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Peltier Effect in Waste Heat Reclamation

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I am David Walden. I am currently pursuing technologies that act in a way that is modular. These technologies would remove the need for high interdependence between entities such as people, states, and countries. It my vision that by implementing such technology we can allow for more people to experience greater freedom without detriment to the global environment. This is my guiding principle for the various research topics I seek to explore.

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Dr. Issa is a professor of Mechanical Engineering at West Texas A&M University. He joined the School of Engineering, Computer Science and Mathematics in 2004. His background is in the area of thermal-fluid sciences, particularly in single and multi-phase heat transfer. He received his B.S. and M.S. degrees in Mechanical Engineering from University of Tennessee, Knoxville, and Ph.D. degree in Mechanical Engineering from University of Pittsburgh. Dr. Issa has 4 years of prior work experience in the aerospace industry and 8 years of experience in the steel rolling industry. His work experience in the aerospace industry included lift-off load studies on the shuttle system, assembly of space station Freedom, hydraulic line model developments of the thrust vector control system, and robot programming for foam and paint stripping of the SRB tunnel covers. While working in the steel industry, he conducted extensive studies on the cooling of rolls and flat products in the hot strip mill, and mill torsional vibration and torque amplification studies. He is a co-inventor on a US patent on the rolling of flat products. His academic activities focus on conducting research in areas that are important to the industry but is fundamental in nature such as using multiphase (air-mist) cooling in the quenching of metals for the steel industry, tempering of glass for the auto industry, and chilling of beef carcasses for the meat processing industry. In addition, he has conducted studies on sustainable energy systems such as wind towers for indoor cooling, green roofs, active solar distillation systems, and the incorporation of phase change materials in conventional building walls. His recent studies focused on the enhancement of the thermal transport in heat exchanger systems using nanofluids. Dr. Issa is an author and co-author of over 50 journal and conference papers in the area of heat transfer and fluid dynamics. He was selected as a Fulbright Scholar to Austria in 2016.

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Session XXXX

Thermoelectric Generation in Waste Heat Recovery Methods

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Abstract

Thermoelectric generators (TEGs) use the Seebeck effect to transform thermal flow into electrical potential, have no moving parts, are low maintenance, have a long material life, and can be readily serviced. These observations of the operations of TEG cladded insulation could act as a new energy recovery technology. To confirm this concept a thermal electric system was designed and tested. The system made use of a cubical structure with four walls embedded with four thermoelectric generators, and a top wall that is just a plywood cover. This produced our base line system with no additional considerations. The second design was a system with a new top plate which consisted of insulation and the plywood. An ideal outcome of this experimental would be defined by a few characteristics that can be measured. The first would be an increase in the average temperature of the whole the system. This was approached by computing internal energy of the parts at their corresponding temperatures and volume. These values do trend higher than the baseline case and proves that introduction of more material would indeed impact the internal energy which also implies that we could remove other material and return to the initial operation in spite of the added insulator. The second characteristic is defined by a new increase in the TEG performance this would be signified by computing the energy losses and comparing these losses to the power generation. This is best approached by utilizing a quasi-steady state conditions and by treating each time interval as its own event the trend can be seen as a function of temperature. This showed that there was a notable improvement of power generation across the system. While the results show promise and show a clear divergence in a positive direction over a large number of data sets a lot of work can be done moving forward. Further, the potential for this project is heavily based upon the concept of utilizing an approach to energy that hopes to diversify our methods of energy production. The advantages of this system are that in comparison to other methods it works with marginal difference of temperature across the boundary of TEG element will still result in a net power generation that is small. The data shows that at small temperature difference, approximate 25˚C, will result in approximately 3 mW of energy. The modified system performed at closer to 4 mW of energy. These values, while marginal, are produced by devices that are about the width and half the length of your debit card and a thickness that is similar to a thin wallet. Further research would be best directed towards moving beyond the limitations placed on the physical geometries of the devices and also optimization of the energy generation electrical system.

Introduction

In both industrial and residential energy concerns, waste heat often accounts for largest percentage of energy. Thermoelectric generators (TEGs) are a useful semiconductor device based upon a phenomenon called the Seebeck effect. This effect is part of a larger relationship called the Thermoelectric effect, which connects the contributions of William Thomson, Johann Seebeck and Jean Peltier[1]. The TEGs convert thermal temperature gradients in heat flux across boundary cause work to be done on electrons. This work produces electrical potential, which can be used in a way that is almost synonymous with a battery. Thermoelectric generators are solid-state devices that do not require any fluids for fuel or cooling, making them non-orientation dependent allowing for use in zero-gravity, deep-sea applications[2], and other places that are often not associated with such electrical generation. This is achieved while also reducing the probability of failure associated with mechanical systems. This flexible application caused by these properties allows for TEGs to be used in a variety of different applications. This applies specifically in industrial energy conservation practices due to the outsized heat losses. This approach also generates a potential for hybridized systems in which heat losses can be used to improve the efficiency of the system without modifying its standard operation. The option to use the energy and to some degree isolate the plant operation from the main line operation[3] is viable one, and the other alternatives, such as finding other uses for the recaptured energy is also feasible. There are several obstacles when trying to rectify the waste heat phenomenon with the standard approaches such as:

- Temperature limits and costs of recovery equipment.
- Most unrecovered waste heat is at lower temperatures (thus lower temperature difference).
- Losses from nontraditional waste heat sources are difficult to recover, but significant.

The generators seem tailor made to address some of those heat loss phenomena. TEGs are often seen as novelty but are assumed to lack practical application. This misconception is derived from a low maximum theoretical efficiency which is 5.4% of the Wattage of the heat losses. This tends to prevent further discussion in the energy market. This obscures the flexibility of the devices and the various ways they can be utilized. This flexibility manifested in a document that approached looking at purely the power generation from piping[3]. Thus, using advanced fluids concepts an a more advanced insulation could be designed to promote heat transfer through specific regions. This would create a tertiary energy system built off the heat exchanges of large more efficient systems with the surrounding thereby reducing the total energy loss and improving the efficiency. This study hopes to build on the further knowledge by focusing the attention on modifying current system designs to put emphasis on manipulating the heat movement. The question that we hope to answer is can a system be modified in such a way to increase the power generation of the TEGs.

Theoretical Approach

The heat flux through the system can be manipulated using the thermal resistance equation analog. The chamber consists of four vertical walls and one cap horizontal wall. The prediction of the energy flow free body diagram of the two systems to be observed is seen below in Figure 1.

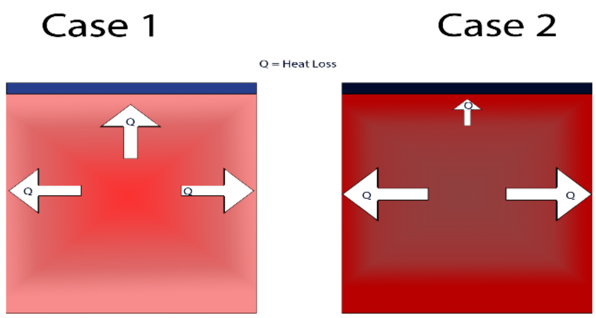


Figure 1 Left Standard System-with lower internal Temperature.

The magnitude of the thermal flux is denoted by the size of the arrows. Case 1 shows a standard distribution through the wall. This is analogous with a baseline case without any additional design considerations. Case 2 will see decreased heat transfer through the top of the apparatus by adding insulation. This will raise the internal energy which will add an increase to power but will also results in targeted heat losses. If these two events both exist, it can be said with certainty that this proves the effectiveness of this scenarios also would predict an improvement in the performance thermoelectric generation performance. This hypothesis will allow for a targeted heat transfer which will force heat through the TEGS at a higher rate to achieve reasonably close to original operational conditions. If and only if this is true can it also be asserted that if a system is modified to create thermal energy channels a higher net efficiency is achieved. If the hypothesis proves to be correct by indicating an increase of output, then it could be optimized further. The thermal-electric energy conversion is a tensor equation[4], however, a simplified form exist. First by applying the thermodynamic principles[5] and the assumption of 1-dimensional heat transfer. Equation 1 is achieved and through a series of assumptions, The Figure of Merit, equation 2, is a 1/°C (1/K) quantity.

$$\dot{Q} = \alpha T_h I - \frac{1}{2} I R_{th}^2 + K \Delta T \tag{1}$$

$$Z = \frac{\alpha^2}{k\rho} \tag{2}$$

The most important measure of success for a material in thermoelectric technology is the Figure of Merit [3][5][6] and specifically the Seebeck Coefficient, α, used in its computation. In equations one the K is actually defined a conducting mass in which the entirety of a system is nested. This further suggest that within the heat loss terms that they can be manipulated to cause an outsized effect on the system itself. The problem when we consider the approach occurs in that the internal energy of the system is proportional to average temperature, which is done as a simplification, and this is shown in equation 3.

$$E_{stored} = \rho V C_v T_{avg} \tag{3}$$

When Used in conjunction with Equation 1 we can use it to change impact the Seebeck coefficient and would work as a function of modification of the K value. This is commonly asserted with accepted lecture material for these materials. This, however, states that by making changes to the thermal conductance you are actually lowering the ability for thermal flux to occur, but when you our observing a complexed system the losses can be manipulated. This would be achieved by removing some of the insulation and replace these small areas with generators. Then adding the appropriate amount of insulation to offset the regions of heat flow that have been introduced. This would create a cladding with embedded TEGs while not diverging from the normal industrial operations.

