Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Food Engineering 77 (2006) 416–420
JOURNAL OF FOOD ENGINEERING
www.elsevier.com/locate/jfoodeng

Model of a sugar factory with bioethanol production in program Sugars™

Svatopluk Henke, Zdenek Bubník *, Andrea Hinková, Vladimir Pour

Institute of Chemical Technology Prague, Department of Carbohydrate Chemistry and Technology, Technická 5, 166 28 Prague 6, Czech Republic

Available online 25 August 2005

Abstract

This work shows an application of the program Sugars™ for modelling and simulation of a sugar factory with subsequent production of bioethanol and animal fodder. The designed scheme was further adjusted and verified using the data from the Czech sugar industry (i.e. processing of 10.000 ton of sugar beet per day, 17% of sucrose in sugar beet, 2.5% of impurities and 98% effectiveness of ethanol fermentation. If all parameters of equipment, operating units and pipelines are set, this scheme enables to calculate a production of refined sugar, bioethanol and other by-products. According to an actual commodity price on the market, one can chose an optimal ratio between sugar and ethanol production.

Keywords: Sugar; Ethanol; Stillage; Modelling; Sugar plant; Fermentation

1. Introduction

The paper deals with an application of the program Sugars™ (see Sugars International LLC) for modelling and simulation of a sugar factory (Alvarez, Baez-Smith, & Weiss, 2001; Morgenroth & Weiss, 2003; Weiss, 1999) with subsequent production of bioethanol and animal fodder.

The used production scheme was developed by Bubnik et al. (1996–2000) in a grant project of the Czech Agricultural Grant Agency (9660461373-01): "*Production and application of ethanol from agricultural sources. Part: Optimization of ethanol production by evaluation of by-products*". The scheme suggested as a non-waste technology starts from a traditional production of raw juice by water extraction of sliced sugar beet. Obtained raw juice can be used either directly for ethanol and sugar production during the campaign, or it can be concentrated in an evaporator and stored for several months. Stillage obtained by fermentation is partly recycled back to the extraction and fermentation stage or used for concentrate dilution. The residual stillage from fermentation is concentrated, mixed with exhausted beet pulp and dried to obtain a fodder. Thus, the outputs are sugar, ethanol and animal fodder.

2. Production scheme description

The used production scheme is shown in Fig. 1. It starts from a traditional production of raw juice by water extraction of sliced sugar beet. Obtained raw juice can be used either directly for ethanol and sugar production during the campaign, or it can be concentrated in an evaporator and stored for several months.

Fresh juice and/or concentrate can be used both for sugar production by cooling crystallization and for fermentation to produce bioethanol. In the first case, juice needs to be purified by two-step filtration involving pulp separation and microfiltration to remove bigger particles, high molecule colorants, proteins and

* Corresponding author. Tel.: +42 2 20443112; fax: +42 2 20445130.
E-mail address: zdenek.bubnik@vscht.cz (Z. Bubník).

0260-8774/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfoodeng.2005.07.007

