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PRESENT AND FUTURE TRENDS IN TECHNOLOGY OF SUGAR BEETS AND POTATOES UNDER LIMITED ENERGY SUPPLY

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The future trends in technology of sugar beets is the reduction of energy supply by using vapor mechanical compression production of refined sugar only from the first extraction step and the fermentation of the remaining molasses as ethanol. In potato processing the main energy recovery comes from using more efficient heat transfer and exchanger. Waste-water and wet by products treatment by methanogenesis is producing bioges used for heating in the plants. Better utilisation of different by products for food and feed is discussed.

INTRODUCTION

Energy, such as fuel, natural gas and electricity, is a big item in any food industry and particularly in industry processing raw material with high water content, such as sugar beet and potato. It has been estimated that the energy consumed per dollar value of sugar beet product is greater than for any other food industry [20]. Process energy in a typical chip/potato snack plant accounts for the one-half to the two-thirds of the total energy and corresponds to the energy directly used to fry, or bake or flake product [18, 23].

A lot of new energy technology has been developed in order to help the supply picture in the future — e.g. solar, wind, geothermal, fusion — but most of these technologies are either too underdeveloped or too expensive to be of any help to food industry in the near future.

Therefore, due to this fact, many food industries have recently tried to recuperate or conserve the maximum of the energy involved by different ways either during processing or/and by effluent treatment or/and by valorization of their by-products.

PRODUCTION

Sugar beets and potatoes are two tubers, which contain almost 80% of water and which are harvested during a limited time over the year. Because their low solid contents, their storage life as such is too short. Therefore various processings have been developed to transform an instable raw material into storable products.

In EEC, 13 millions Tons of sugar have been produced from sugar beets (90 millions Tons), in 1985-1986 which brings EEC the first exporter in the world. Refined sugar is the main product obtained from the conventional processing and used for food. Molasses and pulp are the two by-products essentially used as a feed complement. However, molasses can also be a substrate for fermentation. The production of bioethanol from sugar beet as an octane booster is still under consideration within EEC [6].

As far as potatoes production is concerned, potatoes for starch extraction or for human consumption have to be considered differently. In EEC, 4.5 millions Tons of potatoes for starch extraction have been grown in 1984/85 and 28 millions Tons for human consumption from what 10 to 15% are generally processed into chips, dehydrated potatoes, frozen french fried potatoes and others items [19].

PRESENT TECHNOLOGY

The average composition in percent of sugar beet [5] and potato (Table 1) shows similar content of water and dry matter. The main component of the solids is carbohydrate; sugar (16%) for beet and starch (18.8%) for potato. The amount of cell-wall material is more important in beet with 4.2% of pulp than in potato (crude fiber, 0.6%). On the contrary, protein accounts for 2.0% in potato and only for 0.7% in beet

Table 1. Average composition in per cent

Sugar beet			Potato	
Water		77.5		77.5
Dry matter		22.5		22.5
Carbohydrates	sucrose	16.0	starch	18.8
	others sugar	0.1		
	pulp	4.2	crude fiber	0.6
Protein soluble		0.7	protein	2.0
Organic acids		0.5	fat	0.1
subst. with lime		1.0	ash	1.0

under the form of soluble protein. The minor components of beets are represented by organic acids (0.5%) and precipitable substances with lime (1.0%) [3] whereas in potatoes, they are mainly fat (0.1%) and ash (1.0%).

With such low solids content raw material to be processed, the major problem that industry has to face is to deal with an instable product, consuming a lot of energy to remove the large excess of water.

The present technology is based on the manufacture of the 2 main constituents, sucrose and starch, which become very competitive since the equivalent of sucrose, isoglucose, can be produced from starch under enzymic reaction leading to more interesting technological characteristics [10].

The by-products are recovered and used as such with limited valorization and the waste water effluent is not always either recycled or treated. However, in case of potato for human consumption, diversification in processed potatoes (mainly ready-eat, frozen items) has been well accepted by the consumers and their production is regularly increasing from year to year. This phenomenon tends to encourage the promotion of both valorization and diversification.

ENERGY CONSUMPTION IN PROCESS

Energy can be defined as the capability to either perform work or transfer heat. Both, work and heat transfer are needed in the sugar beet and potato processing.

