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Investigation into thin layer drying rates and equilibrium moisture content of abattoir paunch waste

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ABSTRACT

The work reported in this article was conducted to determine thin layer drying rates and equilibrium moisture contents of abattoir paunch waste. The equilibrium moisture content of paunch varied from 7.14% to 13.12% for drying in air between 35 and 55 °C, and at 40–80% relative humidity. A predictive equilibrium moisture content equation based on the Chung-Pfost model was developed with the constants A found to be 586.72, B (27.461), and C (28.913) with a standard error of ±0.0035. These values were comparable to the published values for wheat and barley. The thin layer drying constant, k, varied from 0.00023 to 0.0029 min^{-n} with an average time exponent, n, value of 1.42 for air temperatures in the range of 35–55 °C. The variation in drying rates demonstrated a significant sensitivity to humidity.

1. Introduction

The Australian Red Meat Processing (RMP) industry is the country's largest food manufacturer and exporter, and is regarded as energy and resource intensive [1]. Australia currently has approximately 150 RMP sites, ranging from beef only, sheep only, to mixed processing facilities [2]. A large RMP plant is defined by Meat and Livestock Australia as processing over 600 head per day of beef, which equates to approximately 42,300 tonnes hot standard carcass weight (tHSCW) per year. Average emissions and water consumption from this level of production are estimated at 554 kg $CO_{2\text{-}e}$ $tHSCW^{-1}$ and 9.4 kL $tHSCW^{-1}$, respectively [3]. In a study of 15 RMP sites, the breakdown of the total energy demand was 31.6% grid electricity, 37% natural gas, 19% coal with 67% of total energy emissions related to electricity use [3]. Improved sustainability performance requires the Australian RMP industry to look towards renewable energy to reduce reliance on fossil fuel sources.

The Australian (and international) RMP industry has several industry-specific waste streams that show potential as renewable energy sources. The main types of organic solid waste generated during meat processing include manure, paunch solids (grass and grain from the first stomach of ruminant animals, and biological solids from wastewater treatment [4]. There are a number of possible treatment methods available to turn abattoir waste into a useful energy source. The British meat industry has had success with co-combustion units using meat and bone meal as a secondary fuel in coal-fired stations or as standalone units/fluidised beds [5–7]. Fluidised beds burn particles by suspending the particles in the air in conjunction with high temperatures. These systems work well as a renewable energy source using biomass comprised of meat and bone meal in countries containing the Bovine Spongiform Encephalopathy (BSE) pathogen (mad cow disease). It benefits doubly, by providing energy generation as well as a way of disposing of a pathogen that cannot be dumped in landfill [8]; [9]. However, in Australia where there is no risk of BSE, the market for meat and bone meal is worth more to the meat industry as a resalable by-product than as a secondary fuel. Research into abattoir waste-to-energy is also being conducted in areas such as; methane capture from covered anaerobic ponds [10], biogas from anaerobic digesters [11,12], dry anaerobic digestion of paunch [13], pre-treatment methods for increasing biogas production in anaerobic co-digesters (including thermal and wet oxidation) [14], and

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de-watering of paunch and DAF sludge using immersion frying [15]. While moist paunch can find use in anaerobic digestion, the drying of paunch promises to be the simplest and cheapest method to convert paunch into an energy source.

In Australia paunch waste has not been successfully incorporated into any waste-to-energy stream including anaerobic digestion. There are a number of finishing procedures for cattle being prepared for slaughter such as lot feeding or pasture finishing which creates difficulty in precisely classifying the composition of paunch [40,41]. However, regardless of the finishing procedure used, approximately 25 kg of paunch is produced per head of cattle (wet weight) or roughly 3.8 kg dry weight [16–18]. A medium sized RMP site (approximately 500 head of cattle per day) produces 60–90 m^3 of paunch per week [19]. Compared to other sources of energy from biomass, paunch has an average energy content of 16.7 MJ/kg dry basis [17]. This is comparable to other biomass crops such as wheat straw, which has an energy content of 17.51 MJ/kg dry basis [20]. Given the average energy content and significant volumes of paunch produced across the industry, paunch may be a viable RMP industry renewable energy fuel source for use in co-combustion units, as a coal substitute, or for pyrolysis [18,19,25,39].

The current best practice for paunch handling includes dry dumping instead of wet dumping [16,21], the separation of the solids from the liquid followed by land disposal of the solids. In essence, this means that the paunch is first dry dumped, the contents are dumped out without the addition of water and then the emptied paunch is umbrella washed. The paunch then passes through some form of dewaterer such as a screw press separator or contra shear screen which is situated above a holding area. The separator dewaters the paunch of most of its surface water, thus separating the liquid from the solid. The resulting liquid waste stream, once separated from the solids, passes to holding ponds while the solid waste is collected [19].

