ACTA TEHNICA CORVINIENSIS – Bulletin of Engineering
Tome VII [2014] Fascicule 3 [July – September]
ISSN: 2067 – 3809

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INVESTIGATION OF MULTI-STAGE THERMO-ELECTRIC SYSTEM BY PSO METHOD AND ICA OPTIMIZATION ALGORITHM

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Abstract: *The aim of this research is to investigate the optimized some properties of thermoelectric system such as efficiency and power production in generator systems. First, the maximum efficiency and power production in multi-stage thermoelectric systems, which are connected electrically in both parallel and series, are computed. Then, the performance of these systems is compared and the priorities of their usage at their operating temperatures are determined. In this study, despite other studies which use thermoelectric characteristics of materials at the average temperature of the system, the characteristic average operating temperatures of each stage is used. The procedures for optimizing the system are the particle swarm optimization method (PSO) and Imperialist competitive algorithm (ICA) and finally these two methods is compared with each other in order to calculate the efficiency of thermoelectric systems and the results of this investigation represent that: ICA method is 5 percent closer to experimental results.*

Keywords: *Thermoelectric systems, Optimization, Efficiency, Generated Power. Swarm optimization method (PSO), Imperialist competitive algorithm (ICA)*

INTRODUCTION

According to recent estimations, fossil fuels will run out in sixty four years, therefore, people will have to turn to new sources of energy.

Using renewable energy such as hydro, wind and solar are among the most accepted, and improving their efficiency and performance has attracted scientists' interest [1]. One method is using energy producing devices with solid state [2]. These devices have low maintenance cost and they operate without polluting the environment.

Thermoelectric devices are divided into two major groups: coolers [3-6] and generators [7-10]. Coolers operate on the basis of Peltier effect and generators operate on the basis of Seebeck effect. Thermoelectric generators produce electricity when there is a temperature difference, and thermoelectric coolers produce a temperature difference in the presence of electricity.

In the present time, the only limitation of using these devices is their low efficiencies; generators at 5-6 percent [11], and the coefficient of performance of coolers is around 1, closer to 4 for a typical system [12].

Thermoelectric materials' characteristics such as thermal conductivity, electrical resistance, seebeck and Peltier coefficients are all functions of temperature [13], which themselves can be topics for researches to investigate.

Yilbas and Sahin suggested a slenderness ratio for maximizing performance [14]. Beside of researches trying to improve thermodynamic material characteristics, a lot of research has done on thermodynamic systems configuration to improve the overall system performance [15-17].

Even with limited performance, some of research effort has led to using these systems in combination of other systems. For example in automotive industry a lot of works have been done in transforming exhaust heat energy to electricity [18-23].

Recently Lee and his colleagues have developed a solar-thermoelectric system which has attracted much attention [24]. They have found Bi_2Te_3, considering its operating temperature, is the best material for a solar-thermoelectric system. In solar energy, Wei He analyzed a design of a heat pipe solar-electric generator unit [25].

THERMOELECTRIC MATERIALS' WORK PROCEDURE

When an electrical conductor is positioned between two different temperatures, the conductor has the ability to transfer the thermal energy from the hot spot to the cold one. In addition, the physical procedure of heat transfer tends to transfer the electrical charge carriers in the direction of the heat transfer.

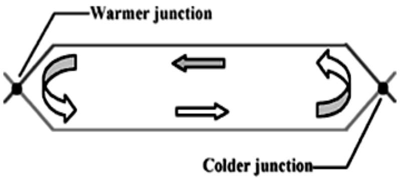

Figure 1. Schema of a simple circuit with 2 wire

This movement of charge carriers can be used to produce electrical current, if we are able to complete the circuit in an effective way.

If the conductor completing the circuit is like the first conductor, the flow of the thermal energy produces an electrical potential for charge carriers' movements in both conductors. Moreover, the electrical potential in one of the conductor is exactly the opposite of that of the other conductor. As a result, there will be no current in the circuit.

If we use two different conductors, we will have a completely different result.

With different abilities of transferring carriers, the produced current resulted from thermal potential in one conductor will dominate the produced current resulted from thermal potential of the other conductor (and in some cases it will completely dominate the other current). The pure effect is a continuous current which is the difference between the produced current of the two conductors.

The presence of this pure current shows that there is an electrical potential along the path of the heat flow which could be easily measure by opening the circuit and using a potentiometer.

Notice that the ability of different materials in producing voltage by presence of a temperature difference is called seebeck effect. The produced voltage, also, is called seebeck voltage. In fact, the produced voltage by the thermocouple is a function of two parameters: the temperature difference between the two points and the characteristics of the used conductors (like dependence on temperature). Of course, thermocouples are used to measure temperatures not to produce power.

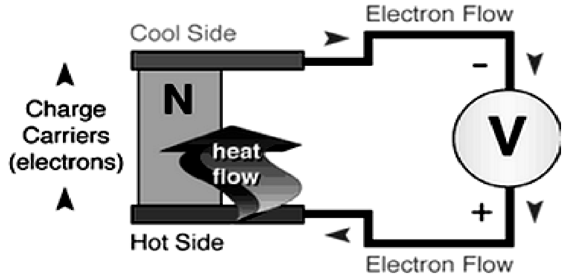

Figure 2. Schema of N-type circle include the voltmeter

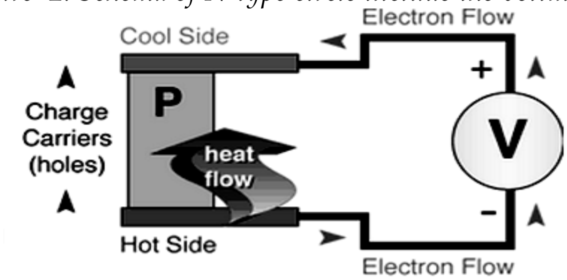

Figure 3. Schema of P-type circle include the voltmeter

Thermo-electric power producing facilities use semi-conductor materials for which the seebeck effect is optimized.