Simulations

To avoid the computational difficulty associated with the computations, SIMULINK, a simulation software, was utilized to perform the two test cases a screen shot of the test cases is shown in Figure 2.

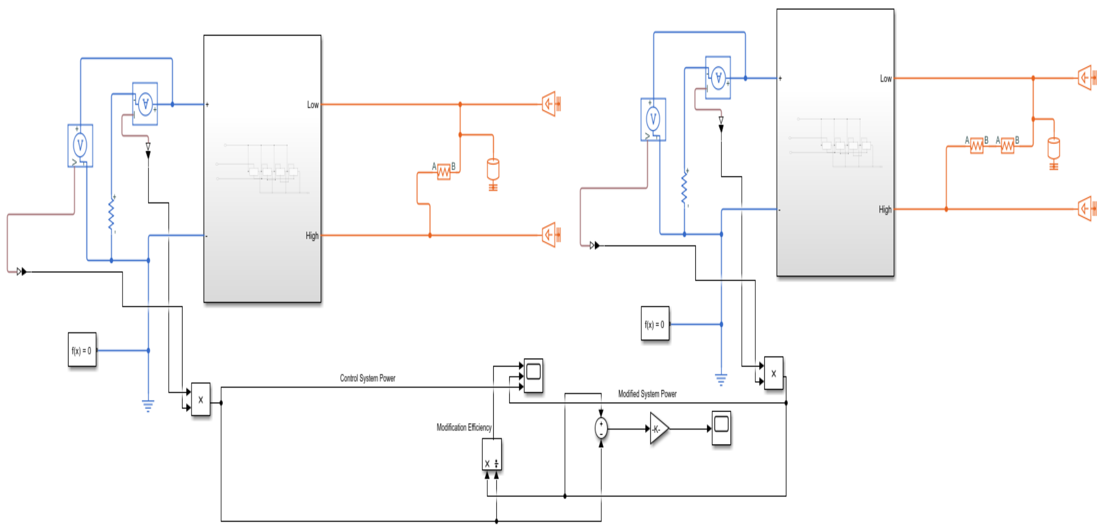


Figure 2. Simulation Set-up of Standard System(left) and Modified Insulated System(right).

The left side is single element and would symbolize your standard system with just a cladded insulation system. If you do not correct for the presence of the TEG's the system will operate at a lower temperature. The right model is the modified system and uses insulation on the side absent generators. This should increase the internal temperature would show an increase in the internal energy. This would be easiest to see by observing if there is a power increase. These are based on a steady state operating condition.

The simulation results at steady state conditions of the shows and improvement over the simple system of just over 5%. This outcome justifies further a physical experiment to confirm practical application.

