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Monographs on Appropriate Industrial Technology
No. 8.

APPROPRIATE INDUSTRIAL TECHNOLOGY FOR SUGAR
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EXPLANATORY NOTES

A full stop (.) is used to indicate decimals.
A comma (,) is used to distinguish thousands and millions.
A slash (/) is used to indicate "per", for example t/a = tonnes per annum.
A slash between dates (for example, 1979/80) indicates an academic, crop or
fiscal year.
A dash between dates (for example, 1970–1979) indicates the full period,
including the beginning and end years.
References to dollars ($) are to United States dollars.
References to rupees (Rs) are to Indian rupees. In October 1978 the value of
the rupee in relation to the dollar was $1 = Rs 7.90.
The word billion means 1,000 million.
The word lakh means 100,000.
The following notes apply to tables:
Three dots (... ) indicate that data are not available or are not sepa­
rately reported.
A dash (–) indicates that the amount is nil or negligible.
A blank indicates that the item is not applicable.
Totals may not add precisely because of rounding.
In addition to the common abbreviations, symbols and terms and those
accepted by the International System of Units (SI), the following have been
used:

Organizations

FAO  Food and Agriculture Organization of the United Nations
ICUMSA  International Commission for Uniform Methods of Sugar
Analysis
ILO  International Labour Organisation

Other abbreviations and symbols

acre  1 acre = 0.405 ha
BX  Brix
cfm  cubic foot per minute
ft  foot (1 ft = 30.5 cm)
hp  horsepower (1 hp = 0.75 kW)
in.  inch (1 in. = 2.54 cm)
MVP  mini vacuum-pan
**EXPLANATORY NOTES (continued)**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>NPV</td>
<td>net present value</td>
</tr>
<tr>
<td>OP</td>
<td>open-pan</td>
</tr>
<tr>
<td>quintal</td>
<td>100 kg</td>
</tr>
<tr>
<td>rpm</td>
<td>revolutions per minute</td>
</tr>
<tr>
<td>tcd</td>
<td>tonne of cane per day</td>
</tr>
<tr>
<td>tch</td>
<td>tonne of cane per hour</td>
</tr>
<tr>
<td>tsa</td>
<td>tonne of sugar per annum</td>
</tr>
<tr>
<td>VP</td>
<td>vacuum-pan</td>
</tr>
<tr>
<td>WG</td>
<td>water (pressure) gauge</td>
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</table>
The concept of appropriate technology was viewed as being the technology mix contributing most to economic, social and environmental objectives, in relation to resource endowments and conditions of application in each country. Appropriate technology was stressed as being a dynamic and flexible concept, which must be responsive to varying conditions and changing situations in different countries.

It was considered that, with widely divergent conditions in developing countries, no single pattern of technology or technologies could be considered as being appropriate, and that a broad spectrum of technologies should be examined and applied. An important overall objective of appropriate technological choice would be the achievement of greater technological self-reliance and increased domestic technological capability, together with fulfilment of other developmental goals. It was noted that, in most developing countries, a major development objective was to provide adequate employment opportunities and fulfilment of basic socio-economic needs of the poorer communities, mostly resident in rural areas. At the same time, some developing countries were faced with considerable shortage of manpower resources; in some other cases, greater emphasis was essential in areas of urban concentration. The appropriate pattern of technological choice and application would need to be determined in the context of socio-economic objectives and a given set of circumstances. The selection and application of appropriate technology would, therefore, imply the use of both large-scale technologies and low-cost small-scale technologies dependent on objectives in a given set of circumstances.

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As part of its effort to foster the rapid industrialization of developing countries, the United Nations Industrial Development Organization (UNIDO), since its inception in 1967, has been concerned with the general problem of developing and transferring industrial technology. The Second General Conference of UNIDO, held at Lima, Peru, in March 1975, gave UNIDO the specific mandate to deal in depth with the subject of appropriate industrial technology. Accordingly, UNIDO has initiated a concerted effort to develop a set of measures to promote the choice and application of appropriate technology in developing countries.

Appropriate industrial technology should not be isolated from the general development objective of rapid and broad-based industrial growth. It is necessary to focus attention on basic industrial development strategies and derive from them the appropriate technology path that has to be taken.

The Lima target, which, expressed in quantitative terms, is a 25 per cent share of world industrial production for the developing countries by the year 2000, has qualitative implications as well. These comprise three essential elements: fulfilling basic socio-economic needs, ensuring maximum development of human resources, and achieving greater social justice through more equitable income distribution. Rapid industrialization does not conflict with these aspirations; on the contrary, it is a prerequisite to realizing them. But, in questioning the basic aims of development, we also question the basic structure of industrial growth and the technology patterns it implies.

Furthermore, it is easy to see that the structure of industrial growth that should be envisaged and the corresponding structure of technology flows should be different from what they are today; a fresh approach is called for. This does not mean that the flow of technology to the modern sector and the application of advanced technologies are unnecessary. On the contrary, it is essential to upgrade the technology base in general, and it is obvious that to provide basic goods and services, there are sectors of industry where advanced or improved technology is clearly necessary. It would be difficult to envisage a situation where the dynamic influence of modern technology is no longer available for industrial growth and development in general. However, an examination of the basic aims of industrial development leads to the conclusion that there must be greater decentralization of industry and reorientation of the design and structure of production.

Such decentralized industry in the developing countries calls for technologies and policy measures that often have to be different from those designed for the production of items for a different environment, that of the developed countries. As a result, there is a two-fold, or dualistic, approach to
an industrial strategy. Moreover, the two elements in such an industrial strategy need to be not only interrelated but also integrated.

In approaching the question of appropriate industrial technology from an examination of basic development needs, a mechanism is necessary to link and integrate appropriate industrial technology to the overall development process. Through such a process the concept of appropriate industrial technology could be placed in the mainstream of the industrial development effort.

It is hoped that these monographs will provide a basis for a better understanding of the concept and use of appropriate industrial technology and thereby contribute to increased co-operation between developing and developed countries and among the developing countries themselves.

It is also hoped that the various programmes of action contained in the monographs will be considered not only by the forthcoming meetings of the United Nations Conference of Science and Technology for Development and UNIDO III but also by interested persons working at the interface over the coming years.

Abd-El Rahman Khane
Executive Director
Preface

To focus attention on issues involved in choosing and applying appropriate technology, UNIDO organized the International Forum on Appropriate Industrial Technology. The Forum was held in two parts: a technical/official-level meeting from 20 to 24 November 1978 at New Delhi and a ministerial-level meeting from 28 to 30 November 1978 at Anand, India.

In response to a recommendation of the ministerial-level meeting, UNIDO, with the help of a generous contribution by the Swedish International Development Authority, is publishing this series of monographs based mainly on documents prepared for the technical/official-level meeting. There is a monograph for each of the thirteen Working Groups into which the meeting was divided: one on the conceptual and policy framework for appropriate industrial technology and twelve on the following industrial sectors:

- Low-cost transport for rural areas
- Paper products and small pulp mills
- Agricultural machinery and implements
- Energy for rural requirements
- Textiles
- Food storage and processing
- Sugar
- Oils and fats
- Drugs and pharmaceuticals
- Light industries and rural workshops
- Construction and building materials
- Basic industries

The monograph on the conceptual and policy framework for appropriate industrial technology also includes the basic part of the report of the ministerial-level meeting and some papers which were prepared for the Second Consultative Group on Appropriate Industrial Technology, which met at Vienna, 26-29 June 1978.
PART ONE

Issues and considerations
INTRODUCTION

Sugar production occupies an important place in the industrialization programmes of many developing countries. Directly or in processed food, sugar furnishes about one seventh of human energy intake in most developed countries. The use of sugar as an energy-giving part of the human diet is rather high in North America and Western Europe but is relatively low in most developing countries. However, forecasts for the next 5 to 10 years indicate that consumption in developing countries will rise. Fluctuations in the world price for sugar in recent years have caused severe difficulties for sugar-importing developing countries with limited foreign exchange and without the apparent benefits of bilateral sugar agreements obtained by many developed countries. Among import substitution industries many developing countries have therefore given high priority to sugar production.

Sugar-cane, a giant grass related to maize and sorghum, is cultivated in tropical and subtropical regions. The sugar beet, a member of the goose-foot family, grows best in cooler latitudes but adapts itself to many climatic conditions. In North America, for example, it is grown in the varying climates of Arizona, the Imperial Valley of California, Alberta, Manitoba and Quebec. The fact that a practically identical product is obtainable from dissimilar plants has made the global dispersal of the industry possible. Sugar is now produced in over 120 countries. Some produce only or primarily for the domestic market while others produce primarily for export, with annual outputs ranging from less than 10,000 t/a to nearly 10 million t/a.

In developing countries sugar production is mostly based on cane since the general geoclimatic conditions of these countries are favourable to its cultivation. The technological options examined here are therefore restricted to production processes based on sugar-cane.

