International Conference on Mechanical, Industrial and Materials Engineering 2024
(ICMIME2024)11-13 December, 2024, RUET, Rajshahi-6204, Bangladesh

Paper ID: 99

Mitigating Global Warming by Waste Heat Recovery from a Brick Kiln to Enhance Thermoelectric Generation

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Abstract

The brick kiln is among the biggest releasers of greenhouse gases, which contributes to global warming. The study investigates the use of thermoelectric generation to produce electricity from the heat generated by the kilns, which can reduce greenhouse gas emissions and provide a renewable energy source. Approximately 10 percent of the heat energy may be turned into electricity via thermoelectric generators. Zigzag brick kilns produce less greenhouse gas than other kilns. In this paper, the heat loss of a brick kiln is calculated while some steps taken to model a thermoelectric waste heat harvesting prototype using SOLIDWORKS and calculate the data using COMSOL Multiphysics Finite Element Analysis Software. In this study ,it is shown almost more than 60% of heat input is lost in the brick kilns during production of 100,000 bricks. Efficiency of a TEG is 5.85% if the average temperature difference remain 290 ºC. This paper tried to improve the TEG technology so that it can be possible to have maximum energy production from a brick kiln and mitigate global warming. Ultimately, this work aims to elevate the dependency on renewable energy, reducing greenhouse gas emissions, improve the typical brick kilns.

Keywords: Thermoelectric Generator (TEG), Brick kilns, COMSOL Multiphysics.

1. Introduction

Brick kilns are significant sources of waste heat, with over 50% of energy lost during coal combustion, which typically consumes 1.3–1.4 tons of coal daily and requires 28,000 MJ per ton burned [1]. This waste heat, defined as thermal energy that does not perform useful work, becomes increasingly difficult to recover as it dissipates into the environment. Effective assessment and design of waste heat recovery systems are crucial to mitigate global warming and resource scarcity, as brick kilns produce substantial CO_2 emissions. Implementing these systems can reduce manufacturing costs and enhance resource conservation, contributing to environmental protection efforts.

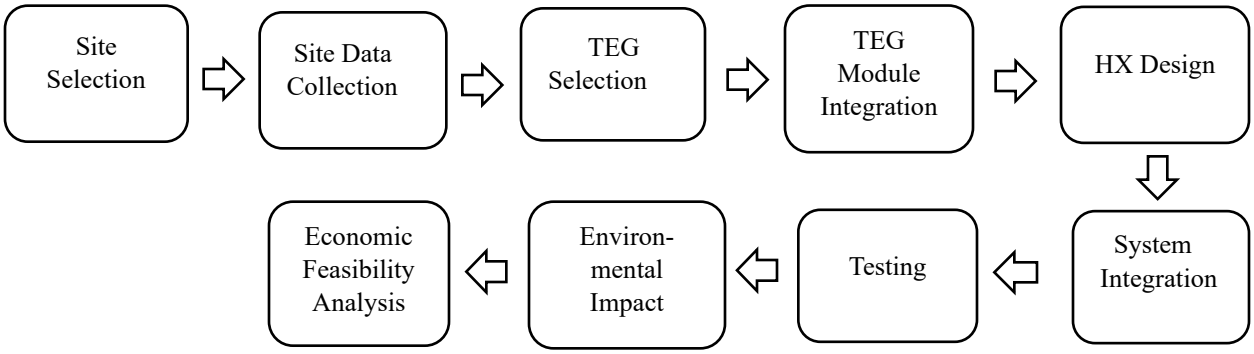
Table 1: Fuel consumption, particulate emission and co2 emission for different brick kiln technologies.[2]

Technology	Fuel Consumption (tons of coal per 100,000 bricks)	Particulate Emission (mg/m^3)	CO2 Emission (tons per 100,000 bricks)
Fixed Chimney Kiln (FCK)	20-25	141 ± 86	3.8
Zigzag Kiln	8-10	128 ± 72	4.2
Hoffmann Kiln	8-10	110 ± 53	3.5-4.0
Tunnel Kiln	5-7	50-100	2.5-3.0
Vertical Shaft Kiln (VSK)	4-6	20-50	2.0-2.5