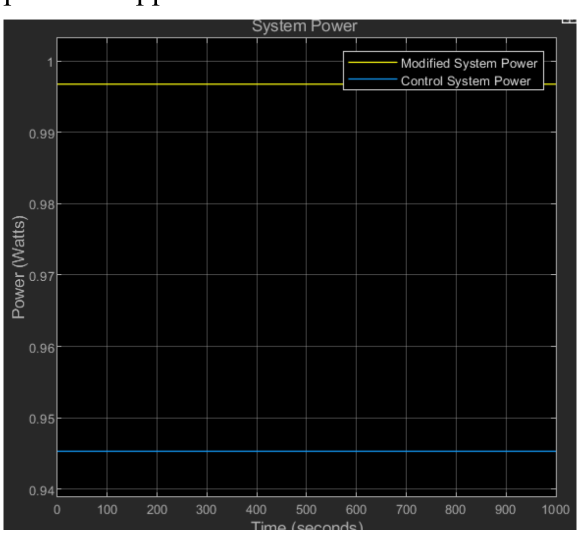


Figure 4. Power Generation Chart

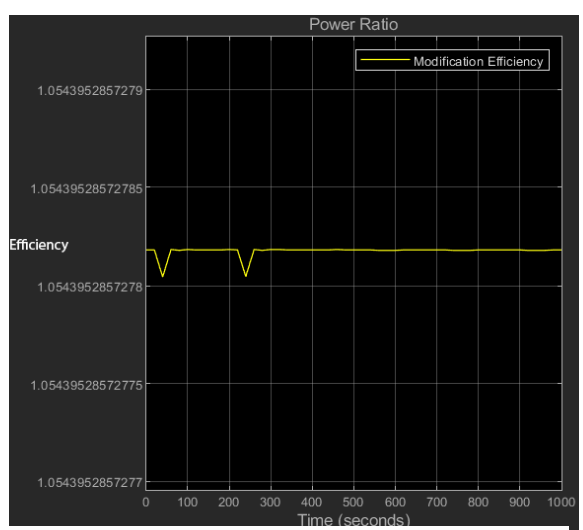
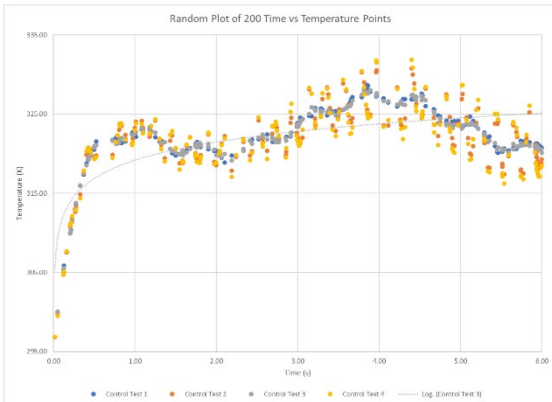


Figure 3 Power generation Efficiency

Experimental Results

Using a data logger, the internal external temperature was tracked, and the electrical power generation of each tile was measured. The average internal temperature of the system was tracked using several data sets these sets performed consistently with only slight data noise being of large concern. In Figure 5 and Figure 6 the resulting plots of a random set was generated from the data sets of 3 hours of 0.25 second time steps.

Figure 6. Control System Temperature Plot



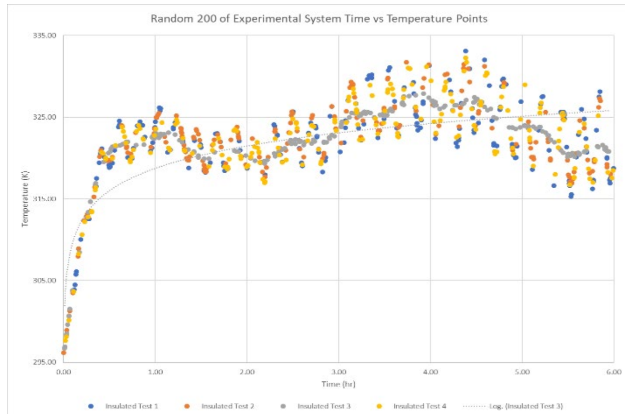


Figure 5 Insulated System Temperature Plot

The next consideration had to do with the with internal energy, using the required material properties[9][3][6]. This resulted in very marginal values and had almost the correlation to the results were only related through the heat loss and heat gains.

To track that models do assert a difference between the logarithmic regression lines are used to present a simple case so as not over represent the phenomenon. It is seen that this result does provide a divergence from the standard power generation of Case 1, shown in Figure 7 below. The values at the first peaks shows an ~4mW and ~5mW for Case 1 and Case 2 respectively.

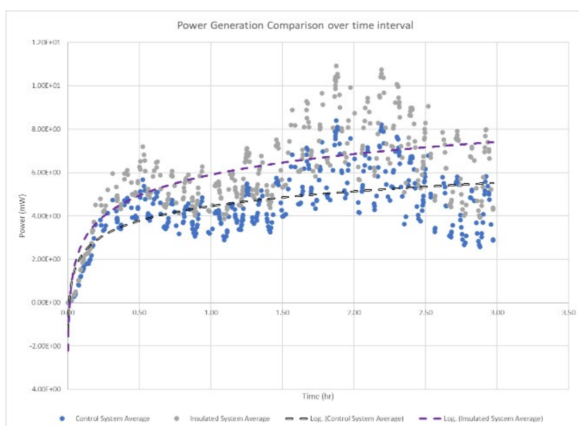


Figure 7 Power Generation of Case 1 and Case 2

Summary and Conclusions

Based upon the data sets and the theoretical considerations, the hypothesis does appear to have basis in practical application. This, however, is only a rudimentary approach. To further solidify such an assertion additional test and approaches should be considered. One consideration would be to promote additional heat transfer through the generators using a heat sink on the TEGS. This would increase the surface area interacting with surrounding thus allows for an increase in the heat exchange. Using the insulation equivalent to offset the increase in the conductivity of the system. This research hopes to give groundwork for more complexed cases for future research. These complicated cases could involve highly advanced and versatile TEGs, such as flexible TEGs[7], micro[8], and nano[4] TEGs. These advanced devices would allow for the optimization of ratio of generators versus insulation. If optimized further the power generation could be increased which was shown to be ~3mW and ~4mW for case 1 and case 2. This could be further increase and may prove it to be economically feasible. In the future, a more precise model using logarithmic regression is being pursued with the current data set. Using the regression model, this technology and approach can be easily adopted without many logistical problems thus promoting its implementation.

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