



Energy and Exergy Analysis of a Two-Stage Thermoelectric Used for Heating and Cooling

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ABSTRACT: In the present study a two-stage thermoelectric heater and a two-stage thermoelectric cooler are analyzed and compared from the perspectives of the first and second laws of thermodynamics. Based on the first law analysis results, for both two-stage thermoelectric heater and cooler, the coefficient of performance optimizes by current variation. The optimal value of coefficient of performance decreases with the hot and cold junctions temperature difference increasing. Based on the exergy analysis results, the exergy efficiency optimizes by the current variation same as the coefficient of performance. Moreover, for the case of heating, increasing the hot and cold side's temperature difference increases the exergy efficiency but for the thermoelectric cooler leads to exergy efficiency reduction. Generally, the amount of exergy efficiency for two-stage thermoelectric cooler is lower than that of two-stage thermoelectric heater. Results show that optimum exergy efficiency of two stage thermoelectric heater is 0.181, 0.193 and 0.208 for hot and cold side temperature differences of 15, 30 and 45 K, respectively. Also, the optimum exergy efficiency of two stage thermoelectric cooler is 0.096, 0.073 and 0.04 for the same temperature differences between hot and cold side temperature differences.

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1- Introduction

Using thermoelectric devices is one of the promising technologies in the past years [1]. Thermoelectric devices can be divided into two parts: thermoelectric heater/cooler and thermoelectric generators. In the thermoelectric heater/cooler performance analysis, Peltier effect plays the main role. Based on Peltier effect, the temperature difference can be obtained using electrical current [2]. This temperature difference can be used for heating or cooling purposes. One of the significant advantages of the thermoelectric devices is their noiseless operation with no moving part and maintenance cost which results in a higher life time [3]. One of the considerable problems of thermoelectric heater/cooler is its low value of the coefficient of performance which is the function of semiconductor figure of merit (ZT). Two-stage thermoelectric devices are one of these tries to achieve a better performance for thermoelectrics. As reported in the literature, the lowest temperature for the cold side in a single-stage thermoelectric cooler is 70 degrees lower than the hot side temperature [4] while in a two-stage thermoelectric cooler it can reach to 100 degrees. Therefore, the advantage of a two-stage thermoelectric device can be clarified in compared to the single-stage [5]. In a two-stage thermoelectric two layers of thermocouples are settled in the series thermally. But based on electrical connection, it can be divided into parallel and series types. In series type, the amount of current for both layers is the same but in the parallel, one to different sources with different values of current can be utilized [6]. In recent years, many studies have been done on two-stage thermoelectrics performance improvement. Xuan et al. [7] investigated two different configurations for two-stage thermoelectric coolers.

By comparing cubic and pyramid configurations, they concluded that the performance of these configurations is the same. The optimization of thermocouples arrangement in a two-stage thermoelectric cooler is carried out by Cheng and Shih [8] by a genetic algorithm method. Based on their results, the genetic algorithm has a high capability for optimization of thermoelectric devices. Robles et al. [9] investigated the structure and exergy efficiency of a two-stage thermoelectric cooler. They stated that in the pyramid configuration the best ratio of the first stage thermocouples number to second stage thermocouples number is 8. Chen et al. [10] analyzed a parallel two-stage thermoelectric cooler. They utilized two different electrical sources which applied different values of a current for each stage and found optimal values of the current for each stage.

Based on literature review, there is no comprehensive comparison between the performance of Two-stage Thermoelectric Heater and Cooler (TTEH & TTEC) from the perspective of first and second laws of thermodynamics. To overcome these shortcomings, a two-stage thermoelectric system is modeled as heater and cooler. The coefficient of the performance as a key variable of energy analysis and exergy efficiency as the target of exergy analysis was calculated and compared for both thermoelectric heater and cooler.

2- System Modeling

Fig. 1 indicates the block diagram of a two-stage thermoelectric device which can be used either for heating or cooling implementation. Also, a real two-stage thermoelectric device is shown in Fig. 1. Temperature-dependent properties of Bismuth telluride is used as thermocouple lengths material. Using the first law of thermodynamic, transferred heat in different sections of the bottom and top layers of two-stage

