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| Manual for the Fluid Milk Process Model and Simulator |
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**Reference.**

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**This simulator uses SuperPro Designer v 8.5, Intelligen, Inc., Scotch Plains, NJ**

**Version 3.0**

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**Appendix A e-mail attachment Materials and Streams Report**

(Dairy Process Full homogenize 40MM kg per yr\_May2013\_SR.xls)

**Appendix B e-mail attachment Economic Evaluation Report**

(Dairy Process Full homogenize 40MM kg per yr\_May2013\_EER.xls)

**Appendix C e-mail attachment Greenhouse Gas Report**

(Greenhouse Gas Report 40MM kg May2013.xls)

**Appendix D e-mail attachment Itemized Cost Report**

(Dairy Process Full homogenize 40MM kg per yr\_May2013\_ICR.xls)

**INTRODUCTION**

The fluid milk and other food processing industries have decreased their impact on the environment through the use of energy management practices. These “Best Practices” resulted in reductions in the amount of electricity and fuel needed to operate a plant and in the greenhouse gas (GHG) emissions associated with the burning of fossil fuels. Many of the Best Practices that have been implemented in processing plants include improvements in lighting, steam production, chilled water production, refrigeration systems, and compressed air systems. Processors have already realized reductions in energy use of up to approximately 10% with the added benefit of reductions in operating costs.

However, to achieve sizeable reductions in energy use and GHG emissions throughout a processing plant, improvements in the efficiency of the entire process, possibly in combination with a conversion to alternative energy sources, must be considered. In the case of fluid milk processing, which is used as a template for other milk and food processing operations in this simulator, significant improvements in the efficiency of the entire fluid milk process may require consideration of the use of alternative processing technologies, such as nonthermal processing technologies, or alternative pasteurization and sterilization systems.

The adoption of alternative energy management systems and/or alternative processing technologies to retrofit an existing processing plant involves significant economic risks. The ability to simulate the fluid milk or other food processing operation is highly desirable since it allows processors to benchmark their existing operations. The benchmarked process can then be used as the starting point to determine the economic feasibility of installing alternative energy management systems, such as solar energy, or alternative processing technologies into an existing plant and to calculate the energy use and GHG emissions associated with the changes. Also, the benchmarked process may be used to explore plant upgrades, expansions and various process schemes and to evaluate technologies that reduce water use and waste.

The Dairy and Functional Foods Research Unit, Eastern Regional Research Center, Agricultural Research Service, United States Department of Agriculture, Wyndmoor, PA has developed this generic fluid milk processing simulation model using **SuperPro Designer, Version 8.5 Build 6** (Intelligen Inc., Scotch Plains, NJ). This simulation model will ultimately allow the dairy and food processing industries to evaluate the economic impact of installing alternative energy management systems and processing technologies directly on a model of their plant and to calculate energy usage and GHG emissions, reported as g CO2 equivalents (e)/ gallon or kg of packaged milk. Future versions of this simulator will include process blocks for various alternative processing technologies and energy management systems.

**OVERVIEW**

Process simulation is a model-based representation of technical processes and unit operations using computer software. There are many chemical engineering process simulation software tools available on the market today, such as Aspen Plus, SuperPro Designer, CHEMCAD and ProSimPlus. We have elected to use SuperPro Designer (Intelligen Inc.) because it is user-friendly and has modeling capabilities which are suitable for this application. **You will need to have a SuperPro Designer software license to run our Fluid Milk Process model. A functional evaluation version of the software is available for download (free of charge) from the Intelligen Inc. website (**[**www.intelligen.com**](http://www.intelligen.com)**).** It is available for the MS Windows 2000, XP, Vista and 7 platforms and requires a Pentium PC (> 800 MHz) with at least 128 MB of RAM, and 400 MB of free hard disk space.

Save the data file **Dairy Process Full Homogenize 40MM kg per yr\_May 2013** from the e-mail attachment into your Documents file. Open the program by clicking on the **SuperPro Designer v 8.5** icon. To view the process flow sheet, click on “Open another process file” and then the icon on the right to locate the **Dairy Process Full Homogenize 40MM kg per yr\_May 2013. A flow sheet for the Fluid Milk Process that has already been modeled will open up.**

We began modeling the milk processing plant by developing a flow diagram (see **FIGURE 1 in Appendix 1**). The icons represent the equipment unit operations in the fluid milk process. The connecting lines indicate the direction in which the streams flow and allow the user to keep track of the streams and components throughout the process model. Stream characteristics include flow rate, temperature, pressure, physical state and components in the stream. SuperPro Designer features a user-friendly interface (see **FIGURE 2 in Appendix 1**) that the user can just point-and-click to modify the values in the flow sheet. The interface is very similar to other MS Windows applications.

For each unit operation, the simulator includes a mathematical model that performs material and energy balance calculations. Based on the material balances, it performs equipment sizing calculations. The initialization of operations is done through the appropriate dialog windows by double-clicking the unit operation icon to specify the process parameters. Users can adjust the process parameters according to their plant data. SuperPro Designer includes more than 140 unit operations to meet the needs of most processes.

The results of the simulation are presented in the form of reports, although you can partially view these results on the screen (Click on the Reports tab). There are several reports generated by the simulation, each focusing on a different topic. The reports are generated (upon request using appropriate menu calls) and saved in a temporary file. The file format of the report can be chosen by the user (e.g. ‘xls’, ‘pdf’, ‘html’, etc.) The following **reports** are generated by SuperPro Designer. Only the SR, EER and ICR reports are demonstrated in this manual.

