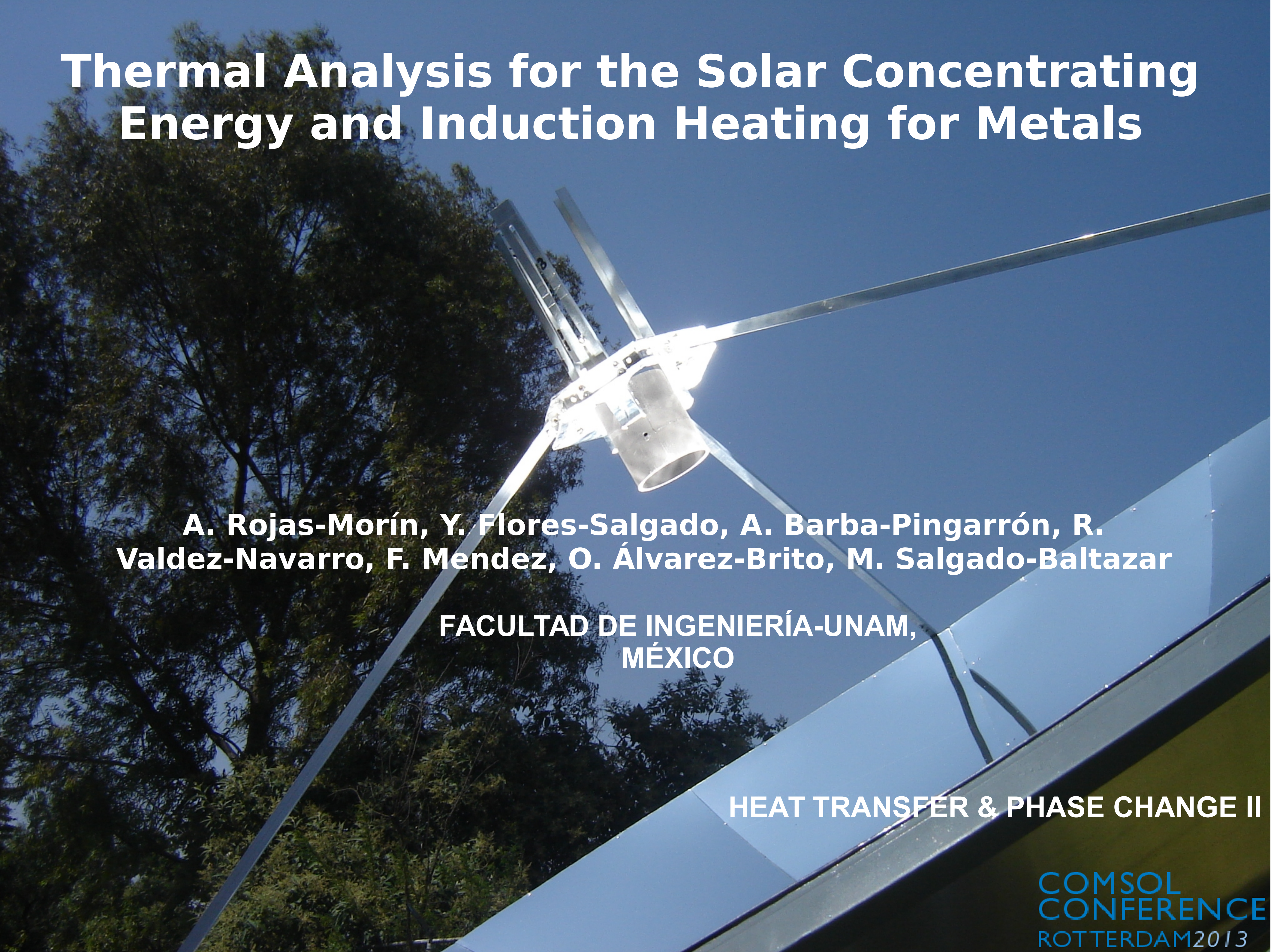
Thermal Analysis for the Solar Concentrating Energy and Induction Heating for Metals



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HEAT TRANSFER & PHASE CHANGE II

