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Comparative analysis of heat transfer coefficient for wood and non-wood pulp fiber

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Abstract. The comparative study for obtained heat transfer coefficient for Acacia Mangium (wood) and Kenaf bast (non-wood) pulp fiber suspension were performed in a close loop circular pipe heat exchanger. During the test study it was observed that the magnitude of heat transfer coefficient strong influenced by the parameters including: fiber type, pulp concentration, characteristics as well as fiber pulping method. At a low fiber suspension concentration and higher flow rates, it was observed that higher values of heat transfer coefficient were achieved than that of water, in contrast, a decrease in heat transfer values were found at increasing concentration and lower pulp suspension. It was found that values of heat transfer coefficient decreases with increasing the fiber flexibility for both Acacia Mangium and Kenaf bast respectively. In the present research work, the fiber dimensions and fiber flexibility are inter-related along with values of heat transfer coefficient of both wood and non-wood fiber suspensions.

Keywords. Comparative analysis, heat transfer coefficient, pulp fiber

1. Introduction

There are diverse application of fiber suspension in various process industries like textile industries, food processing, packaging and most significantly the major and most applicable use of the huge volume of fiber suspension in pulp and paper industry. The raw materials for paper manufacturing are pulp comprises of natural cellulose fiber mostly obtained from wood and non-wood plants. Trees are the core source of wood fiber which constitute both softwood (Pine, Fir, spruce etc.) and hardwood (eucalyptus, ash, Aspen, etc.). Due to the limitations, demand as well as environmental concern of wood source, nonwood plant fibers become a substitute source of natural occurring wood fibers [1-2]. Among them Kenaf is one of the most economical plant-base fibers commonly used for paper and pulp production [3]. Moreover, Kenaf Bast (outer portion) fiber is characterized as long fiber like softwood fibers and commonly used for the production of high grade pulping not only for paper and pulp industry but also for as for textile, filter and composite materials as well [2,4-6].

The studies of heat transfer in the suspension forms have two fold benefits: for the Advancement about substantial models that might control the rejected paper processing and secondly for Different range about industries and can be utilized for planning about the equipment designing for pulp handling and the pipelines for supplying pulp in the paper and pulp industries. In 1994, the heat transfer effects of natural wood and synthetic fibers suspension in water were investigated for the first time. Later on these investigations were further improved for a variety of concentration and at a different flow rates in a pipe-line test setup to achieve more useful results for correlating heat transfer coefficient \( h_C \) to different fiber properties [7-8]. Furthermore, these finding in the form of \( h_C \) correlation to specific fiber properties could be significant in order to retard low quality paper
production. Kazi and Duffy [9] further investigated the correlations and observed that $h_c$ were increases by decreasing fiber concentration and increasing flow velocity using annular pipe heat exchanger. Additionally, heat transfer coefficient ($h_c$) was affected by various pulping method including: mechanical and chemical fiber pulping as well as degree of fiber beating [10-11].

Present research work focus on the comparative analysis of heat transfer coefficient ($h_c$) for Acacia mangium (wood fiber) and Kenaf Bast (non-wood) pulp fiber at various pulp flow and different fiber concentration parameters. Moreover, the effect of different fiber processing on heat transfer coefficient ($h_c$) may also be considered for deep insight monitoring of $h_c$ for hindrance of paper production loss.

2. Methodology

2.1 Materials

Both Kenaf Bast and Acacia mangium fiber samples were prepared by mechanical pulping and chemical pulping process by soda pulping by bleaching acacia mangium and Kenaf bast. All the investigated pulp samples were provided by Forest Research Institute of Malaysia (FRIM).

2.2 Experimental set-up

The experimental test setup consists of storage tank of 100 Liters, a close loop pipe line with an aluminum heat transfer test section having dimensions of (900 mm length and 41.4 mm inner diameter) along a centrifugal pump for pulping the suspension. A magnetic flow meter at the inlet section and pressure drop transducer was installed at the inlet and outlet ends of the test section for measuring the pressure drop. A chiller was connected in parallel to stock tank for maintaining the desired temperature inside the tank. A schematic diagram of the whole set-up has been shown in Figure 1.

![Figure 1. Experimental test section diagram](image)

2.3 Data acquisition

A data logger, Magnetic flow meter and Differential Pressure cell were connected for measuring the inlet, outlet and test section wall temperature, flow rates and pressure drop across the test section. Power of the installed heater at the test section was calculated from the supplied current and voltage to the heater. The obtained data were taken the conditions of steady state, bulk temperature, heating flux and instantaneous conditions.