The basic unit of heat energy used in most english spoken industrial applications is the British Thermal Unit or BTU. In the other european countries, the metric equivalent of the BTU is the calorie. One BTU is the amount of energy required to raise one pound of water one degree F. A "small" calorie is the energy required to raise one gram of water one degree Celsius and the equivalence is 1 BTU = 250 calories, therefore 1 Kcal = 4 BTU. More often, the energy is expressed in Kg equivalent fuel which is the energy liberated by the combustion of 1 kg of fuel corresponding to 10.5 10^3 Kcal or 10.5 therms or 44 10^3 Kjoules.

SUGAR BEET

2.3 10^6 BTU or 6.10^5 Kcal are required to process 1 ton of sugar beets and over this energy, 33% is used by the pulp drying, 62% for the thin juice concentration and 5% for lime production. In EEC [4] the technology has reached a rather lower energy consumption with 19-20 kg equivalent fuel per ton of processed sugar beets and around 10 kg equivalent fuel for pulp drying (3.15 10^5 Kcal). This low energy technology together with a high yield of sugar beet (13 Tons of dry matter per ha) and with high capacities, modern industrial equipment and large internal marketing explains the level reached by EEC as the first sugar exporter in the world. The reduction of energy supply during sugar beet processing can be obtained mainly under both the evaporation step to produce the concentrated syrup and the drying of pulp. Already, the evaporation is carried out, at least in most of the french sugar beet industries by using the steam vapor by stepwise from 130 °C. This "multiple effect" is possible keeping the steam vapor by mechanical compression to a temperature sufficient for evaporation. Such a mechanical compression has allowed to reduce by 4 times the steam consumption. The combined use of steam and self-produced electricity shall be also a way to reduce energy, by using for instance, rotative automated dryer.

In future, not only the reduction of energy has to be taken into account during the technology of sugar beet but also improvement of raw material, diversification in production and valorization of by-products must be investigated. Presently research is carried out on high fermentescible matter content sugar beet cultivar by plant breeding. The in situ modification of the cell-wall material by enzymic reaction could improve sugar extraction. The use of pulp as human dietary fiber due to their high content in hemicelluloses and pectins [11] as well as of pectins after extraction from pulp [12] and modification to render them as gelling and thickening agents [15, 16] are certainly new by-products which could improve the technology. Rombouts and Thibault [15] have just reported the presence of feruloylester substituents in beet pectins which bring the possibilities to increase the apparent molecular mass of soluble pectins by enzymic and chemical cross-linking and which allow such pectins to gel formation. The cross-linked pectins from these gels, isolated by solvent-drying, have an extremely high waterabsorbing capacity. This property should lead, as claimed the authors, to some new applications in food and non-food industries, such as a cloud stabiliser in drinks, or as water absorbing agent in sanitary products, as examples.

The hydrolysis of sucrose into glucose (dextrose) and fructose (levulose) to produce syrup in competition with cereals or potato syrup will be more suitable to the requirement of most of the food and chemical industries except for chocolate and dry-product manufacturers [8]. Their hydrogenation into sorbitol and mannitol could also bring, on the market, competitive chemical products with those from the cereal technology [17]. Modification of sucrose by linkages of fatty acids, leads to sucroglycerides with properties used in food and feed as emulsifier and in detergent industry. Molasses, as fermentation substrate, are already used a great deal for the preparation of ethanol, citric acid, sodium glutamate, L-lysine... The present discussion within EEC, to prepare ethanol as an octane booster from various agricultural products — sugar beet, cereals (wheat

Table 2. Yield in ethanol per ton agricultural raw material and per hectare cultivation

Raw material	Yield ton per ha	Yield ethanol (hl) per ton raw material	Yield ethanol (hl) per ha
Sugar beet	53.5	1	53.5
Wheat	5.5	3.6	20
Maize	6.6	3.6	24
Barley	4.6	3.1	14
Potato	29.5	1.053	31
Wine	75.1	0.1	7.5
Sorghum	4.7	3.3	15
Caroub	5.6	1.75	10

and maize), potato, wine — Table 2) shows that the less expensive production of bioethanol comes from Quota C sugar beet followed by Quota B sugar beet, wheat, Quota A sugar beet, maize and potato 16 (Table 3).