The circuit in Figure (2) shows a simple sample. An N-type semi-conductor circle connected to a voltmeter is shown in this figure.

When heat is transferred from the hot spot to the cold spot, charge carriers are transferred with heat. Heat, also, causes the movement of charge carriers in the return path. For producing power in thermo-electrics, P circle are used too. Figure (3) shows a primary schematic.

Notice the reverse movement of electrons. These are all of the cases of using type-N and P materials in a power producing generator which we can correctly optimize the seebeck effect.

As it is shown in Figure (4), N and P circle are in a parallel position, but are circle from an electrical point of view. Because the electrical current (electrons' movements) is in the opposite direction of the cavity current, the current producing potentials in circle are not each others' opposite.

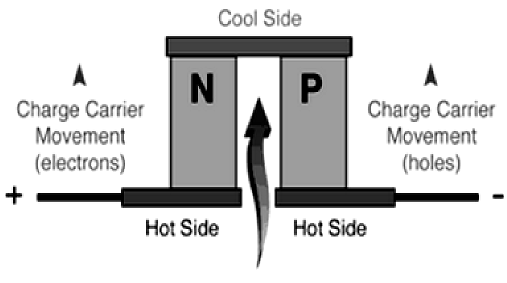

Figure 4. Schema of parallel type

In fact, in practical PEGs, a lot of N and P couples are used to gain applicable voltage.

IMPERIALIST COMPETITIVE ALGORITHM

The optimization problem can be absolutely delineated to find an argument x that related cost $f(x)$ is optimum, it has been widely used in many different position such as industrial planning, resource allocation scheduling, pattern identification. Different methods have been suggested to solve the problem. developmental algorithms such as: particle swarm optimization [26,27], genetic algorithm [28,29], taboo search [30-32], bees algorithm [33-35], and colony optimization [36-38], and simulated annealing [39,40] are collection of algorithms that are suggested and established for solving optimization problem in many different engineering and science fields in last decades. Imperialist competitive algorithm (ICA) is offered for first time by Ateshpaz-Gargari and Lucas in 2007 [41] and established for optimization inspired by the imperialistic competition and has a important relationship to many engineering applications [41]. Like other developmental methods, the proposed algorithm begins with an initial population. Population individual called country that they are in two types: colonies and imperialists who all together form some empires. Imperialistic competition among these empires forms the base of the proposed developmental algorithm. During this contest, feeble empires collapse and powerful empires take possession of their colonies. Imperialistic contest optimistically converge to a position in which there exist just one empire and its colonies are in the same state and have the same cost as the imperialist [41]. Using this algorithm, one may discover the optimum condition of the several functions. In this connecting the suggested model based on retrogression analysis is then embedded into the ICA to optimize the objective function. The aim of optimization algorithms is to discover optimal solution in terms of the variables of the problem (optimization variables). Hence an arrangement of variable values to be optimized is formed. In Genetic Algorithm terminology, this arrange is called "chromosome" but in this Algorithm the term "country" is used for this arrange. In an N_{var}-dimensional optimization problem, a countries an $(1\times N_{var})$ arrange. This arrangement is defined by:

$$Country = [\, p_1, p_2, p_3, \ldots\ldots p_{Nvar}] \qquad (1)$$

The variable values in the country are shown as floating point numbers. The cost of a country is discovered by evaluating the cost function f at the variables $(p_1, p_2, p_3, \ldots\ldots p_{Nvar})$ [41].

$$\text{Then cost} = f(p_1, p_2, p_3, \ldots\ldots p_{Nvar}) \qquad (2)$$

The flowchart of the ICA algorithm is demonstrated in Figure 5.

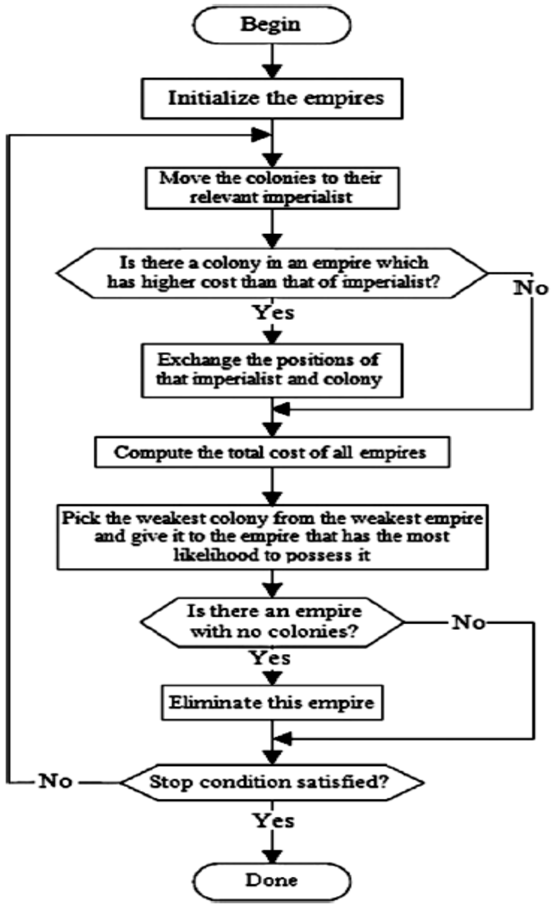

Figure 5. The flowchart of ICA algorithm

To begin the optimization algorithm the initial population of size N_{pop} is produced. The N_{imp} of nearly most powerful countries to form the empires is chosen. The remaining N_{col} of the population is going to be the colonies each of which possessed by an empire. Now, there two kinds of countries: imperialist and colony. To form the initial empires, the colonies are then divided among imperialists, according to their powers. It is the initial number of colonies of an empire must be proportionate to its power in a direct manner. To divide the colonies among imperialists relatively the normalized cost of an imperialist are explained by $C_n = c_n - Max\,\{c_i\}$, where c_n is the cost of nth imperialists, and C_n is its normalized cost. Having the normalized power of each imperialist is explained by [41].

$$Pn=\frac{C_n}{\sum_{i=1}^{Nimp} c_i} \quad (3)$$

From the other point of view, the normalized power of an imperialist is the portion of colonies that must be belonged to that imperialist.

