

# Design, Optimization and Simulation Analysis Using Comsol Multiphysics of a Radiant Heat Water Boiler

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**ABSTRACT:**Energy is lost from different systems in form of radiant heat energy as a result of the energy gradient existing between bodies of higher temperature either to the ambient, surface or any other surrounding media with a relatively lower temperature. The industry tries to limit this lost energy by insulation, however though it is not practical to insulate certain devices as electric cooking coils. The coils work on the principle of conducting heat energy to the utensil placed on it. The surface below the pot however losses a lot of heat via radiation to the surrounding space. This paper therefore discusses on the design and optimisation of a heat recovery system for electric cooker the recovered heat is used to boil water. Egerton university kitchen stoves serves as good case study since the stoves run 24hrs a day for the whole academic semester

**KEYWORDS:**Heat Recovery, Radiation, Heat Exchanges, Stove, Induction Heating, Comsol Multiphysics Software

## I. INTRODUCTION

Electric cooking coils are designed to emit heat as a result of passing potential electric current through a resistive coil, heat dissipated by radiation can be determined from the following expressions. Taking  $P$  = Power input and  $H$  = heat dissipated by radiation then at steady state condition  $P = H$  where  $\eta$  = radiating efficiency,  $T_1$  = temperature of hot body in degree kelvin  $T_2$  = temperature of cold body in degree kelvin and  $e$  = emissivity then the following is true

$$H = 5.67 \eta e \left[ \left( \frac{T_1}{100} \right)^4 - \left( \frac{T_2}{100} \right)^4 \right] \dots \dots \dots (1) P = \frac{V^2}{R} \dots \dots \dots (2)$$

$$R = \frac{\rho}{a} L = \frac{\rho L}{\pi d^2} = \frac{4 \rho L}{\pi d^2} \dots \dots \dots (3) P = \frac{\pi d^2 V^2}{4 \rho L} \text{ OR } \frac{L}{d^2} = \frac{\pi V^2}{4 \rho P} \dots \dots \dots (4)$$

$$\text{Heat dissipated per second} = (\pi d) \cdot 1 \cdot H \dots \dots \dots (5) \frac{\pi d^2 V^2}{4 \rho L} = \pi d L H \text{ OR } \frac{d}{L^2} = \frac{4 \rho H}{V^2} \dots \dots \dots (6)$$

### System Setup

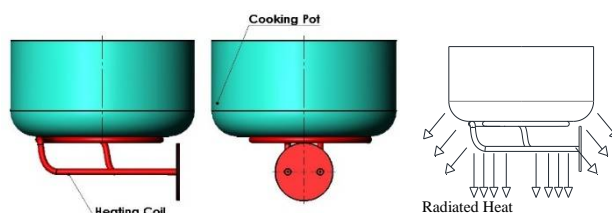


Figure 1 Electric Heating Coil and Cooking Pot Arrangement

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Figure 1. Represents cooking pot and coil arrangement, this arrangement allows heat to be conducted from the coil to the cooking pot giving first priority to cooking as heat follow the easier path of contact. once saturation point is reached where any addition of heat does not increase the pot temperature excess heat is lost via radiation to the surrounding and bottom of the coil, the amount of heat radiated is determined as in equation 1, 5 and 6 respectively depending on the rated power and size of coil.