Table 3. Costs of ethanol production (ECU) from various raw material (based on 1 hl ethanol production)

	Wine	Potato	Sugar beet			Maize	Wheat
			quota A	quota B	quota C		
Cost of raw material	342	57	40	25	20	68.1	53
Transport		3	4	4	4		
Cost of processing	46	30	25	25	25	30	30
Value of by products		5				20	20
Total ECU/hl	388	85	69	54	49	78	63

Source: EEC Committee 1986

Methanogenic fermentation can be used in sugar industry in three different fields:

— wastewater treatment with energy savings and biogas valorization as for steam generation,

— anaerobic digestion of beet pulps and trashes,

— treatment of distillery slops in order to improve energetic balance of ethanol production and to obtain a partial purification of a very polluting effluent.

The first field of application is mainly related to environmental protection.

The second field has a double motivation:

— dropping of pulp dehydratation costs: indeed, the distances between production and consumption areas (for feeding) involve the drying of the pulps to lower their transportation costs and to improve their conservation;

— fear of new increases of fuel costs and research of energy savings, including high-pressured pulps, ensilage of 30% dry matter pulps and low temperature drying.

The water effluent treatment by anaerobic digestion or methanogenesis is now a classical technique which several industrial applications in many countries producing sugar beets [1] use more for depollution (such as odor depollution) than for energy recovery. This is due to the fact the waste water from sugar beet processing is quite diluted containing essentially volatile fatty acids and produces after treatment, in the best cases, a biogas equivalent to only 1 kg fuel per Ton processed sugar beet. In order to recover more energy from the by-products, the technology has been recently applied to pulp and beet trashes. Lescure and Bourlet [9] in collaboration between IRIS and INRA in France, have studied a two step anaerobic process, each resulting from numerous fermentative reactions. About 88% of the pulp substrate could be converted into biogas and a volumic load of 7 $kg.m^3$ of dry solids were converted within 24 hours. With beet trashes digestion, many technological problems were encountered. It was not tested with high loads, but bioconversion rate was about 75%. Considering that treating one ton of beet produces about 50 kg dry matter as pulp and 5 kg dry matter as trashes, these fields give energetic potentials equal to 15 kg and 1.9 kg of fuel equivalent per ton of beet. Nevertheless, an economic evaluation has shown that in the best cases (biggest plants), the payback time of the investment is about 5 years [21]. At last, the treatment of distillery slops in order to improve energetic balance of ethanol production is operational in several industrial plants in Europe, mainly in Italy and France. It could be calculated from experimental results that the produced biogas is approximatively equivalent to 10 kg of fuel per hl of alcohol derived from sugar beet. This would allow to obtain a zero energetic consumption in the distillation workroom.

POTATOES

Starch extraction potato

The technology is mainly based on the extraction of starch after washing, rasping, decantation and screening from the potato pulp. Presently, the starch yield recovery reaches 94%, obtained by recycling the used water-washing. Purity of starch granule is higher than 99.5%. The recovery of pulp and proteins from the fruit water consume energy for both concentrating the fruit water and drying the final product. It is reported by ANSART [2] that, in 1894-1895, a potato starch plant treating 2 tons potatoes per hour with steam generator was using 2600 therms for the production of 1 ton of starch. In 1985, the energy consumption was reduced to 700 therms in a 80 tons/hour plant, (corresponding to 12 kg eq. fuel per ton of processed potato). The energy consumed for drying pulp has also been reduced from 4,500 therms to 2,500 therms (2.75 kg eq. fuel) using rotative automated dryer instead of "bed" dryer. Therefore, the energy consumption during potato starch extraction processing (around 72 kg eq. fuel per ton starch) is 3 times less than in sugar beet processing (around 200-220 kg eq. fuel per ton sugar).

Under limited energy supply, the use of vapor mechanical compression "at multiple effect" is already applied for the treatment of the waste-water. The concentrated syrups are used as fertilizer or feed complement.

Ultrafiltration for concentrating the fruit-water instead of evaporation is also considered to limit energy consumption.

