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A Computational Approach for Optimization of Different Parameter of a Solar Air Heater with Smooth Flat Plate and Artificial Roughness

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Abstract: ***Teaching–Learning-Based Optimization (TLBO) is a newly and advance meta-heuristic optimization method adopted in this paper for optimizing a set of design and operating parameters for solar air heater. In this paper an attempt has been done to optimize the thermal performance of solar air heater with smooth flat plate and with artificially roughness by considering the different operating parameters. Thermal performance is obtained for different values of Reynolds number, Relative roughness pitch, Relative roughness height, Relative groove position and chamfered angle by using Teaching Learning base optimization algorithm. The result obtained from TLBO is more effective and efficient than the other optimization techniques which are consider for mechanical design optimization problems. The final results obtained from this algorithm are compared with experimental results and found to be satisfactory as far as flexibility, convergence rate and computational effort.***

Key Words**: TLBO, Solar air heater, artificially roughness, Thermal Performance.**

I. INTRODUCTION

Energy is a basic requirement for human being and also influences the economic development. The limited sources of conventional fuels have drawn attention of researchers to renewable energies in recent years. Out of alternative energy resources, solar energy is available freely and abundance on earth in the form of radiation. Solar collectors are widely used for utilization of solar energy for various applications. Solar air heaters are simple to design and no complicated tracking mechanism is involved in it and also it is economical [4].

The solar air heaters are having low thermal efficiency due to two reasons: a) low thermal capacity of air and b) a low heat transfer co-efficient between the absorber plate and air flow through duct. In order to make the solar air heater more effective, their thermal efficiency needs to be improved [2].

Thermal performance may be increased by increasing convective heat transfer coefficient. There are two way for increasing heat transfer coefficient either a) increase the area of absorbing surface by using fins or b) create the turbulence on the heat transferring surfaces [2]. For this reason, solar collector surfaces are either roughened or corrugated to increase the thermal performance. To increase the efficiency of such a system, various configurations and designs have been proposed.

The value of parameter effecting thermal performance of solar air heater required to be optimized. So, various researchers attempted using different optimization techniques such as genetic algorithm (GA), particle swarm optimization (PSO) etc. Kalogirou, S.A [5] has applied a combination of artificial neural-networks (ANNs) and genetic algorithms (GAs) to optimize a solar-energy system having flat plate collectors with an intention to maximize its life cycle savings on an industrial heating process system. Kalogirou,S.A [6] had estimated the performance parameters of flat plate solar collectors using ANN and results obtained are compared with actual experimental values. Varun and Siddhartha [7] used GA and PSO [9] technique for optimization for thermal performance of solar air heater with flat absorber plate. Varun et al.[8] applied stochastic iterative perturbation technique to evaluate the optimal thermal performance of flat plate solar air heater. Zou et. al. [10] had implemented TLBO algorithm in multi objective problem, observed this algorithm has less computational time and degree.

In this current work, an attempt has been made to carry out the TLBO technique to obtain the optimal thermal performance of a solar air heater with smooth flat plate and artificial roughness parameters as shown in fig-1.

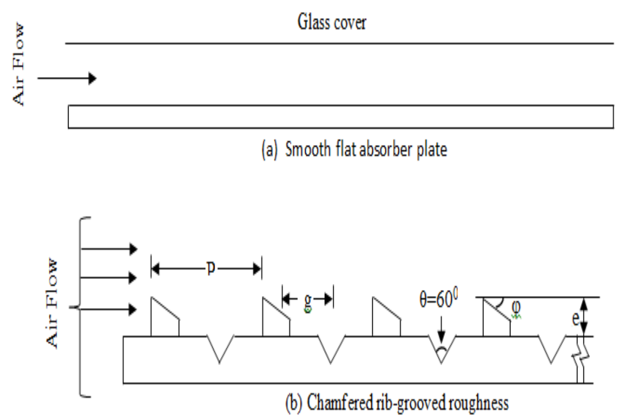

Fig-1: Diagram of solar air heater with different absorber surfaces

The operating and constraints values used in this study are described in Table-1. Reynolds number ,number of glass cover and solar intensity for smooth flat plate solar air heater and relative roughness pitch(P/e),relative roughness height(e/D_h) ,relative groove position (g/P), chamfer angle and Reynolds number, for solar air heater with chamfered groove roughness which are calculated by the proposed technique and finally, the thermal efficiency is calculated.