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1. INTRODUCTION,

Induction heating for manufacturing aplications

Hardening*

annealing*

brazing*

pre-heating*

welding*

forging*

melting *

*EFD Induction, availability on line: http://www.efd-induction.com/

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1. INTRODUCTION, Induction heating

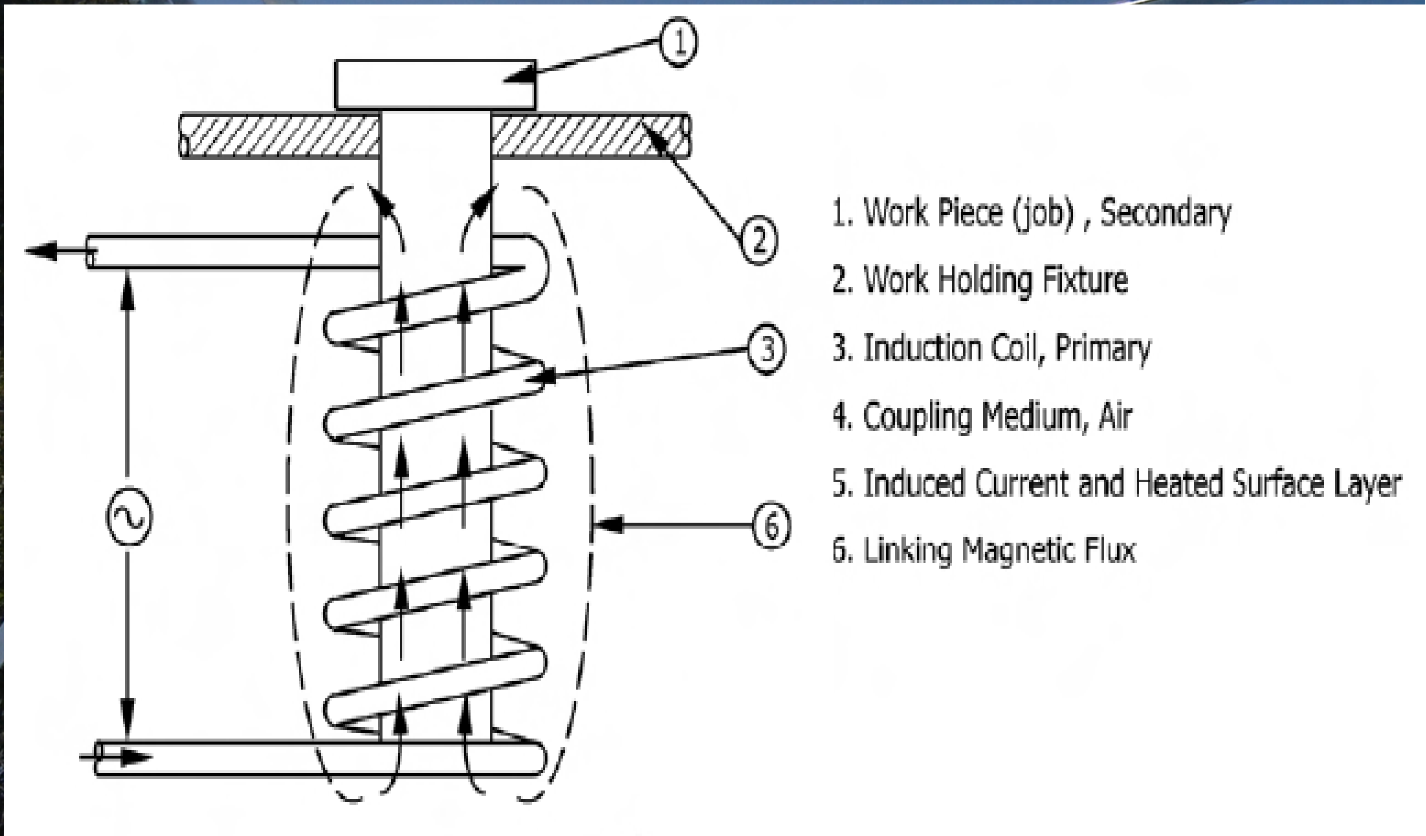
Advantages:

can achieve thermal efficiencies up to 90%. In comparison, methods that use gas as a heat source afford thermal efficiencies of 60%.

