that the present model is appropriate for computing the values of heat transfer coefficient and pressure drop. As can be seen from the Table 3, all linear terms, square terms and interaction term G*x are significant for the heat transfer coefficient model. Among linear terms, x is the most significant and D_i is the least significant factor for heat transfer coefficient. From Table 4 it is clear, all linear terms, square terms x^2, D_i^2 and both interaction terms are important for pressure drop model. For pressure drop, G is most and D_i is the least affecting parameters. However, the large difference between F-value of tube ΔP and h indicates that the diameter has very high influence on pressure drop and has a little influence on heat transfer coefficient.

7.2 Regression Model of Responses

Regression analysis has been performed for heat transfer coefficient (h) and pressure drop (ΔP) of plain flow condensation inside tubes. The value of h and ΔP can be determined by Eqns. 19 and 20 respectively.

For R-245fa:

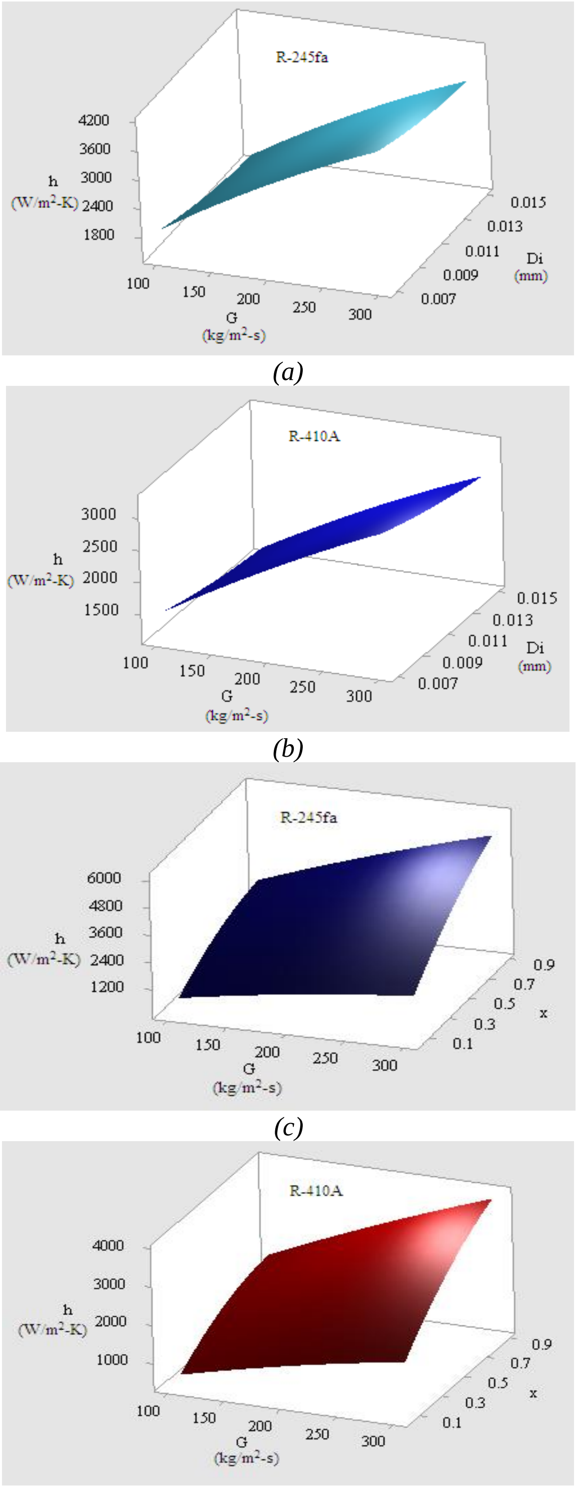
$$h=267+10.49G+3048x-155641D_i-0.01201\,G*G-2084x*x+4659810D_i*D_i+11.802G*x-44.6\,G*D_i \qquad (19a)$$

$$\Delta P=843+21.46G+4450x-465829D_i-0.00039G*G-2851x*x+12364631D_i*D_i+12.11G*x-661G*D_i \qquad (20a)$$

For R-410A

$$h=177+8.565G+2258x-92995D_i-0.00690\,G*G-1584.4x*x+2757000D_i*D_i+7.035G*x-72.8G*D_i \qquad (19b)$$

$$\Delta P=160+4.173G+779x-87154D_i+0.0008G*G-531.8x*x+2834345D_i*D_i+1.811G*x-166.7G*D_i \qquad (20b)$$



(a)