Therefore the initial number of colonies of an empire is going to be:

$$N.C._n = round\{ p_n.N_{col} \} \quad (4)$$

That $N.C._n$ is the initial number of colonies of nth empire and N_{col} is the number of all colonies. To divide the colonies for per imperialist $N.C._n$ of the colonies is selected in random manner and is given them to it. These colonies together with the imperialist are going to form nth empire. A schematic demonstration of the initial population of per empire can be seen in Figure 6.

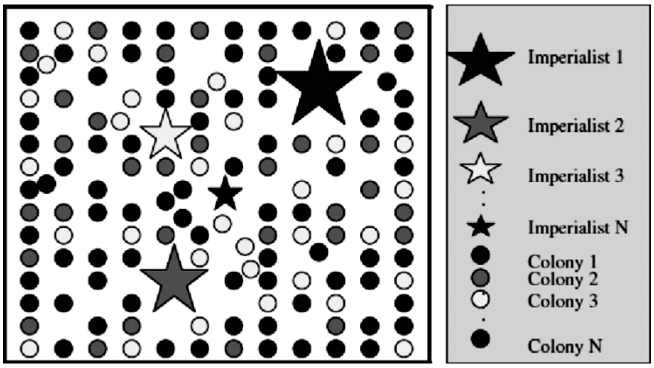

Figure 6. Moving colonies toward their relevant imperialists [41]

As shown in figure, more powerful (bigger) empires have more number of colonies while weaker (smaller) empires have less number [41]. As mentioned above imperialist countries began to enhance their colonies. This reality has been modeled by moving up all the colonies in the direction of imperialist. This movement is demonstrated in Figure 7, where the colony moves in the direction of the imperialist by x units.

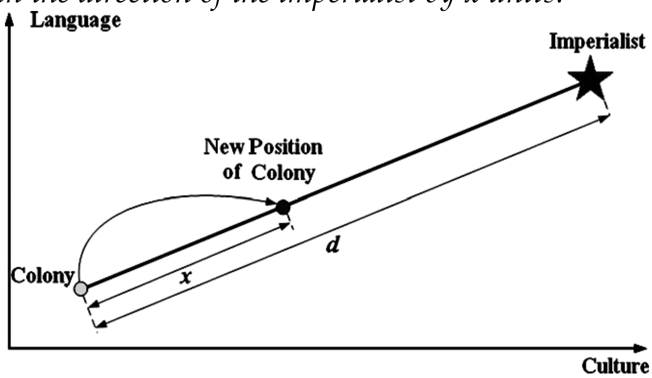

Figure 7. Moving colonies toward their relevant imperialist

The new situation of colony is demonstrated in a darker color. The direction of the movement is the vector from colony in the direction in the direction of imperialist. In Figure 7 x is an accidental (random) variable with uniform or any proper profile [41]. Then for x

$$p \sim U(0, \beta \times d) \quad (5)$$

where β is a number bigger than 1 and d is the distance between imperialist and colony. A β>1, brings out the colonies to get closer to the imperialist position from both sides. To investigate different points around the imperialist an accidental amount of deviation was added to the direction of movement. Figure 8 demonstrates the new direction.

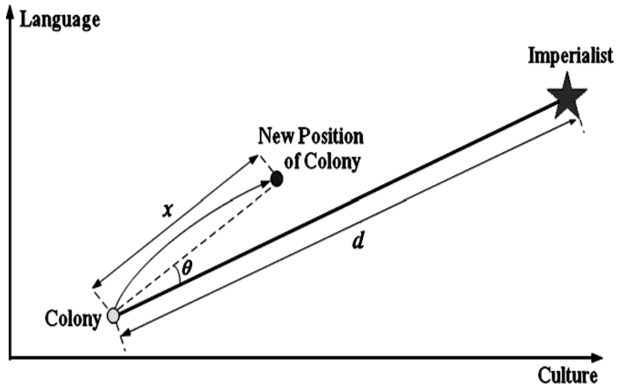

Figure 8. Procedure of the proposed algorithm [41]

In Figure 8, θ is a accidental number with uniform or any proper profile. Then

$$\theta \sim U(-\gamma, \gamma) \quad (6)$$

That γ is a parameter that modifies the deviation from the original direction. However the values of β and γ are arbitrary, in most of our performing a value of about 2 for β and about π/4 (Rad) for γ, have resulted in nice convergence of countries to the global minimum.

PARTICLE SWARM OPTIMIZATION

Particle swarm optimization is a new procedure in solving optimization problems [26]. In this algorithm, there are some things which are called particles and are distributed in the searching space of the function which has to be optimized each particle calculates the amount of the cost function in its own location within the space.

Then, by combining two sets of information of the present location and the best previous location where it used to be, and also, the information of one or some of the best particles of the group, it chooses a direction to move.

This method uses low order relation, which helps the result to converge faster. In this paper, we used violation technique to satisfy the boundary conditions of the problem.

In the PSO method, the motions of the particles are a direct result of adding three components such as global -search, local search, and the previous traveled distance which is multiplied by a set of certain weighting coefficients. In this case, the method to search for the particle could be modified by manipulating the weighting coefficients, but it is better to conduct a wide global search first, and then a local search around the most likely location.

