SUGAR INDUSTRY PROBLEMS, both in beet and cane processing, today involve energy saving, restructuring of plants due to closure of small factories, together with issues of environmental pollution. In trying to contribute, whilst partially solving such problems, the authors have studied the possibility of obtaining sugar directly from thick and raw juices utilizing the cooling-crystallization technique. This latter process, which is carried out under less drastic conditions than the normal procedure, makes possible for equivalent starting juices, production of crystalline sugars having much lower amounts of included mother liquor, and consequently of color and ash. In the case of thick juice the authors suggest the possibility of obtaining white sugar of a commercial type through direct crystallization in several steps, thus achieving both energy and plant saving. As far as the latter aspect is concerned, a “truly continuous” crystallization system has been set up which does not need a preformed magma in a discontinuous boiling pan. With the objective of avoiding environmental pollution problems, which involve both liquid and solid wastes, the possibility of obtaining sugar by cooling-crystallization of raw juice is also taken into consideration. Such a technique would allow us to greatly simplify the processing scheme thus giving remarkable benefits, including economic ones.

KEY WORDS: Cooling-crystallization, continuous crystallization, raw juice, thick juice.

INTRODUCTION

Traditional sugar technology, for both beet and cane processing, is based on the assumption that the crystallization step must follow purification processes which, although based on different criteria, yield mother liquors containing ash and coloring matter contents which are as low as possible. The necessary purification systems weigh heavily on the whole processing scheme, not only as far as energy and processing plant problems are concerned, but also in respect of environmental pollution, particularly regarding solid and liquid wastes. In connection with the latter point, and especially for beet processing, the followings are particularly
onorous: coke and lime utilization, carbonatation mud discharge, and the disposal of waste waters originating from various plants using ion exchange resins both for decolorization or deionization purposes.

The special requirement to have mother liquors available which are as pure as possible is due to the fact that crystallization, although it is in itself a purification process, can promote inside sucrose crystals the inclusion of a certain amount of mother liquor, particularly when carried out in the traditional manner (i.e. at high temperature and through solvent evaporation). In fact, although not excluding the possibility that special substances, colorants included, can preferentially co-crystallize in some parts of the sucrose crystals, when kinetic conditions are sufficiently drastic, inclusion of mother liquor droplets also becomes particularly probable. Thus, Figure 1 demonstrates the presence of these droplets inside a sucrose crystal.
sucrose crystal with reference to one of its faces having a high growth rate. Obviously, because growth conditions vary with supersaturation, temperature and stirring rate increases, all the crystal faces can, in fact, include colored mother liquor droplets, such that the final crystals can contain increasing amounts of coloring matter and ash. To try to avoid these problems as much as possible and to optimize the purification characteristics of the crystallization process, we have now considered the possibility of industrially using the cooling-crystallization (C-C) process. In a first series of experiments we applied the process to thick juice bearing in mind that, particularly under special geographic conditions, its technological characteristics need expensive and complex sugar recycling and refining processes to obtain a commercial product. Then also, the direct crystallization of raw juice has been studied on the basis of the considerable benefits which could be obtained by avoiding the expensive and difficult purification processes mentioned above.

**EXPERIMENTAL RESULTS**

**Cooling-crystallization of thick juice**

From preliminary laboratory tests carried out on beet factory thick juice having a color of 5-6 000 ICUMSA Units we have obtained white sugar of commercial quality, i.e. of about 40 T.U., by using the C-C technique. Such juice was simply concentrated up to the saturation Brix at a temperature of 80-85°C and, after addition of seed, cooled down to about 30-35°C, with a cooling rate of about 10°C per h.

On the basis of these experiments we also tested juices having different purities with the aim of checking whether, through subsequent C-C steps, commercial white sugar could be obtained without having to utilize refining processes. Starting from a standard syrup with a purity quotient of 91 it was possible to obtain white sugar and a run-off syrup having a purity of approx. 86. From the latter it was possible, by adopting the technique mentioned above, to carry out a second C-C yielding further white sugar and a run-off syrup having a purity of approx. 80. After a third step of C-C such a syrup gave white sugar of lower quality which however, when mixed with the two previous products, gave a final mixed sugar which was of commercial quality.