* Material & Streams Report (SR)
* Economic Evaluation Report (EER)
* Cash Flow Analysis Report (CFR)
* Itemized Cost Report (ICR)
* Throughput Analysis Report (THR)
* Environmental Impact Report (EIR)
* Emissions Report (EMS)
* Equipment Report (EQR)
* CIP Skid Report (CSR)
* Input Data Report (IDR)

**Appendix A** (Dairy Process Full homogenize 40MM kg per yr\_May2013\_SR.xls)

**Appendix B** (Dairy Process Full homogenize 40MM kg per yr\_May2013\_EER.xls) **Appendix C** (Greenhouse Gas Report 40MM kg May2013.xls)

**Appendix D** (Dairy Process Full homogenize 40MM kg per yr\_May2013\_ICR.xls) reproduces the Material and Streams Report, the Economic Evaluation Report, the Greenhouse Gas Report and the Itemized Cost Report.

**PROCESS MODEL DESCRIPTION**

A process model for a fluid milk plant processing 40 Million kg per year of fluid milk (11 million gal/year) has been developed based on data obtained through consultation with industrial experts, equipment suppliers and the literature. A simplified flow diagram of the process is shown in **FIGURE 1 of Appendix 1**. The process is not intended to replicate any existing plant but is a generic plant design containing the unit operations and equipment necessary to process milk using conventional HTST pasteurization with full homogenization. **A facility operating 16 hours a day, 260 days a year is used in the model.** Two products, regular whole milk (39.3 million kg per year) and cream (0.7 million kg per year), are produced in the plant.

The fluid milk process depicted by the flow sheet of **FIGURE 1** is roughly separated into sections for milk reception and storage, milk standardization, milk homogenization, milk pasteurization, milk packaging, cold storage, cleaning-in-place (CIP) operations, and wastewater treatment. All pipelines, tanks and equipment for processing are assumed to be constructed of sanitary, food-grade stainless steel and to meet 3A Standards.

The composition of milk used in this simulation is given in **TABLE 1**. Protein accounts for 3.3% of the weight of milk. Lactose, fats and minerals account for 4.9, 3.9 and 0.7% respectively. Users can easily change the composition of the milk according to their feed in the “**Edit Stock Mixtures**” tab dialog box. (See **HOW TO USE THE MODEL** for additional information.) A small amount of dispersed air is assumed to be remaining in the raw milk after milk reception and may be optionally treated using deaerators as discussed below.

**TABLE 1**

**Composition of milk used in simulation**

|  |  |
| --- | --- |
| Component | Mass % |
| Casein | 2.7 |
| Fat | 3.9 |
| Lactose | 4.9 |
| Minerals | 0.7 |
| Water | 87.2 |
| Whey | 0.6 |

The process model begins with storage of the raw milk in the plant silos after delivery from the farms and ends with cold storage of the packaged milk prior to shipment. All stages of production – from milk reception to cold storage of the packaged milk – are included in the model analysis. A representative flow chart of the fluid milk process is given in **FIGURE 3 in Appendix 1**. The process includes steps for receiving and storage, separation, homogenization, pasteurization, cooling, holding, filling and packaging, and refrigeration. **TABLE 2** gives an overview of some of the key unit operations and settings in the process model.

**Milk Reception and Storage**

Raw milk brought into the facility is stored in one of two 25,000 gallon (~95,000 L) refrigerated silo tanks (A-TK-102). These two silos are represented by one icon on the flow sheet. (Other sets of identical equipment items operating in parallel are represented by a single icon as well.) To view the number of equipment items represented by an individual icon, right-click on the icon and select “**Equipment Data**”. Before entering the silo tanks, the milk may be cooled (A-HX-101) to a low temperature, 3.3ºC. The number and size of silo tanks are determined by the raw milk delivery schedules and volume of each delivery. In the model, these silo tanks are sized to hold sufficient raw milk for 16 hours of processing. The float-controlled inlet valve regulates the flow of milk and maintains a constant level in the balance tank. If the supply of milk is interrupted, the level will drop and trigger the flow diversion valve to return the product to the balance tank.

**Standardization**

Cold milk from the balance tank (A-TK-103) is drawn by the timing pump to the first regeneration section of the pasteurizer, the pre-heating section (A-HX-102) where it is heated to 64°C by the pasteurized milk. It may then proceed to the expansion vessel (C-DG-122) for vacuum deaeration treatment. The pressure in the expansion vessel is adjusted to a level equivalent to a boiling point about 8°C below the pre-heating temperature. In our case, the temperature of the deaerated milk will drop to 56°C. The drop in pressure expels the dissolved air which is removed from the vessel by the vacuum pump. The temperature drop in the expansion vessel is modeled by the cooling block, C-HX-106, in our simulation.

