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A comparison of product-based energy intensity metrics for cheese and whey processing

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ABSTRACT

Dairy processing is one of the most energy intensive sectors within the food processing industry. Accordingly, reducing energy use and energy-related air emissions is of critical importance to improve its economic and environmental performance. This paper focuses on product-based energy intensity (PEI) metrics for improving the energy efficiency of dairy processing by presenting a process-by-process (PBP) method to determine PEIs in a multi-product system, with a focus on U.S. dairy processing operations. This method is compared with two alternative methods in the case of a cheese and whey processing system. For all three methods, energy use is allocated on a mass and solids basis. The results show that the PEI values depend highly on the choice of method. In the case of an energy benchmarking program relying on the PBP method, the choice of PEI basis has an impact on the allowances permitted for each plant and should be chosen carefully.

1. Introduction

In the dairy processing sector, raw milk is transformed into a variety of products, such as fluid milk, butter, cheese, yogurt, dry milk powder, and dry whey powder. Dairy processing is among the most energy intensive industries in the food processing industry, and is typically of high economic importance in many world regions. In 2010, the U.S. dairy processing sector generated over $90 billion in product shipments, employed over 130,000 people, and spent more than $721 million on purchased electricity and $542 million on purchased fuel (U.S. Census Bureau, 2010). That same year, the U.S. dairy processing sector consumed more than 9.6 TWh of electricity and 76 petajoules (PJ) of natural gas (U.S. Energy Information Administration, 2010).

Reductions in energy use and energy-related air emissions are of critical importance for improved economic competitiveness and environmental sustainability of the dairy processing industry. Energy efficiency programs play an important role in achieving such reductions, as well as in reducing operating costs. To support energy efficiency programs, policy and industry decision makers rely on a number of energy efficiency measures (Tanaka, 2008) to evaluate the relative efficiency of a process, plant, company, industry, or country.

This paper focuses on the use of *product-based energy intensity* (PEI) metrics, which are defined as the quotient of processing energy input divided by product output (e.g., MJ/kg product). PEI metrics provide a standard comparative basis because energy efficiency is defined in terms of physical product output as opposed to monetary value (i.e. Hyman and Reed, 1995; Freeman et al., 1997; Worrell et al., 1997). This study focuses specifically on the development of PEI metrics within the U.S. dairy processing sector, which provides a compelling example of a multi-product system within the food processing industry. Previous approaches to allocate energy use to unique products within multi-product dairy processes are examined, and alternative approaches are proposed in this study. The methods and results presented here can be generalized to dairy processing in any world region with the appropriate regional data.

1.1. PEI metrics

PEI metrics are useful in supporting energy efficiency programs for several reasons. First, they allow industry managers to establish internal energy benchmarking goals (Ke et al., 2013), and they can also be used to establish energy benchmark comparisons between different facilities. Second, PEI metrics can communicate the environmental footprints of a facility's products to customers, such as

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Nomenclature

List of Symbols and Acronyms

A	allocation factor based on final product characteristics, dimensionless
E	energy consumption (process-level, in terms of primary energy), MJ
E_{I}	energy consumed by processes common to all three products (i.e., cheese, dry whey, whey cream), MJ
E_{II}	energy consumed by processes unique to cheese, MJ
E_{III}	energy consumed by processes common to dry whey and whey cream, MJ
E_{IV}	energy consumed by processes unique to dry whey, MJ
m_o	mass output of product, kg
PEI	product-based energy intensity, MJ/kg
PBP	process-by-process method
SA	subdivision and allocation method
TD	top-down allocation method
x	mass or solids fraction, dimensionless

energy or carbon footprints (Sathaye et al., 2009; Vandenbergh et al., 2011). Third, PEI metrics are valuable to government policy makers, as they provide a quantitative basis for promoting best practices and assessing variations in energy efficiency among plants within a given industry (Boyd and Tunnessen, 2013).

