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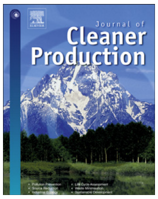

Energy and water self-sufficiency assessment of the white sugar production process in Indonesia using a complex mass balance model

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ABSTRACT

White sugar production consumes considerable amounts of energy and water and, at the same time, generates a substantial amount of material containing energy (biomass) and releases water to the environment. Recycling the biomass as a source of energy and using the released water as a part of the production process will cut fossil fuel and water use. These approaches will significantly save resources and cut the environmental pollution load. The objectives of this study were to analyze the mass balance, assess the energy content of by-products, and build a closed flow of energy and water self-sufficiency in the white sugar production process. A mass balance model was developed to illustrate internal mass-flows and to determine the amount of by-products generated in the production process. The results showed that optimal use of by-products can produce energy and water exceeding the needs of the sugar processing itself, leading to the creation of energy and water self-sufficiency or an independent sugar production process. The potential energy contained in the by-products of a sugar mill with a capacity of 3000 tons of cane per day is approximately 2237 gigacalories per day, which could meet the energy needs of the mill with an excess of 37,081 kWh/day. The mill is also able to produce a net water surplus of 700 m^3 per day. This research demonstrated that a complex mass balance model can be used to assess the level or possibility of sugar mill energy and water self-sufficiency. It is suggested that the sugar production process should be developed as a closed-production system that does not require the input of energy and water from outside the system. Application of this production system at a practical level will contribute to reducing sugar mill pollution, reduce coal and other fossil fuel use and help protect water resources from excessive exploitation. A closed production system can be applied to all industries that process raw material containing energy. In the short term, sugar production should be restricted in its use of fossil fuel, public electricity networks, and water from natural sources. In the long run, sugar mills should become multipurpose factories producing sugar, energy, and water.

1. Introduction

The sugar production process consumes considerable amounts of energy and water. The total energy needs are 200–500 kg of steam and 20–24 kWh of electricity per ton of cane (Bhatt and Rajkumar, 2001; Hariyanto, 2011), and the electricity consumption per ton of cane is 25 kWh, applicable to a sugar mill with a capacity of 3000–7000 tons of cane per day (TCD) (Pippo and Luengo, 2013). The average capacity of a sugar mill in Indonesia is 3000–7000 TCD; therefore, the steam and electrical energy requirements are approximately 600–1500 tons and 75–175 MWh per mill per day, respectively.

The energy needs of the sugar production process will continue to increase with the amount of sugar demanded. However, the energy supply is diminishing. The Ministry of Energy and Mineral Resources (ESDM) noted that energy consumption increases by an average of 7.1% per year, dominated by the industrial sector. It is estimated that the industrial sector will consume 47.3% of the total energy used in 2030 and that consumption will grow by an average of 6.2% per year (ESDM, 2011). This energy mainly comes from fossil oil (41.8%), coal (29%), and gas (23%). The rapid growth of energy demand cannot be sustained by the energy reserves in Indonesia, which are rapidly being depleted. It has been estimated that the reserves can supply oil for only approximately 23 years, gas for 50 years, and coal for 80 years (adapted from ESDM, 2007, 2010).

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Regardless of the accuracy of estimation, it is widely accepted that industrial production, including sugar mills, will face energy limitations in the near future.

Additionally, sugar production also needs water in large quantities: 2.1–2.8 m^3 per ton of cane processed. However, as with energy, the clean water supply is decreasing. The world's clean water supplies are only 2.5% of the total amount of water, of which consumable water is only 1% (Esmeris, 2012). The total amount of clean water available in the world is only 100,000 km^3 per year (Gleick, 1994). Population growth, contamination of water resources due to human activity, water demand for new technologies, and climate change are leading factors in the global water crisis (UNESCO, 2009). Approximately 4% of the ground water stock is already contaminated due to human activities (Esmeris, 2012).

The sugar production process produces by-products containing energy: bagasse, which has a calorific value of 2035 kcal/kg, molasses (2700 kcal/kg), filter cake (3319 kcal/kg) (Moerdokusumo, 1993), and dried leaves (3500 kcal/kg) (Kurniawan, 2009). Use of these materials for energy generation would replace the fossil fuel energy used to set up an energy self-sufficient sugar mill. Bagasse has been used intensively for direct burning in furnaces to supply energy for many purposes, and its use in cogeneration systems is being developed (Guerra et al., 2014; Mishra et al., 2014; Rincón et al., 2013). Bio-ethanol production for energy purposes has also received special attention during the last few decades (Dias et al., 2009; Quintero et al., 2008). Similarly, significant progress has also been made in gasification technology for sugar cane mills (Pellegrini et al., 2010; Pellegrini and Oliveira, 2007; Turn et al., 2002). These development efforts often co-exist with product diversification such as selling ethanol from molasses (Martinelli and Filoso, 2008). Thailand intends to produce 1.92 million liters of bio-ethanol per day (Nguyen et al., 2008); bio-ethanol production from sugarcane is more sustainable (Goldemberg et al., 2008).