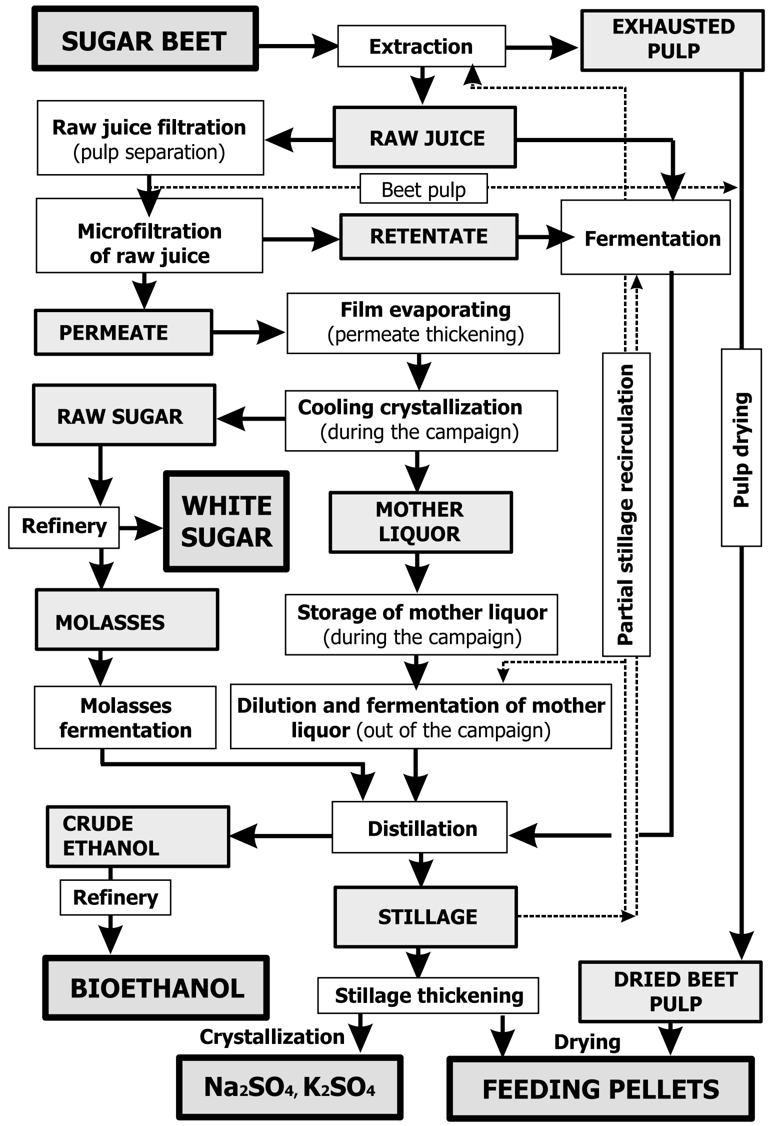

Fig. 1. Complete technological scheme, that would connect sugar and ethanol production (Bubník et al., 1998; Hinková & Bubník, 2001).

microorganisms. (Another possible purifying step, which is not depicted in the scheme, is nanofiltration of permeate obtained by microfiltration. In this step, water content in raw juice is reduced and nonsugars like inorganic ions should be removed as well. Permeate from nanofiltration contains mostly water and ions, thus it can be used for concentrate dilution.) Juice purified by all mentioned membrane techniques (permeate) can be a subject of evaporation and cooling crystallization to obtain sugar.

Retentate from microfiltration (containing all nitrogen substances, beet tissue and other impurities) can be mixed with raw juice and used for fermentation together with mother liquor from crystallization. Scheme also proposes an eventuality to concentrate mother liquor from crystallization and store it by the same way as the concentrate of raw juice.

Stillage obtained by fermentation is partly recycled back to the extraction and fermentation stage or used for concentrate dilution. The residual stillage from fermentation is concentrated, mixed with exhausted beet pulp (which is a residual from beet extraction) and dried to obtain a fodder. A stillage crystallization is another suggested treatment to obtain natrium and potassium sulphate.

This process is suggested as a non-waste technology. The important by-product—molasses—is processed by traditional ethanol fermentation. Thus, the outputs are sugar, ethanol and animal fodder.

If all parameters of equipment, operating units and pipelines are set, this scheme enables to calculate a production of refined sugar, bioethanol and other by-products. According to an actual commodity price on the market, one can chose an optimal ratio between sugar and ethanol production.

3. Program Sugars™ description

Sugars™ is a computer program for calculating heat, material and colour substance balances and providing simulations of refining processes for both beet and cane sugar factories to help management with process decisions and operating strategies for process optimization (Weiss, 1999). Sugars for Windows® is an integrated program using Sugars™ for process simulation and Visio® for a graphical representation of the flow diagram of the simulation model. The integrated program is completely flexible regarding the type of analyzed factory because it uses individual station modules which can be arranged in almost any order to fit the simulated process.

