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Determination of effective thermal conductivity and specific heat capacity of wood pellets

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HIGHLIGHTS

- ▶ Effective thermal conductivity and specific heat capacity of wood pellets were measured.
- ▶ A numerical method was developed for fitting temperature profile curves.
- ▶ Effects of pellet size and moisture contents on the thermal properties were investigated.

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ABSTRACT

Effective thermal conductivity and specific heat capacity are important properties for studying the self-heating during wood pellets storage. A modified line heat source within a wood pellets container was used to determine the thermal conductivity and specific heat capacity of wood pellets with moisture content ranging from 1.4% to 9% w.b. A second order partial differential equation describing transient temperature distribution within the test container was numerically solved for temporal and spatial temperatures. The difference between experimental and numerical temperatures was minimized to estimate an effective thermal conductivity and specific heat capacity for the bulk pellets. The estimated thermal conductivity ranged from 0.146 to 0.192 W/(m K) increasing with moisture content. An empirical relationship among effective thermal conductivity, moisture content and porosity was developed. The dependence of effective thermal conductivity on pellets size was negligible. The estimated specific heat capacity of pellets ranged from 1.074 to 1.253 kJ/(kg K) in the tested range. A relation between specific heat capacity and moisture content was developed for general wood pellets.

1. Introduction

Wood pellets are used as a direct substitute for coal and natural gas or co-fired in small and large facilities for the production of heat and electricity. Wood pellets production and export in North America have been increasing rapidly over the past decade, with the total production in British Columbia (BC) about 1.5 million metric tons (t) in 2010. In BC, wood pellets are normally manufactured from a blend of sawdust and other by-products of logging and saw milling operations. The operations involved in producing wood pellets consist of an initial size reduction and blending, drying, final size reduction, and pressing ground wood to pellets. The commercially produced wood pellets are about 6.1 mm in diameter with a length ranging from 6 to 24 mm (Fig. 2). The density of a single wood pellets is about 1.2 g/cm^3 [1] and the bulk density of pellets in is around 600–750 kg/m^3.

Wood pellets produced in Canada are mostly exported to Europe and shipped in 10,000 t bulk volume ocean-going vessels. Before shipping wood pellets are stored in large silos typically 15 m in diameter and 20 m in height (2500–3500 t) for a period of one to 10 weeks. These storage structures are located at the production plants or at the shipping terminals. Self-heating may occur in the wood pellet silos depending upon the storage conditions (temperature, moisture content and ventilation) and storage period. Self-heating may lead to serious spontaneous fires [2–4]. Several major fire accidents in wood pellets silos have been reported around the world [5–8].

Internal self-heating starts to happen at storage temperature (30–50 °C) and speeds up as the temperature increases [10]. Thermal conductivity and specific heat of wood pellets are two key parameters controlling the rate of heat dissipation within the bulk. It is critical to develop relations between these thermal properties and the state of the material in moisture and temperature in order to predict instantaneous thermal environment within the bulk pellets. A robust model will be a valuable tool for the design of

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Nomenclature

A_S	surface area of a single pellet
B	constant in Eq. (6)
Bi	Biot number, Eq. (8)
C_P	specific heat capacity of bulk material, kJ/(kg K)
$C_{P,dry}$	specific heat capacity of dry bulk material, kJ/(kg K)
$C_{P,M}$	specific heat capacity of moisture (water), kJ/(kg K)
D	diameter of a single pellet
h	convection heat transfer coefficient, W/(m^2 K)
L	length of a single pellet, m
L_C	characteristic length, Eq. (8), m
M	moisture content, % wet based
q_0	power of the heater per square meter, W/m^2
Q	power of the heater per meter, W/m
r	radius of wood pellets container, m
r_0	radius of the heater, m
R	radius of the vessel, m
t	time, Eq. (24), s
T	temperature, K
T_0	initial temperature, K
T_a	temperature profiles obtained from experiments, K
T_C	temperature profiles obtained from numerical solution, K
V	volume of a single pellet
x	dimensionless factor in Eq. (5)

Greek symbol

α	thermal diffusivity, m^2/s
λ_{eff}	effective thermal conductivity of bulk material, W/(m K)
λ_{dry}	effective thermal conductivity of dry bulk material, W/(m K)
λ_{water}	thermal conductivity of water, W/(m K)
λ_s	thermal conductivity of solid (single pellet), W/(m K)
ρ_b	bulk density, kg/m^3
λ_f	thermal conductivity of fluid (air), W/(m K)
ρ_s	specific density of single pellet, kg/m^3
ρ_f	density of air, kg/m^3
ϕ	porosity, volume fraction of the gas (air)

optimum geometry and the operation of large scale pellet storage systems.