**TABLE 2**

**Overview of key unit operations in fluid milk processing model**

|  |  |  |
| --- | --- | --- |
| Unit ID | Description | Detail |
| A-HX-101 | Raw milk cooler | 3.3°C Outlet temperature  Glycol cooling medium |
| A-TK-102 | Silo tanks | 16 h Residence time |
| A-TK-103 | Balance tank | 1 h Residence time |
| B-HX-102 | First pre-heat regenerating section | 64°C Exit temperature of cold milk  7.0°C Exit temperature of pasteurized milk  100 m2 Heat transfer area |
| B-HX-103 | Second pre-heat regenerating section | 72.3°C Exit temperature of cold milk  68.6°C Exit temperature of pasteurized milk  12.1 m2 Heat transfer area |
| B-HX-104 | Milk pasteurizer | 77.2°C Exit temperature of cold milk  5.0 m2 Heat transfer area |
| B-HTB-121 | Milk holding tube | 22 s Residence time |
| C-DG-122, HX-106 | Deaerator | Temperature drop of 8°C |
| C-CS-124 | Centrifugal separator | 162.5 L/min Throughput  40% fat content in overflow  0.05% fat content in underflow  81.7% of cream remix back with skim milk |
| C-TK-105 | Cream holding tank | 4 h Residence time |
| D-HG-127 | Homogenizers | 198 bar pressure drop  63.7°C Exit temperature  52.7 kW Power consumption |
| B-HX-115 | Chiller | 1.7°C Outlet temperature  Glycol cooling medium |
| F-TK-104 | Milk storage tanks | 1.5 h Residence time |
| E-HX-107 | Cream pre-heat regeneration section | 85°C Exit temperature of cold cream  63.6°C Exit temperature of pasteurized cream  0.4 m2 Heat transfer area |
| E-HX-108 | Cream pasteurizer | 90.0°C Exit temperature of cold cream  0.07 m2 Heat transfer area |
| E-HTB-101 | Cream holding tube | 15 s Residence time |
| F-BM-201 | Blow molding – plastic gallon jugs | 2479 jugs per hour  58 g resin per jug  111 kW Operating power |
| F-FL-203 | Milk filling / packaging | 25 kW Operating power |
| G-FL-214 | Cream filling / packaging | 3.7 kW Operating power |
| K-DSR-204 | Cold storage | 650 m2 storage area  555 kW Refrigeration power |
| H-V106 | CIP for Cream Pasteurizer | 5 kW auxiliary power |
| H-V107 | CIP for Milk Pasteurizer | 5 kW auxiliary power |
| H-V108 | CIP for Tank Gardens | 5 kW auxiliary power |
| H-V109 | CIP for Filling Machines | 5 kW auxiliary power |
| I-WT101 | Aeration Tank | 6 h avg. hydraulic residence time  23 h sludge residence time |
| I-WT102 | Clarifier | 1% solids content |
| I-WT103 | Belt Filter Press | 15% solids content |
| I-WT104 | Sludge Dryer | 35% final solids content |

The milk is introduced to the centrifugal separator (C-CS-124) to separate the fat globules from the milk according to density. The cream, i.e. the fat globules, has a lower density than the skim milk and therefore moves inwards in the channels of the centrifuge and discharges through the cream outlet. The fat content in the cream is set at 40% in our model which leaves the skim milk (stream S-106) with a fat content of 0.05%. The separator ejects waste solids on an hourly basis which are directed to the waste management section of the plant.

**Homogenization**

The process plant that we modeled produces two major products, whole milk and cream. In order to produce an optimal amount of 3.25% standardized whole milk, a fraction of cream is routed and remixed with an adequate amount of skim milk. This is achieved by adjusting the split block (C-SP-102) in the model. The surplus cream containing 40% fat is directed to the cream pasteurizer. Adjusting the split block appropriately also allows simulation of a plant producing skim, 1% and 2% milk.

The standardized milk is sent to the high pressure homogenizer (D-HG-127) to reduce the size of the fat globules. Homogenization temperatures normally applied are in the range 55-80°C, and homogenization pressures are between 100 and 250 bar. During homogenization, part of the pressure energy is released as heat; every 40 bar drop in pressure will give a temperature rise of 1°C. In our simulation, milk entered the homogenizer at 59°C and with a pressure drop of 198 bar, milk leaves the homogenizer at 64°C.

**Pasteurization**

After homogenization, milk returns to the pasteurizer which completes the regenerative pre-heating in the second section. Final heating to an assumed pasteurization temperature of 77°C (171 °F) takes place in the heating section (B-HX-104). Milk is heated by hot water at 83°C and held for an assumed time of 22 seconds in the external holding tube. Steam is used to heat water which in turn heats the milk to pasteurization temperature. The pasteurized milk is then used to heat the cold incoming raw milk in the pre-heating section. The cold milk also serves to cool the pasteurized milk. The temperature profile of the three heat exchangers is shown in **FIGURE 4 in Appendix 1**. The heat transfer load from the first two heat exchangers is regenerative heat. Hence, the regeneration efficiency (R) can be calculated by:

Or

*R* = *temperature (t) increase caused by regeneration/total temperature change in milk* =

(T after regeneration – Tfeed)/(Tpasteurization – Tfeed)

where Q1, Q2 and Q3 are the computed heat transfer duties in the three heat exchangers respectively. According to the temperature profile in the model, the calculated regeneration efficiency is 93%.

The efficiency of the heat exchangers (pasteurizers) can be lowered because of surface fouling by milk residues. To account for the decrease in efficiency, the correction factor under the Oper. Cond’s tab in the “Heat-exchanger” operation dialog can be used. This adjusts the heat transfer coefficient and hence the calculated heat transfer area. Decreasing the correction factor will increase the calculated heat transfer area. If fouling is observed in all heat exchangers, the correction factor in each of the heat exchangers will have to be adjusted according to the performance specifications.

