Investigation of size factor: Heat capacity and thermal flux in a U-tube heat exchanger for pasteurization

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Abstract

A serpentine tube heat exchanger is physically constrained by its bend radius. The U-tube bend section of this tubular heat exchanger is thus interesting broadly in terms of fluid flow and heat transfer. This paper presents the tube size dependence of heating profile of this U-tube as is commonly encountered in the design of pasteurizers. Analytical and computational modeling were employed in investigating the heat capacity, heat flux, heating rate and energy use of a U-tube at increasing diameters 9.52, 12.70, 19.05 and 25.40 mm, each at constant 1 mm thickness. SolidWorks 2016 was used in geometric modeling while Ansys v16 was used for transient thermal computational fluid dynamics simulation of the conduit (SS316L) and the product (coconut water). The initial conditions were 5,000 W/(m^2-K) convective heat supply at 95 and 92 °C surface temperature for the conduit and the product, respectively. Both the tube and the product were initially at 30 °C. The tube, whose heating profile was independent of size, reached 90 °C in 2.1 s. For the product, as the tube size increases, the heat capacity increases exponentially ($Q_p = 108.3e^{0.1831x}$) and the heat flux drops down 57% within 40 s. These results are beneficial to designers and engineers in sizing of heaters, minimizing fouling and optimizing energy efficiency as well as pasteurizer processing capacity.

Keywords:
Tubular heat exchanger, heat transfer, modeling and simulation, pasteurizer, coconut water

Introduction

- Pasteurization is a thermal process where the spoilage constituents in a liquid food are heated for a certain time to kill or inactivate them, thereby preserving the food quality for a longer period **(University of Guelph, 2020)**.
- At the core of this thermal treatment is the heat exchanger, which may come in varying forms.
- The geometry dependence of heat and mass transfer is specifically important in determining heat load, calculating rate of heating, sizing the heater, estimating thermal gradient and cold spots, heat recovery, fouling, variable loading and optimizing pasteurizer processing capacity **(Aguiar & Gut, 2014; Gutierrez et al., 2014; Kic & Zajicek, 2015; Narataruksa et al.,, 2010; Negiz et al., 1998; Petermeier et al., 2002)**.
- This paper sought to investigate the geometric relationship of tube size to heat capacity and thermal flux in a U-tube heat exchanger of a pasteurizer.

Methodology

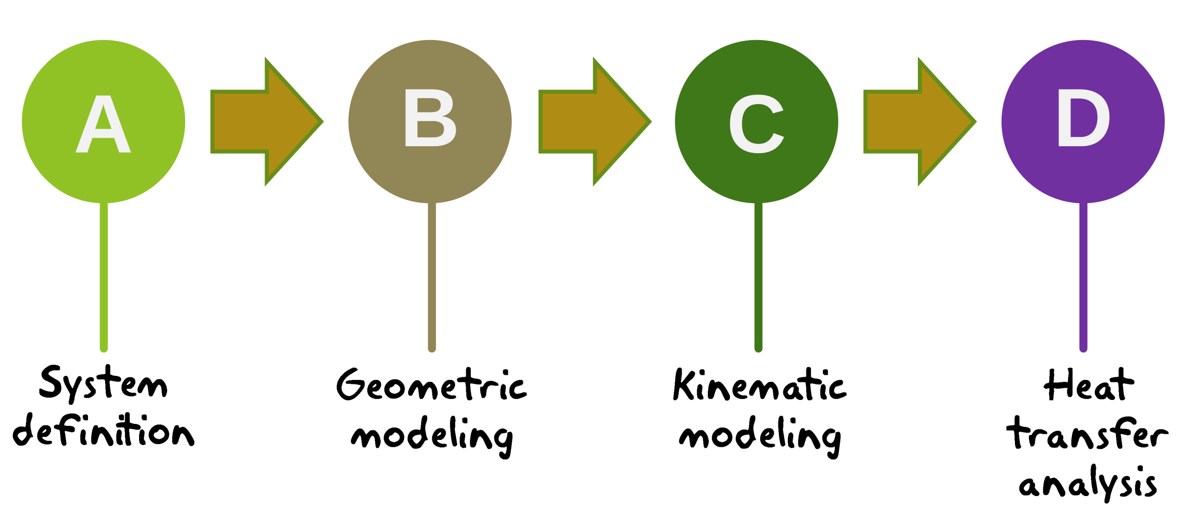


Figure 1. Procedure of investigation.