Inductive heating is a clean process, does not involve combustion, and does not oxidize the work piece surface.

Disadvantage:

the demand for electricity in these processes is also high.

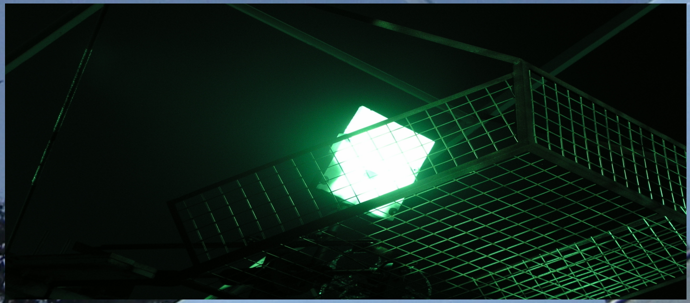


1. INTRODUCTION, Solar energy concentrated

To have some saiving about this energy supply, we can use alternative technologies to heating metals.

In some cases, the temperature interval for these systems is higer than one thousand centigrade deg.

Is for this reason, that we propouse this system for heating metals.



DISTAL I, at the Plataforma Solar de Almería, Spain.

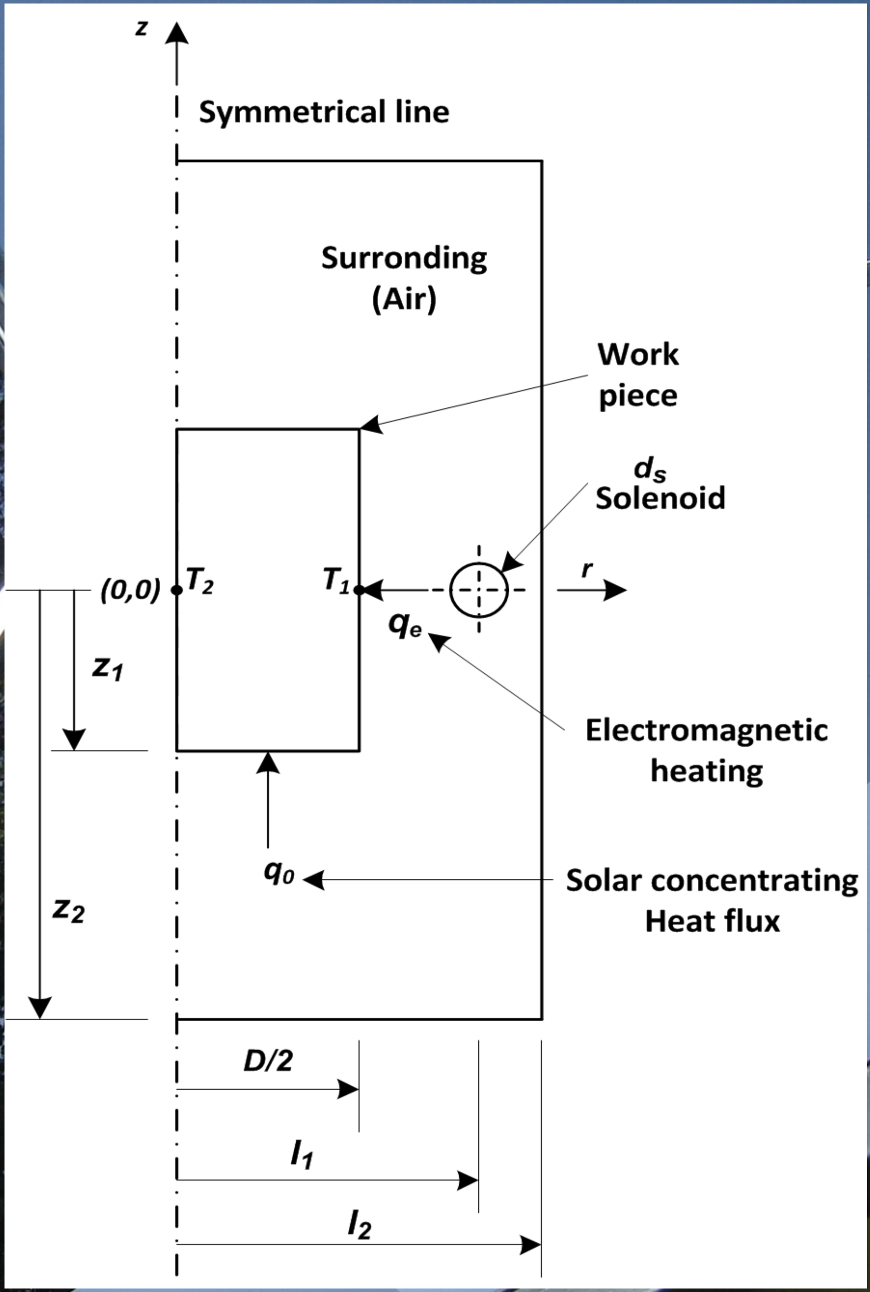
2. Physical model

In this case, the iron work piece possessed a cylindrical axisymmetrical geometry.

On the bottom of the work piece, a heat flux (q_0”) was generated from the solar concentrator.

One cooper coil was placed at L/2, separate from the outer diameter of the work piece.

In this case, electromagnetic heat transfer occurred from the coil (q_e), and only air was present between the coil and the work piece.



3. Use of COMSOL Multiphysics,
3.1 Mathematical model

Maxwell's equations were coupled to the heat transfer equation. The differential form of Ampere's law can be written as follows:

$$\nabla \times H = J + \frac{\partial D}{\partial t}$$

where H is the magnetic field intensity, J is the current density, and D is the electric flux density.

The constitutive relation to the magnetic flux density is given as:

$$B = \mu H$$

where μ is the permeability of the material.

In terms of the vector potential A:

$$B = \nabla \times A$$

In Maxwell-Ampere's law

$$\nabla \times \left(\mu^{-1} \nabla \times A\right) = J + \frac{\partial D}{\partial t}$$

