Heat transfer model in a rotary kiln for the pyrolysis of biomass

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Introduction

Pyrolysis is one of the main thermochemical routes for the conversion of biomass due to its flexibility. ***Char is the product of interest in slow pyrolysis and it has a wide range of applications, from soil amendment to energy production***. For pyrolysis, the rotary kiln (Figure 1) is one of the most promising technologies. In any reactor, the heat transfer is crucial to estimate design parameters.

Objectives

The aim of this work is to develop a heat transfer model for a rotary kiln slow pyrolysis reactor. The aim of the pyrolysis reactor is to transfer the heat to the biomass feedstock until it reaches the target temperature.

Heat transfer methods

There are **three different methods** to transfer heat from the source of heat (reactor wall) to the bed of solids:

Conduction

Conduction heat transfer takes place when there is contact between two bodies or systems at different temperatures.

$$Q_{2\to1}^{cond} = \frac{\lambda_1 \cdot (T_2 - T_1)}{\int_{x_1}^{x_2} \frac{dx}{A(x)}}$$

The formula is different from the general conduction version because the area keeps changing with the depth of the bed of solids or the gases; it is not a simple system where two bodies are in contact through a defined area as the area varies.

The solid receives heat through conduction from the gas and the wall, and the wall also transfers heat to the gas through this method.

Convection

It is produced when at least one of the bodies is moving, normally a fluid, transferring or absorbing heat from the other.

$$Q_{2\to1}^{conv} = h \cdot A \cdot (T_2 - T_1)$$

The most difficult part of this expression is to calculate the convective coefficient *(h),* which is done through correlations which include the Reynolds and Prandtl number for the interaction gas-solid and gas-wall. In addition, the solid is moving along the wall, which is also rotating, and receives heat through convection. The convective heat transfer is calculated through the Peclett number, which is the product of the Prandtl and the Reynolds numbers.

Radiation

The heat is transported through electromagnetic waves generated by thermal activity of matter. Any body generates this energy by having any temperature higher than 0 K.

$$Q_{2\to1}^{rad} = \frac{\sigma \cdot (T_2^4 - T_1^4)}{\frac{(1-\varepsilon_1)}{A_1 \cdot \varepsilon_1} + \frac{1}{A_2 \cdot F_{21}} + \frac{(1-\varepsilon_2)}{A_2 \cdot \varepsilon_2}}$$

One of the biggest difficulties was finding the view factor (F_{21}), which for the interaction wall-solid and wall-gas was defined as the area of solid divided by the sum of the areas of gas and solid. The wall radiates heat to the solid and the gas, and the gas radiates heat to the solid. It is clear from the equation it highly depends on the temperature difference to the power of four, which makes a difference in temperature much more significant.

Legend

Q: heat transferred *[W]*
cond: conduction
conv: convection
rad: radiation
T: temperature *[K]*
1 & 2: bodies with different temperature
λ: thermal conductivity *[W m^{-1}K^{-1}]*
x: dimension along which the heat is transferred *[m]*
A(x): contact area dependant on x-dimension *[m^2]*
h: convective heat transfer *[W m^{-2} K^{-1}]*
σ: Stefan-Boltzmann constant *[5.67 x 10^{-8} W m^{-2} K^{-4}]*
ε: Emissivity of the body *[-]*
F_{21}: view factor from 2 over 1 *[-]*

Reactor specifications

- **Radius:** 2.5 m
- **Length:** 7.7 m
- **Number of steps:** 15
- **Kiln angle:** 1°
- **Rotational speed:** 1.9 rpm
- **Source of heat:** combustion gases (3.6 t/h)
- **Heating method:** indirect heating
- **Heating set-up:** counter-current
- **Initial filling degree:** 0.25
- **Final filling degree:** 0.1
- **Solid input (dry):** 3 t/h
- **Moisture content:** 10 wt.%
- **Feedstock:** woodchips
- **Residence time:** 11 minutes
- **Nitrogen input:** 1 t/h