Many complex mathematical relationships are used by Sugars™ to describe the model of sugar factory, or refinery. Mathematical equations are employed to describe the heat of solutions and crystallization of sugar, boiling point elevation of syrups, specific heat and density of syrups, sugar crystals, insoluble solids, and gases (e.g., vapour, CO_2, NH_3, etc.), solubility of sucrose and supersaturation of massecuites. Additional equations are used to calculate the latent heat of vaporization, specific enthalpy and temperature and pressure relationships for steam (both saturated and superheated). Other algorithms are used to calculate the percentage of crystals in massecuite, steam flow to a heated process stream, centrifugal performance characteristics, colour, etc. The iteration technique is used for model calculation until a balance is obtained within a specified accuracy (normally, 0.01%).

4. Model description

The suggested model consist of the following important parts:

(a) Main way, i.e. production of the white sugar.
(b) Fermentation way.
(c) Pulp way.
(d) Water and steam (predefined models).

4.1. Main production way

It was created from the following operation and devices: beet cutter, pre-heater, extractor, distributor of raw juice, raw juice filter, the falling film evaporator, the syrup melter, continuous pan, batch centrifugal and sugar dryer. The predefined models of program SUGARS™ were applied for these operations. Only two non-standard devices were newly designed in this part of production scheme—distributor of raw juice and raw juice microfilter.

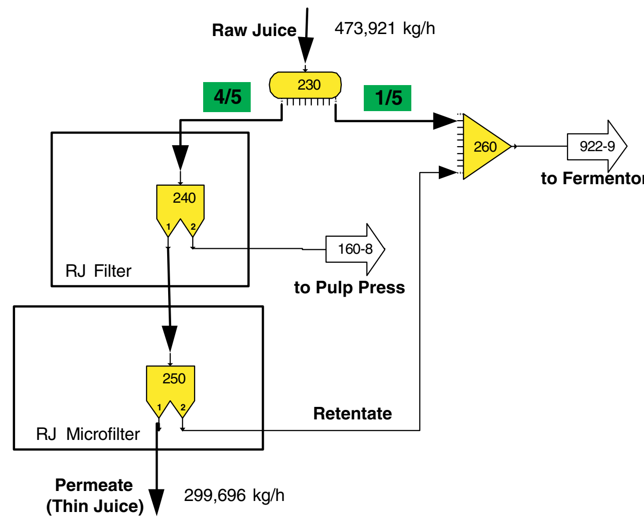

Fig. 2. Distribution of raw juice and purification process.

The main flow of the raw juice is before next processing divided in the raw juice distributor into two flows in the ratio of 4:1. The distributor is modelled as a simple separator with one input and two outputs separating the beet pulp from raw juice (see Fig. 2). Beet pulp contains water, fibres, sucrose and non-sugars (=impurities). One-fifth of the raw juice is then transported direct to the fermenter. The remaining 80% are transported to the raw juice filter, where beet pulp is separated from raw juice.

The raw juice microfilter is modelled as a simple separator with one input and two outputs—permeate and retentate. The permeate with the similar properties as thin juice is transported to the system of five falling film evaporators. Retentate is brought to the fermenter together with one-fifth of the raw juice from the extractor. The raw juice pump delivers the pressure gradient.

4.1.1. Fermentation way (see Fig. 3)

Twenty percent of raw juice mentioned above is mixed with retentate from microfiltration of raw juice and with mother syrup or possibly with a part of the thick juice from the evaporator. The whole mixture is then fermented by *Saccharomyces cerevisiae* to ethanol (Fig. 3).