In a time-harmonic quasi-static state, the reduced potential formulation is applicable:

$$\left(j\omega\sigma - \omega^2 \varepsilon\right) A + \nabla \times \left(\mu^{-1} \nabla \times A\right) = J_e$$

where ω is the angular frequency, and ε is the permittivity of the material.

3.1 Mathematical model (Heat transfer equation)

For the heat transfer analysis, the equation takes on the following form:

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot \left(-k_{th} \nabla T \right) = Q$$

where ρ is the density of the material, C_p is the specific heat capacity, k_{th} is the thermal conductivity and Q is the heat source.

The boundary conditions for the heat transfer equation can be expressed as follows:

At the work piece surface, a surface-to-ambient radiation boundary condition occurs:

$$q = \varepsilon_{th} \sigma_{th} \left(T_{amb}^4 - T^4 \right)$$

where ε_{th} is the surface emissivity, σ_{th} is the Stefan-Boltzmann constant, and T_{amb} is ambient temperature.

At the bottom of the work piece, a heat flux boundary condition is applicable:

$$q_0 = -k_{th} \nabla T$$

where q_0 is the heat flux.

3.2 Model parameters

To resolve the mathematical model, the following parameters were employed in COMSOL:

frequency transient = 10 kHz

coil current = 500 A

heat flux = 200 kW/m^2

ambient temperature = 293.15 K

With these parameters, COMSOL was used to resolve the mathematical model for induction heating only.

Subsequently, a second analysis was performed to resolve the model under heat flux boundary conditions.

The analyses provided the corresponding temperature changes of the work piece surface, the temperature profile of the two points and the magnetic fields of the work piece.