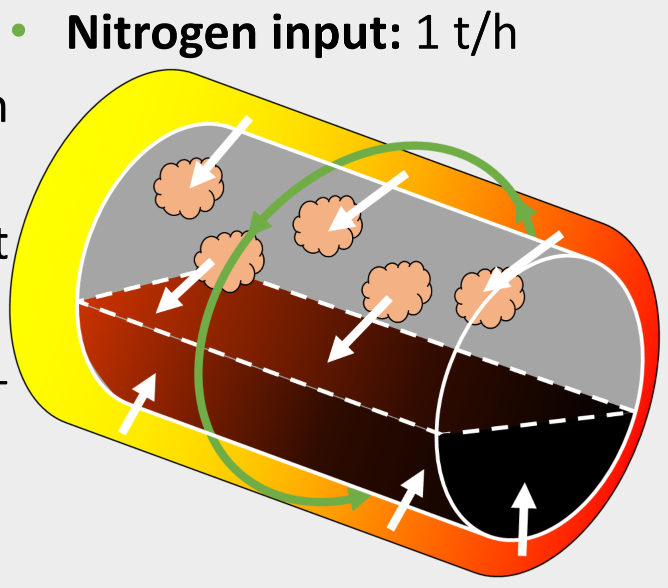
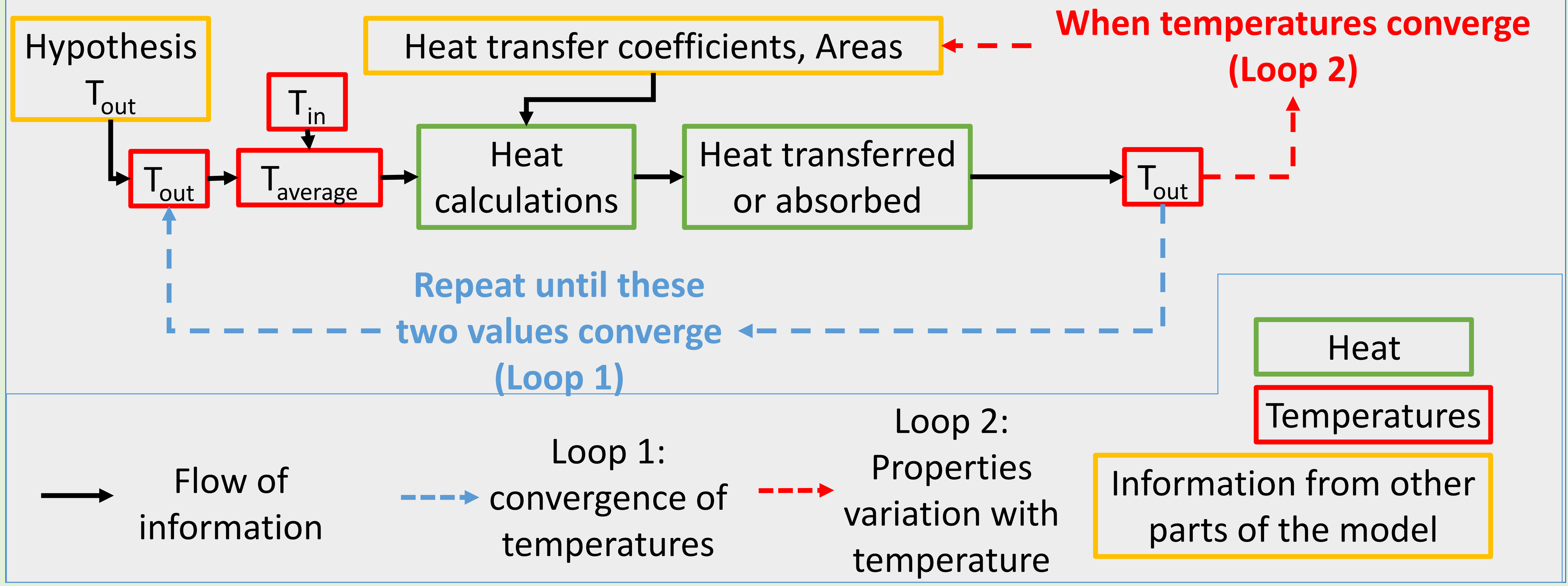