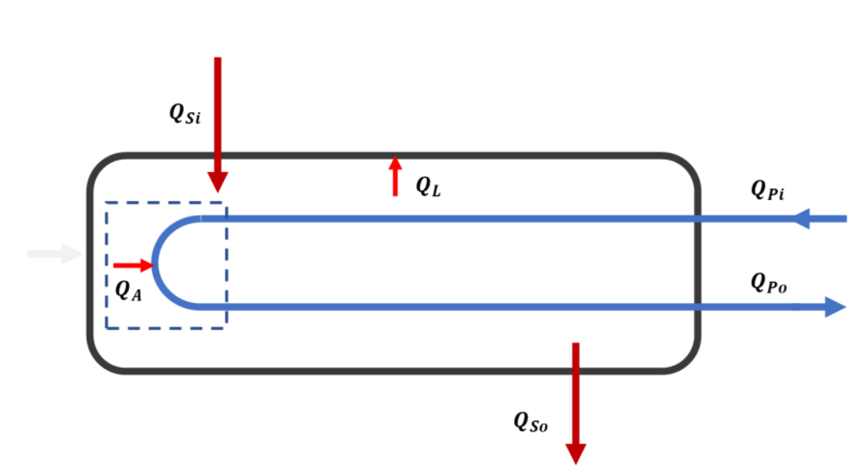


Figure 2. A model of shell and tube heat exchanger showing heat flow (red) and product flow in a tube (blue).