In PSO method, finding optimal weights for faster convergence, accurate space search and better performance is a challenging problem for scientists [27].

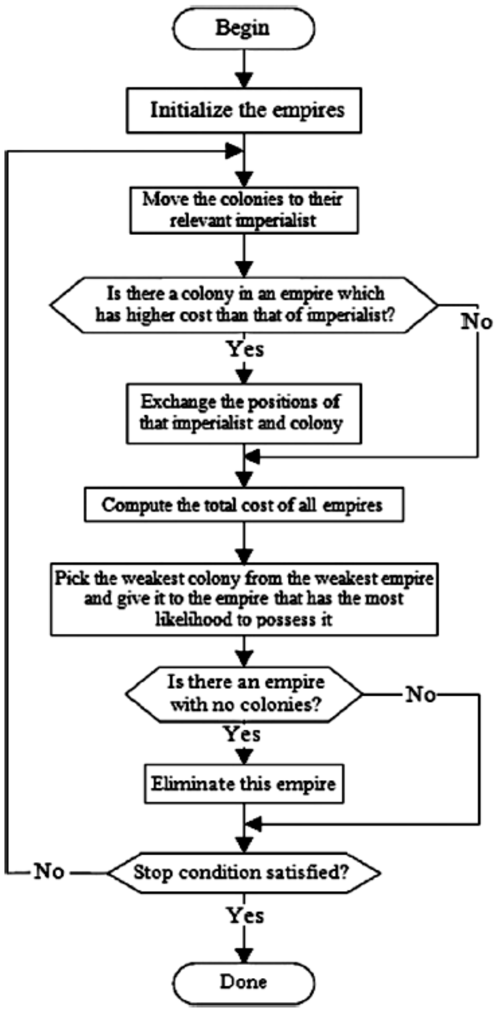

Figure 9. Flowchart of PSO algorithm

This research looks for an optimal arrangement of Single-stage through four-stage thermo-electric generators, taking their operating temperatures into consideration.

Different stages of the system are connected to each other in parallel and in series, and the results of these systems are compared to each other. Bi_2Te_3 is used as the thermoelectric material which is a very useful and practical substance for this application.

DEFINING THE MODEL

Schematic and structural definitions of the model

Structural model of thermoelectric systems is presented in Figure (10):

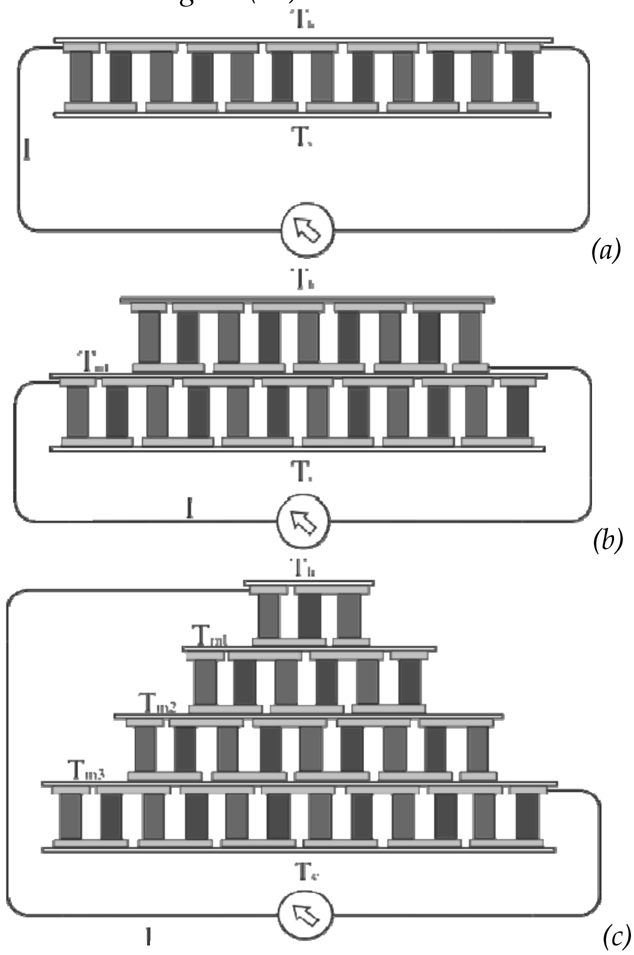

Figure 10. The thermoelectric system,(a) the single-stage system,(b) the two-stage series system, and (c) the four-stage series system

The two-stage series system is composed of two single-stage systems which are on top of one another, connected by a wire in series. This concept of two-stage thermoelectric systems can be extended to four-stage thermoelectric systems, as shown in Figure 10 (c) and.

Structural model of parallel thermoelectric systems is shown in Figure (11).

Multi-stage parallel thermoelectric systems are similar to the series thermoelectric systems with only one difference, which is, the produced power enters the circuit in each stage.

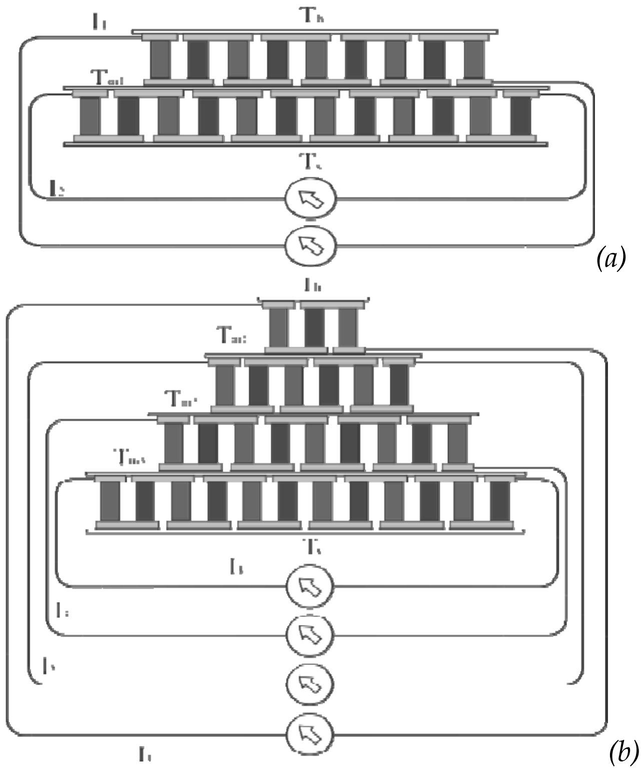

Figure 11. The parallel thermoelectric system, (a) the two-stage system, (b) the four-stage system