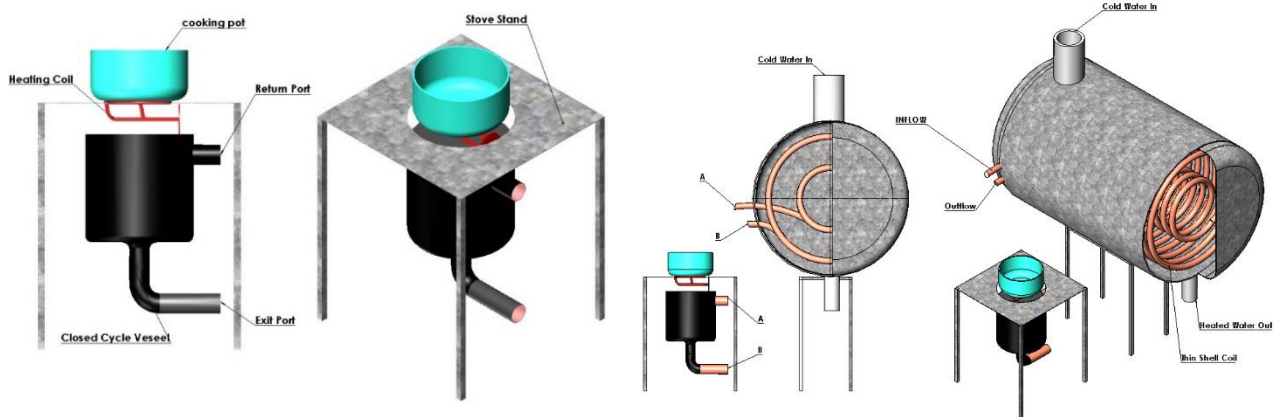


Figure 2 Heating Vessel Assembly Modelling using Solid Works Figure 3 Heating Vessel and Water Boiling Tank Assembly

A sealed copper vessel was introduced in the air domain below the coil it connect to an external water tank through pipe tubing wound into the tank forming a closed loop filled with distilled water. The radiated lost heat energy is absorbed by this vessel raising the water temperature inside it. The temperature difference between the vessel and thin shell coil creates temperature gradient and heat is moved to the cold spiral region by convection. The heating vessel is connected to the thin shell coil at port A-A and B-B indicated in figure 3 above forming a closed loop with distilled water. This channel fluid gains heat and pressure. High temperature and pressure facilitate the water to super-heat. Fresh water entering the tank does not mix with the superheated water in the closed loop but gain heat throw the thin shell spiral tube immersed into it. The rate of heating the water depend on the temperature gradient created and the coil surface area it is exposed to.

## II. PERFORMANCE OPTIMIZATION

The system has several areas that can be optimised so as to improve performance without changing major design features, they include painting the closed cycle vessel under the coil black the colour prevents reflection of heat energy changing the wavelength thus the vessel gains more heat when painted black. The second item to optimize is the fluid in the closed loop vessel hard and distilled water boils at different temperature. Distilled water takes more heat to boil and most suitable for use as it is a major requirement for maximum temperature to reach the thin shelled coil. The last optimization item determined after simulation is the distance the closed loop vessel is to the coil, the closer it is to the coil the more heat it gains.

Table 1 Commercial Electric Coil Specifications

Type	Coil Heating Element Pipe
Sheath material	SUS304 Electric Spiral Heater
Voltage	110V----240V
Watt	200W----2000W
Tube diameter	8mm---20.00mm
Surface treatment	Visual bright and Clean ,no scar, Polishing

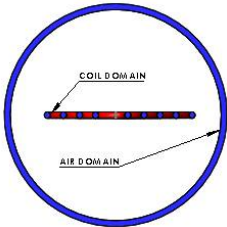


Figure 4 Coil and Air Domain

Generally, large burners heat between 1,472 and 1,652 degrees Fahrenheit when turned up to the maximum heating temperature and Small burner's heat between 932 and 1,112 degrees F