Results

Heat Capacity

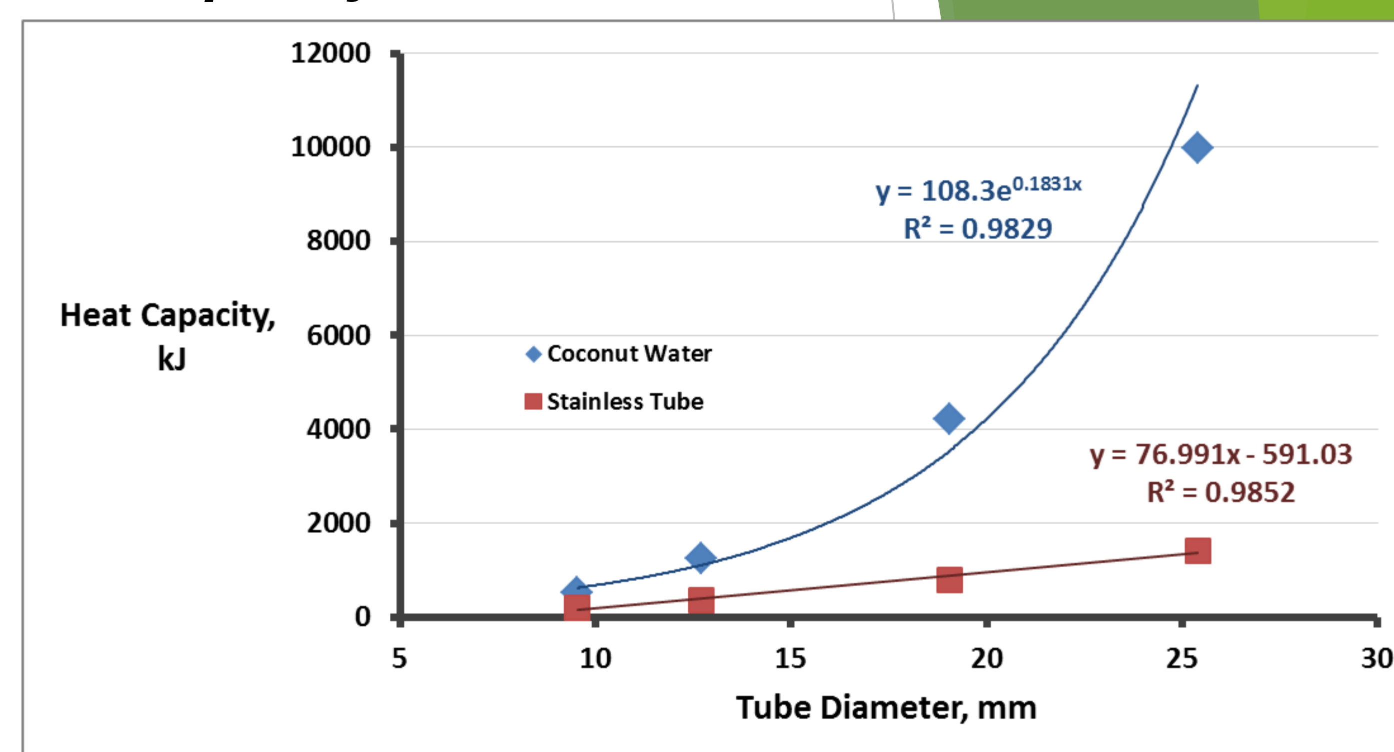
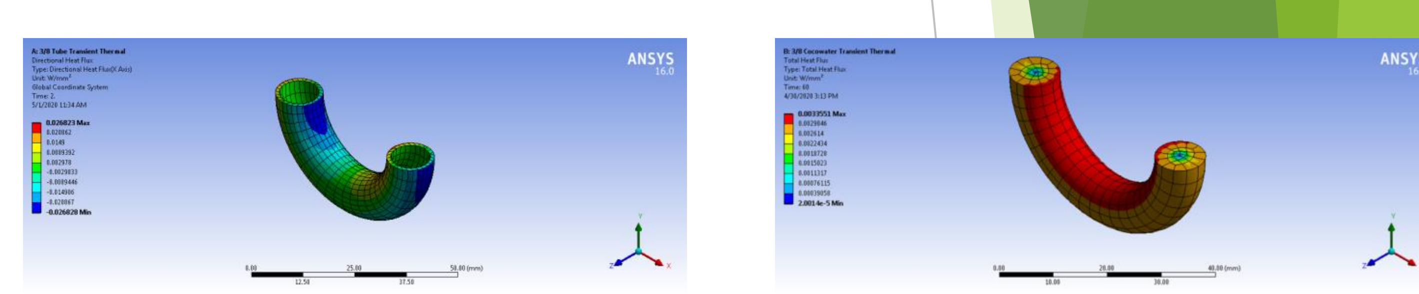
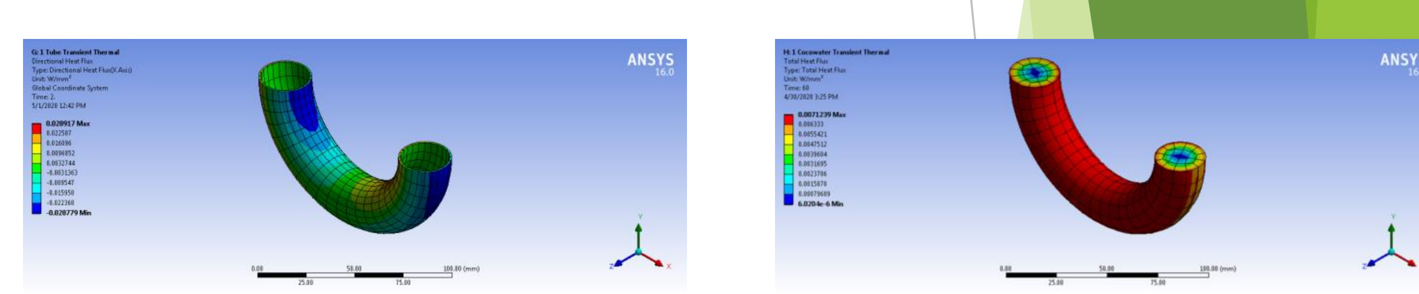


Figure 3. Heat capacity of the conduit and the product at varying tube sizes.