Table-1: The constraints of the problem are:

Smooth Flat plate	Chamfered groove roughness
$1 < N < 3$;	$4.5 \le P/e \le 10$
$600 < S < 1000$;	$0.022 \le e/D_h \le 0.04$
$2000 < Re < 20{,}000$;	$0.3 \le g/P \le 0.6$
	$5^0 \le \varphi \le 30^0$
	$2000 \le Re \le 20000$

II. TLBO METHOLOGY

Teaching–learning-based optimization is nature-inspired algorithm proposed by Rao [12] which is based on the effect of influence of a teacher on learners output in a class. In this algorithm, a group of learners are considered as population and different offered subjects to the learners are considered as different design parameters and a learner's result is analogous to the 'fitness' value for the optimization problem. The teacher is considered as the best solution in the entire population [12].

The working of TLBO algorithm is divided into two parts, 'Teacher phase' and 'Learner phase'. Let assume two different teachers, T_1 and T_2, are teaching a subject of same content to the same merit level students in two different classes. Fig- 2,[12] shows marks distribution obtained by the students of two different classes examined by the respective teachers. A curve 1 and 2 in fig- 2, represents the marks obtained by the students taught by teacher T_1 and T_2 respectively. Marks obtained considered to be in normal distributions. So, Normal distribution is defined as:

$$f(X) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left\{-(x-\mu)^2 / 2\sigma^2\right\} \quad (1)$$

Where is the variance, is the mean and x is any value of which normal distribution function is required. It is observed from Fig- 2, curve-2 represents better results than curve-1 and thus, it concludes that teacher T_2 is better than teacher T_1 in terms of teaching. The main difference between both the results is their mean (M_1 & M_2 are respective mean for curve-1 and curve-2).This shows that a good teacher produces a better mean for the results of the students. Students also learn from interaction between themselves, which helps in their results [11-15].

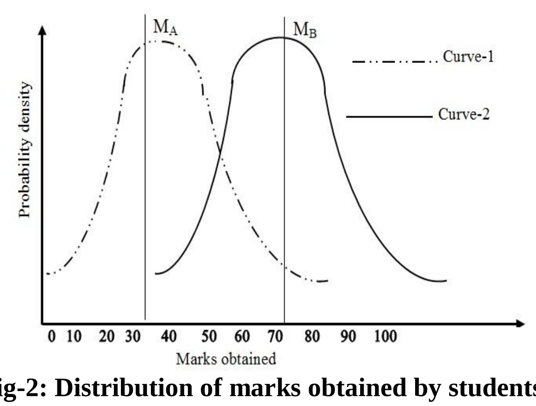

Fig-2: Distribution of marks obtained by students taught by two different teachers

Probability density of marks obtained for students in a class having mean M_A and M_B for curve-A and curve-B respectively are shown in Fig- 3, [12]. Teacher is considered as the most knowledgeable person in the society, so the teacher is pretended as the best learner, and this is shown by T_A in Fig-3. Student will try to increase his knowledge level and which help to attain good marks. So, a teacher increases the mean of the class according to his or her capability. In Fig-3, Teacher T_A will make his or her effort to move mean M_A towards their own level, thereby increasing the student's level to a new mean M_B. Teacher T_A will try to put maximum effort into teaching, but students will gain knowledge according to the quality of teaching delivered by a teacher and the quality of students present in the class, [11-15]. The qualities of the students are evaluated from the mean value of the population. Teacher T_A puts efforts in so as to increase the quality of the students from M_A to M_B, at which stage the students require a new teacher, of superior quality than themselves, i.e. in this case the new teacher is T_B. Hence, there will be a new curve-B with new teacher T_B. The teacher tries to spread knowledge among the method which uses a population of solutions to proceed to the global solution [11].