Pasteurization requires that the milk is held for a specified time. The appropriate length for the holding tube can be calculated by the flow rate (Q) of milk and the diameter (D) of the holding tube using the formula:

where an efficiency factor, η, of 0.85 is used in the model.

**Cream pasteurization**

Surplus cream is first heated by hot pasteurized cream in the regenerator section of the cream pasteurizer (E-HX-107) to approximately 85°C. It is then passed through the heater section (E-HX108) where hot water on opposite sides of the plates heats the cream to a temperature of at least 90°C. The cream flows through the holding tube where it is held for a calculated time of 15 seconds.

**Cooling**

The cold incoming milk cools the pasteurized milk to about 7°C in the regenerative sections. The pasteurized milk then proceeds to a chiller (B-HX-115) where it is chilled with a glycol solution to 1.7°C.

**Holding / Storage**

After cooling, the milk is pumped to one of the two buffer storage tanks (F-TK-104) and from there to filling. If filling is interrupted, the processed milk is buffered in the tank until operation can be resumed. A buffer capacity corresponding to 1.5 hours of normal operation; i.e., 16,000 L (4000 gal) is used in the simulation.

**Blow molding**

The blow molding operation (F-BM-201) is modeled as a unit operation in the simulation. We assume that only high density polyethylene (HDPE) gallon jugs are produced in this facility and are used solely for milk packaging. Paper containers are purchased for cream packaging. We have found that most of the fluid milk processing plants in U.S. manufacture their milk plastic containers in-house, especially gallon jugs and ½ gallon jugs. The majority of processed milk is packaged in gallon jugs.

The number of jugs produced per hour of blow mold operation is calculated based on the amount of milk processed. No excess jugs are produced in the facility. Fifty-eight grams of resin are required to produce one plastic gallon jug. The average utility for blow molding is assigned as 0.045 kWh per jug.

**Filling / Packaging**

Plastic jugs produced by blow molding in the facility are used to package the processed milk. The plastic jugs are filled and packaged with the processed milk (F-FL-203) at a rate of 2479 units per hour. An electrical power of 0.01 kW per bottle is assigned for the fillers.

Cream is packaged in purchased paper pint containers. The containers are filled in the cream filler (G-FL-214) with electrical power of 0.01 kW per container.

**Cold Storage**

In order to capture the utility consumption associated with refrigeration of milk and cream after packaging, a cold storage unit block (K-DSR-204) is included in the model. It allows us to enter the size of the cold storage area and the refrigeration energy consumption. A 650 sq. m (7,000 sq. ft.) cold storage area is assumed in our base model, with the capacity to store about 1.5 days of processed milk. For larger plants, we have assumed cold storage areas as large as 4,600 sq. m, although users may enter their own value.

With respect to the refrigeration energy consumption, different scenarios may be examined. An electrical energy consumption of 13.5 kWh per sq. m per day (1.25 kWh per square foot per day) may be assigned to take into account storage that occurs at the plant, at a distribution center and in the retail case. The refrigeration energy consumption may also be assigned a much lower value of 0.840 kWh per sq. m per day (0.078 kWh sq. ft per day). This value is specific for refrigerated warehouses (ASHRAE Handbook, Heating, Ventilating, and Air-conditioning Applications, 2007). Users may assign their own value.

A significant amount of water is used by the ultrasonic case washers in the cold storage area. It is assumed that 6,000 L per day of water is used for case washing.

**Cleaning-in-Place (CIP)**

The unit procedure icons of the cleaning operations are displayed in green in the flow sheet. Two CIP skids are used in our simulation, one for the silos, tanks and filling machines and the other for the pasteurizers. The cleaning steps sequences are as follows:

Skid #1 (milk silos, tanks, and filling machines)

1. Flush with warm water at 45°C for 10 minutes.
2. Circulate the caustic cleaning solution at 75°C for 10 minutes.
3. Rinse with water at 45°C for 5 minutes.
4. Disinfect with hot water at 95°C for 5 minutes.
5. Gradual cooling with water at 25°C for 10 minutes.

Skid #2 (pasteurizers)

1. Flush with warm water at 45°C for 10 minutes.
2. Circulate with caustic cleaning solution at 75°C for 30 minutes.
3. Rinse with water at 45°C for 5 minutes.
4. Circulate with acidic cleaning solution at 70°C for 20 minutes.
5. Rinse with water at 25°C for 15 minutes.
6. Disinfect with hot water at 95°C for 15 minutes.

A typical dairy may have about 30 cleaning operations a day. For the purpose of simulating the amount of material and energy used in the overall cleaning operation, it was decided to model each cleaning step as one cycle per day, 260 operating days per year.

The volumetric flow rate per vessel internal surface area is set at 12.7 L/m2-min. Since the sizing of the equipment is calculated by the program, the amount of water and cleaning solution used in the CIP operation can be calculated. According to our simulation, 11 million kg water, 6000 kg acid detergent and 16,000 kg alkaline detergent are used in the CIP operations annually for the base model. The annual energy consumption for CIP operations includes 6800 kWh auxiliary power and 1300 MT steam.