Mathematical definition of the model

The system's inlet heat, outlet heat, and work in a single-stage thermoelectric system are calculated using the second law of thermodynamics as follows [28]:

$$Q_{in} = N \, x \, [ST_h I - \frac{1}{2} R_{in} I^2 + K(T_h - T_c)] \quad (7)$$

$$Q_{out} = N \, x \, [ST_C I + \frac{1}{2} R_{in} I^2 + K(T_h - T_c)] \quad (8)$$

The cost functions in this study are the system's efficiency and produced power, which are based on thermodynamic laws. The produced power of the system is calculated as follows:

$$P = Q_{in} - Q_{out} = N \, x \, [SI(T_h - T_c) - RinI^2] \quad (9)$$

Also, the systems efficiency is given by:

$$\eta = \frac{P}{Q_{in}} \quad (10)$$

In order to extend the above equations to multi-stage systems, these equations must be applied to each stage. Considering the thermodynamic condition emphasizing the equivalence of the inlet and outlet heat transfer during each stage, at the end, equations (9) and (10) are applied to the whole system. In this case, the lender coefficient of the thermoelectric couple, are considered to be: G=5 x 10^{-3} [m].

- ✓ *In a parallel two-stage thermoelectric generator, there are five optimization variables as follow: T_m, I_1, I_2, N_1, N_2. In a series two-stage thermoelectric generator, I1 equals I2; as a result, the number of optimization variables reduces to four. Thermodynamic condition in two-stage systems is $Q_{outlet\ from\ stage\ 1} = Q_{inlet\ to\ stage\ 2}$ which should be satisfied during the optimization process.*
- ✓ *In a parallel three-stage thermoelectric system, there are eight optimization variables as follow: T_{m1}, T_{m2}, I_1, I_2, I_3, N_1, N_2, N_3 In a series three-stage thermoelectric system I_1, I_2, and I_3 are equal; as a result, the number of optimization variables reduces to six. Thermodynamic conditions in three-stage systems are $Q_{outlet\ from\ stage\ 1} = Q_{inlet\ to\ stage\ 2}$ and $Q_{outlet\ from\ stage\ 2} = Q_{inlet\ to\ stage3}$ which should be satisfied during the optimization process.*
- ✓ *In a parallel four-stage thermoelectric system, there are eleven optimization variables as follow: T_{m1}, T_{m2}, T_{m3}, I_1, I_2, I_3, N_1, N_2, N_3. In a series four-stage thermoelectric system I_1, I_2, I_3, and I_4 are equal; as a result, the number of optimization variables reduces to eight. Thermodynamic conditions in four-stage systems are $Q_{outlet\ from\ stage\ 1} = Q_{inlet\ to\ stage\ 2}$, $Q_{outlet\ from\ stage\ 2} = Q_{inlet\ to\ stage\ 3}$ and $Q_{outlet\ from\ stage\ 3} = Q_{inlet\ to\ stage\ 4}$ which should be satisfied during the optimization process.*

For example, the equations of entering and exiting heats in a parallel three-stage thermo-electric system are:

$$Q_{1,in} = N_1 x [S_1 T_h I_1 - \frac{1}{2} R_1 I_1^2 + K_1 (T_h - T_{m1})] \quad (11)$$

$$Q_{1,out} = N_1 x [S_1 T_{m1} I_1 - \frac{1}{2} R_1 I_1^2 + K_1 (T_h - T_{m1})] \quad (12)$$

$$Q_{2,in} = N_2 x [S_2 T_{m1} I_2 - \frac{1}{2} R_2 I_2^2 + K_2 (T_{m1} - T_{m2})] \quad (13)$$

$$Q_{2,out} = N_2 x [S_2 T_{m2} I_2 - \frac{1}{2} R_2 I_2^2 + K_2 (T_{m1} - T_{m2})] \quad (14)$$

$$Q_{3,in} = N_3 x [S_3 T_{m2} I_3 - \frac{1}{2} R_3 I_3^2 + K_3 (T_{m2} - T_c)] \quad (15)$$

$$Q_{3,out} = N_3 x [S_3 T_c I_3 - \frac{1}{2} R_3 I_3^2 + K_3 (T_{m2} - T_c)] \quad (16)$$

$$P = Q_{1,\,in} - Q_{3,\,out} \quad (17)$$

$$\eta = \frac{P}{Q_{1,3in}} \quad (18)$$

If we substitute I for I_1, I_2, and I_3 in equations (11) to (16), the equations of a series thermoelectric system could be obtained.

Characteristics of the thermoelectric material Bi_2Te_3 (K, R, S) are available in [29].

In this case, the following equation is used for the number of thermoelectric couples:

$$\sum_{i=1}^{j\ \text{numberofch anges}} N_i = 100 \qquad (19)$$

RESULTS AND DISCUSSION

The obtained mathematical equations presented in mathematical model section were optimized under the specified conditions, and the values of the desired cost function were calculated, and the independent parameters associated with the values were found. Now, the results of series and parallel thermoelectric systems are going to be compared.