As in sugar beet processing, research is also carried out to improve the use of by-products in food and non-food industries. Wilhelm and Kempf [24] have recently reported the use of potato protein in paper industry. Coagulated potato protein was modified to test their protecting properties with definite particle size in micro-capsules coated papers, mainly to yield better whiteness, reduced water binding capacity and to adjust the necessary stability. From laboratory results, developed and optimized production scheme for transcript papers, the authors claimed the advantages of potato protein in such application as well as for their low price. Potato starch has a lot of others applications both in food and non-food industries (textile, adhesives, water and mineral treatments, pharmacy...) as native or chemically or thermally processed [2].

Methanogenic fermentation is also used in potato industry. Anaerobic purification of the waste-water produced by the potato processing factory of AVEBE [13] serves three distinct purposes: the removal of organic matter, the reduction and subsequent removal of sulfate and the generation of "biogas" (mainly methane and carbon dioxide) to be used as a fuel. The waste-water passes during the anaerobic purification, a sedimentation pond, a first Upflow reactor and an Upflow Anaerobic Sludge Blanket (UASB) methane reactor. The fermentation of free-aminoacids and smaller peptides has been shown to occur in the sedimentation pond and first reactor. Proteins and longer peptides were degraded in the first reactor and in the methane reactor. The decrease in COD and TOC content of the waste water between influent sedimentation pond and effluent methane reactor was 83 and 71% respectively. In the effluent of the first reactor, 60% od the inorganic sulfur was present as sulfide.

POTATO FOR HUMAN CONSUMPTION

10-15% of human consumption potatoes have been processed in 1984-1985, with a net increase year after year. In France, from 94,910 Tons of potatoes in 1966 — 67, 591, 101 Tons have been transformed in 1984-1985. Among the processed potatoes, in 1984, 45.5% are dehydrated potatoes, 28.0% french fried, 18.4% chips and 8% frozen and others items (Eurostat, 1986). It means that an increase of energy use is expected from potato industry.

In a typical potato chips fryer heater, as described by Wentz [23], somewhere between 30 and 33% of the fuel input will go right up the heat exchanger stack. About 64% of the heat actually applied to the cooking oil is eventually vented to the atmosphere. About one percent of the energy is retained in the potato chips as they emerge from the fryer and perhaps 2% of the fuel energy becomes radiated heat from the surfaces of the duct work or the fryer itself.

Therefore, fuel conservation in such potato industry has been accomplished by using more efficient heat transfer surface (such as finned tubes) in the heat exchanger and by reducing the water carry over into the fryer from the raw slice rising process. Recovered heat also reduced fuel consumption and is used in potato processed industry to heat rinse water, raise the raw slice temperature via and under the hood conveyor, heat plant water, preheat combustion air, or to heat space (specially in northern climates). The best suited equipment types to heat recovery in the chip industry are the boosters heaters and the shell and tube exchangers.

The use of the run-around loops is also an energy conservation system. This system can be a closed loop filled with a glycol solution which alternately picks up and gives up heat as it circulates through the system. The steam stream can also pass through the coils heating water used for make up blanching potatoes slices before frying. This steam stream is also utilized for building heating in conjunction with ventilation system. Some assumptions on energy conservation opportunities during processing have been listed by Wentz 23 (Table 4). The use of a cooking oil booster could save 11.5% fuel with a payback of 1.9 year. The rinse water heating, combustion air preheat and space heating run around loops would save 2.9 and 6.9% fuel with a payback of 3.8, 2.1(and 3.8 years respectively. One of the most efficient recovery comes from the use of an under hood

Table 4. Energy conservation opportunities in chip/snack industry*)

Description	% fuel savings	Years pay back
Cooking oil booster	11.5	1.9
Rinse water heating	2.9	3.8
Combustion air preheat	6.4	2.1
Space heating run around loops		3.8
Under hood conveyor	10.0	2.8

*) Wentz PC/SFA'S 1978

conveyor saving 10.0% fuel with a payback of 2.8 years, as it is observed in Flodor Firm in France.