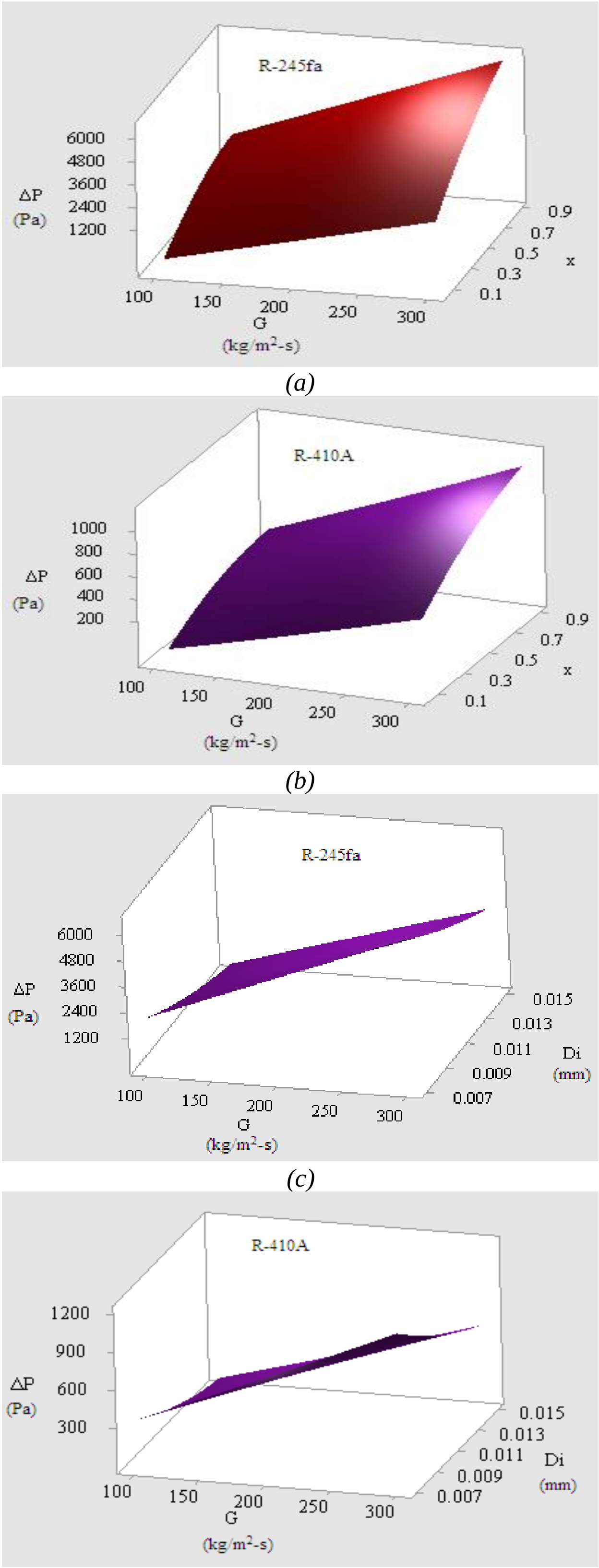
(b)

(c)

(d)

Figure.2 Effect of Parameters on Heat Transfer Coefficient.

The accuracy of the regression models are examined by parameter R^2. The value of parameter closer to 100 percent, the model will be more perfect. For the present study, R^2 are more than 99 percent for h and ΔP.



(a)

(b)

(c)

(d)

Figure.3 Effect of parameters on Pressure Drop.

7.3 Response Surface Analysis

Response surface analysis has been done for condensation heat transfer coefficient and pressure drop in smooth horizontal tubes. The heat transfer coefficient and pressure drop variation with effective factors, refrigerant mass velocity (G), quality (x) and tube diameter (D_i), are displayed in Figures 3 and 4, respectively.

Following inferences may be drawn from the Figures 2 and 3:

(a) Increasing mass flux and quality of refrigerants enhances the heat transfer coefficient. Its highest value is obtained at 300 kg/m^2-s and 0.9 and lowest for 100 kg/m^2-s and 0.1 of mass flux and quality of refrigerants respectively.

(b) Decreasing tube diameter increases the heat transfer coefficient for all values of mass flux and its maximum value is achieved for 7 mm of tube diameter and 300 kg/m^2-s mass flux of refrigerants.

(c) For the entire range of mass flux, decreasing the quality of refrigerants decreases the pressure drop. Its minimum value is obtained for 0.1 vapor quality and 100 kg/m^2-s mass velocity.

(d) For all mass fluxes, increasing the diameter of tube decreases the pressure drop. Its lowest value is attained for tube diameter 15 mm and mass flux 100 kg/m^2-s.