(a)Teacher Phase

As shown in Fig-3, a good teacher influence mean of a class leads increment from M_A to M_B. A good teacher tries to bring his or her student up to his or her level in terms of knowledge. But in reality this is not possible and a teacher can only improve the mean of a class up to some extent depending on the capability of the class. This follows a random process depending on many factors [11-15].

Let M_i be the mean and T_i be the teacher at any iteration i. T_i will try to move mean M_i towards its own level, so now the new mean will be T_i designated as M_{new}. The solution is updated according to the difference between the existing and the new mean given by [11-15].

$$Difference\_Mean = r_i\left(M_{new} - T_F M_i\right) \quad (2)$$

where T_F is a teaching factor that decides the value of the mean to be changed, and r_i is a random number in the range (0, 1).

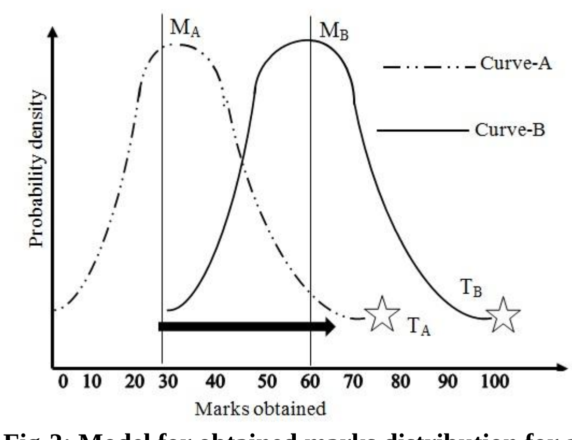

Fig-3: Model for obtained marks distribution for a group of student

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The value of T_F can be either 1 or 2 which is again a heuristic step and decided randomly with equal probability [10-13].

$$T_F = round\left[1 + rand(0,1)\{2-1\}\right] \quad (3)$$

This difference modifies the existing solution according to the following expression:

$$X_{new,i} = X_{old,i} + Difference\_Mean_i \quad (4)$$

(b) Student Phase

Student increase their knowledge by two different means: one through input from the teacher and other through interaction between themselves [11-15]. A student interacts randomly with other student with the help of group discussions, presentations, formal communications, etc. A learner learns something new if the other learner has more knowledge than him or her. Learner modification is expressed by [11-15].

For i=1; and initial population size (P_n)
Randomly select another learner X_j such that $i \neq j$
If $f(X_i) \prec f(X_j)$

$$X_{new,i} = X_{old,i} + r_i(X_i - X_j) \quad (5)$$

Else

$$X_{new,i} = X_{old,i} + r_i(X_j - X_i) \quad (6)$$

Accept X_{new} if it gives a better function value.

III.PROPOSED TLBO ALGORITHMS FOR OPTIMIZATION OF THERMAL PERFORMANCE

The performance of an Solar air heater with smooth plate and chamfered rib-grooved can be determined on the basis of detailed consideration of heat transfer phenomena as ASHRAE Standards [1], and the correlations for the coefficient of heat transfer developed for smooth plate by Klien S.A.[5 and 6] and the correlations of chamfered rib-grooved for the coefficient of heat transfer developed by Layek [16-19].