Reasons of efficiency and power decrease by increasing temperature

As it was observed from the obtained results, the efficiency (at the temperatures higher than 700K) and the produced power (at temperatures higher than 1000K) decline. The reasons for this behavior will be discussed further.

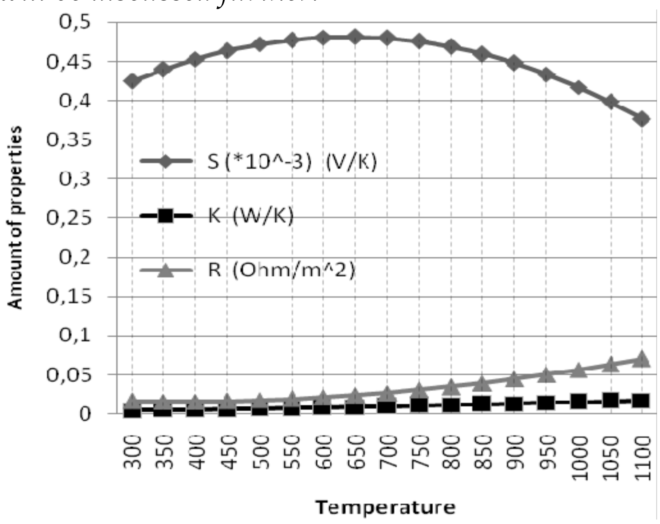

Figure 12. Changes of the characteristics of the thermoelectric material (Bi_2Te_3) with mean temperature of hot surface and cold surface

Thermoelectric properties obtained by using the average temperatures of hot and cold surfaces. From Figure (12), it can be seen that R and K variables ascend as the temperature increases, but the S variable (seebeck coefficient) starts to decrease once the mean temperature exceeds 650K. In solving the governing equations of the inlet and outlet heat and the produced power in a single-stage thermoelectric system (eq (7),(8) and (9)), the K variable is eliminated in the equation, which calculates the produced power.

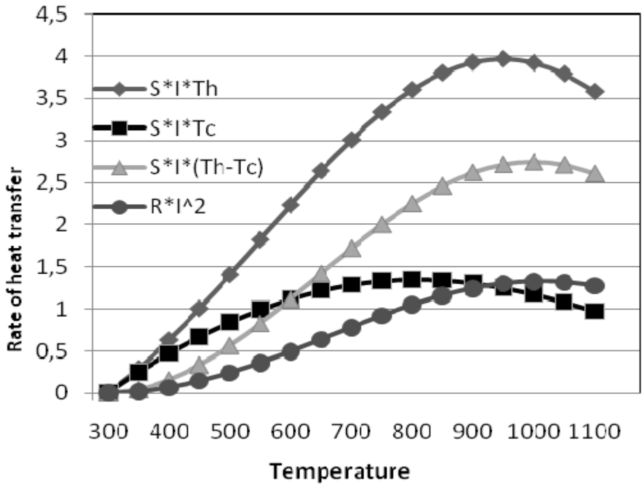

Figure 13. Effect of differences of constituted elements of system on rate of heat transfer

The reason why the produced power decreases at temperatures higher than 1000K is because the seebeck coefficient decreases, resulting in the decrease of the term SI (T_h-T_c).

The ascending behavior of R and the descending behavior of S at mean temperatures above 650K, also have an impact on the rate at which power is produced. As it was mentioned earlier, the efficiency of a thermoelectric system equals eq(10) The numerator of this equation behaves exactly the same as the procedure mentioned in the previous section, but in the denominator, the rate of conductive heat transfer is added to the other effective elements of the system's power.

As it can be seen in figure 12 the K coefficient has ascending behavior with respect to temperature. In addition, the term (T_h-T_c) has ascending behavior as the surface temperature increases; as a result, the amount of the conductive heat transfer dramatically increases which makes the denominator grow faster than the numerator which leads to the decreasing behavior of the efficiency at temperatures above 700K. The same behavior can be observed in multi-stage thermoelectric systems.

However, in multi-stage systems the common part temperature of the stages can be determined in order to decrease the undesired effect of decreasing seebeck coefficient on the ascending heat conduction which leads to lower efficiency.

Not to mention that the descending slope of the efficiency could be decreased as well. It is also worth mentioning that in order to improve the *thermoelectric characteristics of materials, the produced power, the efficiency of the system and the seebeck coefficient should be increased, and the electrical resistance coefficient along with the thermal conductivity should be decreased.*

Optimizing the efficiency of the system

As it can be seen in figure 13, in series thermo-electric systems, the efficiency of the system has approximately the same value in single-, two-, and four-stage thermo-electric systems until the hot surface temperature reach 600K (assuming the cold surface has a temperature of 300K).

However, as the temperature of the hot surface increases beyond 600K, the efficiency of the single-stage system decreases dramatically, and around 1600K, the efficiency and produced power approach zero. On the other hand, in two-, and four-stage thermo-electric systems, although the efficiency decreases at higher temperatures, its slope is far less than that of the single-stage system.