1. OBJECTIVES

The production and trade data on sugar provided in the background papers reveal that:

(a) Developed countries produce most of the beet-sugar while developing countries produce most of the cane-sugar;
(b) Production of beet-sugar has increased by about 6 per cent since 1970–1971, that of cane-sugar by about 16 per cent;

(c) Non-centrifugal sugar such as panela, panela and jaggery account for over 10 per cent of the total production of about 94 million t/a;

(d) Developed countries have a relatively high per capita consumption while that of developing countries is relatively low.

These figures do not indicate the distribution of sugar consumption by end-use, but analysis of domestic and industrial consumption would probably reveal a major distinction between developed and developing countries. In the United States of America in 1973 approximately 70 per cent of sucrose and other sweeteners were delivered as industrial sugar, that is, for use in processed foods and beverages. In comparison, in 1975 sugar used for industrial purposes accounted for 4.3 per cent of total consumption in Kenya and 6.1 per cent in Ethiopia.

Rapid population increase and gradual improvement of the standard of living are expected to increase the demand for sugar in developing countries significantly. Food and Agriculture Organization of the United Nations (FAO) projections to 1980 and 1985 suggest an average increase of 15.7 per cent and 32.2 per cent, respectively, over 1975 levels of world demand. When broken down by region, however, increased demand is heavily concentrated in the developing regions. By 1985 demand is expected to increase over 1975 levels by 57 per cent in Africa, 69 per cent in Asia, 55 per cent in the Far East and Oceania, 41 per cent in Latin America and 58 per cent in the Middle East.

These estimates indicate the great need for increased sugar production in the near future and evaluations of alternative technologies must consider the limited time available to build up increased production capacity.

II. REVIEW OF ALTERNATIVE TECHNOLOGIES

Although economies of scale have produced a trend towards ever larger installations, existing sugar factories differ widely in size. Influenced by the relative availability and costs of the factors of production, sugar technology in industrialized countries has developed towards substituting capital for labour. Labour requirements have been steadily reduced but required capital investment has increased. The capital cost of sugar factories has risen sharply and is estimated to be about $1,000 or more per tonne of sugar output for medium-sized vacuum pan plants.

During the last two decades smaller plants using the open pan (OP) process have been set up in many developing countries. The survival of small plants using this labour-intensive technology side by side with large plants using the most modern labour-saving equipment is now being examined by developing countries which have adopted employment-oriented industrial development strategies.

Essentially, sugar processing consists of a series of liquid solid separations to isolate the sucrose formed by photosynthesis in living plants. Four basic processes are involved: juice extraction, purification, evaporation and
crystallization. These are at present carried out by various methods and on various scales ranging from small animal-powered cottage units to large, highly automated units. Different types of sugar are made but most types can be produced without regard to the size, design and complexity of the equipment used. Technological pluralism is a characteristic of sugar production that reflects the historical development and wide geographical distribution of the industry.

Modern industrial sugar making employs basically two methods, namely, the open pan (OP) process and the vacuum pan (VP) process. Neither is technologically dominant but the number of hybrid technologies actually available is much more limited in practice than in theory. The use of cane carriers (conveyors), filter presses and mechanical dryers in OP plants, for example, has been borrowed from VP technology. Generally, however, the use of VP equipment in small factories would be uneconomic because it is designed for large-scale production and would usually be operated under capacity. In principle OP equipment can be used to produce any amount of sugar but if this were done in centralized locations, serious problems of organization and efficiency would arise. Similarly, traditional non-centrifugal sugar technology now incorporates certain features of OP technology such as power crushers, crystallization with stirring and improved furnaces. Although the present discussion is concerned mainly with OP and VP technologies, the production of block sugar for rural consumption should be encouraged in certain situations.

Technological advances in the past 25 years have also permitted the OP process to produce a near substitute for the mill white sugar produced by the highly sophisticated VP process. In fact, the first product of the OP process (about two thirds of the total output) approaches the quality of plantation white sugar made in factories. The invert sugars and non-sugars in subsequent batches, although harmless, may give a dull, off-white product with less lustrous and uniform crystals than the VP product. Although OP sugar may not be wholly substitutable for VP sugar, particularly for use in the food, soft drink and pharmaceutical industries, it is pure enough to be an acceptable substitute for domestic consumption. Consumer preference for mill white sugar rather than certain grades of OP sugar should not be overlooked unless the latter has a distinct price advantage.

Implications of technology choice

The sugar mill has been described as a “factory in the field”. Depending on the technology adopted, it can help regenerate and transform a rural environment or it can sap the vitality and destroy the identity of the environment altogether.

Technological options involving a range of operating scales, from small-scale OP factories (100 t/d) to large-scale VP factories (20,000 t/d), are now available. However, it is important to evaluate the appropriateness of alternative technologies not only in terms of their commercial viability but also, and more significantly, in terms of their compatibility with the overall development objectives of a given country. Policy instruments must be developed to facilitate both the choice and operation of an appropriate
technology. The sugar industry operates within a relatively rigid production and marketing system where pricing and production efficiency criteria, although of decisive importance for economic performance, must often be modified by equally important considerations of social or general development relevance.

The common practice of comparing large-scale (VP) and small-scale (OP) sugar-processing technologies is to compare the relative output efficiency of a given capital input. A variant of this practice is to calculate the capital, labour and other factors of production required to manufacture a given quantity of sugar with alternative technologies. For example, with these simplified assumptions:

<table>
<thead>
<tr>
<th></th>
<th>OP plant</th>
<th>VP plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed capital cost</td>
<td>$250,000</td>
<td>$7,500,000</td>
</tr>
<tr>
<td>Number of workers</td>
<td>180</td>
<td>720</td>
</tr>
<tr>
<td>Sugar output</td>
<td>750 t/d</td>
<td>15,000 t/d</td>
</tr>
</tbody>
</table>

it is found that:

1 VP plant = 30 OP plants in terms of capital cost
1 VP plant = 20 OP plants in terms of sugar output

Hence, the sugar output from a capital investment of $7,500,000 is:

- in 1 VP plant 15,000 t/d
- in 30 OP plants 22,500 t/d

and a capital investment of $7,500,000 generates employment for:

- in 1 VP plant 720 persons
- in 30 OP plants 5,400 persons

Conversely, to produce 15,000 t of sugar requires:

- by VP technology $7,500,000 and 720 persons
- by OP technology $5,000,000 and 3,600 persons

According to current estimates, sugar output from 28 OP plants of 150 tonnes of cane per day (tcd) capacity would equal the output of a single VP factory with a capacity of 100 tonnes of cane per hour (tch). The total fixed capital cost of the 28 OP plants would amount to $14.28 million as compared to $31.94 million for the 100 tch VP plant. Employment in 28 OP plants would be 7,364 as compared to 464 in 1 VP plant. The estimated capital requirement of 56 OP plants would be 52 per cent of the capital requirement of one 200 tch VP plant with the cumulative potential of the latter.

Not only is the capital cost of establishing a number of small OP plants absolutely lower than that of building a single large VP plant of equivalent capacity but the development of sugar production based on OP technology can

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1See "Technological choices in sugar processing" in this monograph.
2See "Appropriate technology in cane-sugar production" in this monograph.
also be better phase, and adjusted to the availability of cane, investible resources, manpower and other scarce inputs than can the development of sugar production based on VP technology.

Accordingly, small plants with low initial and overhead costs appear to be more economical in areas where the development of cane supplies would take a number of years than large capital-intensive plants with excess capacities. OP technology is particularly relevant to situations characterized by dispersed and modest cane supplies, small domestic markets dependent on imports, inadequate infrastructure, limited capital and high levels of rural unemployment and underemployment. Characteristically all of these factors exist in varying degrees in all developing countries.

Decisions about production methods and production scale are linked to the question of how to supply the plant with the quality and quantity of cane it needs to operate. The way industry relates to the land and the population which sustains it is a crucial consideration in technology assessment.

Current development strategies emphasize redistributing income, increasing economic opportunities for the poorest members of rural communities and balancing agricultural development. The central question here is whether these goals are better served through mass participation in the sugar industry as wage labourers (as in the case of a plantation-based sugar industry) or as cane growers (as in the case of a sugar industry based on the outgrower system).

A sugar factory needs a reliable supply of cane. This consideration is especially important for large-scale, capital-intensive VP plants to prevent capital wastage through excess capacity. The solution to this problem in many parts of the world has been to centralize control over both land and labour as fully as possible. Until the nineteenth century slave and indentured labour within the framework of a pure plantation economy carried this solution to its logical extreme. Political and economic developments may appear to have liquidated this system but plantations have survived in various forms and, to the sugar industry, they continue to offer certain attractions. However, the theoretical advantages to the factory of centrally controlled production must also be compatible with the environment in which it operates. It has been argued that the needs of a large-scale factory operating on a mixed-crop agricultural base would tend to upset the existing agro-economical balance and would lead to the emergence of a sugar-cane monoculture in which the entire agricultural economy would be subordinated to the sugar factory. This would alienate the local population from traditional agriculture, which represents a balanced and largely self-sufficient food-cum-cash-crop economy, and would perhaps lead to the emergence of a class of landless labourers.