Working from these results, the C-C process in three steps as shown in Figure 2A, is proposed. The total sugar yield is about 79% from the three stages, and can also be raised to about 86% if the sugar obtained from the final step of traditional low-boiling crystallization is remelted, thus increasing the starting standard syrup purity. Each of the steps which we propose can be considered as a single continuous cooling-crystallization (C.C.C) process. In fact, the saturated
G. MANTOVANI AND G. VACCARI

1st STEP
THICK JUICE

CONCENTRATION

1st CRYSTALLIZATION
1st SUGAR RUN OFF

CONCENTRATION

2nd CRYSTALLIZATION
2nd SUGAR RUN OFF

CONCENTRATION

3rd CRYSTALLIZATION
3rd SUGAR RUN OFF

WHITE SUGAR
LOW BOILING

A

JUICE

CONCENTRATION

SEED

CONTINUOUS COOLING CRYSTALLIZATION

MAGMA

CENTRIFUGATION RUN OFF
SUGAR

B

FIGURE 2. Cooling-crystallization: A) scheme of a process in three stages; B) scheme of a single stage of the process shown in A).
juice obtained by concentration can feed a reactor of the plug-flow type where the magma, which develops owing to the simultaneous addition of seed, slowly cools from the top to the bottom utilizing a counter-current cooling of water (Figure 2B). This procedure of C.C.C. has been tested by using a pilot plant capable of producing one ton of white sugar per day (Figure 3A). Figure 3B shows the details of the continuous cooling crystallizer. Following the favorable results obtained with beet thick juice, we have carried out some laboratory experiments on cane thick juice without encountering appreciable difficulties. In particular we have used cane thick juice kindly supplied by the Centre d’Essay de Recherche et de Formation la Bretagne, Sainte Clotilde, la Reunion. In spite of the exceptional turbidity of the juice it was possible to obtain by C-C white sugar having a color of approx. 80 I.U. and an ash content of 0.0066%. In Figure 4A, a sample of the sugar obtained is compared with both raw and refined cane sugar. As shown in Figure 4B the crystals obtained evidently do not show inclusions of coloring matter, and their size is obviously related to the amount of seed supplied at the start.

Cooling-crystallization of raw juice

Likewise for C-C of raw juice, laboratory experiments were carried out initially, and these were followed by later tests using a small size pilot plant. The problems to be solved were of two types, viz, 1) to try to minimize inversion on
FIGURE 4. A) Visual comparison between: (1) raw cane sugar, (2) refined cane sugar, (3) sugar obtained from cooling-crystallization of cane thick juice. B) Crystals obtained from cooling-crystallization of cane thick juice.
account of dealing with a product having a naturally acid pH, and 2) to avoid as far as possible the occurrence of foaming during the concentration step.

The beet factory raw juice, after preliminary filtration of suspended particles and soil originating from beet roots, was concentrated under a high vacuum, about 8 kPa so that the concentration temperature remained in the region of 40°C, at least at the start. The conditions ensured avoidance of the difficulties mentioned above, because sucrose inversion was within low limits and foam phenomena occurred only at the start from occluded air in the juice.

After a series of laboratory experiments carried out on small volumes in a Rotavapor, we used a pilot evaporator having a total volume of about 50 litres and heated by steam (Figure 5). In both cases, when the concentration was about 50% dry substance, the temperature was gradually increased up to about 85°C whilst the solids increased to 80-85%. From this point, after addition of a suitable amount of seed, a slow cooling was commenced, about 10°C per h, in a water-jacketed crystallizer down to about 30-40°C. After centrifugation of the magma obtained at the end of the cooling, the run-off syrup was again concentrated by following the same procedure described above and a second C-C was carried out at a slower cooling rate. Whilst the sugar obtained from the first crystallization showed, after further affination via artificial massecuite, the characteristics of commercial white sugar, that originating from the second crystalli-

FIGURE 5. Pilot plant employed for the concentration of raw juice.
G. MANTOVANI AND G. VACCARI

vaporation practically met the raw sugar requirements. The total yield of sugar was about 80% whilst the final molasses purity quotient was approximately 50, depending upon the technological characteristics of the starting juice. In Figure 6 the simplified flow diagram of the various steps of the process is shown.