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thermoelectric can be written as follows [11]:

$$Q_{C1} = n(\alpha IT_2 - 0.5RI^2 - K(T_m - T_2)) \quad (1)$$

$$Q_{H1} = n(\alpha IT_m + 0.5RI^2 - K(T_m - T_2)) \quad (2)$$

$$Q_{C2} = m(\alpha IT_m - 0.5RI^2 - K(T_1 - T_m)) \quad (3)$$

$$Q_{H2} = m(\alpha IT_1 + 0.5RI^2 - K(T_1 - T_m)) \quad (4)$$

In equations above, Q_{C1} is the absorbed heat by the first stage and Q_{H2} is the released heat by the second stage of two-stage thermoelectric. Also, T_m is the inter-stage temperature which can be calculated by equating Q_{C2} and Q_{H1} . Consumed power by the two-stage thermoelectric can be written as follows [11]:

$$P_{in} = P_1 + P_2 = (Q_{H1} - Q_{C1}) + (Q_{H2} - Q_{C2}) \quad (5)$$

Using energy balance equations and considering constant values of T_c and T_{hp} , the following equations give T_1 and T_2 [11]:

$$Q_{C1} = U_c A_c (T_c - T_2) \quad (6)$$

$$Q_{H2} = U_h A_h (T_1 - T_h) \quad (7)$$

For the case of TTEH, the value of Q_{H2} is the main target and for the case of TTEC, the value of Q_{C2} is important. Therefore, the Coefficient of Performance (COP) and the second law efficiency for the TTEH and TTEC can be written as follows [11]:

$$COP_{HEATER} = \frac{Q_{H2}}{P_{in}} \quad (8)$$

$$\varepsilon_{HEATER} = \frac{Ex_{Q_{H2}}}{P_{in}} \quad (9)$$

$$COP_{COOLER} = \frac{Q_{C1}}{P_{in}} \quad (10)$$

$$\varepsilon_{COOLER} = \frac{Ex_{Q_{C1}}}{P_{in}} \quad (11)$$

3- Results and Discussion

The simultaneous effects of the current and cold side temperature on the COP are shown in Fig. 2, considering fixed hot side temperature. Referring to Fig. 2, changing the current optimizes the COP of TTEC for all cold side temperatures. Also, the value of maximum COP decreases and takes place in the higher values of the current by decreasing the T_c .

Fig. 3 represents the variation in two-stage thermoelectric heater COP by varying the current in different values of hot side temperature. Referring to Fig. 3, by varying the current and temperature difference between hot and cold junctions, COP of the thermoelectric heater behaves similarly to that of the thermoelectric cooler.

The influence of T_c and current on the exergy efficiency of the two-stage thermoelectric cooler is depicted in Fig. 4. Similar to the coefficient of the performance, the exergy efficiency is optimized by the current variation. As can be seen, reducing T_c decreases the maximized exergy efficiency of the thermoelectric cooler. Also, by increasing temperature difference between hot and cold sides, maximum exergy efficiency takes place in higher amounts of current.

Fig. 5 illustrates the exergy efficiency variation of the thermoelectric heater by the change in the current for different values of T_{hp} . Referring to Fig. 5, opposite to the

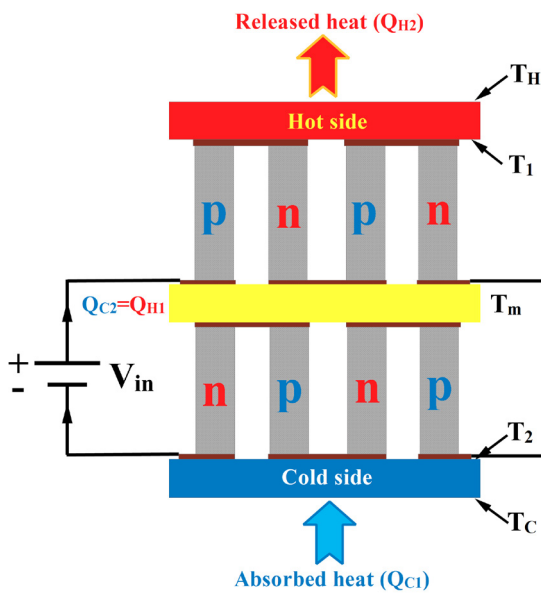


Figure 1. Schematic diagram of the two-stage thermoelectric device

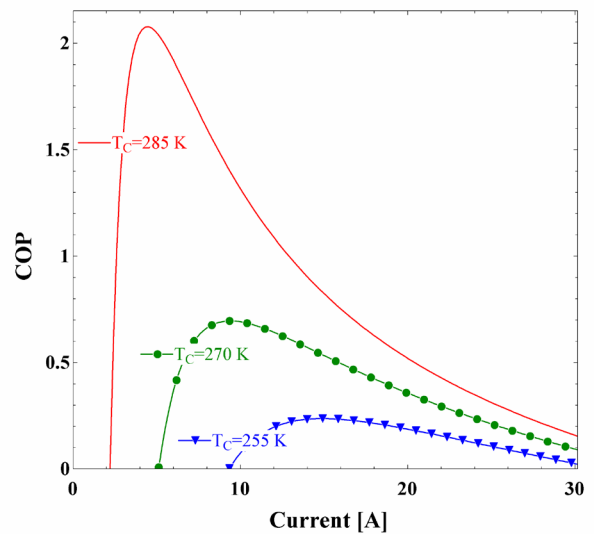


Figure 2. COP of two-stage thermoelectric cooler versus current in different values of T_c