(a)Problem formulation

The objective function for thermal performance of solar air heater can be proposed as:

$$\text{Maximize } \eta = F_o\left[\tau\alpha - \left(\frac{T_o - T_i}{S}\right)U_o\right] \quad (7)$$

The different relations used for calculating overall loss coefficient (U_0), heat removal factor at outlet (F_0) and temperature rise are computed by equations:

For smooth flat plate solar air heater

$$U_o = \left[\frac{N}{\left(\frac{C}{T_p}\right)\left[\frac{T_p - T_a}{N + f_1}\right]^{0.33}} + \frac{1}{h_w}\right]^{-1} + \frac{\sigma(T_p - T_a)(T_p^2 + T_a^2)}{\left[\varepsilon_p + 0.05N(1-\varepsilon_p)\right]^{-1} + \left[\frac{2N + f_1 - 1}{\varepsilon_g}\right] - N} + \frac{K_i}{t} \quad (8)$$

Where

$$f_1 = (1 - 0.04h_w + 0.005h_w^2)(1 + 0.091N)$$

$$C = 250(1 - 0.0044(\beta - 90))$$

For solar air heater with chamfered rib groove roughness

$$U_o = \left[\left\{\frac{12.75\left[(T_p - T_g)\cos\beta\right]^{0.264}}{(T_p + T_g)^{0.46} L_s^{0.21}} + \frac{\sigma\left((T_p^2 + T_g^2)(T_p + T_g)\right)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_g} - 1}\right\}^{-1} + \left\{h_w + \sigma\varepsilon_g\left(T_g^2 + T_a^2\right)(T_g + T_a)\right\}^{-1} + \frac{t_g}{k_g}\right]^{-1} \quad (9)$$

And $h_w = 5.7 + 3.8V_w$

$$F_o = \frac{Gc_p}{U_o}\left[1 - \exp\left(\frac{-U_oF_1}{Gc_p}\right)\right] \quad (10)$$

For smooth flat plate solar air heater

$$N_u = \frac{0.0192\,P_r\,R_e^{0.75}}{1 + 1.22(P_r - 2)R_e^{-1/8}} \quad (11)$$

For solar air heater with chamfered groove roughness

$$N_u = \left[\begin{array}{l} 0.00225(e/D)^{0.52}(P/e)^{1.72} \\ R_e^{0.92}(g/P)^{-1.21}(\phi)^{1.24} \\ \times\exp\left[-0.46\{\ln(P/e)\}^2\right] \\ \times\exp\left[-0.74\{\ln(g/P)\}^2\right] \\ \times\exp\left[-0.22\{\ln(\phi)\}^2\right] \end{array}\right] \quad (10)$$

$$h_c = \frac{N_u c_p \mu}{P_r D_h} \quad (11)$$

$$F_1 = \frac{h_c}{h_c + U_o} \quad (12)$$

$$G = m / A_c$$

$$T_o - T_i = \left[\frac{(\tau\alpha) S - U_o (T_p - T_a)}{m c_p} \right] \times A_c \quad (13)$$

(b) Proposed TLBO alogoritm for optimaztion of Thermal performanace

Step 1: Initialize: $L, W, S, R_e, \varepsilon_p, \beta, c_p,$ $\Pr, \mu, k_i, k_a, m, v_w, T_a,$ $T_p, t, \tau\alpha, \sigma, \varepsilon_g$

Step 2: Initialize number of students (population), termination criterion.

Step 3: Calculate the mean of each design variable

Step 4: Identify the best solution (teacher)

Step 5: Modify solution based on best solution
$X_{new}=X_{old} + r\ (X_{teacher} - (T_F)Mean)$

Step 6: Is new solution better than existing?
If, yes then, Select any two solutions randomly X_i and X_j

Step 7: check that X_i better than X_j
Yes then, $X_{new}=X_{old}+ r\ (X_i-X_j)$
No then, $X_{new}=X_{old}+ r\ (X_i-X_j)$

Step 8: Is new solution better than existing?
Check, Is termination criteria satisfied?

Step 9: If No, then, again calculate the mean of each design variable.