Thermoelectric generators (TEGs) have gained significant attention as sustainable energy solutions, particularly for converting waste heat into electricity. Utilizing semiconducting materials, TEGs generate electric current when subjected to a temperature gradient, making them suitable for applications such as waste heat recovery, portable power generation, and energy harvesting [3]. Historically, brick kilns have relied on outdated technologies, with the "Clamp kiln" being the earliest form of brick-burning technology. TEGs, which consist of thermocouples made from different semiconductor materials, convert heat into electricity with minimal emissions, thereby reducing reliance on fossil fuels. Initially used in the 1970s by NASA for space applications, TEGs have since expanded into various industrial

sectors for waste heat recovery [4]. Incredibly, TEG applications range from high to small scale in industries. TEG has recently been used to recover energy from the human body [5-6]. This study aims to design and simulate a TEG-based waste heat recovery prototype for brick kilns, identify optimal installation points, analyze functionality, and evaluate economic feasibility.

2.Methodology



2.1 Site selection

When selecting a location for waste heat recovery from brick kilns, it's important to choose kilns that are typical of those used in the region to ensure that the study is relevant and useful.



Fig 1: Inside the brick kiln

A)	B)	C) & D)
Knil upper surface	Inside the Furnace	Blower Pathway

2.2 Site data collection

Table 2: Collected data from the site of brick kilns

Parameter	Value
Fuel	Bituminous coal
Firing stage	Full firing
Temperature (ambient)	25°C (77°F)
Wind speed	2.4 m/s (5.3 mph)
Humidity	0.6
Kiln design	Hoffmann kiln

Parameter	Value
Firing chamber	1200°C (2192°F)
Upper kiln walls	800-1000°C (1472-1832°F)
Lower kiln walls	500-700°C (932-1292°F)
Blower pathway	400-600°C (752-1112°F)
Heat flux (average)	500-700 W/m²

2.3 TEG selection

Because of high power and high thermal flow density across the area, TEG (TE-MOD-18W9V-56 from TEG pro) was used in this study.

Table 3: Thermoelectrical module specifications

Specification	Value	Units
Hot side temperature (Th)	320	°C
Cold side temperature (Tc)	28	°C
Heat flow density (Q')	18	W/cm²
Thermal conductivity (k)	1.5	W/m-K
Open circuit voltage (Voc)	9	VDC
AC resistance (Rac)	2.5	ohms
Electrical resistivity (ρ)	1.25 x 10^{-5}	ohm-m
Figure of merit (ZT)	1.2	-
See-Beck coefficient (α)	250	μV/K

2.4 Heat exchanger design

The task is to create a heat exchanger that is capable of efficiently capturing waste heat from the exhaust gases of a brick kiln. The design needs to be optimized to maximize its heat transfer surface area and enhance its overall thermal efficiency.

Table 4: Heat sink parameters

Part	Value	Unit
Heat sink base	42×42×1.5	mm
Fins	1×42×14	mm
Number of fins	14	-
h	2073571.628	W/(m2 .K)

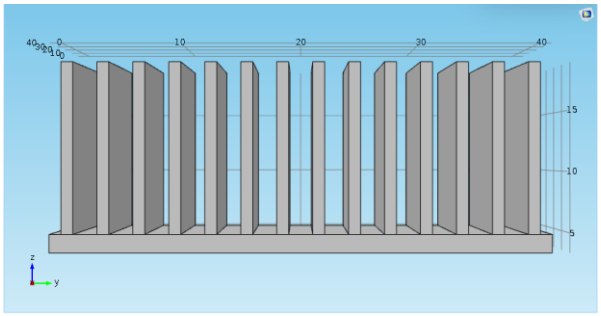


Fig 2: Heat exchanger designed with COMSOL

2.5 System integration

Initially, different parts of the thermoelectric generator prototype were designed using SOLIDWORKS software, employing the general measurements obtained from the market. It consists of a Heat sink from which is made of aluminum, a heat source that is fin and four thermoelectric module.