The choice of a system most appropriate to a given environment will depend on the land and the population in the proposed project area. In areas of high population density and intensive cropping, such as Kenya, the outgrower system, supporting a number of small-scale OP plants, may be more appropriate. On the other hand, in areas of low population density and vast uncultivated lands, large-scale factories with a plantation base, preferably in the public sector, may be more appropriate.

The growth of the sugar industry makes integrated rural development
possible, provided that the technology adopted is in harmony with the general level of technological development. To the degree that the technology chosen does not correspond to the development level of its environment, the industry parasitizes the rural economy. According to a recent study,3 in most developing countries up to 35 per cent of the equipment required for an OP plant—tanks, heating beds and furnaces—can be fabricated locally with local skills and materials. OP technology could be easily adapted to the level of technological development of developing countries. Indigenous engineering capabilities could be developed to service imported components, later to make replacement parts, and finally to make these components domestically. This would not, however, be possible at present in the case of large-scale VP technology which uses highly sophisticated, automated processes and equipment. Not only would the basic equipment and spare parts for large-scale VP plants have to be imported indefinitely but their high level of technological sophistication would also provide little or no opportunity to develop domestic engineering capabilities for some time to come.

Small-scale, relatively simple technologies requiring relatively low capital investment are a sure way to promote the rapid industrialization of developing countries, including integrated and balanced regional development through dispersal of industries and broad-based entrepreneurship. A sugar industry based on OP technology is clearly more capable of being dispersed regionally than one comprising a few large VP factories. The capital cost of establishing a new large-scale plantation mill complex in a developing country has become almost prohibitive for private enterprise. On the other hand, by virtue of its small scale, in some situations OP technology may be the only way to produce sugar, not only as a substitute for present imports but also to meet increased future needs. OP technology is also compatible with available domestic investment, managerial and technological capabilities. Equipment for small-scale processing plants is already being manufactured in some developing countries and much of the equipment needed can be made locally by small workshops anywhere. The level of skill required to maintain and repair these small-scale plants is already more or less available in developing countries or could be easily acquired. The kind of cane production required for small-scale OP plants harmonizes with the need to diversify agriculture without displacing the agricultural population through plantation cane cropping. Small-scale OP technology is also compatible with the policy objectives of dispersing industry, broadening the base of entrepreneurship and preventing concentration of economic power in the hands of a few.

Options

From the foregoing discussion it is apparent that the choice of appropriate sugar technology involves consideration of a wide range of factors. In addition to differences in product quality and labour requirements, assessment of technological alternatives must include consideration of extraneous factors related to overall development goals.

3See "Mini sugar technology in India" in this monograph.
Clearly, compromises are necessary and the balance will be determined by policy goals and specific circumstances. The small-scale OP process would appear to be appropriate to situations characterized by conditions such as mixed agricultural cropping patterns, small domestic markets, inadequate infrastructure, capital scarcity and widespread unemployment or underemployment. It would be misleading, however, to suggest that actual policy options would involve complete acceptance of one process and total rejection of alternatives.

The appropriateness of alternative sugar processing technologies should be reviewed at the planning stage of a sugar development programme and not at the evaluation stage of an existing project. Low capital cost per unit of output and employment; low technical, managerial and organizational skill requirements; and its flexibility and adaptability to a wide spectrum of local conditions obviously indicate the choice of small-scale sugar technology. However, the ability of developing countries to adopt moderately advanced technology quickly should not be underestimated. The view that technology and scale of operation in sugar production always go together can no longer be maintained. It was formerly believed that limited infrastructure would necessitate the adoption of OP technology. It is now possible to envision the adoption of VP technology as well, if only on a small scale.

However, instruments of fiscal policy such as price and wage regulations must be fashioned to facilitate both the choice and operation of a technology. Questions such as these, rather than the analysis of output and cost-flow projections, lie at the heart of selecting appropriate sugar technology.

**Energy**

The energy required to produce cane-sugar can be provided by burning bagasse, the fibrous residue of sugar-cane. However, instead of properly utilizing available bagasse, many small-scale processing plants buy electricity or burn wood or fuel oil to produce the heat and steam they require.

Three aspects of energy production and use in sugar-cane processing require special consideration:

(a) Conservation of energy through effective care and maintenance of equipment, through design and use of heat recovery and heat saving devices, and through effective process control;

(b) Sale of surplus steam and electricity, which could be produced by burning surplus bagasse, to other users;

(c) Using surplus steam and electricity to power a distilling plant which could produce fuel alcohol.

Depending on local conditions and needs careful considerations must be given to energy questions since some by-products of sugar-cane processing constitute renewable resources.
RESEARCH AND DEVELOPMENT

For the past hundred years, R and D on sugar have been mainly concerned with refining basic processes and improving machinery and equipment. The transition from batch to continuous operations, the introduction of instrumentation, computerized process-control systems and automation have received particular attention. The aim has been to improve product quality, eliminate losses, increase throughput and reduce labour requirements. Depending on the relative availability of the factors of production, processing technology in industrialized countries has generally developed towards substituting capital for labour. The utility of the resultant capital-intensive, sophisticated, large-scale technology, which was primarily oriented towards the needs of plantation agriculture, has been questioned by some developing countries. These countries lack capital and skilled labour and want to generate employment, broaden the base of entrepreneurship and disperse industry.

Until recently, systematic R and D on alternative processing technologies for developing countries have been seldom and not at all in proportion to the share of developing countries in total sugar production. From what is known about the relative efficiencies of small-scale and large-scale technologies, it is clear that technological innovations should aim at improving the sugar recovery, fuel economy and product quality of small-scale technologies while preserving the advantages of low capital intensity, high employment intensity and modest skill requirements. If the evolution of small-scale technology is to proceed at a faster pace than hitherto and generate a range of feasible alternatives to suit conditions in different countries, it must be provided with the same kind of institutional and regulatory supports that have promoted world-wide diffusion of large-scale processing technologies. A concrete programme of action for individual countries and international organizations such as UNIDO is needed.

For example, R and D must be directed towards eliminating inadequacies from small-scale technology to make it more appropriate to specific local situations in developing countries, particularly where scarce labour and high wages necessitate economies, and to improve product quality. Specifically, R and D should be addressed to these problems: increased juice recovery, reduced sucrose loss from inversion and caramelization, and reduced fuel consumption. In solving these problems, however, the need to preserve the present advantages of the OP technology—relatively low capital cost per unit of investment and per unit of output—should be kept in view.

Simultaneously, both the feasibility and the economics of decentralization of some of the operations involved in manufacturing crystalline sugar should also be investigated. Co-ordination of the dispersed traditional sector now producing the block sugar variously called gur, panela and jaggery with the organized sector will improve the vitality of the traditional sector. Neutral gur, for example, was at one time made in India for subsequent refining; in Thailand both non-centrifugal "red" sugar and syrup are reprocessed in large sugar factories to produce mill white sugar; in Venezuela small mills produce syrup for further processing elsewhere.

Attention should also be given to modifications of VP technology. It is well-known that valuable sucrose content is lost if the time between the harvesting
of sugar-cane and its crushing is longer than 48 hours. One solution to this problem might be to transport the juice rather than the cane, provided that decentralized milling is reasonably efficient and also that technical innovations such as solar cooling make it possible to store the cooled juice longer than is now possible. All such possibilities should be carefully examined since they could very well contribute to decentralizing sugar production.

**Issues and considerations**

In the prevailing circumstances of developing countries small-scale OP technology and, where possible, small-scale VP technology for the production of crystalline sugar and the traditional technologies for the production of block sugar and syrup for further processing in sugar mills would appear to be more appropriate than large-scale VP technology. The advantages of OP technology are low capital intensity; high employment potential; limited need for skilled manpower; unlimited scope for linkages with other production sectors, especially with indigenous engineering and training facilities; compatibility with existing land-use patterns; and adjustability of the scale of operations to cane supplies and sugar demand.

More attention should also be given to the by-products of sugar production. Bagasse, for example, can not only be used as fuel, it can also be used in the production of pulp and paper, furfural and other chemicals, building materials and animal feed. In addition to its use in alcohol production, molasses can be used in the production of animal feed.

**IV. POLICY**

The choice and operation of appropriate technology depend primarily on the policies adopted by governments to enhance its viability and encourage its application.

Fiscal policy instruments such as price and wage regulations are needed to facilitate both choice and operation of appropriate technology. Pricing and distribution policies should be devised to improve the competitiveness of small-scale technologies by creating conditions for improving efficiency and product quality. Also, as noted earlier, OP plants cannot thrive if the market is swamped with relatively cheap VP sugar or if the price of non-centrifugal sugar is set so low that it becomes more profitable to produce an inferior grade of sugar. The adoption and operation of small-scale technology should be encouraged through a rational and co-ordinated scheme of fiscal incentives and subsidies. The realization of long-term development goals would justify the price protection given to the small-scale sugar industry in the initial stages of its development even if such protection results in relatively higher short-term domestic sugar prices.
Useful policy measures would include the following:

The lending policies of public financial institutions should support the establishment of small-scale units. Where co-operative small-scale units are set up, governments should provide seed capital and otherwise participate substantially in organizing such undertakings. While the basic equipment of small-scale plants may have to be imported initially, a phased programme should be undertaken to manufacture it in the sugar-producing countries themselves. Increased sugar yield should be encouraged through improved agricultural practices and better co-ordination of harvest and transport operations. A comprehensive national sugar policy should cover both production (growing, transporting and processing sugar-cane) and distribution (pricing and marketing).