7.4 Parameters Optimization

At first, both the responses, heat transfer coefficient and pressure drop, are optimized separately using TLBO and RSM methods. The optimization results have been listed in Tables 5 and 6. As could be observed from the Tables, the maximum heat transfer coefficients 5620.91 and 4150.97 W/m^2-K are obtained using RSM at G = 300 kg/m^2-s, x = 0.9 and D_i = 7 mm for R-245fa and R-410A respectively. However, the lowest pressure drop 167 and 43.4 Pa are obtained with G = 100 kg/m^2-s, x = 0.1 and D_i = 15 mm for R-245fa and R-410A respectively. The maximum heat transfer coefficient 5626.5 W/m^2-K is obtained using TLBO with G = 297 kg/m^2-s, x = 0.875 and D_i = 7.5 mm for R-245fa and the highest heat transfer coefficient 4165 W/m2-K is obtained at G = 299.36 kg/m^2-s, x = 0.894 and D_i = 7.22 mm. The minimum pressure drop obtained using TLBO is 162 Pa and 40.83 Pa for R-245fa and R-410A respectively. The optimum parameters required corresponding to minimum pressure drop are, G = 107.9 kg/m^2-s, x = 0.14 and D_i = 13.6 mm for R-245fa and G = 105.85 kg/m^2-s, x = 0.12 and D_i = 14.35 mm for R-410A.

Table 5. Results obtained by RSM and TLBO for heat transfer coefficient.

Parameters	R-245fa		R-410A	
	RSM	TLBO	RSM	TLBO
G (kg/m^2-s)	300	297	300	299.36
x	0.9	0.875	0.9	0.894
D_i (mm)	7	7.50	7	7.22
h_{max} (W/m^2-K)	**5620.91**	**5626.5**	**4150.97**	**4165.68**

Table 6. Results obtained by RSM and TLBO for pressure drop.

Parameters	R-245fa		R-410A	
	RSM	TLBO	RSM	TLBO
G (kg/m^2-s)	100	107.9	100	105.85
x	0.1	0.14	0.1	0.12
D_i (mm)	15	13.6	15	14.35
ΔP_{min} (Pa)	**167**	**162**	**43.4**	**40.83**

The heat transfer and pressure drop are two contradictory parameters for all heat exchanging devices. The improvement of first causes decline of second. Therefore, multi-objective optimization technique is used to optimize the two responses simultaneously. The multi-optimization results obtained using RSM and TLBO for R-245fa and R-410A has been listed in Table 7. As could be observed from this table, the optimum heat transfer coefficient and pressure drop using RSM and TLBO are obtained with high value of refrigerant vapor quality and tube diameter. The optimum vapor quality predicted by both the methods is almost close to 0.9 for the refrigerants which is close to maximum range of quality. The optimum tube diameters predicted by RSM and TLBO are between 13 mm and 14 mm. The optimum heat transfer coefficient and pressure drop are obtained using RSM with mass flux 176.76 kg/m^2-s and 191 kg/m^2-s for R-245fa and R-410A respectively, while using TLBO are 172.45 kg/m^2-s and 188.09 kg/m2-s for the same refrigerants.

From above tables it can also be concluded that for the same objective function, the results obtained using TLBO is better than that of RSM.

Table 7 Results obtained by RSM and TLBO for heat transfer coefficient and pressure drop.

Parameters	R-245fa		R-410A	
	RSM	TLBO	RSM	TLBO
G (kg/m^2-s)	176.76	172.45	191	188.09
x	0.9	0.88	0.9	0.87
D_i (mm)	15	13.3	15	13.84
ΔP_{min} (Pa)	2288.63	2159.4	420.73	394.58
h_{max} (W/m^2-K)	3275.24	3282.6	2535.90	2539.23

8. Conclusions

In the present paper, optimization of refrigerants vapor flow in the horizontal smooth tubes has been effectively applied using TLBO and RSM methods. The design variables, G, x, D_i were optimized with an aim to maximize heat transfer and minimize pressure drop simultaneously. First, Taguchi's L_{25} orthogonal array of experimental design is formulated based on heat transfer coefficient and pressure drop correlations. The same experimental design data were used for multi-objective optimization of refrigerant vapor flow using RSM optimization method. The same objective functions were also optimized using TLBO. The results indicated that high value of vapor quality and tube diameter yields optimum value of objective function, while mass velocity should neither low nor high for the same. The results also indicated that the TLBO technique yields better objective function value as compare to RSM approach.

Nomenclature

D_i : Tube diameter (mm)
Fr : Froude number
f_f : Liquid friction factor
f_g : Vapor friction factor
g : Gravitational acceleration(m/s^2)
G : Mass flux (kg/m^2-s)
h : Heat transfer coefficient (W/m^2-K)
K : Thermal conductivity (W/m- K)
L : Length of tube (mm)
Pr : Prandtl number
P_r : Reduced pressure
P_{sat} : Saturation pressure (Pa)
P_{cri} : Critical pressure (Pa)
Re : Reynolds number
We : Weber number
x : Vapor quality

σ : Surface tension (N/m)
μ_g : Vapor viscosity (N-s/m^2)
μ_f : Liquid viscosity (N-s/m^2)
ρ_f : Liquid density (kg/m^3)
ρ_g : Vapor density (kg/m^3)
ρ_H : Homogenous density
Φ^2_{fr} : Friedel's two phase multiplier

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