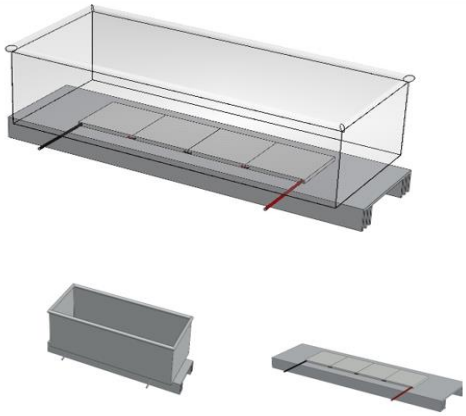


Fig 3: SOLIDWORKS model of the prototype

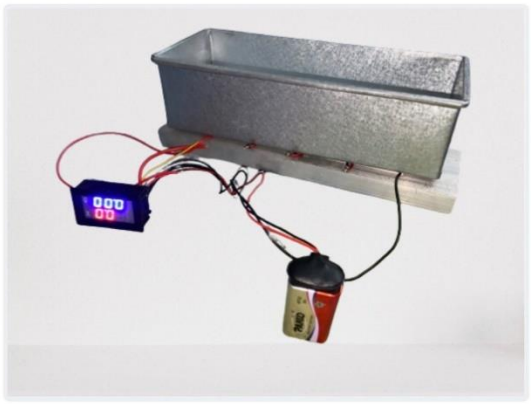


Fig 4: Set up of the prototype

2.6 Performance testing

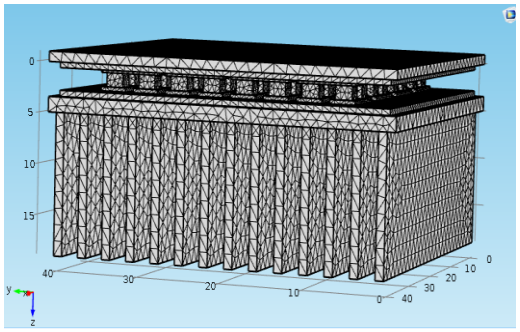


Fig 5: Meshing in COMSOL

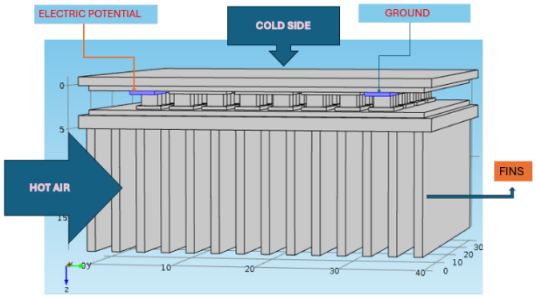


Fig 6: 3D model in COMSOL

3. Results And Discussion

The primary objective of this study is to investigate the viability of implementing Thermoelectric Generators (TEG) for harnessing waste heat in brick kilns by using the TEG systems for water cooling. Finding the energy loss in the brick kilns, analyzing the data of COMSOL simulation, the comparison of theoretical and simulation values, such as load resistance, voltage, current, and power over time, to capture system stability was investigated in this research.

3.1 Calculated waste of energy in brick kilns in percentage

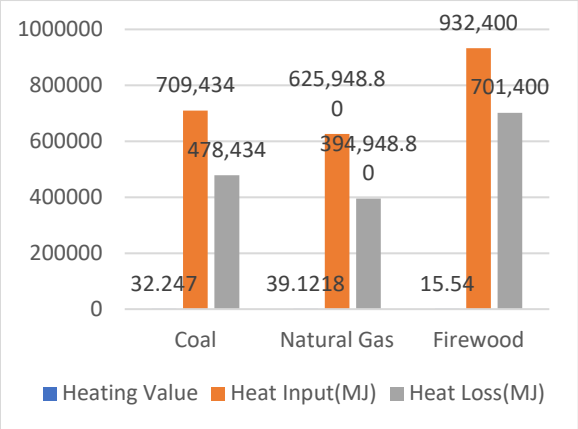


Fig 7: Graphical representation of heat loss for different types of fuel.

Table 5: Waste of energy in brick kilns in percentage

Fuel Type	Heating Value	Heat Input(MJ)	Heat Loss(MJ)	Percentage Heat Loss(%)
Coal	32.247 MJ/kg	709,434	478,434	67.44
Natural Gas	39.1218 MJ/m^3	625,948.8	394,948.8	63.1
Firewood	15.54 MJ/kg	932,400	701,400	75.22

3.2 COMSOL Temp Analysis

The maximum surface temperature on the hot side and the minimum surface temperature on the cool side of the TEG modules were recorded from the COMSOL simulation. The TEG modules are numbered sequentially from left to right, with modules 1 through 4 located on the top row and measured temperatures are given in table 6.

