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Pipeline transport of biomass: Experimental development of wheat straw slurry pressure loss gradients

*Jason Luk, Hossein Safaei Mohamadabadi, Amit Kumar**

Department of Mechanical Engineering, 4-9 Mechanical Engineering Building, University of Alberta, Edmonton, Alberta T6G 2G8, Canada

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ABSTRACT

Pipeline transport in the form of a slurry can reduce the cost of transportation of biomass material to a biorefinery, as compared to trucks. This research experimentally studies the hydraulics of slurries of wheat straw with water for pipeline transport. Slurries with a range of particle sizes and saturated solid mass fractions are examined in a laboratory-scale 50 mm diameter carbon steel pipeline system. Slurries with particles approximately 3 mm long can flow with saturated solid mass fractions of up to 30%. Pressure loss gradients results suggest the influence of drag reducing fibre suspensions. This phenomenon enables slurry pressure losses to be below that of the carrier fluid alone (water) and be achieved with sufficiently long particle sizes, low saturated solid mass fractions and high velocities. Our results suggest that to reduce pressure losses per unit biomass material, slurries should have short particle sizes, to allow high saturated solid mass fractions to be pumped at low velocities. With the pipeline system and slurries examined in this study, slurries with particles approximately 3 mm long and saturated solid mass fractions of 20–30% pumped at 1.5 m s^{-1} experience the lowest pressure losses. This result helps in the design and optimal operation of biomass slurry pipeline systems.

1. Introduction

Biorefineries produce fuels at capacities significantly below that of conventional petroleum refineries. Capital and operating costs per unit output are disproportionately high, in part, due to economies of scale [1]. The capacity is mainly constrained by the high transportation costs of biomass feedstock [2–4]. For example, a large 960 dam^3 annual capacity cellulosic ethanol plant that would require 15 trucks per hour to deliver 2 Mt of feedstock (dry mass) per year [5], would be still small in comparison to the first phase of the Sturgeon petroleum refinery under development in Alberta, Canada, which will have approximately three times the fuel production capacity [6]. Supply of feedstock by pipeline instead of trucks enables petroleum refineries to achieve large capacities and benefit from economies of scale [7].

Pipeline transport of solids in the form of fine particle slurries over long distances is a mature and well established technology. One example is the 439 km Black Mesa coal slurry pipeline in Arizona, which began operation in 1970 with a coal mass fraction of 50% [8]. Water-based biomass slurry can be

* *Corresponding author*. Tel.: +1 780 492 7797; fax: +1 780 492 2200.
E-mail address: Amit.Kumar@ualberta.ca (A. Kumar).
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prepared at satellite locations, and pumped through a (possibly branched) pipeline system to a centralized biorefinery. Water absorption by the biomass materials destined for ethanol production in a slurry pipeline may not be a concern, and may even be advantageous. Depending on the ethanol production technology, feedstock may be ultimately prepared into slurry form for pretreatment and saccharification followed by fermentation, regardless of the means of transportation [4,5]. Whether or not excess water would be transported in the pipeline (and need for a second return pipeline) depends on the type of carrier fluid (which could be fuel oil for combustion), water content of the harvested material, saturated solid mass fractions that can be practically achieved and the specific production processes used by the biorefinery [2].

A preliminary body of experimental work has been developed on water-based wood chip biomass slurries [9,10]. It has been found to be economically competitive with truck transportation at high solid mass fractions (30% wet biomass) and large capacities (2 Mt annually (dry mass)) [2]. However, other lignocellulosic biomass materials have yet to be investigated.

Unlike woodchips, some biomass materials, such as straw, are long and fibrous. The ability for suspended fibres to reduce the drag resistance of a liquid through a pipeline has been established in literature. Vaseleski and Metzner [11] experimented on nylon fibres in PVC tubing. They determined that the drag reduction occurs because the long fibrous material dampens turbulence [11]. Similar findings are reported by Kato and Mizunuma [12] for asbestos fibres and by Kazi et al. [13] for wood pulp.