**Wastewater Treatment**

Wastewater from the CIP operations, case washing, and sludge from the separator is pretreated prior to disposal. The unit procedure icons for wastewater treatment are displayed in blue in the flow sheet. The wastewater (influent) stream and the recycled sludge stream are sent to the aeration tank (I-WT-101) for bio-oxidation of the organic material. The aeration tank operates at an average hydraulic residence time of 6 hours with an average sludge residence time of 23 hours. The aeration blowers maintain a minimum diffused air concentration of 20 mg/L. The degradation of organic material in the waste stream is given by (Santamarina, Environmental Progress, Vol.16, No.4, 1997, P.268):

Casein / Lactose ===> Biomass + H2O + CO2

1 g 0.4 g 0.3 g 0.3 g

The waste stream is then clarified (I-WT-102) where 99% of the biomass is removed and is thickened to about 1% w/w solids content. The liquid effluent which contains mostly water is disposed of as aqueous waste. 75% of the sludge stream is recycled back to the aeration tank. The rest is pumped to a belt filter press (I-WT-103) where it is concentrated to 15% solids content. The removed water containing small amounts of biomass and dissolved solids is sent back to the aeration tank. The concentrated sludge stream is dewatered to a final solids concentration of 35% w/w using the sludge dryer (I-WT-104). The dried sludge is disposed of as solid waste.

**PROCESS SIMULATION RESULTS**

**MATERIAL BALANCES**

**TABLE 3** provides information on the raw material requirements for the entire flow sheet. The quantities are displayed in kg/year and kg/hour and were extracted from the Excel version of the **Material & Streams report** (**Appendix A** in the e-mail attachment). The report also breaks down the amounts of raw material used in each section of the process. Details of each stream are displayed in the report.

**TABLE 3**

**Raw material requirements for the entire flow sheet**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| BULK MATERIALS (Entire Process) | | | | | |  |  |  |
| Material |  |  |  | kg/year |  |  | kg/hour | |  |
| Milk |  |  |  | 39,998,961 |  |  | 9615 | |  |
| Oxygen |  |  |  | 500 |  |  | 0 | |  |
| Water |  |  |  | 10,751,254 |  |  | 2584 | |  |
| Resin |  |  |  | 597,735 |  |  | 144 | |  |
| Paper |  |  |  | 62,646 |  |  | 15 | |  |
| Caustic cleaning soln | | |  | 1,687,072 |  |  | 406 | |  |
| Acid cleaning soln | |  |  | 587,822 |  |  | 141 | |  |
| TOTAL |  |  |  | 53,685,990 |  |  | 12,905 | |  |

On an annual basis, the plant processes 40 million kg and produces 39.3 million kg of whole milk and 0.7 million kg. It is assumed that all processed milk is packaged in plastic gallon jugs and cream in paper pint containers. **TABLE 4** below shows the annual production rates of the two products. The information was extracted from Section 9H of the Economic Evaluation report (**Appendix B**).

**TABLE 4**

**Annual production rates of products in the milk processing plant**

|  |  |  |  |
| --- | --- | --- | --- |
| Revenue Rates |  |  |  |
| Pint cream in 'CREAM' (Revenue) |  | 1,566,153 | Entities/yr |
| Filled Gallon milk in 'PASTEURIZED MILK' (Main Revenue) |  | 10,305,783 | Entities/yr |

**ENERGY BALANCES**

Utility consumption in the process is calculated based on the power utilized, the type of heating/cooling transfer agents used, and the heating/cooling requirements. **TABLE 5**, generated from the **Economic Evaluation report** (**Appendix B**), gives a summary of the utilities used in the process. The **Itemized Cost report** displays a detailed breakdown of the utility type used in each section/procedure. The utilities breakdown gives the user a better understanding of where the “hot spots” for utility consumption are. The utility usage data of **TABLE 5** are considered ‘bare numbers” since they are related to energy usage by the unit operations alone. A 25% allowance (Plant Design and Economics for Chemical Engineers by Peters and Timmerhaus, 2003) is then added to the electrical usage estimates to account for line losses and contingencies. The electrical energy used to generate steam, cooling water and chilling agents are also taken into account by estimating the power consumption from their sources.

A 20% allowance is added to the natural gas use to account for the inefficiency of the conversion of natural gas energy to steam energy in the boiler. This value is based on discussions with various boiler manufacturers and will vary depending on the design and operation of a specific boiler. This value may be set by the user.

Total electricity and natural gas consumption are then converted to the common units of BTU for comparison. A conversion factor of 3412 BTU per 1 kWh is used in electricity calculations. For natural gas, the specific enthalpy of 1200 BTU per one pound of steam is used. **FIGURE 5** displays the distribution of the utilities by sections used in the process. In this case, electrical energy for cold storage was set to 13.5 kWh per sq. m per d. Cold storage and cleaning-in-place operations are the largest energy users, accounting for 48% and 20.4% of the total respectively, and are followed by milk packaging with 11.7% of energy use.

**TABLE 5**

**Summary of utilities used in milk processing plant**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| UTILITIES COST (2008 prices) - PROCESS SUMMARY | | | | | | | | | | | | | | | | | |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Utility | | | | Unit Cost  ($) | | Annual Amount | | | Ref.  Units | | | Annual Cost  ($) | | | % | | |
| Std Power | | | | 0.06 | | 3,277,823 | | | kW-h | | | 196,669 | | | 81.94 | | |
| Steam | | | | 12.00 | | 1,865 | | | MT | | | 22,386 | | | 9.33 | | |
| Cooling Water | | | | 0.07 | | 65,988 | | | MT | | | 4,619 | | | 1.92 | | |
| Glycol | | | | 0.35 | | 46684 | | | MT | | | 16,339 | | | 6.81 | | |
| TOTAL | | | |  |  |  |  |  |  |  |  | 268,987 | | | 100.00 | | |