Table 6: Temperature measurements on TEG modules

TEG Module	Thot (°C)	Tcool (°C)	ΔT (°C)
1	213.5	35.8	177.7
2	208.6	38.65	169.95
3	211.74	38.11	173.63
4	209.48	36.17	173.31

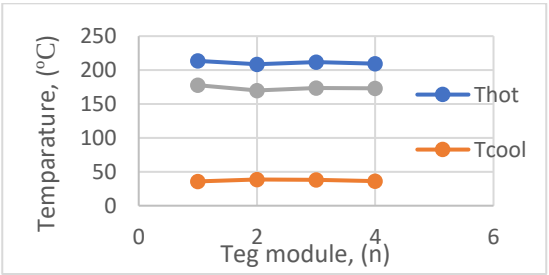


Fig 8: Graphical representation COMSOL temperature readings

3.3 COMSOL Power Analysis

There is taken some subsequent analysis is taken focused on the potential electrical output of the TEG modules, referencing Howard [7],here collected multiple voltage and current measurements from experimental trials. At first, the modules were configured in series, paired with a load resistor ($R_{(load)}$). To ensure their performance metrics Howard [7] conducted characterization tests on individual TEG modules. To determine their open-circuit voltage (V_{oc}) and internal equivalent resistance (R_{re}), each module was tested using a hot plate. Voltage and Resistance are also expressed as functions of the temperature difference (ΔT) across the module, as depicted in Equations 1 and 2,

V_{oc}= 0.0187 T_{diff} − 0.0051 ----------(1)

R_{re} = 0.0078 T_{diff} + 2.1829 ----------(2)

Each TEG module is like a battery with internal resistance. As with the experimental measurements, the open-circuit voltages and internal resistances for each module can be calculated based on their respective temperature differentials. According to Kirchhoff's loop rule,

$\sum V = 0 = V_{oc\text{-}TEG1} - IR_{eq\text{-}TEG1} + V_{oc\text{-}TEG2} - IR_{eq\text{-}TEG2} + V_{oc\text{-}TEG3} - IR_{eq\text{-}TEG3} + V_{oc\text{-}TEG4} - IR_{eq\text{-}TEG4} - IR_{load}$ ----------(3)

Load current, I_{load}, can be calculated from Equation 3,

$$I_{load}=I=\frac{\sum_{i=1}^{4} V_{oci}}{R_{oad}+\sum_{i=1}^{4} \mathrm{Re}qi} \text{ ----------(4)}$$

The load voltage can be calculated via Ohm's Law in Equation 6, and the power can be calculated across the load resistor, as shown in Equation 6.

$V_{load}=I_{load}R_{load}$ ----------(5)

$P = I_{load}V_{load}$ ----------(6)

While wired in series TEG modules placement is trivial, as the generated open-circuit voltages and internal resistances depend on the differential temperatures of each module only.

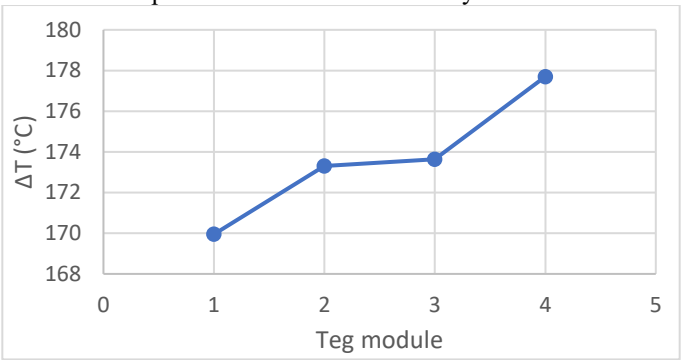


Fig 9: Differential temperature of the experimental data and the simulation values.

Load resistance values, theoretical voltage, current and power values were derived from the simulated differential temperatures by using Equations 1 to 6, as shown in table 8. The incompatibility between the theoretical values and the values from the COMSOL model are illustrated in Figures 10 and 11.

Table 7: Theoretical values from COSMOL.