A foundation for developing PEIs for the food processing industry can be found in Ramírez et al. (2006a), which used metrics based on energy use per unit of physical output in the Dutch food industry. Calculating PEIs is straightforward on the surface, but determining industry-wide PEI metrics presents certain complications, especially for industries producing multiple products (Patterson, 1996; Walker et al., 2014). Determining the amount of energy used to manufacture a unique product in a multi-product system can be difficult since products share processes in common, energy and mass flows are often interchanged between processes, and energy use at the process level may not be closely monitored. Another complication is that the allocation of energy use to particular products may not be performed in a standard fashion from one facility to another. This can be problematic when establishing industry-wide benchmarks since the method used to allocate energy use to the different products is not consistent from one facility to another, which precludes direct comparison of PEI metrics across an industry.

1.2. Energy use studies and energy allocation methods

General background on resource utilization in the dairy processing sector has been provided in a comprehensive review by Rad and Lewis (2014), which provides an up-to-date view on water use, energy use, and waste water management in the dairy processing sector. Regarding cheese processing, energy use has been examined for specific products such as different types of cheese and dry whey powder (Xu et al., 2009; Zehr, 1997; Ramírez et al., 2006b) and technologies such as pasteurization and membrane filtration (Ozyurt et al., 2004; Molinari et al., 1995). The potential for reducing energy use in U.S. cheese processing is highlighted by the work of Xu et al. (2009), which shows an energy intensity of cheese ranging from 2.3 to 16.8 MJ/kg cheese. Other reports on best practices provide information on energy use and energy-efficient technologies (Brush et al., 2011; European Commission, 2006) used in the cheese processing sector.

While these reports provide a means to identify key hotspots to reduce energy use and emissions, they do not assign energy use to individual products within a multi-product system. Energy use in cheese and whey processing is also reported in life cycle assessments (LCAs) (Berlin, 2002; Kim et al., 2013), but such energy use data tends to be aggregated instead of specified at the process level. As a result, energy used in cheese processing systems tends to be allocated in top-down fashion due to lack of data for individual processes. With this top-down (TD) approach, energy use at the plant level is allocated to the various products based on some economic or physical basis that characterizes the product outputs. Typical bases include economic value, mass, and milk solids content (solids) (Feitz et al., 2007).

Table 1 summarizes allocation bases that have been applied in the literature to date to various products in cheese processing plants. In terms of physical bases, a *solids* basis has most often been used, as opposed to *mass*. To justify this choice, one argument is that the most important aspect in cheese processing is the solids content, and that milk, which contains 80% water, can be seen simply as a carrier of the milk solids (Feitz et al., 2007).

To improve on the TD method, Feitz et al. (2007) developed a resource allocation method for the dairy processing sector based on specific physico-chemical attributes of 11 products. The study determined allocation factors for different resources used such as water use, electricity, and thermal energy based on data from 17 dairy processing plants in Australia. However, the method proposed by Feitz et al., still relies on energy use data at the plant level.

To date, there is a dearth of literature discussing allocation using process level energy data in the cheese processing sector. One exception is Aguirre-Villegas et al. (2012a), which explores different methods to allocate energy use to each product output in a cheese and whey processing system. The authors suggest the best approach is a "subdivision and allocation" (SA) method using a solids basis. The SA method divides the processing system into four categories to distinguish the processes common to all three products and the processes considered unique to each individual product. The SA method thus takes advantage of energy use data at the process level, and applies TD method allocation only for energy use considered to be common to all three products.

The SA method still requires TD method allocation which may explain why mass is not used as an allocation basis. However, mass is a fundamental physical property, and mass flow data are generally readily available within the typical dairy processing plant. Therefore, using mass as a basis is feasible when process-level data on energy use are available. The current study fills the existing methodological gap by presenting a process-by-process (PBP) method for estimating energy use in a multi-product dairy processing facility on a mass allocation basis. The proposed method relies on a bottom-up calculation of the PEI that utilizes PBP energy use. Unlike other methods, this method does not require TD method allocation. The method used in the current study has been discussed in the literature by Wang et al. (2004) in the case of the petroleum refining industry. Relying on a general framework developed by Walker et al. (submitted for publication), the current study applies the framework to the real world case of U.S. cheese and whey processing, and compares results found through previous allocation methods. The method is applied using data for U.S. dairy processing facilities, but can be extended to any facility with the appropriate data.