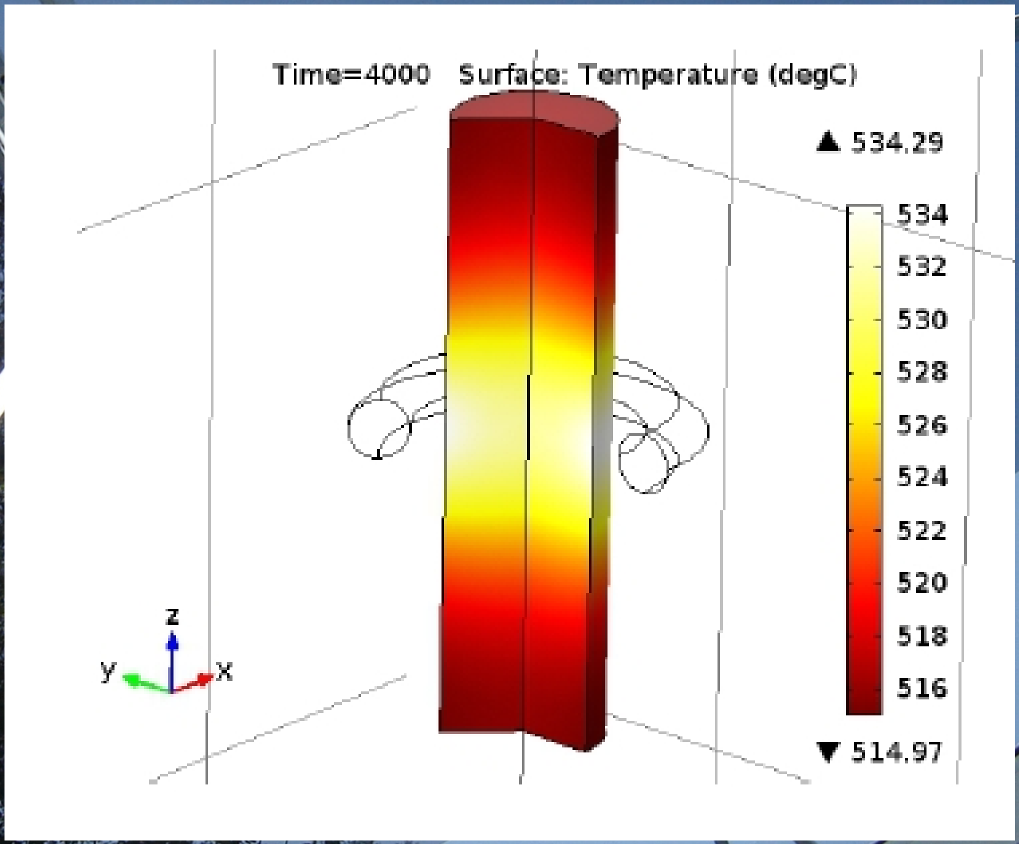
4. Results and Discussion (Only induction heating)

Figure shows the temperature distribution of the work piece in the presence of induction heating.

The interval simulation for the analysis
was 0-4000 s.

At 4000 s, a maximum temperature of 534°C was observed in the middle section of the work piece.

At the bottom or top of the work piece, the temperature was 515°C.



4. Results and Discussion (induction heating and concentrated solar energy)

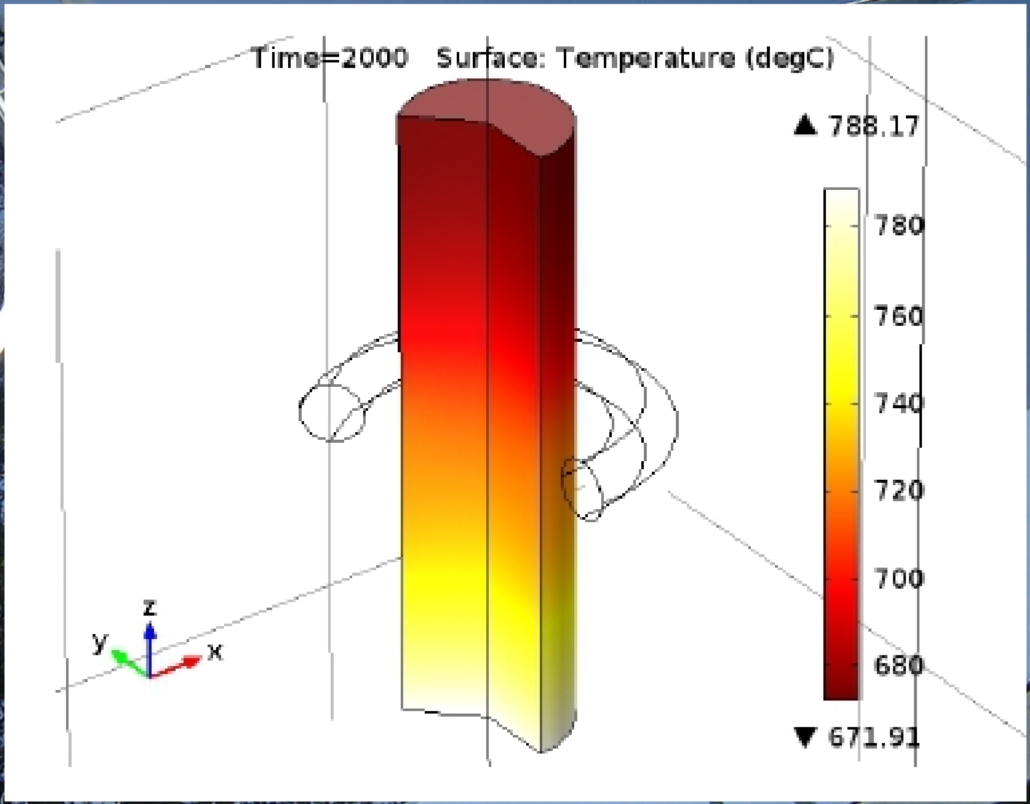
Figure shows the temperature distribution of the work piece due to induction heating and the introduction of concentrated solar energy at the bottom of the work piece (heat flux).