The waste water characteristics in potato processing industry are different than those of sugar industry. With a COD of 2000-6000 ppm, temperature 30-35 °C, pH 4.5-6.0 and suspended solids lower than 1.0 ml/l, methanogenic fermentation of such waste water from french fried potato processing has led to the production of 30 to 35 M3/hour of biogas containing 80% CH_4 [14].

Equivalent results have been obtained on a laboratory-scale by Verrier [22].

Flodor Firm, in France, has recently invested in a methane reactor for the treatment of their waste water coming from french fried, flakes and chips production, and hopes to obtain by this way a 5-10% reduction of the total plant energy.

CONCLUSION

The future trends in sugar beet and potatoes technology under a limited energy supply could be summarized as follows:

As raw material, the production of variety with increase dry matter and fermentescible nutrient by plant breeding;

In technology, the evolution in the equipment by using vapor mechanical compression, membranes processes (ultrafiltration reverse osmosis), ion exchange process, rotative automated dryer, the automation in the equipment and the use of combined energy including the generated biogas.

The waste water effluent treatment by methanogenesis and the recovery of produced biogas as steam generator, water heating...

The valorization of by-products such as beet pulp and trashes, protein potato for food and non-food industrial uses.

LITERATURE

1. Albagnac G., Lescure J. P., Verrier D.: Méthanisation des effluents, état de l'art en France et en Europe 5éme Journées scientifiques et techniques, l'Eau, la Recherche et l'Environnement, Lille, 25-27 october 1983.
2. Ansart M.: La fécule de pomme de terre et autres amidons in "Histoire des Sciences et Techniques dans les Industries Agricoles et Alimentaires". Ed.: R. Scriban, Pub.: Lavoisier, Paris 1986 (in press).
3. Camirand W. M., Randall J. M., Zaragosa E. M., Neumann H.: J. of the ASSBT 1981, **21** (2), 159.
4. Cultivar: Documentation agricole — spécial betteraves no 189, 140 p., Dec., 1985.
5. Devillers P.: La sucrerie in Cultivar, documentation agricole — spécial betteraves 1985 (189), 117.

6. EEC Committee. L'avenir du Bioethanol en Europe. European Agency for Information and Bruxelles Club. Ed. Y. Clarisse, January 1986.
7. Grison C.: La pomme de tere: caractéristiques et qualités alimentaires. Pub: APRIA, Paris 1983.
8. Guerin B.: Acad. Agric. seance 16 october 1985.
9. Lescure J. P., Bourlet P.: Ind. Alim. Agric., 1984, **101**, 601.
10. Mercier C.: Ind. Alim. Agric., 1982, **99** (10), 787.
11. Michel F., Thibault J. F., Pruvost G.: French Patent no 8516746, 1985a.
12. Michel F., Thibault J. F., Mercier C., Heitz F., Pouillaude F.: J. Food Science 1985b, **50**, 1499.
13. Nanninga H. J., Gottschal J. C.: Wat. Res., 1986, **20** (1), 97.
14. Pette K. C., Versprille A. I.: Application of the U. A. S. B. — Concept for waste water treatment in. Anaerobic Digestion 1981. Eds: Hughes et al. Pub: Elsevier Biochemical Press B. V., 1982, 121.
15. Rombouts F. M., Thibault J. F.: Sugar beet pectins: chemical structure and gelation trough oxidative coupling — ACS Symposium Series no 310. Chemistry and Function of Pectins. Marshall L. Fishman and Joseph H. Jen, Editors, ch. 5, 1986, 49.
16. Rombouts F. M., Thibault J. F., Mercier C.: French Patent no 8307208, 1983. European Patent no 84 — 400 485 — 8, 1984.
17. Sucrerie Francaise. Sucrerie Francaise no 98, 409, October 1985.
18. Sullivan J. W. jr.: Energy conservation in the non-processing operation of a snack food plant. PC/SFA'S Production management report, part I, 1978, 1.
19. Talburt W., Smith O.: Potato processing 3rd ed. Pub: The Avi Publishing Co. Inc., 1975.
20. Unger S. G.: Food Technol., 1975, **29** (12), 33.
21. Verrier D., Lescure J. P.: Biogas coupled with sugar production — 1rst Workshop on "Elaboration for a problem-oriented strategic decision matrix for research projects in agriculture in brief Agricultural Surpluses. OBERURSEL (RFA), 6-8 January 1986.
22. Verrier D., Moletta R., Albagnac G.: Anaerobic digestion of vegetable canning wastewaters by the anaerobic contact process: operational experience, presented at the 3rd Anaerobic Digestion Symposium, Boston 1983.
23. Wentz C. H.: Energy conservation in the processing operations of a snack food plant. PC/SFA'S Production management report, part II, 1978, 19.
24. Wilhelm E., Kempf W.: Die Starke 1986, **38** (7), 238.