2.4 Experimental procedures

All the investigated wood and nonwood fiber samples were supplied by FRIM. A known quantity of the fiber sample were disintegrated in the disintegrator equipment up to 3500 rpm until the whole fiber bunches were uniformly dispersed, before sending to the experiment test rig [12]. All the experimental settings are tabulated in Table 1.
Table 1. Experimental conditions

| Test variable parameters | Desire range |
|-------------------------|-------------|
| Velocity                | 0.4 - 2.8 m/s |
| Pulp bulk temperature   | 30 °C |
| Fiber concentration     | 0.2 - 0.6 wt.% |
| Heat flux               | 34 k Watt/cm² |

The surface temperatures (Ts), wall resistances (λ/δ), temperature of thermocouples (Ttc), and heat flux (q'), relation was calculated using equation (1).

\[ T_s = T_{tc} - \frac{q'}{(\lambda/\delta)} \]  

(1)

Where \( \lambda \) is thermal conductivity of test section and \( \delta \) represents thermocouple distances of thermocouple from the inner surface of the pipe.

The value of heat transfer coefficient \( h_c \) is calculated from the test section wall temperature \( T_s \), the pulp bulk temperature \( T_b \) and heat flux \( q \), using the following equation (2).

\[ h_c = \frac{q'}{(T_s - T_b)} \]  

(2)

Equation (3) and equation (4) are used for the evaluation of bulk temperature \( T_b \) and Nusselt number (Nu), and obtained by the following equation (3) and equation (4).

\[ T_b = \left( \frac{X}{L} \right) [T_{out} - T_{in}] + T_{in} \]  

(3)

\[ N_u = \frac{(h_{avg} D)}{K} \]  

(4)

Where, X and L represent the distances of thermocouples tips in the flow direction and the heated length-wise respectively.

3. Results and discussions

3.1 Effect of fiber concentration on heat transfer coefficient \( (h_c) \)

Heat transfer coefficient \( (h_c) \) data at three different weight concentrations (0.2 wt.%, 0.4 wt.%, 0.6 wt.%) of acacia mangium and kenaf bast fiber suspensions together with water are shown in Figure 2. The obtained results in a comparison with water run and the three concentrations of both samples suggested that flow of fiber suspension at velocities lower than 1 m/s results in a lower heat transfer coefficient than water. Moreover, concentration effects on heat transfer coefficient are more dominated when the velocity increases beyond 2 m/s. However, at the middle and high velocities range the suspensions with the lowest concentration (0.2 wt.%) tends to show the heat transfer coefficient higher than water in the case of acacia mangium only.

The present research work reveals that the mechanically pulped kenaf have \( h_c \) values lower than the corresponding values of water during the course of velocity as well as concentration excluding for a lower fiber concentration of 0.2 wt.% which exhibit a higher \( h_c \) values than that of water data at the velocity higher than 0.8 m/s. It was investigated that heat transfer coefficient significantly decreases with increasing the fiber suspension concentration and increases with the decrease in the concentration of kenaf bast fiber pulp.

In fact, the thermal conductivity of fiber suspension have a thermal conductivity lower than water, due to this particular fiber behavior, the enhancement of \( h_c \) contributed by fibers by the virtue of modification of turbulent eddies.
3.2 Effect of fiber bleaching on heat transfer coefficient ($h_C$)

The effect of fiber bleaching on $h_C$ were examined by AMB and KBB pulps, and prepared by AM and KB pulp fiber. Figure 3 represents the heat transfer coefficient ($h_C$) over a variety of velocity for water, bleached AM and bleached KB at fiber concentration 0.6 wt% and at bulk temperature 30 °C.

The experimental data indicate that the values of $h_C$ for both bleached fiber pulp are lower than the corresponding values for water throughout the range of velocities. The result of bleaching lead a net increase in fiber flexibility, which further lead a lower $h_C$ value as compared to unbleached pulp fiber. Moreover the bleached KB are more flexible as compared to bleached AM, therefore $h_C$ values for bleached KB are lower to the corresponding bleached AM pulp fiber as obvious in Figure 3. Same results were achieved by the other researcher as well [13]. During chemical pulping, fiber swelling and fiber detachment within fiber and from fiber wall occur due to lignin removal (after bleaching) from pulp fiber producing a more flexible fiber and lower $h_C$ values.

4. Conclusion

Significant differences in the values of $h_C$ were observed after fiber pulping process including: fiber concentration and fiber pulp bleaching of both wood (acacia mangium) and nonwood (kenaf bast) pulp fiber suspensions. Up to certain limits of fiber pulp suspension concentration, a considerable amount
of $h_c$ values have been observed. Moreover, bleaching of pulp suspension provides a more flexible and more uniform fiber surface with a lower $h_c$ values. By adopting proper fiber pulping processes, fiber quality can be improved by changing fiber pulp characteristics for the production of special products.

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