Considering the share of small-scale and traditional technologies in total world production of sugar, resources devoted to R and D on these technologies are extremely meagre. This is because such R and D has been mainly undertaken in developing countries where financial and technical resources are characteristically inadequate.

V. PROGRAMME OF ACTION

Small-scale technology has maintained itself in spite of the trend towards large-scale production because of its relevance to situations which characterize many developing countries. Given adequate R and D support, there is no reason why the efficiency of small-scale technology cannot be improved further.

Basic small-scale sugar technology is well known. Its present inadequacies, such as excessive fuel consumption in juice purification and concentration, need immediate attention. Studies of the technological inadequacies of small-scale processing undertaken in various countries should be co-ordinated.

Another characteristic of the small-scale process is its labour-intensity. The process should therefore also be adapted to situations in developing countries characterized by a high cost of labour per unit of employment. Small-scale technology is at present oriented to situations characterized by high unemployment and low wages but in developing countries where there is an inverse relationship between employment and nominal wages, labour-intensive technologies are not economic.

The special relevance of small-scale sugar technology to almost all developing countries makes it both appropriate and necessary to conduct collective R and D on the technological problems of small-scale production. All cane producing developing countries might participate in such R and D under the aegis of an international organization. An international R and D institution might study the technological deficiencies of the small-scale process while national institutions could concentrate on operational problems of local relevance. The unco-ordinated R and D now being undertaken in both developing and developed countries could then be integrated meaningfully. Such an international institution could also facilitate the concentration of scarce and scattered R and D capabilities for better and more purposeful application.
Intermediate small-scale sugar technology now represents a viable alternative to large-scale technology. The present inadequacies of small-scale technology can be corrected through purposeful R and D. Small-scale technology also blends well with the development objectives of developing countries, including rapid industrialization, balanced agricultural development, dispersal of industry, broadening the entrepreneurial base, expanding employment opportunities, distributing wealth and income equitably and raising the living standard of the rural poor. The choice of sugar technology is thus a political option and must be supported directly and indirectly by public policy.
Report of the Working Group

The principal alternative technologies available for the production of sweetening agents from cane are: the small-scale production method capable of processing about 100 tonnes of cane per day (tcd), whether from open-pan sulphitation (OP) or mini vacuum-pan sulphitation (MVP) units, and the large-scale vacuum-pan sulphitation (VP) units producing plantation white sugar.

The disadvantages of OP factories are relatively low sugar yield and high fuel consumption but these disadvantages are largely offset by low capital cost and high labour input per tonne of product. Some 8,000 OP units are operating satisfactorily in India; two are operating and two more are expected to begin operations shortly in Kenya; one such unit is operating in Ghana.

An MVP factory has been operating at the National Sugar Institute, Kanpur, India. It is a scaled-down version of standard VP technology with fairly high yield, good thermal efficiency and high labour input; its capital cost is about four times that of OP technology for the same capacity.

A large VP factory is a very efficient and fairly sophisticated unit with low labour but a much higher capital cost per unit of input capacity than an OP factory. However, production cost per unit of output is lower for VP factories than for OP factories.

In isolated locations where cane production is low, small-scale technology is applicable; where cane production is high and marketing facilities are satisfactory, large-scale technology would seem preferable unless labour and financial considerations indicate otherwise.

Country experience

The main products and uses of sugar-cane in India in 1972–1977 were:

<table>
<thead>
<tr>
<th>Sugar-cane production (millions of tonnes)</th>
<th>Product</th>
<th>Proportion of total (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>Gur</td>
<td>46</td>
</tr>
<tr>
<td>41</td>
<td>Plantation white</td>
<td>29</td>
</tr>
<tr>
<td>18</td>
<td>Khandsari</td>
<td>13</td>
</tr>
<tr>
<td>17</td>
<td>For chewing and seed</td>
<td>12</td>
</tr>
<tr>
<td>141</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

Gur is solidified and clarified cane juice with no production of molasses. It is hard, crystalline and brownish-yellow in colour. It contains all of the nutrients and sweetening substances present in cane. It is popular and has wide consumer acceptance. Its domestic wholesale selling price is about $120 per tonne.
Khandsari (OP sugar) is produced by about 8,000 factories. Many of them use vegetable clarifcats but modern units clarify by sulphitation. A total yield of 6.4—7.5 per cent of cane can be obtained in modern sulphitation units in three grades as follows:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>5.0—5.5%</td>
</tr>
<tr>
<td>II</td>
<td>1.0—1.5%</td>
</tr>
<tr>
<td>III</td>
<td>0.4—0.5%</td>
</tr>
</tbody>
</table>

Khandsari I has a polarization of about 99.4 per cent and looks almost as white and lustrous as plantation white sugar. Its wholesale selling price is about $0.24 per kilogram.

Plantation white sugar is produced by about 300 factories with a recovery of 9.8 per cent and a polarization of 99.8 per cent. Its domestic wholesale price is about $310 per tonne.

If conditions warrant small-scale production technology, due consideration should be given to the choice between OP and MVP technology. Comparative data on both processes are given below:

<table>
<thead>
<tr>
<th></th>
<th>OP unit</th>
<th>MVP unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (tcd)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Recovery (%)</td>
<td>7.0</td>
<td>9.5</td>
</tr>
<tr>
<td>Capital cost of unit (million $)</td>
<td>0.25</td>
<td>1.00</td>
</tr>
<tr>
<td>Employment</td>
<td>180</td>
<td>280</td>
</tr>
<tr>
<td>Fuel adequacy</td>
<td>4—6 per cent extra fuel required</td>
<td>self-sufficient</td>
</tr>
<tr>
<td>Annual output of sugar (t)</td>
<td>770 (110 days)</td>
<td>1330 (140 days)</td>
</tr>
<tr>
<td>Capital cost per unit of annual output ($/t)</td>
<td>325</td>
<td>752</td>
</tr>
<tr>
<td>Capital cost per man-day of employment ($/t)</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>Production of sugar equivalent to plantation white per 100 t of cane processed (t)</td>
<td>6.5</td>
<td>9.5</td>
</tr>
<tr>
<td>Cane required to produce 1 t of equivalent plantation white sugar (t)</td>
<td>14.3</td>
<td>10.6</td>
</tr>
<tr>
<td>Production cost per tonne of sugar (based on a cane price of $15/t) ($/t)</td>
<td>400</td>
<td>328</td>
</tr>
</tbody>
</table>

These data seem to indicate that both alternatives have their merits. However, MVP technology appears more promising than OP technology.

The experience of Indonesia is limited but similar to that of India. About 1.1 million tonnes of sugar are produced in 55 large-scale VP factories in Java; some 300,000 t of sugar are imported yearly. Indonesia has a long-term plan to increase production. Some gur is also produced. The possibility of establishing a few OP factories is being considered but it is feared that the quality of the sugar produced may not be acceptable. Little is known about the optimum capacity of an OP unit (whether 50 or 100 or 200 tcd).

Ethiopian experience in sugar production is fairly recent. Annual production at present is 100,000 t of plantation white sugar; expansion of annual
production to 150,000 t is planned. Because labour is scarce in Ethiopia a large-scale VP factory was established.

Kenya produces 300,000 t of sugar annually of which more than 95 per cent is accounted for by six large VP factories producing white sugar. Part of the balance is produced by two OP units; two more OP units are planned. OP technology was chosen for areas where cane supply and infrastructure would not have supported a large VP factory.

In Mauritius 21 large-scale VP units are producing about 700,000 tonnes of raw sugar annually. There is little interest in scaling down production units here; on the contrary, the number of large-scale units is gradually increasing. Local production of sugarmaking equipment has been a great advantage and has brought savings as high as 50 per cent when compared with imported equipment. The more thorough utilization of sugar-cane by-products has been an important factor in strengthening the economy of the sugar industry. Research has permitted the industry to remain competitive on the world market at all times. The production of indigenous varieties of cane is almost a prerequisite for progress. The local research institute, which has established its priorities in accordance with the actual requirements of the country, has provided protection against pests and diseases.

Alternatives to bagasse as fuel for the sugar industry

Most developing countries have long-term priority plans to establish a paper industry to replace current and future paper imports. These plans are beset, however, with serious techno-economic limitations arising mainly from the size, sophistication and cost of conventional paper plants based on wood pulp but also from the limited domestic market. Since these countries also have plans to develop and expand existing sugar production, it has been suggested that bagasse be used to produce pulp and paper rather than be used as fuel for sugar production.