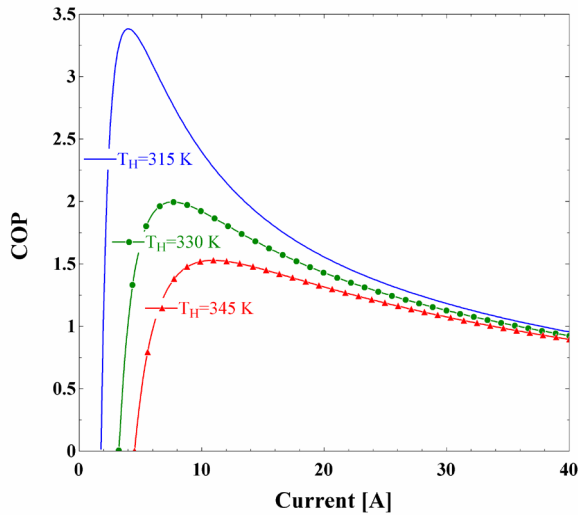


Figure 3. COP of two-stage thermoelectric heater versus current in different values of T_H

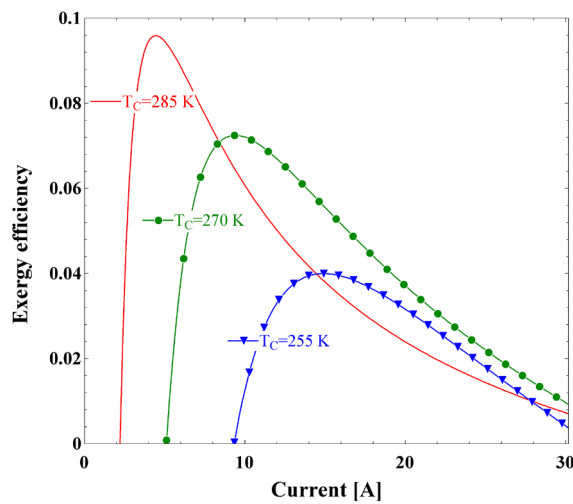


Figure 4. Exergy efficiency of two-stage thermoelectric cooler versus current in different values of T_C

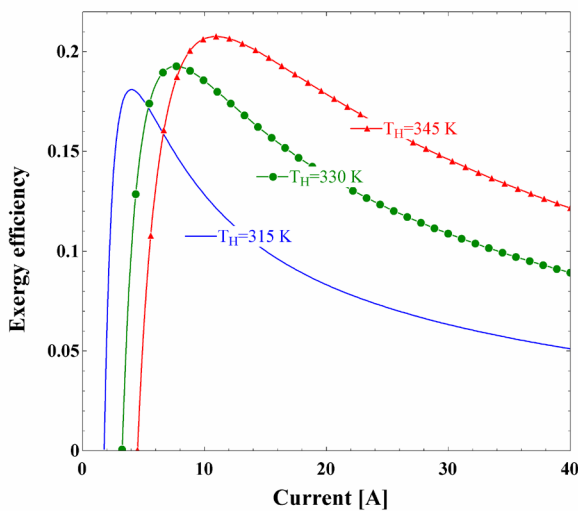


Figure 5. Exergy efficiency of two-stage thermoelectric heater versus current in different values of T_H

thermoelectric cooler, increasing the temperature difference between hot and cold junctions of the thermoelectric device increases the exergy efficiency of thermoelectric heater.

4- Conclusions

The main obtained results are as follows:

- In both TTEC and TTEH, COP and exergy efficiency are maximized by the current variation.
- By increasing the temperature difference between hot and cold sides, the value of optimum current increases.
- Exergy efficiency in TTEH increases and decreases by increasing the temperature difference between hot and cold sides, respectively.
- Increasing the hot side temperature in the TTEH and decreasing the cold side temperature in the TTEC decreases the value of COP.
- The value of COP and exergy is higher than that of TTEC for the same temperature differences in the same range of current.

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