Australian abattoirs currently undertake one of several options to address paunch waste management, including: i) removing paunch and other solids off-site, ii) composting material on-site and used on-site, and iii) composting material on-site and used off-site. In the Australian RMP industry it is an absolute waste product with inherent disposal/treatment difficulties such as its high biochemical oxygen demand (BOD) [17,22–24]. Paunch's high BOD prevents it from being allowed to enter surface or ground water thus, presenting drainage issues [18]. Paunch as a biofuel could enable a problematic organic waste product to become a useful energy source for abattoirs.

1.1. Barriers to the implementation of paunch as a renewable energy source

The lack of progress in implementing paunch as a renewable energy source is due to the high initial moisture content (MC) of the material, approximately 80–85% when dewatered of surface water [17,18]. Bridle [25] reported that burning paunch with 70% wet basis (w.b) MC would be suitable as a waste disposal method with the paunch itself providing little or no energy. For energy gain such as use in pyrolysis, the moisture content of paunch needs to be reduced to 20% [25]. If paunch were to be used as a coal substitute or for co-combustion, the paunch would need a substantially lower MC than 70% (w.b) for efficient boiler output, as water content impacts boiler output and is boiler specific. Boiler efficiency loss is approximately 0.1% for each 1% increase in MC [26]. Coal ranges in MC from 2.2% to 39% depending on the type of coal. If boiler output drops due to MC it is possible to increase the feed rate of the boiler to increase the output. However, a more efficient way is to decrease the initial MC of the feedstock (assuming the energy consumed and cost in drying is less than the additional energy extracted from the drier feedstock). To achieve this, drying is required to lower the initial MC in order for paunch to become a biofuel. Therefore, the drying of paunch is the major drawback in implementing paunch as a renewable energy source.

1.2. Previous studies in paunch characterization

Early studies (e.g. [27]), suggested that paunch could be dried using a gas-fired dehydrator and then used as a feed additive. Of the studies that specifically relate to paunch drying, the drying constants reported are of little value due to the constants either being specific to the dryer used in that particular study or only performed at one temperature (35 °C) (e.g., [28,29]). However, the earlier findings associated with the performance of paunch drying are beneficial to the body of knowledge into paunch behaviour. Farmer et al. [30] revealed that drying times were increased by 10–12 days if the crust was not agitated during drying Farmer et al. [28] reported the design of a modified solar still using direct solar energy and solar-regenerated desiccant for low-insolation days, which showed that paunch moisture could be reduced from 80% to 30% in 5 days. Griffith and Brusewitz [29] used a tunnel dryer to determine drying rates for 35 °C at 2.5–10 cm depth. An assumption was made that air temperature was not controllable in a dryer whereas relative humidity could be manipulated by controlling the ratio of recirculated to fresh air. Accordingly, the study investigated drying rates at 35 °C air temperature with 20, 50, 80% relative humidity, respectively. Griffith and Brusewitz [29] preliminary drying constant, k, for paunch ranged from 0.005 to 0.108 hr^{-1} and was significantly affected by paunch content (ration diet) as opposed to the drying conditions. Their main experiment gave the average drying constant, k, as 1.17 ± 0.41, which was significantly different to their preliminary rates.

There are several methods available for drying organic materials. Solar and sun drying are relatively inexpensive methods to reduce moisture content without having to rely on fossil fuel run dryers. Sun drying of paunch (spreading a thin layer of product over an area to dry in the sun) is not an appropriate drying method for most Australian abattoirs due to the large surface area required for drying. While most Australian abattoirs do have access to vacant land it is generally reserved for wastewater treatment ponds, which are then irrigated onto crops growing on adjacent land. Due to limitations in available space there is a particular need to design a suitable paunch dryer which takes into account industry constraints. Solar drying may be a suitable method for moisture reduction. However, optimum dryer design is reliant on information such as drying rates under set conditions, the initial and desired final moisture content of a product, and the equilibrium moisture content [31]. Without this information it is not possible to design a suitable dryer or to determine whether a dryer is operating under optimum conditions. Therefore, determination of drying rates and equilibrium moisture content for a range of operating conditions was performed to allow a detailed understanding of paunch characteristics.

2. Methodology

2.1. Thin layer drying

Thin layer dryers can be used to experimentally determine drying constants, which can be used to select and test drying equipment and are the basis of many deep-bed drying models [32,33]. A thin layer is defined as 'a layer of material exposed fully to an airstream during drying. The depth (thickness) of the layer should be uniform and should not exceed three layers of particles' [32]. This is achievable with paunch although particle size is not

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