the interval simulation was 0-2000 s.

In the middle of the work piece, a maximum temperature of 730°C was observed.

However, the temperature reached nearly 790°C at the bottom of the work piece.

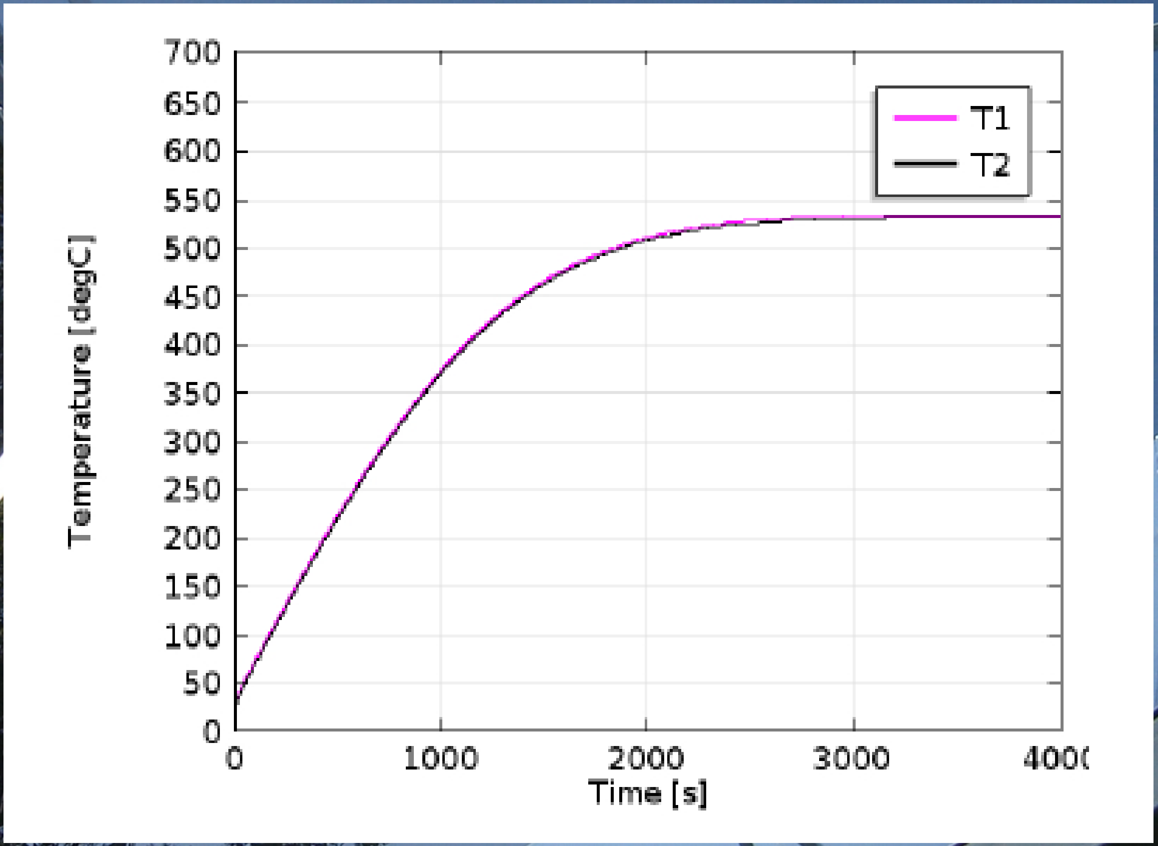
At the top of the work piece, the temperature was 670°C.