4.1.2. Fermenter

The model of the station is based on several subsystems; reactor—one input and one output, separator—one input and one output and cooler—one input and

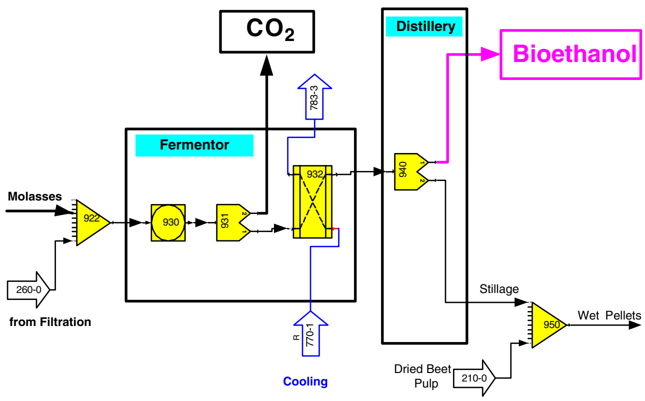

Fig. 3. Fermentation stage.

one output. The first of them—reactor—provides the conversion of the part of the sucrose and appropriate amount of water to ethanol and carbon dioxide. The separator designed as a simple divider is used to remove carbon dioxide from the remaining reaction mixture. Because of the exothermic bioreaction, the forming heat is removed by cooling water. The cooler is designed as a conventional plate heat exchanger with water as a cooling medium. The (fermented broth) is transported to the distillation column.

4.1.3. Distillery

The model of the station is simple and has one input and two outputs. The distillation column is suggested as a simple separator fractionating the mixture (fermented broth) into two parts—bioethanol and the other substances, i.e. stillage. The fermented broth is transported to the distillery, where ethanol is distilled off. Stillage is directly mixed with dried exhausted beet pulp, thus the feeding pellets are obtained.

Table 1
Example of balance

	Mass t/h	Dry matter %	Sucrose %	Purity %
Extraction				
Sugar beet	417	24.0	17.0	
Raw juice	474	16.4	14.8	90.2
Desugarized pulp	459	7.0	1.1	
Pulp press water	391		1.1	
Water for extraction	126			
Pressed pulp	69	32.4	0.9	
Juice purification and sugar production				
Raw juice to fermentor	95	16.4	14.8	90.2
Raw juice to membrane	379	16.4	14.8	90.2
Permeate	300	15.4	15.0	97.4
Retentate (to fermentor)	79	20.2	14.2	70.3
Thick juice (from permeate)	71	65.0	63.4	97.5
White sugar	22			
Mother syrup (to fermentor)	31	76.1	72.4	95.1
Ethanol and feed pellets production				
Ethanol	22			
Carbon dioxide	24			
Stillage	160	7.7	0.6	
Wet pellets	205	16.9	0.8	
Dry pellets	38	85	3.8	

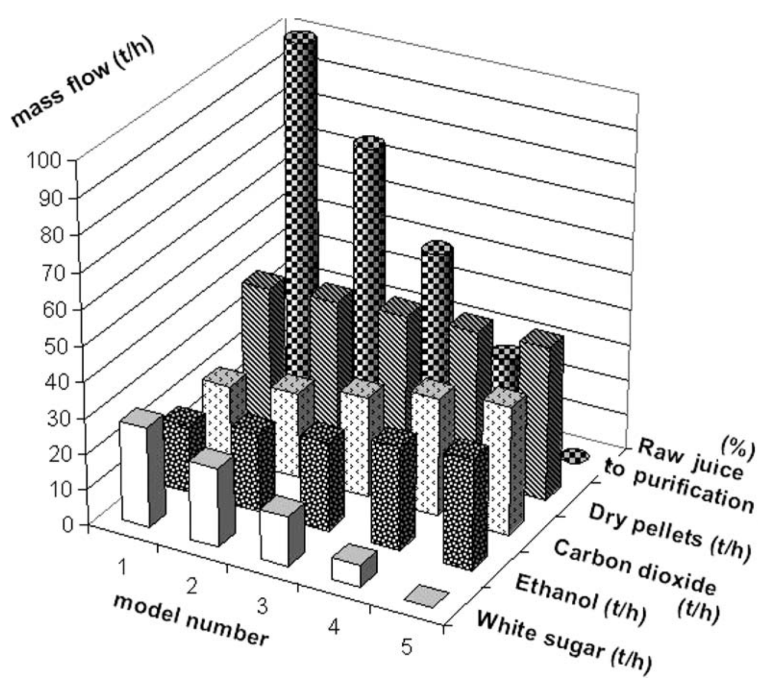

Fig. 4. Results of mass balance.