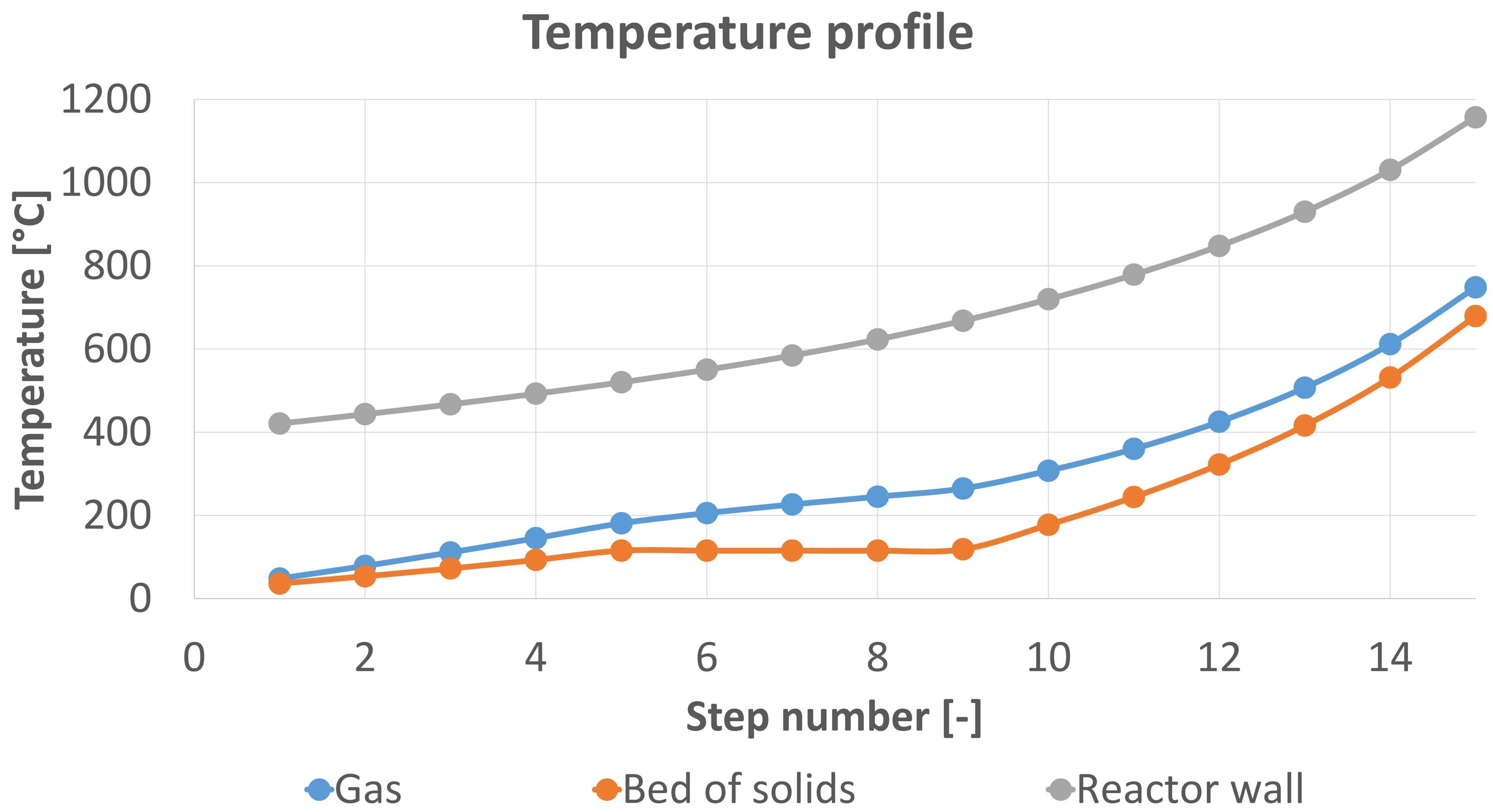