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STAN OBECNY I TENDENCJE PRZYSZŁOŚCIOWE W TECHNOLOGII PRZEROBU BURAKA CUKROWEGO I ZIEMNIAKA W WARUNKACH OGRANICZEŃ ENERGETYCZNYCH

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Streszczenie

Kraje EWG produkują 13 mln t cukru (1985-86), co stanowi 12% produkcji światowej. Są one największym eksporterem cukru. Plon buraków — 13 t suchej

masy z 1 ha. Zużycie energii 19-20 kg równoważników paliwa na tonę cukru. Na suszenie wytłoków zużywa się 10 równoważników paliwa. Przemysł charakteryzuje się nowoczesnymi urządzeniami o wysokiej wydajności. Duży rynek wewnętrzny i wzrastające zapotrzebowanie na cukier, zarówno rafinowany jak i nierafinowany. Brak specjalizacji pomiędzy krajami EWG sprzyja utrzymywaniu zakładów o mniejszej sprawności i tym samym produkujących drożej. System subsydiowania produkcji, jak również określenie maksymalnej liczby produktów, podobnie jak w USA, sprzyja używaniu innych czynników słodzących, jak również poszukiwaniu nowych możliwości przetworzenia, np. bioetanol.

W przyszłości, ograniczenia energetyczne sprzyjać powinny wykorzystaniu kompresji mechanicznej w wyparkach, jak również kombinowanemu użyciu pary i energii elektrycznej wytworzonej w zakładach. Produkcja cukru tylko z pierwszej ekstrakcji i fermentacji etanolowej pozostałej w melasie masy cukru. Odpadki płynne i stałe mogą być przetwarzane na energię przez fermentację beztlenową. Badania naukowe dotyczą wzrostu zawartości substancji fermentujących przez metody hodowlane technologii ekstrakcji, waloryzacji produktów ubocznych, co powinno przyczynić się do poprawy produkcji i ceny.

Niektóre przykłady postępu dotyczyć mogą modyfikacji "in situ" ścian komórkowych w celu lepszej ekstrakcji, wykorzystywania wysłodków buraczanych jako błonnika dietetycznego dla ludzi. Otrzymywanie pektyn oraz ich modyfikacja powinny prowadzić do udoskonalenia technologii. Następnie hydroliza sacharozy w celu otrzymania syropu glukozy i fruktozy może być konkurencyjna w stosunku do syropu ze zbóż. Również rozważa się uwodornienie cukrów do sorbitolu i mannitolu do urozmaicenia surowców dla przemysłu przetwórczego.

Produkcja ziemniaków w krajach EWG na cele skrobiowe wynosiła 4,5 mln t i 28 mln t na cele spożywcze. Jedna z technologii jest oparta na ekstrakcji skrobi po myciu, rozcieraniu, dekantacji i cedzeniu pulpy ziemniaczanej. Wydajność skrobi wynosi 94%. Znaczne ilości energii zużywa się na suszenie pulpy i zagęszczenie wód sokowych. Zmniejszenie zużycia energii jest możliwe przez zastosowanie mechanicznej kompresji i wykorzystanie procesów membranowych. W przetwórstwie ziemniaków spożywczych głównym źródłem oszczędności energii jest sprawne przenoszenie wymienników ciepła. Ze ścieków można wytwarzać biogaz jako źródło energii.

W obu technologiach ewolucja wyposażenia jej automatyzacji, wykorzystywanie kombinowanych źródeł energii (paliwo, elektryczność, węgiel i gaz naturalny), wytworzenie biogazu, zwiększenie liczby produktów gotowych, uszlachetnienie produktów ubocznych powinno przyczynić się do poprawy efektywności.