Many sugar mills already generate energy to meet their own needs and even generate surplus energy. The Belle Vue mill in Mauritius produces 105 GWh of electricity from bagasse by processing 210 tons of cane per hour (Deepchand, 2005). Approximately 26% of the electricity supply in Mauritius (Ramjeawon, 2008) and 10% in Hawaii are produced by sugar mills (WADE, 2004). Cogeneration can produce 10,500 MWh of electricity, which exceeds the plant's operational needs of 3500 MWh, resulting in an excess of 7000 MWh during the milling season that could be sold by sugar mills to generate additional income. For example, NSL Sugars Limited and Boumar Amman in Karnataka, India have been able to generate 30 MW of electricity and 120 kL of ethanol per day (Tayibnapis, 2013). In Zimbabwe, sugar mills have the potential to generate 210 MWh of electricity (Mbohwa, 2003). In South Africa, a sugar mill can produce 1 GWh of energy by processing 6000 tons of sugarcane (Mashoko et al., 2013). Bagasse and eucalyptus have been used by sugar mills to produce electricity in Nicaragua (Broek et al., 2000), indicating that bagasse may be replaced by or combined with other forms of biomass for power generation to generate energy continuously throughout the year. These alternative means of using by-products may lead to the development of independent energy and water process flows (closed production processes) for white sugar mills, thus increasing the efficiency of the production process.

Sugarcane is an energy crop (Waclawovsky et al., 2010) with a typical composition of 15% dissolved matter (13% sucrose and 2% other sugars, mainly glucose and fructose), 15% fiber (insoluble), and 70% water. Therefore, the main process is evaporating water from cane, which yields as much as 700 L per ton of cane processed, which may be used to supply the water needed in the production process. This water can be collected through a condenser so that its quality is very good, i.e., it is free of pollutants and non-water components. Additional treatment is necessary to meet the quality requirements of processing water and other uses, including bottled water production.

Based on these facts, this research aimed to develop an energy and water self-sufficient sugar production process. The main foci of the study were to assess the utilization of by-products as an energy source, assess and describe the cycle of mass and energy in the sugar mills, assess the efficiency of the process, assess the potential generation of energy from by-products and design an independent energy and water sugar-production process flow. Therefore, the goal of this research was to set up a sugar production process with independent energy and water, minimal input, and optimal output based on the principles of mass and energy balances. To meet these goals, we took the following steps: (1) analyzed the mass balance of white sugar production, (2) assessed the energy content and conversion of by-products into energy, and (3) designed a model of an energy and water self-sufficient sugar-production process (with minimal input, optimal output). This study refers to the Subang sugar mill (West Java, Indonesia), which has a capacity of 3000 tons of cane per day.

2. Method

The expected result of this research was the sufficiency level of energy and water in white sugar production. For this reason, it was of primary importance to define the boundary of the production system from which the mass balance model was created. Material flows were expressed in mathematical equations indicating relationships and mass transfers among and between compartments. Primary and secondary data were collected to prove these equations.

2.1. Data collection

Data were collected from primary sources (the actual mass balance of the Subang sugar mill) and secondary data (research reports, journals, thesis, dissertations, books, magazines, and official data of the sugar mill) that include the mass flow of the production process, energy and water requirements, sources of energy, and by-product generation. Most secondary data sources were derived from sugar mill production data on, for example, by-products used for energy. The field research was conducted at the Subang sugar mill (West Java, Indonesia).

The field observation in the sugar mill was undertaken based on the process lines, from cane reception to packaging. The mill supervisor and process engineer accompanied the researcher and explained each process (input–output) and provided data. Data were copied and include material flows in and out of each compartment, energy consumption and process conditions. The collected data were then used to analyze energy consumption and the process efficiency of the sugar mill, which were then compared with model outputs (Appendix 1 summarizes the sugar mill data collected and used in this research).

2.2. System boundary

The sugar production process is a complex system that involves many factors and constraints, which are connected to one another. Factors and constraints are the materials and energy input, by-products, and energy and water requirements. A comprehensive approach was used to find the optimal solution of energy and water use. Therefore, a systems approach was used to analyze the flow of mass and the energy and water needs, including the potential energy from by-products of the sugar-production process.

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