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# Engineering process and cost model for a conventional corn wet milling facility☆

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ARTICLE INFO

*Article history:*
Received 22 December 2006
Received in revised form
9 August 2007
Accepted 17 August 2007

*Keywords:*
Corn
Wet milling
Coproducts
Technical Cost Model
Process simulation
Economics

ABSTRACT

Conventional wet milling of corn is a process designed for the recovery and purification of starch and several coproducts (germ, gluten, fiber and steep liquor). The total starch produced by the wet milling industry in the USA in 2004 equaled 21.5 billion kg, including modified starches and starches used for sweeteners and ethanol production.

Process engineering and cost models for a corn wet milling process (for steeping and milling facilities) have been developed for a "generic" processing plant with a capacity of 2.54 million kg of corn per day (100,000 bu/day). The process includes grain cleaning, steeping, germ separation and recovery, fiber separation and recovery, gluten separation and recovery and starch separation. Information for the development of the models was obtained from a variety of technical sources including commercial wet milling companies, industry experts and equipment suppliers. The models were developed using process and cost simulation software (SuperPro Designer®) and include processing information such as composition and flow rates of the various process streams, descriptions of the various unit operations and detailed breakdowns of the operating and capital cost of the facility.

Based on the information from the model, we can estimate the cost of production per kilogram of starch using the input prices for corn and other wet milling coproducts. We have also used the model to conduct a variety of sensitivity studies utilizing modifications such as feedstock costs, corn compositional variations, and the sale of wet corn gluten feed. The model is also being used as a base-case for the development of models to test alternative processing technologies and to help in the scale-up and commercialization of new wet milling technologies.

This model is available upon request from the authors for educational, non-commercial and research uses.

Published by Elsevier B.V.

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0926-6690/$ – see front matter Published by Elsevier B.V.
doi:10.1016/j.indcrop.2007.08.002

## 1. Introduction

Conventional wet milling of corn is a process designed for the recovery and purification of starch and several coproducts. The US corn wet milling industry can trace its beginnings back to 1844 when Thomas Kingsford, working at Wm. Colgate & Company in Jersey City, NJ, convinced his employer to try a new alkali process for extracting starch from corn. This plant became the world's first dedicated corn starch plant. Kingsford built his own corn wet milling facility a few years later in Oswego, NY (CRA, 2000). Many changes in processing and equipment have occurred over the last 160 years. The total starch produced by the wet milling industry in 2004 equaled 21.5 billion kg, including modified starches and starches used for sweeteners and ethanol production (CRA, 2005).

Prior to the 1880s, the corn refining industry simply discarded fiber, germ and protein from corn. Refiners began realizing the value of non-starch corn products to turn them into animal feed and extract corn oil from germ. These extractions not only decrease the production price of starch but also decrease starch loses and increased its quality.

Currently the end products of the wet milling process are starch slurry, germ, corn gluten feed and corn gluten meal. Starch is the primary product of the process (Blanchard, 1992). It is used with minimal further processing as a food additive or as an adhesive. Economically more important is its conversion to corn sweeteners and ethanol. Typical starch slurry leaving the mill house has 60% moisture content.

The germ is used for corn oil production and the resulting meal used for animal feed or added back to the corn gluten feed. Corn oil, the most valuable component of the corn kernel, is recovered from the germ by expelling or more often by solvent extraction. More than a million tonnes of corn oil are produced annually in the United States (Gunstone, 2006). Typical germ contains 48% oil, 13% protein, 12% starch, 2% ash and 3% moisture.

Corn gluten feed is the fiber rich component removed in the wet milling process. It is a high fiber, low protein feed used as energy, protein and fiber source for beef cattle. Corn gluten feed is produced by combining concentrated steepwater with the fiber during the separation process. This coproduct typically contains 60% fiber and 20% protein (White and Johnson, 2003).

Corn gluten meal is the high protein, low fiber fraction extracted during the wet milling process. It is used as an energy, protein, vitamin and mineral source for poultry and swine. The final corn gluten meal has typically 60% protein and 10% moisture (Blanchard, 1992; CRA, 1989).

Computer simulation models have been used successfully to understand processes and the physical and economical implications of experimental modifications. We developed engineering and economic models for the corn wet milling process (steeping and milling facilities) as research tools to help in the evaluation and optimization of the process and to aid in future process development. The models were developed using the software SuperPro Designer®, Version 7.0 (Intelligen Inc., Scotch Plains, NJ), based on previous models (Johnston et al., 2004) developed originally in Aspen Plus® (Aspen Technologies Inc., Cambridge, MA) and Microsoft Excel (Microsoft Corporation, Redmond, WA). Information on the corn wet milling process was obtained from various technical sources including commercial wet milling companies, industry experts and equipment suppliers.

## 2. Process model description

The conventional wet milling process includes many steps for the recovery and purification of starch and all coproducts (germ, gluten meal, and corn gluten feed). Our model is based on a "generic" processing plant with a capacity of 2.54 million kg of corn per day. The process and model is divided in six main sections, which include grain handling, steeping, germ separation and recovery, fiber separation and recovery, gluten separation and recovery and starch washing and recovery (Fig. 1). The unit operations in the model are identified by a number ID based on each one of the 6 sections (100's for grain handling, 200's for steeping, etc.) and the type of operation (one or two letters to identify equipment). All wet milling plants in US or around the world are quite similar in steeping and milling facilities. Depending upon the final end product (modified starch, glucose, High Fructose Corn Syrup (HFCS), ethanol or other fermentation products), downstream differences (after milling) exist in unit operations among wet milling plants. For greater usability and consistency in wet milling unit operations, this model was designed for only steeping and milling facilities (up to starch recovery). According to individual user requirements, additional downstream processes could be added if there is a need to model more specific products. Product yields generated from the model are shown in Table 1. The product yields are in line with information in Blanchard (1992) and from personal communication with Dorr Oliver (2002) and members of CRA. Table 2 shows the main unit operations and settings in the process model.

### 2.1. *Grain handling*

The corn is received in the facility and held in storage silos prior to cleaning. Small and large foreign matter in the corn is then removed to prevent clogging the screens, increasing viscosity during the process and affecting the quality of the finished products. This is represented in our model as a waste of 2.4% debris of total capacity. The silo in our model is sized to hold enough corn for 3 days of operation. Included in this area are also weighing and handling equipment. The cleaned corn is weighed and sent to steeping.

### 2.2. *Steeping*

The clean corn is soaked in a dilute $SO_2$ solution (steep acid), under controlled conditions of time and temperature. Steeping is the chemical processing step where the protein matrix is broken down to release the starch granules so they can be separated during subsequently milling. The objective of steeping is to facilitate the separation process by softening the kernel, increasing the moisture content of the grains and removing soluble matter. The overall efficiency of the wet milling process is dependent on the proper steeping of the corn. In practice, the steeping is done in a semi-continuous counter-