If yes, then obtained final value of solution

IV.RESULTS AND DISCUSSION

In this present work, the simulation is carried in MATLAB for different cases for smooth plate and roughened surface:

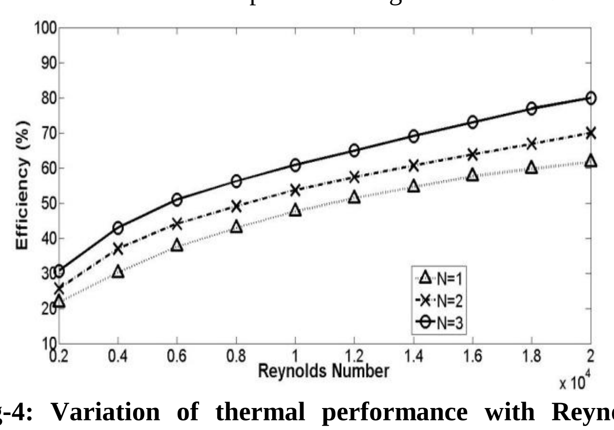

Fig-4: Variation of thermal performance with Reynolds number (Re) for different number of glass plates at S= 600 W/m^2

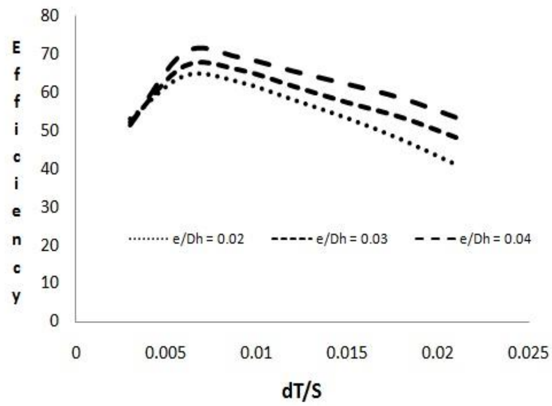

Fig-5: Effect of relative roughness height on efficiency

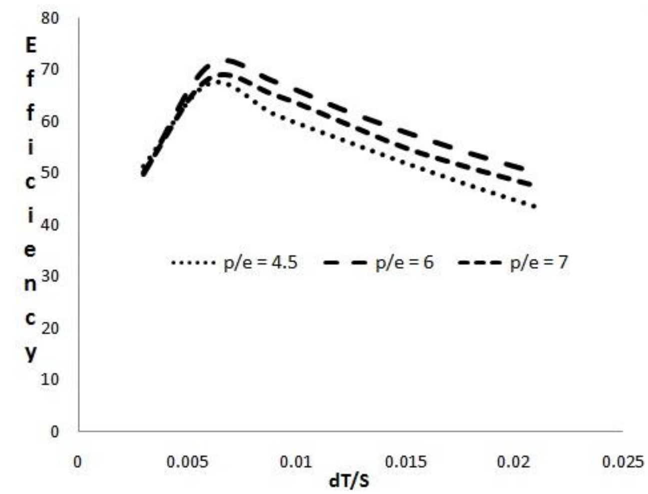

Fig-6: Effect of relative roughness pitch on efficiency

The TLBO iterations at different operating parameters shown in Table 1, for solar air heater with smooth plate and chamfered rib groove roughness respectively and the fig-4 is plotted for smooth plate solar air heater and fig, 5,6, 7 and 8 are been plotted for chamfered rib roughness on basic of data obtained from TLBO optimization technique.