### III. SIMULATION RESULTS AND DISCUSSIONS

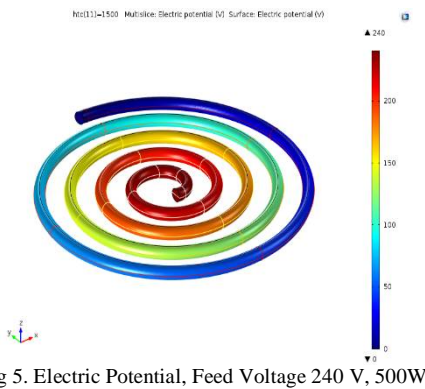


Fig 5. Electric Potential, Feed Voltage 240 V, 500W

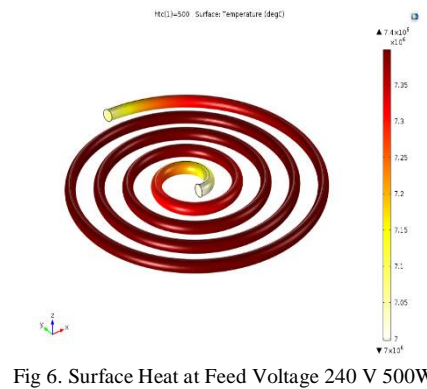


Fig 6. Surface Heat at Feed Voltage 240 V 500W

Figure 5 and 6 represents the electric potential feed voltage and surface heat attained with the coil, the input parameter was 500Volt fed at one terminal and the other terminal set as ground. The current and the material resistance generated the resistive heating as seen in figure 5 where the potential difference varies along the length the coil indicating changes in resistance with length.

### IV. EXPERIMENTAL SET-UP AND RESULTS

The system works on the principle of surface to surface radiated heat from the coil and closed circuit vessel taking emissivity  $\epsilon$ , reflectivity  $\rho$ , absorptivity  $\alpha$  and temperature  $T$  then the total radiative flux  $G$  into the closed vessel and the outgoing radiative flux  $J$  from the coil can be derived from the following relationships

$$J = \epsilon \sigma T^4 + PG \text{ Heat flux from the coil} \dots \dots \dots (7)$$

$$\text{The net inwards radiative heat flux } q \text{ is then } q = G - J \dots \dots \dots (8)$$

$$q = (1 - P) G - \epsilon \sigma T^4 \text{ Eliminating } J \text{ from equation 8 and 9} \dots \dots \dots (9)$$

$$q = \epsilon \sigma (T_{ambient}^4 - T^4) \text{ The ambient behaves as a black body} \dots \dots \dots (10)$$

$$q = \epsilon (-\sigma T^4 + G) \text{ Heat flux to the closed loop vessel} \dots \dots \dots (11)$$

Since solid surfaces behave like ideal gray where absorptivity and emissivity and are all equal

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The system is designed by Solid Works software, figure 2 and 3 above with a coil horizontal diameter of 20 inches and having a circular coil thickness of 20mm. the 3D model was then imported into Comsol Multiphysics simulation program via Solid work live-link and simulated for surface to surface radiation.

Left hand diagram in figure 5 below represents the air domain where radiative heat is felt, the diagram shows heat domain extending to a distance of about 800 mm around the coil. This indicates that heat is absorbed by all the surfaces of the vessel introduced below the coil. The right hand image in figure 5 represent simulation result and displays the ambient irradiation heat flux it indicates clearly that only the coil radiates heat and with the vessel considered to act as a gray surface it absorbs the heat. For accuracy the absorptivity was taken to be 0.85 with the coil reflectivity considered as 0.

The color code in figure 8 indicates irradiation heat flux of between 250 to 300 W/m<sup>2</sup> based on it dimensions, resistivity and a feed current of 2000 watts.