4. Results and Discussion, Temperature changes at T1 and T2 due to induction heating.

Figure shows the temperature change of the work piece at T1 and T2, due to induction heating.

The transient state ended at 3000 s, and the maximum temperature was 534°C



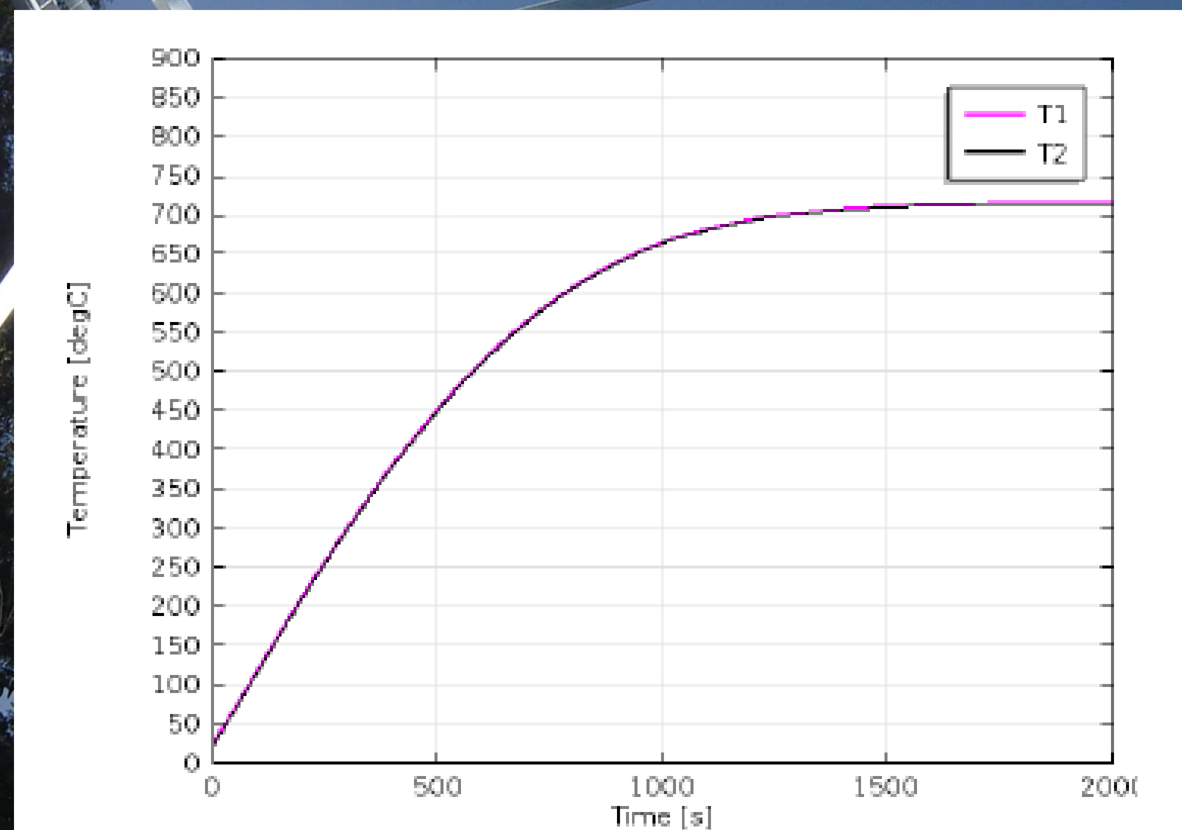
4. Results and Discussion, (Temperature changes at T1 and T2 due to induction heating and concentrated solar energy)

Figure shows the temperature change of the work piece at T1 and T2. The transient state ended after 1600 s, and the maximum temperature was 790°C.