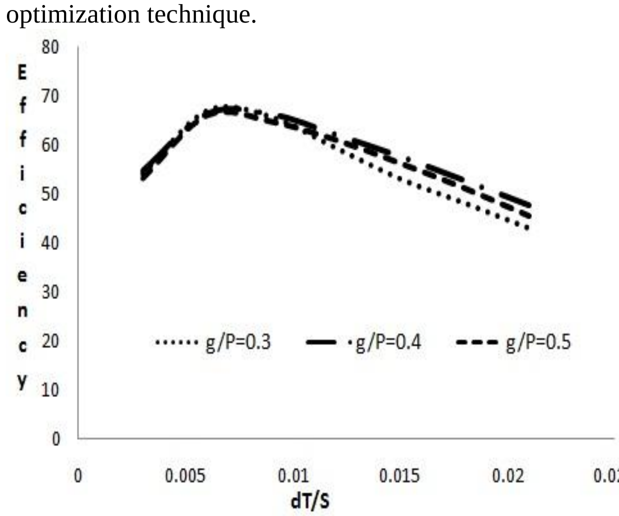

Fig-7: Effect of relative groove position on efficiency

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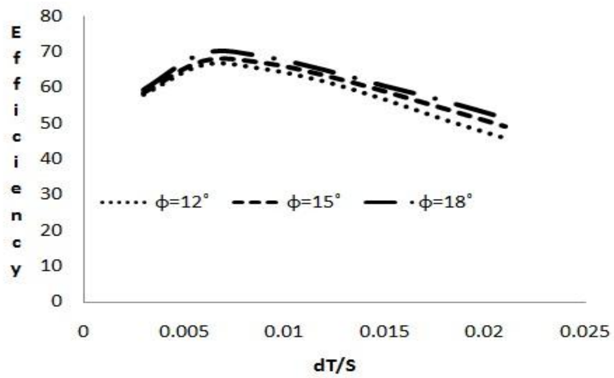

Fig-8: Effect of chamfer angle on efficiency

The results obtained from the TLBO algorithm for smooth plate and chamfered rib groove roughness are being tested with PSO algorithm [9] and experimental data [16-19] respectively for assuring its accuracy, authenticity and robustness.

When the algorithm was executed, it was found that the values of thermal efficiency obtained from this algorithm are in good harmony with experimental thermal efficiency (η).

This proves that the proposed algorithm gives a clear idea regarding operating parameters and domain of optimum set of solar air heater with smooth roughness and artificial roughness.

V. CONCULSION

The conclusions which are derived from this work:

1. The TLBO algorithm was successfully proposed for finding the optimal set of design and operating parameters at which thermal performance of solar air heater with chamfered rib groove roughness is maximum.

2. The maximum thermal efficiency for solar air heater smooth roughness based upon this algorithm was comes out to be 65.92% at N= 3, S =600 W/m^2, Re=20000, v = 1 m/s, β=19.77^0, ε_p=0.91, T_o-T_i=10.89 K and with chamfered rib groove was comes out to be 71.29% at P/e=6,e/D_h =0.04,g/P=0.4,and φ=18^0 .

3. The algorithm helps to a researcher to explore their design and operating variables for attainment of maximum thermal efficiency of solar air heater.

Nomenclature

A_p	Area of absorber plate (m^2)
Ac	Cross-sectional area of duct (m^2)
D_h	Hydraulic diameter (m)
F_o	Heat removal factor referred to outlet temperature (dimensionless)
G	Mass velocity (Kg/sm^2)
h	convective heat transfer coefficient(W/m^2K)
V_w	Wind velocity (m/sec)
h_w	wind convection coefficient(W/m^2K)
S	Solar radiation (W/m^2)
m	mass flow rate of air(Kg/sec)
N	number of glass cover
Pr	Prandtl number
Re	Reynolds number
Nu	Nusselt number
t	Thickness of insulating material(m)
T_a	Ambient temperature of air (K)
T_i	Inlet temperature of air (K)
T_o	outlet temperature of air (K)
T_p	Temperature of absorber plate (K)
U_o	overall heat loss coefficient (W/m^2K)
K_a	Thermal conductivity of air (W/mK)
K_i	Thermal conductivity of insulating material (W/mK)

Greek Alphabet

c_p	Specific heat of air (J/kgK)
ε_p	Emissivity of plate (dimensions)
ε_g	Emissivity of glass (dime
τα	Transmittance-absorptance(dimensionless)
α	Tilt Angle
η	Thermal efficiency

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