The diversion of bagasse now used as fuel by existing sugar production units might create serious technological difficulties and necessitate additional investment for modification of existing steam-raising equipment and might also adversely affect the operational economics of existing sugar mills. However, where low-cost local alternative fuel is available, there may be a case for using bagasse to produce pulp and paper.

Developing countries planning to establish or expand sugar production should allow for the possibility of using alternative fuels and of making bagasse available for small-scale paper production. The economics of using alternative fuels should be taken into account in feasibility studies for establishing integrated sugar and paper industries.

Policy

It is apparent from the foregoing discussion that choosing appropriate technology involves consideration of many factors, especially differences in product quality, capital cost, and labour requirements.

Agricultural and socio-economic factors should also be carefully considered
before finally choosing appropriate technology. Agronomic considerations such as land suitability, cane varieties and competitive crops and availability of labour and transport in a given area must also be taken into account before a decision can be reached. The choice of technology should depend on circumstances and the development objectives of each country. Small-scale sugar production appears to be more appropriate in situations characterized by small domestic markets, inadequate infrastructure, capital scarcity and widespread unemployment. This does not mean, however, that the actual policy option would mean absolute choice of one process to the exclusion of other alternatives. If a given policy stresses low capital cost per unit output and employment; low-level technical, managerial and organizational skill requirements; and a technology which can be adapted easily to varying local conditions, choice is obviously restricted to small-scale sugar production. However, the capacity of developing countries to adopt moderately advanced technology quickly should not be underestimated. The view that technology and scale of operations in sugar production are always related is no longer tenable. It was formerly thought that limited infrastructure would necessitate the adoption of OP technology only. It is now clear that VP technology can also be adapted to small-scale production.

Programme of action

No industry can achieve significant progress without some R and D. In developing countries, however, R and D should not be limited to improving processes or technology. The ultimate objective of R and D should be to promote the well-being of the population, especially the poorer section.

Since small-scale sugar production technology appears to satisfy the requirements of certain situations, it is important that it be made the subject of systematic research. Unfortunately except for the meritorious but very limited efforts of some developing countries, this has not been the case so far.

The establishment of an international research institution to undertake specialized R and D on small-scale production technology appears to be eminently desirable. However, to expedite this urgently required work, it might be preferable to commission existing institutions to perform such R and D on a regional basis under a United Nations Industrial Development Organization (UNIDO) programme to be formulated for this purpose.

Specifically the R and D programme should include attention to these problems: improving cane varieties, juice quality and crop husbandry; efficient use of fertilizers, especially nitrogenous fertilizers; efficient adaptation of harvesting and transport equipment to local conditions; increasing milling efficiency and fuel economy; reducing sucrose loss, especially by inversion; reducing fuel consumption; developing continuous operations; storing and conserving raw materials and finished products; efficient use of by-products, especially bagasse as raw material for paper; better use of surplus labour during slack seasons.

Technological expertise, machinery manufacturing capacity and training facilities in the field of sugar production now exist in a number of developing
countries. Co-operation between these countries and other developing countries would greatly accelerate the development of the sugar industry in the latter. UNIDO could play a positive and useful role in promoting such co-operation not only by promoting the flow of technological information but also by facilitating the transfer of technology and training of personnel.

The experience of the National Sugar Institute, Kanpur, India, suggests that it would be desirable to make a techno-economic appraisal of small-scale VP boiling. Because this study would be relevant to many developing countries embarking on sugar production, UNIDO should commission such a study.

The exchange of information between countries by visits, seminars and publications would help improve technology more quickly. To facilitate international comparisons each sugar-producing country should provide UNIDO with annual statistics on production, employment, and kind and scale of technologies used to give a precise profile of the sugar industry in each country. The accuracy of the data would be the responsibility of the governments concerned; all data should be expressed in standard international units.
PART TWO

Selected background papers
Appropriate technology in cane-sugar production

B. A. Bhat and F. Duguid*

Evaluation of alternative technologies

Sugar technology cannot be chosen without consideration of socio-economic and climatic factors. This paper compares techniques and scales in two different agricultural environments: a long season of 270 days of cane crushing per year excluding downtime and a short season of 150 days; and at two cane prices. The lower price is representative of plantation production; the higher price is representative of outgrower production.

Long season. Alternative technologies are first evaluated for the long season. Five are vacuum-pan (VP) technologies; three are open-pan (OP) technologies. Comparative data on these technologies are given in table 1.

The data on VP technologies relate to two levels of scale, two generically different techniques and two sources of equipment. The first unit is capable of crushing 200 tonnes of cane per hour (tch); the remaining four units are each capable of crushing 100. The largest VP unit and the first 100-tch unit are assumed to use equipment from Europe with milling rather than diffusion at the juice extraction stage. The second 100-tch unit uses the same technology but equipment from India; the third and fourth 100-tch units use European and Indian equipment respectively with milling plus diffusion introduced at the juice extraction stage. The diffusion equipment is of European origin. This comparison of 100-tch units would also apply to 200-tch units.

OP units with capacities of 90 tonnes of cane per day (tcd), 150 tcd, and 220 tcd are also considered.

In the VP technologies using milling for juice extraction, a sucrose recovery rate of 80 per cent from cane containing 13 per cent sucrose is assumed. The introduction of diffusion increases the recovery of sucrose but since this equipment may be unfamiliar to the operators it has been assumed that the recovery rate would remain the same as that for milling during the first five years of operation before rising to 82 per cent. This is a conservative assumption because recovery rates of approximately 85 per cent have been reported from two African countries and from India. In OP technology, the highest recovery rate, reported from India, is about 62 per cent. Since OP technology is relatively

*Research Fellows, David Livingstone Institute of Overseas Development Studies, University of Strathclyde, Glasgow, United Kingdom of Great Britain and Northern Ireland.
<table>
<thead>
<tr>
<th>Item</th>
<th>VP European (milling)</th>
<th>VP European (milling)</th>
<th>VP Indian (milling)</th>
<th>VP Indian (diffusion)</th>
<th>OP</th>
<th>OP</th>
<th>OP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td>200 tch</td>
<td>100 tch</td>
<td>100 tch</td>
<td>100 tch</td>
<td>90 tcd</td>
<td>150 tcd</td>
<td>220 tcd</td>
</tr>
<tr>
<td>Output (tsa)</td>
<td>110 000</td>
<td>55 000</td>
<td>55 000</td>
<td>55 600</td>
<td>1 182</td>
<td>1 970</td>
<td>2 888</td>
</tr>
<tr>
<td>Utilization (24-hour basis)</td>
<td></td>
<td></td>
<td>216 days of 270-day season</td>
<td>202 days of 270-day season</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial fixed investment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total absolute (thousand $)</td>
<td>49 060</td>
<td>29 440</td>
<td>17 470</td>
<td>28 590</td>
<td>16 460</td>
<td>188</td>
<td>243</td>
</tr>
<tr>
<td>(Per tsa ($))</td>
<td>446</td>
<td>535</td>
<td>318</td>
<td>514</td>
<td>296</td>
<td>159</td>
<td>123</td>
</tr>
<tr>
<td>Working capital (thousand $)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8 950</td>
<td>4 560</td>
<td>4 560</td>
<td>4 560</td>
<td>45</td>
<td>74</td>
<td>109</td>
</tr>
<tr>
<td>Per 100 tsa</td>
<td>0.78</td>
<td>1.19</td>
<td>1.19</td>
<td>1.18</td>
<td>1.18</td>
<td>15.06</td>
<td>13.96</td>
</tr>
<tr>
<td>Unskilled</td>
<td>286</td>
<td>260</td>
<td>260</td>
<td>260</td>
<td>125</td>
<td>205</td>
<td>255</td>
</tr>
<tr>
<td>Per 100 tsa</td>
<td>0.26</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
<td>10.58</td>
<td>10.41</td>
<td>8.83</td>
</tr>
<tr>
<td>Annual operating costs (thousand $)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20 337</td>
<td>11 012</td>
<td>11 642</td>
<td>10 979</td>
<td>11 579</td>
<td>359</td>
<td>563</td>
</tr>
<tr>
<td>Cane</td>
<td>12 960</td>
<td>6 480</td>
<td>6 480</td>
<td>6 480</td>
<td>6 480</td>
<td>227</td>
<td>379</td>
</tr>
<tr>
<td>Wages and salaries</td>
<td>1 174</td>
<td>1 027</td>
<td>1 027</td>
<td>1 027</td>
<td>1 027</td>
<td>79</td>
<td>100</td>
</tr>
<tr>
<td>Materials</td>
<td>3 994</td>
<td>2 146</td>
<td>2 146</td>
<td>2 143</td>
<td>2 143</td>
<td>43</td>
<td>71</td>
</tr>
<tr>
<td>Repairs and maintenance</td>
<td>2 208</td>
<td>1 359</td>
<td>1 989</td>
<td>1 329</td>
<td>1 929</td>
<td>10</td>
<td>13</td>
</tr>
</tbody>
</table>
TABLE 2. COMPARATIVE DATA ON ALTERNATIVE SUGAR TECHNOLOGIES (SHORT SEASON)