**GREENHOUSE GAS EMISSIONS FROM DAIRY PLANT UTILITIES**

GHG emissions are calculated from the dairy plant utilities usage. Total greenhouse gas emissions are reported in carbon dioxide equivalent (CO2e) units using the Global Warming Potential (GWP) conversion of 23 kg CO2e per kg CH4, 296 kg CO2e per kg NO2 and 1 kg CO2e per kg CO2. The total GHG emissions (source energy and emissions) for utilities (electricity and fuels) are calculated using the energy and emission factors from Deru and Torcellini (NREL Tech Rep. #NREL/TP-55-38617, June 2007). The energy and emission factors account for the conversion inefficiencies at the power plant and the transmission and distribution losses from the power plant to the facility. The energy and emission factors also include the precombustion effects, which are the energy and emissions associated with extracting, processing, and delivering fuel to the point of use in a power plant or a building.

The source emission factor (combustion and precombustion) of delivered electricity is 0.758 kg (1.67 lbs) of CO2e per kWh on a national basis, thus the electricity consumption contributes 3,239,686 kg CO2e annually or 0.081 kg CO2e per kg of processed milk for our example.

The precombustion and combustion emission factors of natural gas delivered to the facility are 0.446 and 1.97 kg CO2e per m3 respectively, for a source emission factor of 2.416 kg CO2e per m3 of natural gas. In other units, the source emission factor for natural gas is 146.6 lbs of CO2e/million BTU or 0.06312 kg of CO2e/MJ. According to our model, the total natural gas required to generate the steam usage contributes 393,709 kg CO2e annually or 0.0098 kg CO2e per kg of processed milk.

Overall, dairy plant utilities contribute 0.091 kg CO2e per kg of processed milk. Other emissions from processing including chemical usage, purchased items, and wastewater treatment facilities are not included in this calculation.

An emissions report that shows the impact of the dairy processing facility modeled in SuperPro Designer on GHG emissions was developed. (**Appendix C – Greenhouse Gas Report 40MM kg May2013.xlsx**) This was done by electronically linking the results from the SuperPro Designer **Itemized Cost Report (Appendix D)** to an Excel spreadsheet which then calculated the greenhouse gases. The generated “**Dairy Greenhouse Gas Report**” must be placed in the same directory where the SuperPro Designer’s “**Itemized Cost Report**” will be located. Care must be taken to verify that no modification has been made to the SuperPro Dairy Processing file such as additional materials or utilities since this can change the location of the linked data in the Itemized Cost Report and give incorrect calculated results in the Greenhouse Gas Report. When the simulation is run (‘Solve M&E Balances’ on the Tasks menu) and the **Itemized Cost Report** generated, the Excel **Greenhouse Gas Report** will calculate and display the GHG emissions accordingly.

The breakdown of GHG emissions by sections is calculated based on the utility consumption generated from the model. **FIGURE 6** displays the distribution of GHG emissions from the dairy processing facility. Utilities from cold storage, using the high value of electrical energy consumption of 13.5 kWh per sq. m per d, contribute the most to total GHG emissions, accounting for 60.2% of total emissions, followed by milk packaging, 14.7% and cleaning-in-place operations, 7.8%. Milk pasteurization, homogenization and standardization each account for about 4-6%. See Tomasula et al. (2013) for results using the value of 0.840 kWh per sq. m per d (refrigerated warehouse) or using a value of 0.0 kWh per sq. m per d (cold storage-free basis).

**COST ANALYSIS AND ECONOMIC EVALUATION**

An important feature of our simulation is that it performs preliminary economic evaluations through estimation of capital and operating costs.

**Equipment Costs**

The costs of the major process equipment are based on information received from equipment suppliers and from in-house estimating sources. To access the **Equipment Data** dialog, select the ‘**Equipment Data**’ menu option from a unit procedure’s command menu (right-click the procedure icon). From this dialog, the user can specify the purchase cost of the equipment under the **Purchase Cost** tab. SuperPro Designer has built-in models that estimate the cost of equipment based on its size variable. You may also provide your own equipment costs through the **User-Defined Cost Model**. The User-Defined Cost Model allows the user to adjust their own equipment costs with size variables.

**Materials Costs**

The annual cost of each material is calculated by multiplying its unit cost by the corresponding annual amount utilized in the process. The purchasing price of the material can be specified under the **Pure Component Properties Dialog: Economics** tab. To access this dialog, click **Pure Components > Register, Edit/View Properties** on the Tasks menu and double-click on the desired component from the list of registered pure components. Pricing information for the various materials is based on current published market prices and information available in the National Agricultural Statistics Service (NASS) reports.

**Utility Costs**

Utility (electricity, steam, cooling water and cooling agent) requirements of the various equipment operations are calculated and totaled within the simulation. These utilities are treated as purchased utilities and the unit costs for each of them can be easily changed by the user **(Tasks > Other Resources > Heat Transfer Agents)**. Utility charges are estimated based on current market conditions. **TABLE 5** shows the summary of the utilities used in the process, their unit cost and annual cost.

**Capital Costs**

The capital costs of the process have been developed from the costs of the individual pieces of equipment and their installation factors. The total installed cost of the plant was calculated from the total equipment costs through the use of Lang factors. Total plant costs include: the supply and installation of the process equipment; all support materials such as piping, electrical, instrumentation, foundations, and buildings to house the equipment; facilities design and construction management; and, start-up expenses. The total plant cost is estimated at two times the cost of the process equipment used in this cost analysis.

