Thermal Modelling of the Torrefaction Process

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Introduction

So far, the torrefaction process was conducted on the micro-wave-based technique. This technique requires varying power and frequency. That eventually causes an uneven thermal pre-treatment due to intermolecular friction within the structure. A drawback pertaining to micro-wave restricts its utilisation for the limited period (Zh et al, 2017). Some studies on micro-wave torrefaction were conducted and it was reported that energy yield of municipal waste and Leucaena was surged by 21% and 7%, respectively, but the effect of thermal condition on the material behaviour was omitted (Huang et al., 2017). In another study on Lemongrass, the torrefaction was performed at 200–300°C, which consequently, increased the carbon by 124%. The obtained biochar was later densified with the help of binding agent, starch (Yu et al., 2020). But overall process merely increased the cost of production and the torrefaction technique was performed without considering effect of temperature distribution on the material. The similar kind of technique was conducted for wet torrefaction of microalgal hydrolysate. The narrow range of temperature was used for holding time of 5–10 minutes, but the effect of thermal condition on the productivity of bioethanol was overlooked (Siritheerasas et al., 2017). The agro-based residue char was used as an absorber to undermine the effect of microwave irradiance on MSW. The concept of addition of bagasse char fairly worked, but the overall change in fixed carbon was nearly constant (Siritheerasas et al., 2017). After summing up the study, it was noticed that the interaction between biochar and the MSW was not provided. Wang et al. (2012) reported that the calorific value of rice husk was bolstered by 26%, while it was 57% for sugarcane during micro-wave torrefaction. They had seen that the size, processing time and heat flux had a phenomenal impact on the torrefaction process (Wang et al., 2012). The wheat and barley straw in a microwave heating system was carbonised owing to microwave irradiance, which merely increased the energy density by 14–15 (Satpathy et al., 2014). The various studies on the similar technique were conducted, but the effect of temperature was not clearly stated nor its effect on physical traits of biomass was stated (Yek et al., 2020).

This work focussed on the thermal modelling of raw pinecones pellets subjected to quasi-static torrefaction in a resistivity heating system. The effect of thermal profile and thermo-fluid properties of inert gas on temperature distribution of pellet was examined by the bvp4c technique.

Material and Methods

Thermal Modelling of the Pinecone Pellet

The ordinary heat transfer equation was solved using bvp4c in MATLAB2015a. The effect of conduction and convection on temperature distribution was only studied. The different value of Nusselt and Reynold numbers of nitrogen flow was used to examines the effect of interacting atmosphere on the pinecone pellet. The effect of porosity was considered to be negligibly small. The 2-D conduction equation was considered at a varying heat flux. The effect of surface irregularity along the top and bottom surface was excluded during the simulation. The mixed boundary condition was applied during computation process. The thermal / heat transfer parameters related is provided in Table 3.

Table 1. The thermal / heat transfer parameters for a pinecone pellet

C (kJ·kg-1·K-1)	k (W·m-1·K-1)	$\bar{h}$ (W·m-2·K-1)	Nu	Re
3.51	11.27	2.55	0.00439	798.85

The heat equation used for determining temperature distribution across the pellet was given by the following equation:

$$\rho_m C \frac{\partial T}{\partial t} - \nabla \cdot (k\nabla T) = Q + h(T_{\text{ext}} - T) \quad (1)$$

The generalised Neumann and Dirichlet boundary conditions applied at the interface are provided by

$$\hat{n}.k\nabla T + hT = g \quad (2)$$

and

$$J.T = r \quad (3)$$

Results and Discussion

Temperature distribution across pinecone pellet upon the torrefaction in the Joule heating system was examined with the help of finite element analysis. The effect of processing time along with the varying heat flux is shown in Fig. 1. Having seen the numerical solution, it was concluded that the temperature along the diametrical axis of pellet would increase by 0.37% at the core of pellet as the heat flux is elevated by 4.10%. Similarly, the temperature would lie in domain of 524–526 K along the traverse axis of the biofuel pellet. A surge of 2.1–2.5% above the furnace temperature was estimated at interior region of pellet, whereas it was around 0.19–0.57% rise

Conclusion

This work was pertaining to analyse the biofuel pellet which underwent thermal pre-treatment at constant temperature for varying time interval. From the study, it was found that thermal characteristic of pellet would be drastically changed when it was pre-treated at varying heat flux for different processing time. It was estimated that temperature was surged by 0.37% when the heat flux was allowed to vary from 81.55 $kW.m^{-2}$ to 86.068 $kW.m^{-2}$. Similarly, it was 2.1 to 2.5% at the interior region of the pellet. The effect of processing time allowed the pellet to attain a thermal equipotential along the dimension of pellet. Thermal gradient was elevated by 50% at the end of the torrefaction process. The temperature gradient was estimated to be dropped by 48% along the centre axis of pellet. The spatial characteristic was merely seen with time rather than a quantitative deviation in the thermal gradient.

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