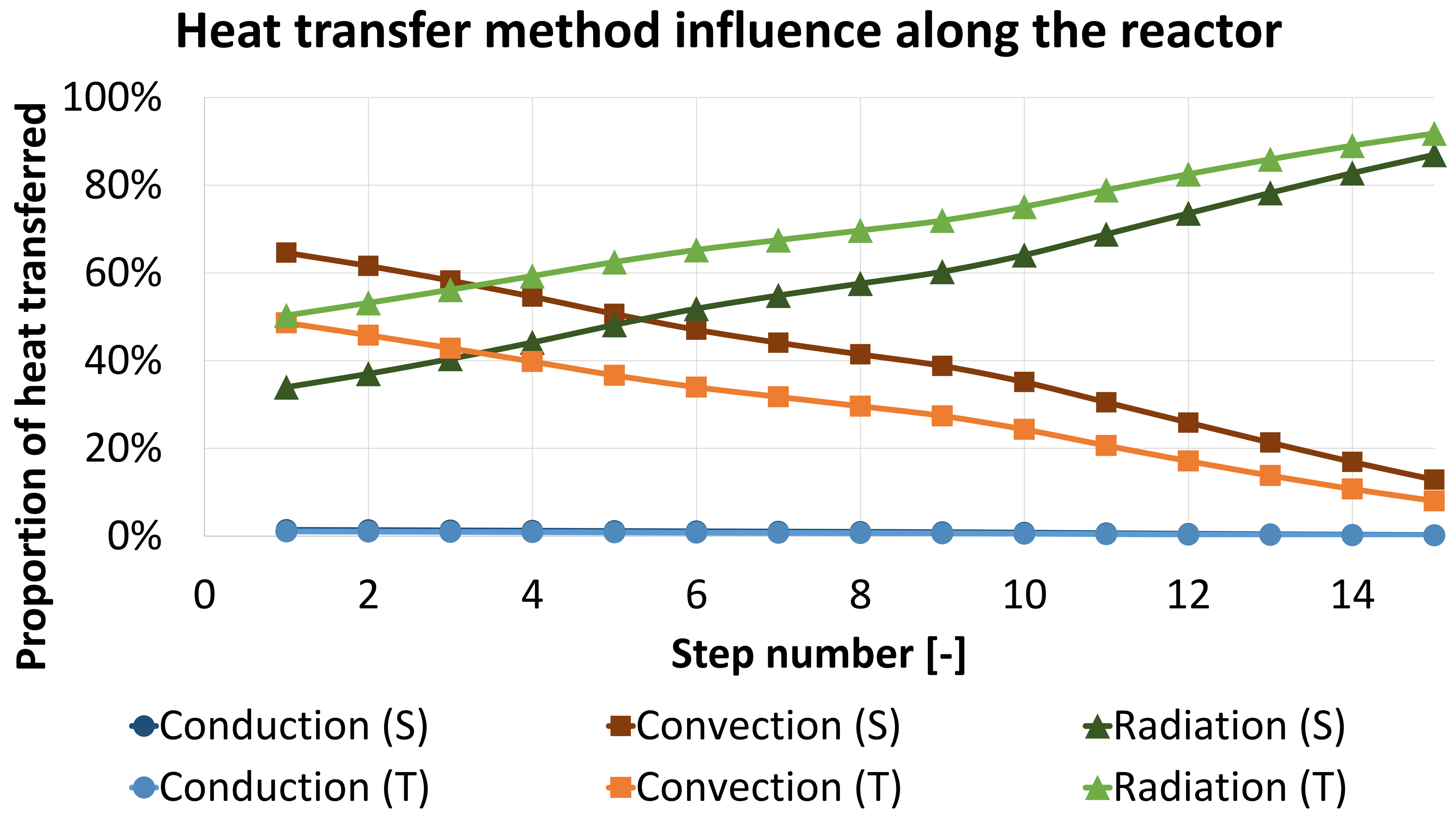
Figure 1: Rotary kiln scheme

Methodology



Results





Conclusions

From the results, the heat transfer by conduction is almost negligible and the influence of convection decreases along the reactor. The heat transfer model is part of the design of the reactor. It has to be coupled with other parts which contain the information about the kinetics of the process or the possibility of introducing flights. All these models influence each other, so will be integrated in the final version.

Acknowledgements

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