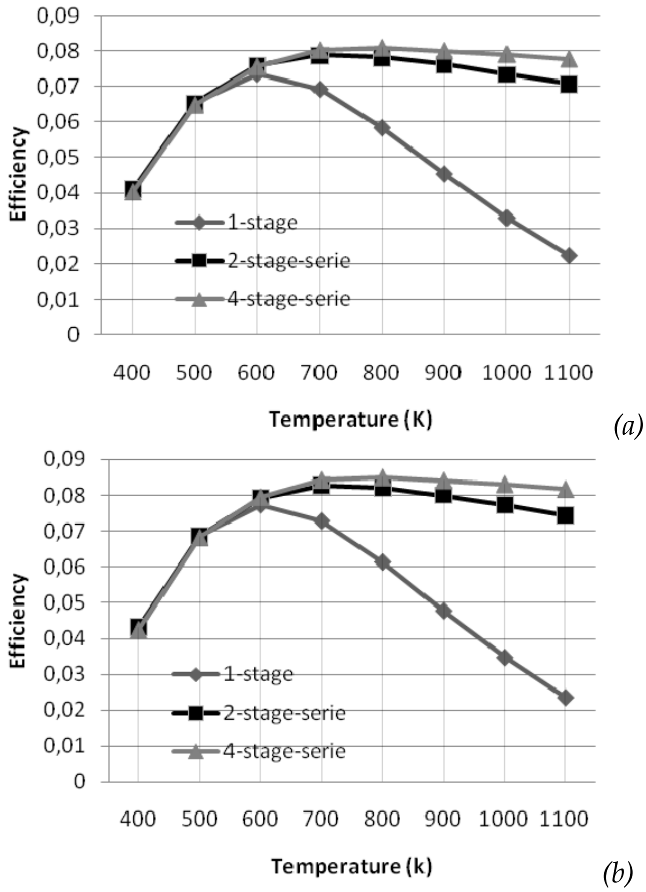

Figure 14. The effect of hot surface's temperature and number of stages in a series thermo-electric system (a) is based on PSO method and (b) is based on ICA method

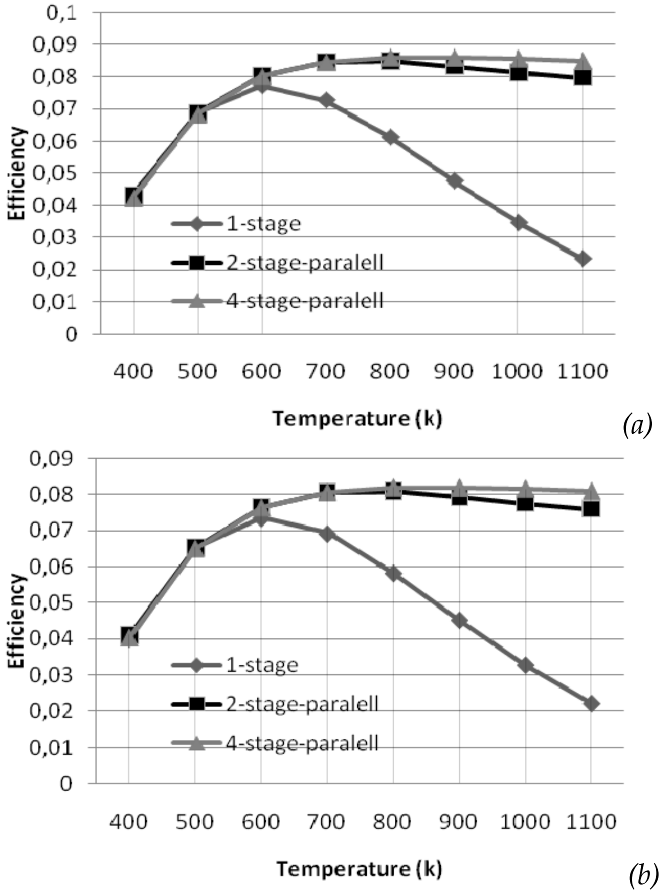

Figure 15. The effect of hot surface's temperature and number of stages in a parallel thermo-electric system (a) is based on PSO method and (b) is based on ICA method

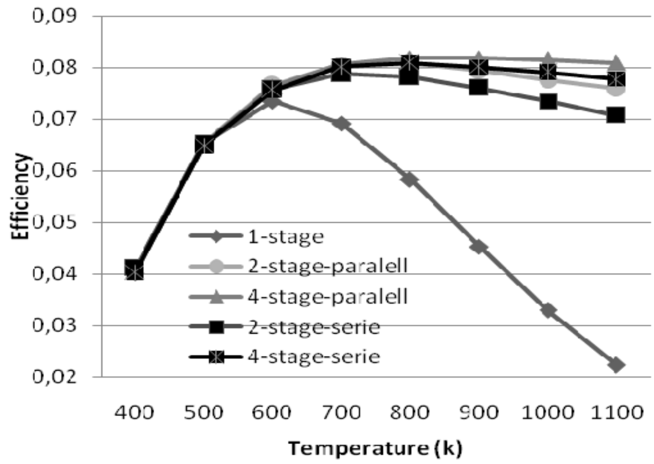

Figure 16. The effect of hot surface's temperature and number of stages in a parallel and series thermo-electric system base on PSO method

By comparing figures (17) and (18), it could be determined that the behavior of the parallel thermo-electric system is highly similar to that of the series system.

Like series thermo-electric systems, in parallel thermo-electric systems, the maximum efficiency is independent of the number of stages till it reaches *the temperature of 600K, but at temperatures higher than 600K, the maximum efficiency in the single-stage thermo-electric decreases dramatically and loses its advantages over the systems with more than one stage.*

It is clear that in multi-stage parallel thermo-electric systems, the efficiency is slightly higher than that of the series systems. By increasing the number of stages, not only the efficiency increase, but also less power is obtained for 100 thermo-electric couples, which is an important advantage of these systems, where we have constraints on space.

Optimizing the generated power of the system

As it is shown in figure 17, the maximum power among the series thermo-electric systems is produced in the single-stage thermo-electric system. Where, as the temperature of the hot surface increases up to 1000K, the produced power has an ascending manner. Beyond 1000K the trend begins to decent. As the number of the stages increases to 2 and higher, the overall amount of produced power decrease, but there is no descending trend until the temperature reaches 1100K.