The maximum temperature at T1 or T2 was significantly higher when induction heating was coupled with concentrated solar energy.

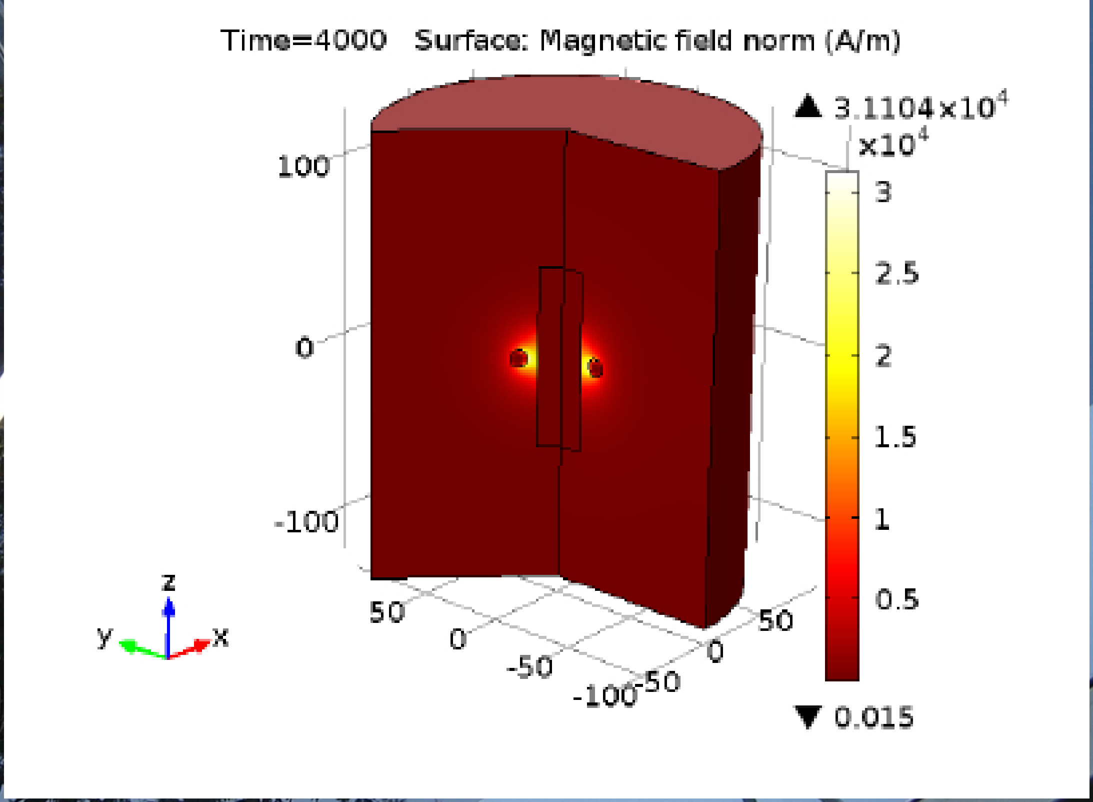
At 1600 s, a stationary state was observed, in contrast, when only induction heating was employed, a stationary state occurred at 3000 s.

Clearly, energy was conserved when the work piece was heated using concentrated solar energy.



4. Results and Discussion, (Magnetic field between the coil and the work piece)

Figure shows the magnetic field between the coil and the work piece, which reached a maximum of 3.11×10^4 A/m at a coil excitation of 500 A.



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5. Conclusions

Induction heating is one of the most efficient methods of heating materials but is expensive because a significant amount of energy is required.

When concentrated solar energy is combined with induction heating, a considerable amount of energy can be saved.

The present paper showed that the maximum surface temperature of the work piece increased to 534°C *at 3000 s* in the presence of induction heating only.

In contrast, when concentrated solar energy was supplied at the bottom of the work piece, a maximum temperature of 790°C was observed after 1300 *s*.

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6. References

1. Y., Deshmukh, Industrial Heating, pp. 425-428. Taylor and Francis (2005).

2. AC/DC Module, *User´s Guide*, COMSOL.

3.Heat Transfer Module, *User´s Guide*, COMSOL.

Acknowledgments

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Thank you for your attention¡¡¡