**TABLE 6** provides the estimated capital costs of the dairy processing facility by section. Details of the equipment are displayed in the **Economic Evaluation Report** (Appendix B). A capital cost of $21.0 million is estimated for this 40 million kg per year fluid milk processing plant.

**TABLE 6**

Estimated capital costs of the dairy processing facility

|  |  |
| --- | --- |
| Section | Capital Costs (US$ thousands) |
| Raw Milk Storage | 583 |
| Milk Standardization | 958 |
| Milk Pasteurization | 208 |
| Homogenization | 691 |
| Cream Pasteurization | 53 |
| Milk Packaging | 3,680 |
| Cream Packaging | 934 |
| Cleaning-in-Place | 1,933 |
| Wastewater Treatment | 1,907 |
| Cold Storage | 320 |
| Building & Aux costs | 10,000 |
| Total | 21,266 |

**Operating Costs**

Annual operating costs are calculated by summing the raw materials costs, utility costs, charges for facility plant operators (salaries), maintenance costs, an allowance for insurance and miscellaneous expenses, waste disposal costs, and an allowance for depreciation. **TABLE 7** displays a summary of annual operating costs for the 40 million kg per year milk processing facility. The co-product credit, indicated by a minus sign, is for the sale of cream.

**TABLE 7**

Annual operating costs for a 40 Million kg per year fluid milk processing facility

|  |  |  |
| --- | --- | --- |
|  | US$/year | |
| Raw materials |  | |
| Raw milk | 14,418,000 |
| Caustic cleaning solution | 23,000 |
| Acid cleaning solution | 30,000 |
| Resin | 1,515,000 |
| Water | 4,000 |
| Paper pint container | 31,000 |
| Utilities |  |
| Electricity | 197,000 |
| Steam | 22,000 |
| Cooling water | 5,000 |
| Glycol | 16,000 |
| Labor and maintenance |  |
| Plant operators | 4,992,000 |
| Maintenance | 638,000 |
| Insurance and misc. | 330,000 |
| Waste disposal cost | 4,000 |
| Depreciation (10 years straight line) | 2,127,000 |
| Subtotal  Co-product credit | 24,352,000   * 1,550,000 |
| Net Operating Cost | 22,802,000 |

These analysis results are presented in the Executive Summary dialog (select menu **View > Executive Summary)** and also in the form of three detailed reports, **Economic Evaluation Report (ERR), Itemized Cost Report (ICR) and Cash Flow Analysis Report (CFR).**

As shown in **Appendix B**, the **Economic Evaluation Report** contains the key results of the economic analysis of the process, a listing of all capital cost items, operating cost components including materials costs, labor costs and utilities costs, and finally a comprehensive profitability analysis. **Section 8** of the **EER** report shows the annual operating cost breakdown of the process. Raw materials contribute 66% of the total operating costs, followed by labor costs (20%), facility-dependent costs (13%), and utilities (1%).

**Unit Production Costs**

The annual operating cost minus the credit from the sale of the cream co-product gives the net operating cost. The unit production cost is calculated by prorating the annual net operating cost. Base on a yearly production of 10,305,783 gallons (40 million kg) of processed milk and an annual net operating cost of $ 22,802,000, the unit production cost is approximately $ 2.21 per gallon. If the sale of the cream co-product is not included, then unit production costs would be $2.36 per gallon.

**HOW TO USE THE MODEL**

This process simulation model provides the base case model for a generic fluid milk processing plant. In order to evaluate the feasibility of alternative processing technologies or energy management systems, the base case model has to be modified to simulate those conditions. The following examples show some of the possible modifications. Before making any changes to the base model, save the model under a different file name and work on that file. Examples for changes to alternative processing technologies or energy management systems will be included in a future version of this manual. (For more detailed information, check the Help file and the SPD Tutorial.)

**Changes in Raw Milk Composition**

**TABLE 1** shows the composition of milk used in this simulation. To change the composition of milk according to the user’s feed, select **Tasks > Stock Mixture**s **> Register, Edit/View Properties** from the main menu of the application. This selection will bring up the **Stock Mixture Registration Dialog**; double-click ‘**Milk**’ from the list of the registered mixtures. The Stock Mixture Properties Dialog will appear. From this dialog, users can edit the composition of their feed under the **Composition tab**. The composition of the mixture ‘Milk’ is described on a mass basis. All of the mixture’s ingredients must add up to 100%. To keep the changes you made on the selected mixture’s properties, exit the Stock Mixture Properties Dialog by clicking on ‘OK’. They will become permanent when you exit the Stock Mixture Registration Dialog by clicking ‘OK’.

**Changes in Flow Rate, Temperature and Pressure of a Stream**

To change the flow rate of an input stream, double-click on the stream in the flow diagram to open the **Input Stream Dialog box**. In the ‘**Composition, etc.**’ tab, users can change the mass flow rate, temperature and pressure of the input stream according to their feed. To save the changes, click ‘OK’ in the Input Stream Dialog.

**Change in Process Parameters**

The process parameters of an operation can be modified by double-clicking on the unit operation icon. This will bring up the ‘**Operation Data**’ dialog box for that operation. The user can access or modify the simulation data for an operation, such as the operating conditions, volumes, utilities, and labor-related information. This data is grouped into several tabs. Different tabs may be available for different operations. For example, in a ‘Heat-exchanger’ operation, the temperature profile can be specified in the **Oper. Cond’s** tab. The program will calculate the heat exchanger load and heat transfer area based on the stream flows and performance criteria. After making the change, click ‘OK’ in the ‘**Operation Data’** Dialog to save the change and return to the flow sheet.