<table>
<thead>
<tr>
<th>Item</th>
<th>VP European (milling)</th>
<th>VP Indian (diffusion)</th>
<th>OP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td>200 tch</td>
<td>130 tch</td>
<td>220 tcd</td>
</tr>
<tr>
<td>Output (tsa)</td>
<td>61 100</td>
<td>30 550</td>
<td>1 601</td>
</tr>
<tr>
<td>Utilization (24-hour basis)</td>
<td>120 days of 150-day season</td>
<td>112 days of 150-day season</td>
<td></td>
</tr>
<tr>
<td>Initial fixed investment</td>
<td>Absolute (thousand $)</td>
<td>49 060</td>
<td>16 460</td>
</tr>
<tr>
<td></td>
<td>Per tsa ($)</td>
<td>803</td>
<td>539</td>
</tr>
<tr>
<td>Working capital (thousand $)</td>
<td>8 950</td>
<td>4 550</td>
<td>109</td>
</tr>
<tr>
<td>Employment</td>
<td>Total</td>
<td>856</td>
<td>657</td>
</tr>
<tr>
<td></td>
<td>Per 100 tsa</td>
<td>1.40</td>
<td>2.15</td>
</tr>
<tr>
<td></td>
<td>Unskilled</td>
<td>286</td>
<td>260</td>
</tr>
<tr>
<td></td>
<td>Per 100 tsa</td>
<td>0.47</td>
<td>0.85</td>
</tr>
</tbody>
</table>

untried elsewhere two recovery rates, 50 per cent and 61.5 per cent, have been used in the evaluation.

Each technology is evaluated at wage rates which approximate prevailing wage rates in East Africa at three real rates of discount: 5, 10 and 20 per cent. A project life of 25 years of production, with development corresponding broadly to reported rates in Africa, and a selling price for sugar of $300/t have been assumed. Although $300/t is substantially higher than current world market prices, it broadly corresponds to the price situation in domestic East African markets. It has been further assumed that 65 per cent of OP sugar could command the same price as that produced in VP units; that the next 25 per cent would sell at $270/t; and the remaining 10 per cent at $225/t.

Profitability as measured by the net present value (NPV) of investment per unit of annual output of the alternative technologies is set out in table 3. It must be borne in mind that these estimates, and indeed all the data in this section, are illustrative rather than definitive.

At a discount rate of 5 per cent, the larger VP technology is the most profitable technology. A comparison of the three 100-tch technologies shows that profitability is further increased by the use of Indian equipment or diffusion or both. It is interesting to note that at the higher recovery rate, the 220-tcd OP technology is superior to both European milling and diffusion at 100 tch.

At a discount rate of 10 per cent, the larger VP technology is preferable only at the higher cane price. At a cane price of $12.50/t, the 220-tcd OP technology with higher sucrose recovery rate is the most profitable; under these conditions the 150-tcd OP technology is superior to each of the 100-tch VP technologies.

At the highest discount rate all VP and the smallest OP technologies become unprofitable, although losses are smaller than those of the lower recovery OP variants. However, at the lower cane price of $12.50/t and higher sucrose recovery rate both the 150- and 220-tcd OP technologies are profitable.
<table>
<thead>
<tr>
<th>Discount rate (per cent)</th>
<th>200 tch European (milling)</th>
<th>100 tch European (milling)</th>
<th>100 tch Indian (milling)</th>
<th>Indian (diffusion)</th>
<th>European (diffusion)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High cane price&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Low cane price&lt;sup&gt;b&lt;/sup&gt;</td>
<td>High cane price&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Low cane price&lt;sup&gt;b&lt;/sup&gt;</td>
<td>High cane price&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>577</td>
<td>862</td>
<td>272</td>
<td>557</td>
<td>350</td>
</tr>
<tr>
<td>10</td>
<td>118</td>
<td>284</td>
<td>-104</td>
<td>53</td>
<td>17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Discount rate (per cent)</th>
<th>90 TCD</th>
<th>150 TCD</th>
<th>220 TCD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High cane price&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Low cane price&lt;sup&gt;b&lt;/sup&gt;</td>
<td>High cane price&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>-975</td>
<td>-156</td>
<td>212</td>
</tr>
<tr>
<td>10</td>
<td>-670</td>
<td>-178</td>
<td>-398</td>
</tr>
</tbody>
</table>

<sup>a</sup>Cane price of $15 per tonne.<br>
<sup>b</sup>Cane price of $12.50 per tonne.<br>
<sup>c</sup>50 per cent sucrose recovery.<br>
<sup>d</sup>61.5 per cent sucrose recovery.
<table>
<thead>
<tr>
<th>Discount rate (per cent)</th>
<th>220-tci VP European (milling)</th>
<th>100-tci VP Indian (diffusion)</th>
<th>220-tci VP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High cane price^{a}</td>
<td>Low cane price^{b}</td>
<td>High cane price^{a}</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>302</td>
<td>154</td>
</tr>
</tbody>
</table>

\^{a}Cane price of $15 per tonne.
\^{b}Cane price of $12.50 per tonne.
\^{c}50 per cent sucrose recovery.
\^{d}61.5 per cent sucrose recovery.
Short season. For the short season three technologies have been selected for evaluation: the 1-tch European milling, the 100-tch Indian diffusion, and the 220-tcd OP plant. Comparative data on these technologies are given in Table 2. The profitability of these technologies is set out in Table 4.

At a discount rate of 5 per cent, the most profitable technology is the 100-tch Indian milling plus diffusion. It would be expected from the results in Table 3 that a higher-scale Indian milling plus diffusion technology would be even more profitable. The OP technology with the higher recovery rate is superior to the 290-tch European milling technology.

At a discount rate of 10 per cent, the two VP technologies are unprofitable, although losses are smaller than those for the lower recovery rate variant of the OP technology. The higher recovery rate variant of the 220-tcd factory is profitable at the lower cane price.

At the highest discount rate, the only profitable technique is again the higher recovery rate variant of the OP technology. It is interesting to note that even at the lower recovery rate this OP variant is more efficient than both VP technologies.

Policy implications

Broadly speaking, the objective of economic development is the generation of a surplus and as much equality of income, employment, and dispersal of industry as is consistent with this aim. Certain policy implications emerge from the preceding production and profitability projections.

Financial and social profitability

One measure of the surplus anticipated from a project was seen to be the net present value; the ranking of alternative technologies on this basis has been discussed. The lowest discount rate, 5 per cent, may be taken as an approximation of the "market" discount rate; the highest, 20 per cent, as an approximation of the "social" discount rate. This reflects the general view that in developing countries capital is relatively scarce in comparison with labour and that for a variety of reasons the "market" rate does not reflect this scarcity.

At the lowest discount rate VP technologies are superior for both long and short season production. At the highest discount rate the only profitable technologies are variants of the two larger OP units. In short season production at discount rates of 10–20 per cent the higher recovery 220-tcd OP technology is superior to the two VP technologies. However, the 220-tcd OP technology is only profit-making at the $12.50/t cane price. At a discount rate of 20 per cent even the lower recovery OP variant is more efficient than the VP technologies.

Capital rationing

Another measure of profitability which considered the possibility of capital rationing is the NPV per unit of capital invested. On this basis, the three more efficient technologies are ranked in Table 5.
Employment

From tables 1 and 2 it can be seen that OP technology offers greater employment potential than VP technology. For any quantity of sugar produced, for example, the 220-tcd OP units would employ respectively about 14 times and 9 times as many workers as the 200-tch and 100-tch VP units. OP technology, however, employs a much smaller proportion of skilled and semi-skilled workers than does VP technology.

Dispersal of industry

A sugar industry based on OP technology or a combination of large and small-scale units is clearly more capable of being dispersed throughout a region or country than an industry based on a small number of large VP units. Because of the lower sucrose recovery rate of OP technology, however, the aggregate land requirement for sugar-cane cultivation is higher than that for VP technology; this may be of great significance in areas where suitable or even cultivable land is scarce such as in Egypt. Potential advantages of scattered small-scale units include: diversification of agriculture by adding a cash crop to the traditional system rather than replacing it by monoculture; and minimal displacement of population.

By virtue of its small-scale it is possible to envisage situations where OP technology may be the only way to produce sugar at all. Indonesia, for example, is considering the introduction of this technology to its outer islands because importing the small quantities of sugar required from centralized production areas is difficult or costly or both.

Many developing countries are already producing non-centrifugal sugar. At the very least this means that sugar-cane is grown, that simple crushers are being used, and that some experience of crushing and boiling operations has been acquired. In sum, a potential base for the development of OP technology and its integration with any existing national sugar industry exists.

Effect of machinery sources on technology and policy options

The primary source of equipment for VP technology, at least for many African developing countries, has been European turnkey suppliers. This situation has developed partly for historical reasons and partly because alternative developing country sources have only recently entered the market.