Thermal Flux



(a)



(b)

Figure 4. Heat flux for (a) the smallest and (b) the biggest tube.

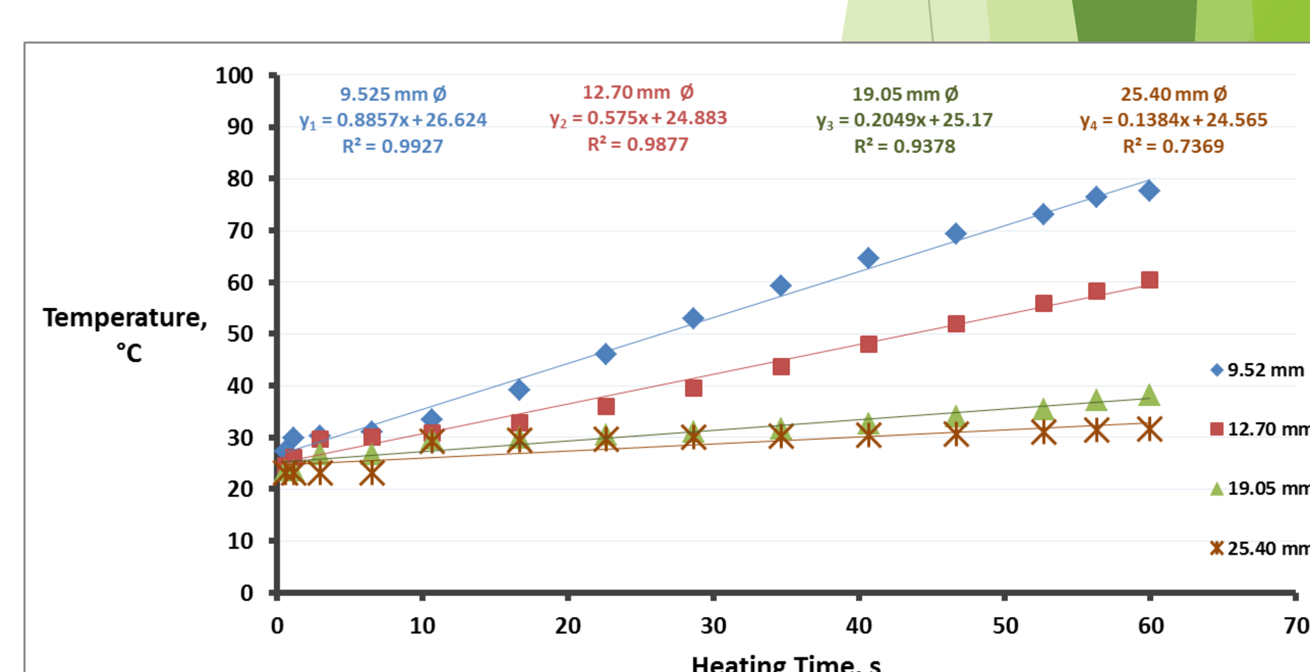


Figure 5. Minute temperature and thermal gradient at constant convective heat load for varying tube sizes.

Conclusions

- The thermal resistance of the stainless conduit to heating is very minimal compared to the coconut water product;
- As the tube size increases, the heat capacity of the product increases (exponential) significantly more than the conduit (linear);
- For all tube sizes, the heat flux, although initially dispersed, slows down relatively fast (57% drop within 40 s);
- As the product gets bigger linearly by diameter and exponentially by volume, the heating rate drops logarithmically ($T_{t=60\,s}$ =-48ln(x) + 183.65)**;**
- The energy use per unit volume of the product decreases logarithmically (Q_u = -29.65lnx + 235.36) as the tube diameter increases.