We have experimentally studied the hydraulics of wheat straw slurries with water for pipeline transport in this paper. Pressure loss gradients are measured over a range of particle sizes, solid mass fractions, and velocities. Wheat straw is selected as it is an abundant potential source of cellulosic biomass in Western Canada.

2. Materials and methods

This section is separated into three parts. In Section 2.1, the equipment used in the laboratory setup is detailed. In Section 2.2, the feedstock and its preparation are explained. Finally, Section 2.3 discusses the preparation and pressure loss measurement. A more detailed overview of the materials and methods used in this study is available in the literature [14].

2.1. Laboratory setup

This experimental work is conducted with a 50 mm diameter, 12.8 m length laboratory-scale pipeline loop. Slurry is prepared with a 0.4 kW mixer [15] within a 0.55 m^3 mixing tank. A 7.5 kW centrifugal pump [13] moves the slurry through a water bath, which is used as a heat sink to control the temperature of the slurry. A transparent viewing section enabled observation to ensure data is collected for samples with solid particles suspended within the flow, as opposed to accumulating at the bottom of the pipeline. An electromagnetic flowmeter [16] and resistance thermometer [17] monitor the bulk velocity (hereafter referred to as *velocity*) and temperature of the slurry, respectively.

The pressure drop test section of the loop is an 8.5 m straight length of 50 mm diameter steel pipe. Compression spring pressure gauges [18] are installed at either end of this length, while allowing a clearance of 20 pipe diameters after and 5 pipe diameters before other fittings. After the test section, the slurry is returned to the mixing tank. A generalized schematic of this flow path is shown in Fig. 1.

2.2. Wheat straw preparation

Wheat straw is a byproduct of wheat (*Triticum aestivum*) and is readily available in Western Canada. All feedstock was harvested at Desseault Farms, Westlock, Alberta, Canada (45° 25′ 10″, −95° 26′ 36″) in fall 2009 and stored outdoors, in large piles, under tarps, until delivery in spring 2010.

The delivered 15–20 kg bales of straw are chopped using a cutting mill [19]. A particle size distribution from less than 1 mm to over 25 mm is produced [20]. When pumped within an industrial scale pipeline over 300 mm in diameter, this narrow range could be significant; however, a smaller tolerance is desired in the laboratory-scale system.

The chopped wheat straw is passed through a screen shaker [21]. A stack of screens of descending square openings of 19 mm, 13 mm, 6 mm, 4 mm, 3 mm, 1 mm is used. The shaker is operated for 2 min [22] for each load. The material collected on the 4 mm, 3 mm and 1 mm trays is collected for testing. These samples are referred to hereafter as Long, Medium and Short straw particle sizes, respectively, as itemized in Table 1.

2.3. Slurry testing

In an earlier study, it was determined that water absorption of wheat straw is only significant throughout the first 24 h of the mixing process [14]. Although the straw could be successfully pumped at low velocities after significantly less processing time, all data sets are collected at saturation point for consistency. This also more accurately represents material transported in long distance pipelines, which would inevitably reach saturation within the pipeline. The mass fraction of water in saturated material ranged from 77.5% for short particle samples to 79.0% for long, while particle density was 1060 kg m^{-3}

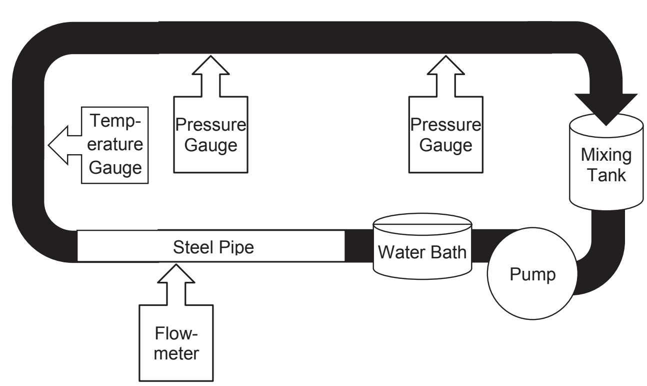

Fig. 1 – Schematic of experimental setup.