4.2. Pulp way (pulp press and pulp dryer)

The exhausted beet pulp is transported into the pulp presses. The whole model of the station has one input—exhausted pulp and two outputs—pressed pulp and press water. Press water is then heated by the fourth vapour and returned to the extractor. The pressed pulp is transferred to the pulp dryer.

The predefined model of the pulp dryer was used. It has two inputs—pressed pulp and heating steam and three outputs—condensate of heating steam, vapours from dried pressed pulp and dry beet pulp. Dried beet pulp is mixed with stillage behind the distillation column to form a material for the feeding pellet producing.

5. Results of model application

In order to adjust the model, values common in the Czech sugar industry were applied. However, it is just the first approximation, which will be more specified and further solved with precise parameters for given particular cases and applications.

The input parameters:

(a) Sugar beet:
Mass flow: 10,000 ton of sugar beet per day, i.e. 417,000 kg/h,
Temperature: 6 °C (sugar beet or sugar slices before extraction).

(b) Composition of beet or slices:
Water: 76%, Sucrose: 17%,
Impurities: 2.5%,
Fibre (insoluble matter): 4.5%.

(c) Ethanol—98% efficiency of sucrose conversion to ethanol.

Example of a mass balance is given in Table 1 and in Fig. 4.

6. Conclusion

The program Sugars™ for modelling and simulation of a sugar factory was successfully applied on a new technological scheme with consequent production of bioethanol (Bubník et al., 1998). However, obtained results do not represent the real plant but serve for verification of the model behaviour.

Permeate crystallization is suggested as an one-step procedure with white sugar yield of 50%. Mother liquor from the crystallization goes to fermentation. According to the requirements and commodity price, i.e. price ratio of sugar to ethanol, we can prefer either production of sugar (by production enlarging into 2–3 product scheme) or ethanol (e.g. by the change of the ratio in the raw juice distributor).

Several procedures are suggested for feeding pellets production which will be verified in further work:

(a) Stillage can be concentrated and added to dried beet pellets, this mixture needs to be pressed and then dried. This procedure is assumed in this work.

(b) Dry beet mixing with stillage followed by drying and pelleting is another possibility which will be tested.

(c) Salt content in dried beet pulp can be reduced by crystallization, as is shown in Fig. 1. Also this potentiality will be evaluated.

Another question raised during this task solution is the content of residual sugar in feeding pellets. Also in this case it is necessary to solve the economic balance of the suggested scheme in consideration to the requirements of fodder market.

References

Alvarez, J., Baez-Smith, C., & Weiss, W. (2001). Modeling the new technology raw sugar factory/refinery using Sugars™ for Windows®. *International Sugar Journal, 103*, 1231.

Bubník, Z. et al. (1998). *Production and application of ethanol from agricultural sources. Part: Optimization of ethanol production by evaluation of by-products*. Project of the Czech Agricultural Grant Agency No.: 9660461373-01, 1996–1998.

Hinková, A., & Bubník, Z. (2001). Sugar beet as a raw material for bioethanol production. *Czech Journal of Food Science, 19*, 224–234.

Morgenroth, B., & Weiss, W. (2003). Advanced monitoring systems for process control. In *Proceedings of the 22nd general assembly C.I.T.S.* (pp. 121–130). Madrid, Spain, Berlin: Bartens Pub. Co.

Sugars International LLC., Available from www.sugarsonline.com.

Weiss, W. (1999). Sugars™ for Windows®—a revolutionary update. In *Proceedings of the 21st general assembly C.I.T.S.* (pp. 82–96). Antwerp, Belgium Berlin: Bartens Pub. Co.