**Adding Processing Steps (unit procedures)**

Users may want to add processing steps (unit operations) to the existing processes in the flow sheet. To add a unit operation to the flowsheet, first select the desired unit procedure in the **‘Unit Procedures’** menu. For example, select **Storage/Blending > Bulk > Continuous > in a Receiving Tank**. Move the mouse cursor to where you would like to place the unit operation in the flow sheet area. The next mouse-click will place the icon of the selected unit operation in that location. SuperPro Designer will automatically add a default procedure name (P-1), equipment name (V-101) and procedure description (Storage) below the icon.

After you add a unit operation to the process flow sheet, you can add streams. There are three types of streams, inlet, intermediate and outlet streams. In order to add streams to the flow sheet, you must first click Connect Mode (  ) in the Main toolbar. For an input (feed) stream, click on an empty area in the flow sheet to initiate drawing of the stream, move the mouse cursor to the desired inlet port of the destination unit operation and click on the port to terminate the stream line.

To add an intermediate stream, move the mouse cursor over the desired outlet port of the source unit operation and click on the port to initiate drawing of the stream line. Move the mouse cursor to the desired inlet port of the destination unit operation and click on the port to terminate the stream line.

To add an outlet (product) stream, move the mouse cursor over the desired outlet port of the source unit operation and click on the port to initiate drawing of the stream line. Double-clicking an empty area in the flow sheet will terminate the stream line.

**Modification in Cleaning-in-Place Operations**

The cleaning operation of the dairy plant is modeled as five separated CIP units: silos, tank gardens, filling machines, and cream and milk pasteurizers. Cold components (silos, tanks and filling machines) are simulated in Skid #1 while hot components (milk and cream pasteurizers) are simulated in Skid #2.

To access or modify the simulation parameters of the CIP operation, right-click the CIP procedure icon on the flow sheet and move the mouse pointer over the ‘**Operation Data’** to bring up a drop-down list of all cleaning steps. Clicking on an operation in that list will bring up its ‘**Operation Data’** dialog. Through this dialog, the user can modify the simulation data for that cleaning step. The amount of cleaning agent used for cleaning a piece of equipment is calculated based on one of the five specification options (the cleaning agent total volume, the agent specific volume, the cleaning agent rate, the cleaning agents rate per unit of circumference or the cleaning agent rate per unit of internal surface). We have chosen to set the cleaning agent rate per unit of internal surface to 12.7 L/m2-min. The internal surface area is determined by the size of the equipment which can be accessed by right-clicking the CIP icon and selecting ‘**Equipment Data’**. The duration of each cleaning step and the cleaning agent can also be specified through this dialog box.

Utilities used during the cleaning operation (under the ‘Operation Data’ tab) can be specified under the ‘**Labor**, etc’ tab. Unfortunately, the energy used to heat the cleaning solution is not accounted for in the program. We are required to manually calculate the energy consumption and enter it under the ‘**Heating**’ section of this dialog. The auxiliary operating power used during each cleaning operation is specified under the ‘**Power**’ section. Click ‘OK’ to save the change and return to the flow sheet.

At any point, you could click ‘**Solve M&E Balances’** on the Tasks menu to perform the simulation. This will cause the program to perform the mass and energy balances for the entire process, and estimate the sizes of all pieces of equipment that are in ‘**Design Mode’**. A report will be generated and displayed by clicking the appropriate report option on the Reports menu.

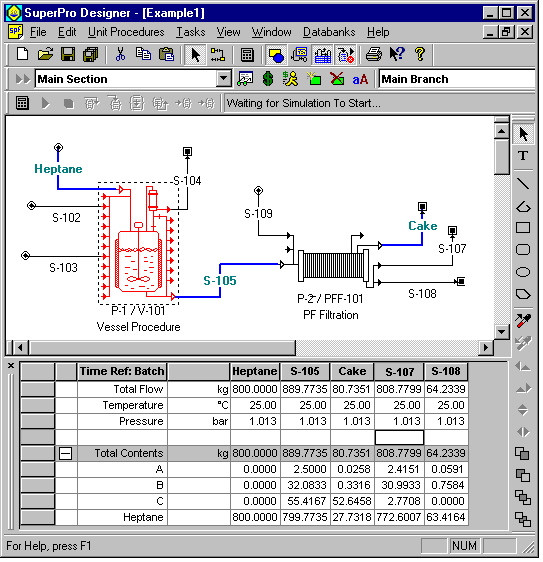


**APPENDIX 1**

**FIGURE 1 Simplified flow diagram of the fluid milk processing plant**



**FIGURE 2 SuperPro Designer user interface**



**FIGURE 3 Flow chart of fluid milk through production**

Shipment

Filling / packaging

Holding tanks

Cooling

Separation

Receiving and storage

Raw milk

Blow molding

Refrigeration

Pasteurization

Homogenization

Skim milk

Cream

Cleaning-in-Place

Wastewater Treatment

**FIGURE 4 Temperature profile of the plate heat exchangers**



**FIGURE 5 Distribution of utility consumption by section in the fluid milk process**

**FIGURE 6 Distribution of greenhouse gas emissions of the milk processing plant**

Total GHG emission

0.091 kg CO2e per kg milk