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<thead>
<tr>
<th>TABLE 5. PROFITABILITY OF THE THREE MORE EFFICIENT TECHNOLOGIES</th>
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<tr>
<td>(Net present value at 5 per cent unit of capital invested)</td>
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<table>
<thead>
<tr>
<th></th>
<th>200-tch VP</th>
<th>100-tch VP</th>
<th>220-tcd OP</th>
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<tbody>
<tr>
<td></td>
<td>Long season</td>
<td>Low recovery</td>
<td>High recovery</td>
</tr>
<tr>
<td></td>
<td>Short season</td>
<td>Low recovery</td>
<td>High recovery</td>
</tr>
<tr>
<td>High cane price</td>
<td>1.09</td>
<td>-3.54</td>
<td>1.60</td>
</tr>
<tr>
<td>Low cane price</td>
<td>1.64</td>
<td>-0.27</td>
<td>4.26</td>
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<tr>
<td>High cane price</td>
<td>0.03</td>
<td>-2.88</td>
<td>0.02</td>
</tr>
<tr>
<td>Low cane price</td>
<td>0.32</td>
<td>-1.19</td>
<td>1.39</td>
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The above projections have shown that developing country VP technologies can be both cheaper and more profitable than European technologies. Furthermore, the milling plus diffusion variant appears to be more efficient than milling alone and as yet diffusion is not offered as part of a standard European package. This technique also offers secondary employment possibilities if the necessary equipment is manufactured in local workshops as is done, for example, in India and Mauritius.

Conclusions

In some circumstances there may be a conflict between surplus (NPV) maximization and other developmental goals. To plan a national sugar policy, which must be an integral part of overall development policy, a judgement has to be made as to which trade-offs are acceptable. Table 6 illustrates three factors which must be taken into account to produce, say, 110,000 tsa, which represents largest scale, long season output. A cane price of $12.50/t and discount rates of 5 and 10 per cent are assumed.

In a long season 38 OP units would create 11,794 more jobs than one 200-tch VP unit at a cost of $28.3 million in NPV discounted at 5 per cent. Thus the cost of creating each additional job by choosing OP technology would be equivalent to a single lump sum expenditure of about $2,400 and might be a feasible way to reduce unemployment. It should, however, be noted that $2,400 is about 10 times the per capita gross domestic product of a number of developing countries.

At a discount rate of 10 per cent the choice of OP technology would clearly be superior, if the higher sucrose recovery rate can be attained.

In a short season 69 OP units producing 110,000 tsa would create 20,438 more jobs than four 100-tch VP units at a cost of $7.7 million in NPV discounted at 5 per cent. The cost of creating each additional job would be $380 which is substantially lower than was estimated for a long season. At 10 per cent

<table>
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<th>TABLE 6. INVESTMENT, NPV AND LABOUR NEEDED TO PRODUCE 110,000 TSA</th>
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<tr>
<td><strong>Long season</strong></td>
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<td><strong>Item</strong></td>
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<tr>
<td>Total investment (thousand $)</td>
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<tr>
<td>NPV (thousand $) at 5 per cent</td>
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<tr>
<td>Total employment</td>
</tr>
<tr>
<td><strong>200-tch VP</strong></td>
</tr>
<tr>
<td><strong>European (milling)</strong></td>
</tr>
<tr>
<td><strong>Absolute</strong></td>
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<tr>
<td><strong>Relative</strong></td>
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<tr>
<td><strong>100-tch VP</strong></td>
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<tr>
<td><strong>Indian (diffusion)</strong></td>
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<tr>
<td><strong>Absolute</strong></td>
</tr>
<tr>
<td><strong>Relative</strong></td>
</tr>
<tr>
<td><strong>220-tch OP</strong></td>
</tr>
<tr>
<td><strong>Higher recovery</strong></td>
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<tr>
<td><strong>Absolute</strong></td>
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<td><strong>Relative</strong></td>
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<td><strong>Short season</strong></td>
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the OP alternative is again superior; it is also superior to the 200-tch VP variant at both 5 and 10 per cent.

In sum, under certain conditions there need be no conflict between the economic efficiency of the sugar industry and other developmental goals, especially higher employment and widespread dispersal of industry.
Technological choices in sugar processing

G. B. Hagelberg* and E. W. Krause**

Introduction

Essentially sugar processing consists of a series of liquid-solid separations to isolate the sucrose formed by photosynthesis in living plants. Four basic processes are involved: juice extraction, purification, evaporation and crystallization. These processes are carried out by various methods on a scale ranging from small, animal-powered cottage enterprises to large, highly automated factories. This technological pluralism reflects the historical development and wide geographical distribution of the sugar industry.

Sugar-cane has been grown for thousands of years but the earliest firm evidence for remelting and recrystallizing raw sugar comes from Persia in the seventh century. The Arabs spread the cultivation and processing of sugar-cane westward throughout the Mediterranean. From Spain the industry had moved to Madeira, the Canary Islands, the Azores and West Africa by the fifteenth century. The sugar industry in the Western hemisphere began in 1493 when Columbus took seed cane and expert cultivators from the Canary Islands to Hispaniola.

By contrast, the manufacture of sugar from beets is relatively recent. Although long used as a vegetable and in medicine, beets did not become a commercial source of sugar until the beginning of the nineteenth century. This development followed the discovery that beet roots contained a substance identical with cane-sugar. The first beet-sugar factory was established in Europe about 1800, the first in the United States of America in 1838. The development of the beet-sugar industry in the nineteenth century probably provides the earliest example of the market for an important tropical product being seriously eroded by the application of modern scientific methods in industrializing countries.

Sugar-cane, a giant grass related to maize and sorghum, grows in the tropical and subtropical regions of the world; sugar-beet grows best in cooler latitudes. The fact that a product practically identical in its refined state is

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obtainable from two dissimilar plants has made the global dispersion of the sugar industry possible.

According to statistics of the Food and Agriculture Organization of the United Nations (FAO) some 20–25 million hectares of beet and cane are being currently harvested, largely for processing into sugar. Cane accounts for about 60 per cent of total production. Sugar is produced in over 100 countries with annual national outputs ranging from less than 10,000 to more than 10 million t/a of sugar of various types. World production amounts to some 100 million t/a; about 60 per cent of it is produced in developing countries.

The modern sugar industry began in the 1880s when the essential elements of modern sugar manufacturing (multiple-mill extraction, diffusion, clarification with lime, carbon dioxide or sulphur dioxide, vacuum boiling, and centrifuging) came into use. These new techniques, however, did not altogether supplant earlier techniques whose survival in various parts of the world continues to contribute to the present diversity of sugar manufacturing. This makes the sugar industry a fertile field for the study of appropriate technologies.

The search for appropriate technologies is particularly important because the capital cost of conventional sugar factories has risen sharply in recent years. Current estimates of $1,000 or more per tonne of sugar produced per annum (tsa) are being quoted for medium-sized vacuum-pan (VP) plants. Thus the capital cost of establishing large plants in developing countries has grown beyond the resources of private enterprise and can be financed only by governments and international lending agencies.

The evolution of employment-oriented development strategies has questioned the appropriateness of costly conventional technology to the conditions found in many developing countries. The survival of small plants employing much manual labour in batch operations side by side with large automated factories operating on a continuous production system appears in a new light as attention focuses on the employment-creating potential of small-scale labour-intensive sugar processing. The comparison of different technologies has been difficult, however, and the extent to which labour-intensive methods may be economic has been a matter of some controversy. Much technical and economic data is available on the VP sector of the industry but gaps and inconsistencies appear when attempts are made to use these data for technological comparisons.

By contrast, few data on open-pan (OP) processing are available and they are narrowly based. Virtually all current reports relate directly to or are inspired by experience in India. Until very recently few researchers in India have systematically carried out R and D on small-scale sugar processing and their efforts have hardly been in proportion to the contribution of small-scale processing to total sugar production. From what is known about the relative efficiency of small- and large-scale processing, it is clear that innovations should try to increase the sugar recovery and reduce the fuel consumption of small-scale technologies, that is, they should try to make them less material-intensive and to improve the product while preserving the advantages of low capital cost per unit of output and modest skill requirements.

A new integrated system of juice evaporation that meets these criteria has been designed and will be tested shortly. Other equipment and processes are
also being studied to determine their adaptability to small-scale sugar manufacturing. Although a modern technologically sophisticated, large-scale sugar industry has developed in the last hundred years, artisan processors produce more sugar now than at any previous time.

The time to start thinking about the appropriateness of different sugar processing technologies is at the outset of a sugar development programme and not at the evaluation stage of a particular project. Processing cannot be considered in isolation. The factory is one part of a three-part production system: cane growing, transport and processing. Because of the need to harvest cane at the point of optimum maturity and to process it without delay, organization is a crucial factor in sugar production. As a rule, it is simpler and cheaper to increase sugar yield through better agricultural practices and better co-ordination of harvesting and transport operations than it is to do so by sophisticated equipment and procedures in the processing plant. However, an OP plant, for example, cannot be expected to thrive if the market is flooded with relatively cheap VP sugar or if the price of non-centrifugal sugar is set at such a high level that it is more profitable to discard the sulphitation apparatus, crystallizers and centrifuges and produce an inferior grade of sugar.