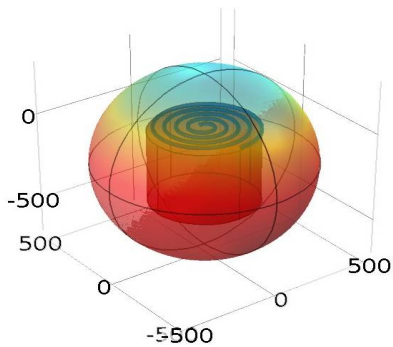


Figure 7 Radiation Air domain

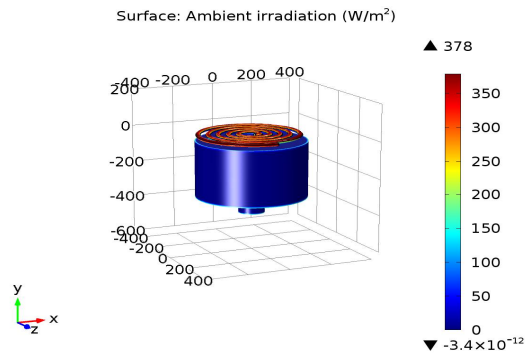


Figure 8 Ambient Irradiation Heat flux

Figure 9 below represent surface heat flux absorbed by the vessel it is shown that after the ambient air temperature gains heat and rises from 273 K over a duration of time it transmits almost the same heat flux as it receives from the coil. This is a positive indication that when the coil is operated over long hours then maximum temperatures are attained in the air domain. It is evident that substantial amount of heat is gained. Coil surface temperatures of about 1200 degrees centigrade noticed radiated heat of 600 degrees centigrade at the top surface and decreases as the can moves further from the heat source.

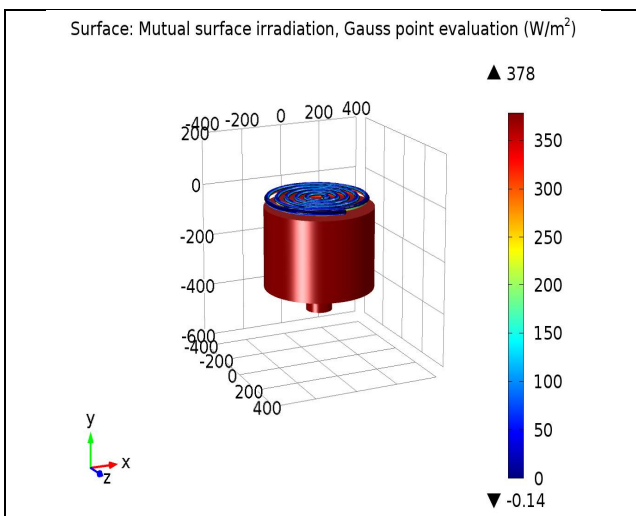


Figure 9 Surface to Surface irradiation heat flux

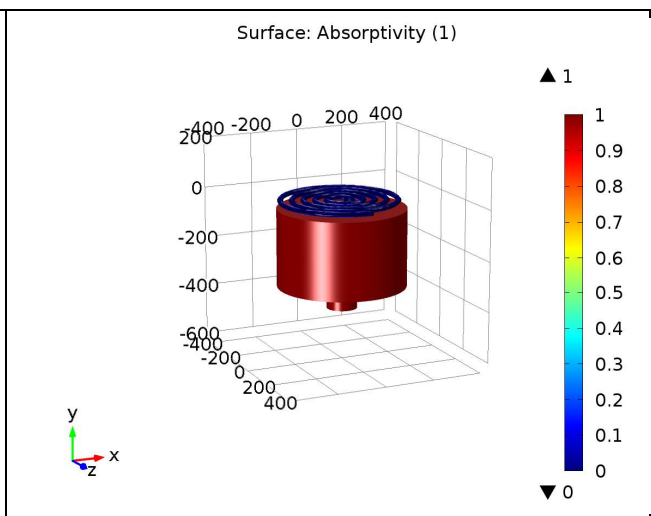


Figure 10 Surface Absorptivity

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Figure 10 likewise displays the surface emissivity and absorptivity of the two surfaces the coil does not absorb heat flux from the surround with a reflectivity value of between 0 and 0.15 and the Absorptivity of the vessel being between 0.8 and 0.95 both considering material impurities.

## V. CONCLUSION

The simulation results justifies that substantial amount of heat flux is gained by the vessel from coils subjected to long operation hours. The heat can be tapped and recovered to heat the water in the closed loop vessel. We know that water boils at 100 degrees centigrade and therefore expects heated water under pressure to be superheated. Results on the heat levels in the superheated coil form the second part of this research study

## VI. ACKNOWLEDGEMENT

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