Many experiments have been carried out to measure thermal properties for various forms of woody and herbaceous materials and to develop empirical correlations (Table 1). For solid wood, Kollman and Cote [11] proposed empirical equations for estimating thermal properties as a function of density and moisture contents from 5% to 35%. Adl-Zarrabi et al. [12] measured thermal properties

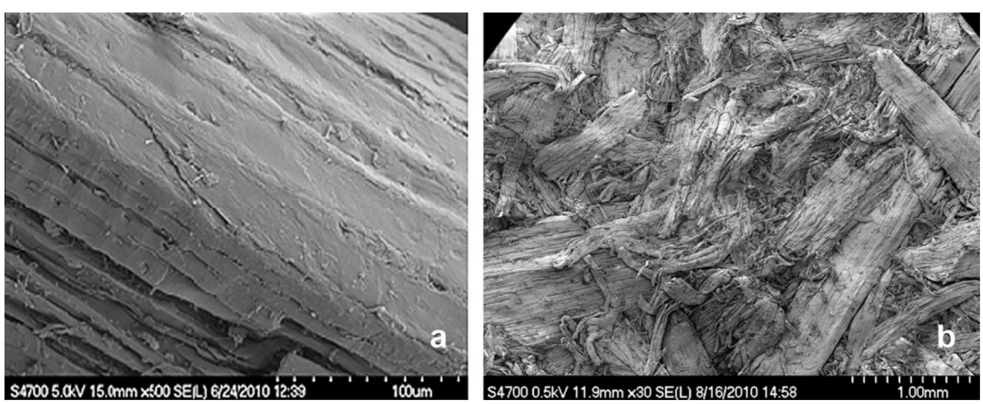
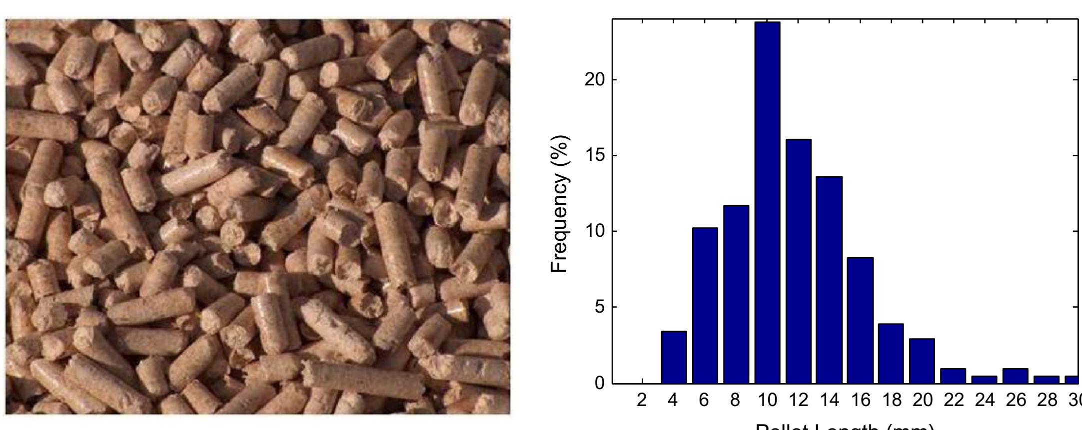


Fig. 1. SEM pictures: (a) ground wood particle by hammermill with 1.7 mm screen opening with ×500 magnification [18]; (b) cross section of pellets with ×30 magnification [19].



Wood pellets produced from saw dust.

Pellets sample 1

Fig. 2. Picture of saw dust pellets and size distribution of pellet samples used in thermal properties experiments.