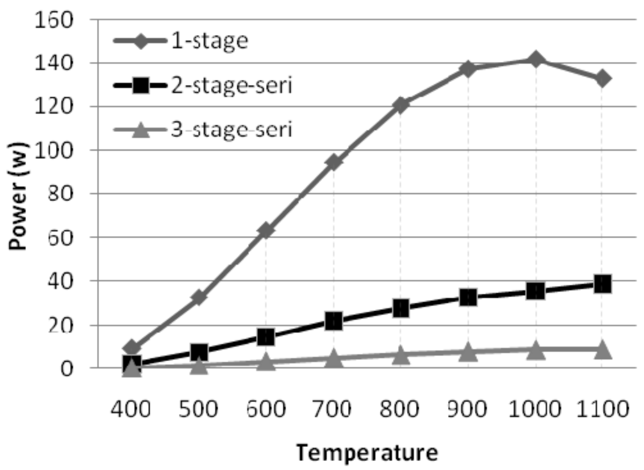

Figure 17. The effect of the hot surface's temperature and the number of stages on the produced power in Watt in series design

During efficiency optimization, the parallel thermo-electric system had a better efficiency respect to the series one. The same result was obtained during produced power optimization. The parallel systems with more stages have a higher produced power slope, than that of the series ones. Therefore, the power produced in a parallel system is significantly higher than that of a series system.

It is worth mentioning that the results are obtained when there are 100 couples of thermo-electric series which are divided between the stages when there are several stages in the system. This distribution of thermo-electric couples among different stages results smaller systems, where this is considered as one of important advantages of these systems.

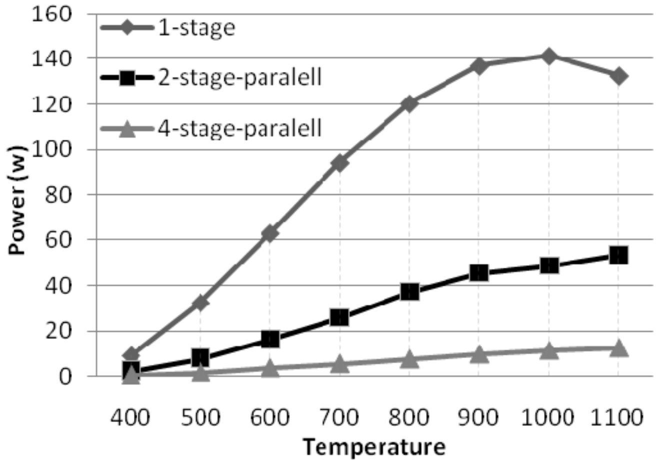

Figure 18. The effect of the hot surface's temperature and the number of stages on the produced power in Watt in parallel design

CONCLUSION

The objective of this study is to find a model of physical and electrical design for thermo-electric systems in order to have the highest efficiency and produced power. Based on the results, the following conclusions are made.

In single-stage systems the hot and cold surface temperatures highly affect the output values of the system; as an example, the efficiency and produced power increase up to 600K and 1000K, respectively.

If the temperature of the hot surface is less than 600K, using single-stage systems is preferred because there is no noticeable difference between the efficiency of a single-stage system and that of a multi-stage system. However, the amount of power produced is higher for a single-stage system. On the other hand, if the temperature exceeds 600K, multi-stage systems have a better efficiency. However, the produced power of a single-stage system will still be higher.

Nevertheless, in multi-stage systems with equal number of couples, sometimes the space occupied is half and in some cases one third of the single-stage system which is important when there is a limitation on the available space.

As it is clear from the results, parallel systems have higher efficiency and produced more power than series systems, and at temperatures higher than 600K, the associate graph has a lower slope in efficiency decrease, so parallel systems have a more stable performance at higher or variable temperatures although this stability does not guarantee the stable output numbers.

The fact that design and control of multi-stage systems, especially parallel ones, is highly complicated and expensive, should be considered when choosing a system. It could be concluded that even under the best conditions, the output efficiency of a parallel multi-stage system is slightly higher than 8 percent which is not a substantial improvement. So using multi-stage thermo-electric systems over single-stage ones is not advantageous, unless there are some limitations on space, or the purpose is to produce little amount of electricity and the typical systems are not affordable. If the usage of a thermo-electric system is desired, the multi-stage parallel systems are the better choice, given the results of this study. However, These systems are far from ideal. Thanks to the improvements in the realm of nanotechnology, there is hope to improve the thermo-electric characteristics of materials such as the Seebeck effect, the Peltier effect, heat conductivity, and electric resistance; as a result, it is possible in the near future that power production systems, solid state cooling and heating systems such as thermo-electric systems will leave the conventional systems behind in both efficiency and power production.

The procedures for optimizing the thermoelectric system are the particle swarm optimization method (PSO) and Imperialist competitive algorithm (ICA) and these two methods is compared with each other in order to calculate the efficiency of thermoelectric system as shown in Figure 14 and Figure 15 the results of these methods for both series and parallel systems are close to each other, but the results of this investigation represent that: ICA method is 5 percent closer to experimental results.

NOMENCLATURE

T_h : Temperature of hot surface
T_c : Temperature of cold surface
T_{m1} : Temperature of surface between stage1 and stage2 at multi-stage systems
T_{m2} : Temperature of surface between stage2 and stage3 at multi-stage systems
T_{m3} : Temperature of surface between stage3 and stage4 at multi-stage systems
S :seebeck coefficient of a thermoelectric circle
R : electric resistance of a thermoelectric circle
k : heat conductivity of a thermoelectric circle
G : slenderness ratio
I : electric current at series systems
I_o : electric current at parallel system at stage(1-4)
N_o: number of thermoelectric circle at stage (1-4)
Q_{in} : inlet heat to system
Q_{out} : outlet heat from system
P : generation power by system
η : efficiency of thermoelectric system

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ISSN:2067-3809