CONCLUSIONS

From our experiments as a whole, which are described in detail in the references, the following conclusions can be drawn:

- By adopting the C-C technique it is possible to obtain white sugar from impure products such as thick juice having high color or even from raw juice.
- The C-C technique could very well fit the conditions for setting up a truly continuous crystallization system, viz. crystallization which does not simply grow preformed magma in a discontinuous boiling pan.
- Energy consumption seems to favor C-C in comparison with traditional techniques.

FIGURE 6. Flow diagram showing the various steps of the whole process.
Direct raw juice crystallization could remove, especially in the case of beet processing, the problems associated with necessary plant requirements and those of a pollution type, related to the purification procedures.

Although most of our experiments concern beet processing, and only some preliminary laboratory tests have been carried out on C-C of cane thick juice, we believe that our present results represent a valid starting point for the development of a wider series of experiments involving also the cane area. It is to be anticipated that, especially for direct crystallization of cane raw juice, some difficulties could arise due to the peculiar chemical-physical characteristics of the raw juice, for instance. However, we are convinced that such difficulties do not represent an insurmountable obstacle.

REFERENCES

G. Mantovani et G. Vaccari

University of Ferrara
Via Luigi Borsari, 46 Ferrara 44100, Italy

RESUME

L'industrie de la betterave, comme celle de la canne, fait face à plusieurs problèmes, par exemple l'économie d'énergie, la fermeture des petites sucreries et la pollution. La cristallisation du sucre, directement à partir du sirop ou de la liqueur, en se servant de la cristallisation par refroidissement, d'adresse à ces problèmes. Comme les conditions de travail dans ce procédé sont bien moins drastiques, on peut s'attendre à des niveaux d'inclusions de liqueurs mère bien plus faibles dans le sucre. En conséquence, la couleur et les cendres seront plus faibles. En sucrerie de betteraves, les auteurs pensent qu'il serait possible d'obtenir du sucre blanc à partir du sirop après évaporation par cristallisation directe en plusieurs étapes. Cela économiserait de l'énergie et de l'équipement. Cette cristallisation serait vraiment continue et ne requiert pas la formation d'un magma dans une cuite discontinue. La possibilité de cristalliser du sucre par refroidissement à partir du jus, est aussi considérée car cela éliminerait la pollution liquide et solide. Cette technique aurait des avantages remarquables.
ENFRIAMIENTO-CRISTALIZACIÓN DE MELADURA Y JUGOS CRUDOS

G. Mantovani y G. Vaccari
University de Ferrara
Via Luigi Borsari, 46 Ferrara 44100, Italia

RESUMEN

Los problemas de la industria azucarera, en el procesamiento de remolacha y caña incluyen hoy en día economías de energía, restructuration de las fábricas debido al cierre de las pequeñas, conjuntamente con las necesidades de protección al ambiente. Tratando de contribuir mientras resuelven parcialmente tales problemas, los autores han estudiado la posibilidad de obtener azúcar directamente de meladura y jugo crudo utilizando la técnica de enfriamiento-cristalización. Este último procedimiento, que se lleva a cabo bajo condiciones menos drásticas que el procedimiento normal, hace posible con jugos equivalentes inicialmente, la producción de cristales de azúcar conteniendo cantidades muy inferiores de licores madre, y consecuentemente de color y ceniza. En el caso de meladura los autores sugieren la posibilidad de obtener azúcar blanca de calidad comercial a través de cristalización directa en varias etapas, obteniendo así economías de energía y planta. En cuanto concierne este último aspecto, se ha montado un sistema verdaderamente continuo de cristalización que no requiere magma preformada en un tacho discontinuo. Con el objeto de evitar problemas de contaminación del ambiente, que incluye deshechos tanto líquidos como sólidos, la posibilidad de obtener azúcar por el proceso de enfriamiento-cristalización de jugos crudos también ha sido tomada en consideración. Esta técnica nos permitiría simplificar grandemente el esquema de procesamiento produciendo en esta forma beneficios extraordinarios, incluyendo los económicos.

Palabras claves: Enfriamiento-cristalización, cristalización continua, jugo crudo, meladura.