$R_{(load)}$ (Ω)	$V_{(load)}$ (V)	$I_{(load)}$ (A)	Power (W)
1.00	0.856	0.856	0.733
10.00	5.37	0.537	2.884
20.00	7.58	0.379	2.873
33.00	9.075	0.275	2.496
47.00	9.964	0.212	2.112
55.00	10.313	0.188	1.934

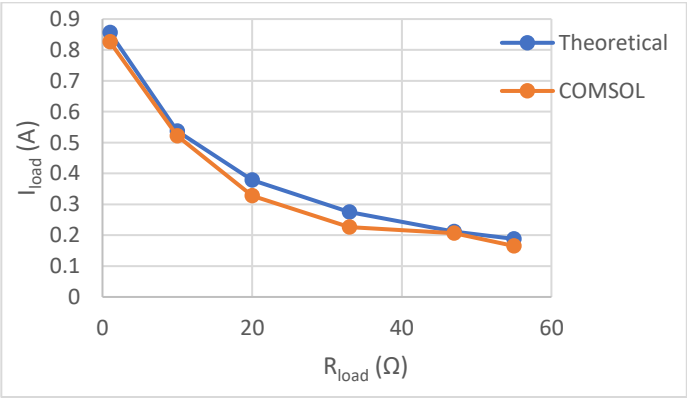


Fig 10: Current Vs. Load Resistance theoretical values

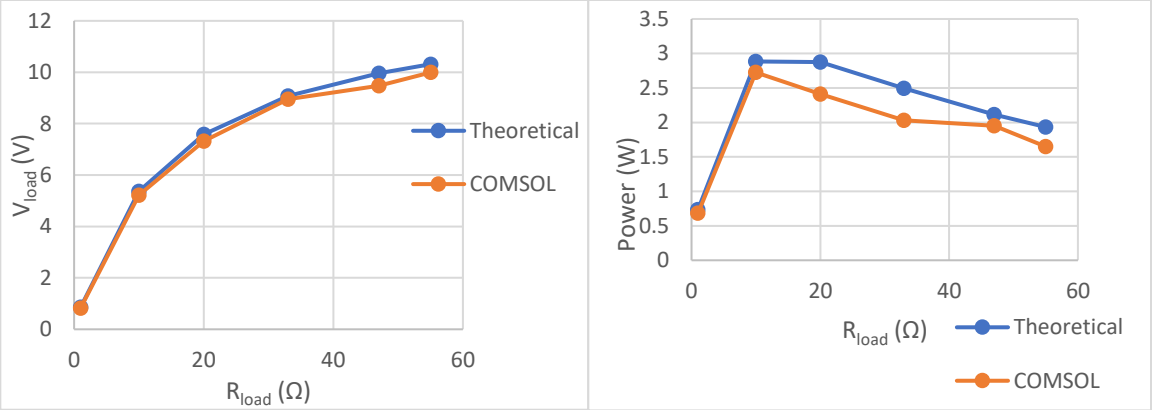


Fig 11: Voltage vs. Load Resistance & Power vs. Load Resistance of theoretical values using differential temperatures and COMSOL model's values.

3.4 Conversion Efficiency

However, the temperature difference does not exceed the maximum operating temperature so that it does not damage our TEG module. The TEG operates with an efficiency of 5.85% at its optimum case. Again, a maximum efficiency of 4.71 % can be achieved by using a closed-loop water cooling installed with a radiator , while the forced-air cooling method can ensure a maximum efficiency of 4.47%[8].

4. Conclusion

The paper provides a detailed overview of heat losses in brick kilns using various fuel types and highlights the thermoelectric effect's potential in generating electricity from waste heat, aiding in global warming mitigation. The simulation results demonstrate the feasibility of using TEGs in brick kilns, with higher temperature differences resulting in increased electrical power generation. The TEG operates with an efficiency of 5.85% at its optimum case. Alternatively, using a closed-loop water cooling method with a radiator can achieve a maximum efficiency of 4.71%, while the forced-air cooling method has a maximum efficiency of 4.47%[8].While the actual experimental setup has been hindered by the lack of equipment such as FLIR cameras or infrared Testo. To enhance thermoelectric generator performance by improving material thermoelectric properties and gaining experience in thermoelectric fabrication are recommended.

5. References

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