Technologies and products

Since sugar manufacturing in developing countries is primarily based on cane, further discussion will be confined to processing this raw material. Millable sugar-cane stalks are composed of approximately 75 per cent water; the remainder is divided almost equally between fibre and soluble solids. Sucrose accounts for 70–90 per cent of the soluble solids and the simple sugars glucose and fructose for another 4–8 per cent. Unlike sugar-beets, cane cannot be stored without excessive deterioration and must be processed as quickly as possible after harvesting.

There are three basic cane processing techniques: (a) OP non-centrifugal; (b) OP centrifugal; (c) VP centrifugal.

(a) **OP non-centrifugal**

Upright iron mills turned by oxen are still the main equipment used by tens of thousands of Asian and Latin American cottage-scale processing units. Extraction is poor and generally a third or more of the sugar contained in the cane is lost in the bagasse, the fibrous residue remaining after milling. Larger plants use simple motor-driven horizontal crushers with higher throughput and slightly more efficient extraction.

The juice extracted is boiled in shallow open pans heated directly by a bagasse or wood fire. Small amounts of chemical or vegetable clarificants are added to the hot juice and the impurities rising to the surface as scum are skimmed off. Boiling is continued until a thick syrup with a dry matter content of about 95 per cent is obtained. At the striking point, when sugar crystals form spontaneously in the supersaturated liquid, the pan is removed from the fire; its contents are cooled by vigorous stirring. Poured into moulds the dense mass of fine crystals and syrup solidifies into blocks or cubes of a light to dark-brown
colour. Alternatively, powdered sugar is obtained by manual rubbing. The final product is practically dehydrated raw cane juice.

The technical efficiency of cottage production is far lower than that of large-scale factories. The product yield of about 10 per cent on cane is comparable, however, because few of the non-sucrose components are removed from the juice.

The composition of this type of sugar varies according to the quality of the cane and the method of processing. In those areas of Asia and Latin America where non-centrifugal sugars are widely used, consumers are reported to consider artisan sugar as useful as centrifugal sugar. Artisan non-centrifugal sugars are primarily destined for household consumption. Because of the impurities they contain, they have few direct applications in food processing industries and their shelf-life is generally limited.

(b) OP centrifugal

The yield from this procedure was extremely low in relation to the cane processed and the industry was threatened with extinction until the introduction of small hand-operated or motor-driven centrifuges about fifty years ago raised the sugar recovery rate.

For the last twenty years much of the R and D on small-scale sugar processing technology has been directed toward perfecting a low-cost technology to manufacture a sugar approaching the quality of plantation white sugar which would offer an economically viable alternative to conventional large-scale sugar technology. Initial steps in this direction were taken by improving milling equipment and furnaces, and were incorporated in the design of a modern small-scale processing plant. The main new element was a scaled-down version of the lime sulphitation process of juice purification used in conventional large-scale sugar technology. For this reason plants built according to this design are known as OP sulphitation units.

A typical OP unit of the present generation is equipped with two sets of cane knives and two three-roller mills with hydraulic loading. Some 20 per cent of the sucrose contained in the cane is still lost; it is retained by the bagasse and no amount of dry milling can reduce the residue to anything but an approximately equal mixture of fibre and juice. The extracted juice is purified by lime sulphitation; heating and settling take place in open pans and tanks. Presses are used to filter the muds. The clear juice is concentrated in a series of open pans arranged over a furnace burning bagasse and wood. After having been boiled to maximum workable consistency, the massecuite is discharged to crystallizers fitted with a stirring device. Finally, the product is centrifuged and dried. The molasses from the first, second and often even the third centrifugal separations are reboiled. The sugar yield of OP plants averages about 7 per cent and is below the level achieved by large-scale plants. The first product (roughly two thirds of total output) approaches the quality of plantation white sugar made in VP factories. The second, third and fourth OP products are inferior and bring correspondingly lower prices.

Many OP plants have been set up in India since the early 1960s, and they now number about 1,200.
The growth of sugar technology can be studied in a number of technical manuals. The *Cane Sugar Handbook* by Meade, for example, gives detailed descriptions of the equipment and techniques of large-scale sugar manufacturing. A recent directory of cane-sugar mills lists some 1,500 installations in more than 80 countries. But all these conventional cane-sugar factories have the same basic technology, that is, mill trains consisting of up to seven three-roller units. To increase the extraction of sucrose, water or diluted juice is sprayed on the blanket of bagasse as it emerges from each milling unit but the last, a process termed imbibition. In the most efficient mills less than 5 per cent of the sucrose in the cane is lost in the bagasse. Imbibition is also possible in small-scale plants equipped with multiple mills but it means that more water must be evaporated. In addition to higher fuel costs, some of the sucrose gained by wet milling is lost through inversion during boiling in open pans.

VP factories generate steam for power, for heating juice and for evaporation. Most of the water in the juice is evaporated in a process employing a series of closed vessels, usually four, connected in such a way that the vapour outlet of one becomes the source of steam for the next. Each succeeding vessel has a higher vacuum so that the juice boils at progressively lower temperatures as it passes through the set. By this arrangement, a given quantity of steam supplied to the first vessel will evaporate approximately as many times its weight of water as there are vessels in the set. Crystallization takes place in vacuum pans at a much lower temperature than in open pans under atmospheric pressure. The advantages of lower boiling temperatures are less inversion, higher sucrose recovery and less colour formation. While it is not possible to reduce the temperature of OP boiling, inversion losses and colour formation can be minimized by shortening the boiling time.

VP factories produce either raw sugar (a granular product usually containing 95 per cent or more sucrose and varying in colour from light yellow to dark brown which is processed further in separate refineries) or various direct consumption grades. VP factories recover about 10 per cent sugar and 3 per cent final molasses per tonne of cane processed.

The world-wide structure of the conventional sugar industry tends towards fewer and larger units. In many countries average plant size has trebled or quadrupled in recent years. In the view of some experts, the minimum economically viable capacity for new VP factories now lies at 1,250 tcd. This is the size of the standard factory now built in India. However, smaller factories can still be found even in countries that have become a byword for modern large-scale sugar processing such as Argentina, the Dominican Republic and Mexico; and within the last ten years conventional sugar factories with far lower capacities have been built in Gabon, Rwanda and Sierra Leone.

**Criteria for comparing and evaluating alternative sugar-processing technologies**

On the average a VP plant requires 10 t of cane to produce 1 t of sugar; an OP plant requires 14 t of cane to produce 1 t of sugar. The difference can be
mitigated by the higher final molasses yield of OP technology, if there is a suitable outlet for this by-product. Assuming an agricultural yield of 50 t of cane per hectare, this means that 3,000 hectares of cane must be harvested and processed to produce 15,000 t of sugar in a VP factory; to produce the same quantity of OP sugar, cane from 4,200 hectares is needed. Similarly, a modern VP plant is self-sufficient in fuel and should even accumulate surplus bagasse but an OP plant needs additional energy inputs. In sum, in terms of cane processing and fuel consumption, present OP technology is less efficient than VP technology.

On the other hand, small-scale units enjoy an advantage over large-scale units in that the cost per unit in terms of sugar output is lower. The construction of several small-scale units can be more easily adapted to the growth of local technological capabilities than can one large-scale project. While it can be argued that small OP units waste cane because of their lower recovery rate, it can also be argued that large units which do not operate at rated capacity because cane is lacking waste capital. This point is germane to new cane-growing regions because it is not economically sound to erect large sugar factories where present cane supplies are insufficient. Until the necessary agricultural capability to supply a large mill has been developed, it seems preferable to set up small factories. Furthermore, the risk that production estimates will not be fulfilled because of machinery break-downs is greater with one larger factory than with a number of small plants.

Obviously, the choice of sugar processing technology entails many considerations. In addition to differences in product quality and different capital and labour requirements, the ranking of technological alternatives is influenced by recovery rate, length of operating season, utilization of installed capacity, fuel consumption, cane and sugar prices, and wages.

R and D on intermediate sugar-processing technologies

The comparison of currently available small-scale sugar-processing technologies identifies features which should guide future development:

(a) Low capital cost per unit of output should be preserved;

(b) The relatively low level of technical, managerial and organizational skills required should be maintained. Innovations in juice purification and concentration should try to replace traditional sugar boiling by more easily acquired operational routines;

(c) Technological development should concentrate on improving sugar recovery, fuel economy, labour productivity and product quality;

(d) Technology must be adaptable to a wide range of local conditions and requirements.

OP boiling has several drawbacks: excessive fuel consumption (even with improved furnaces OP units are believed to need as much as 10 t of firewood per 100 t of cane processed in addition to bagasse); considerable sucrose loss due to inversion and caramelization; and high labour requirements.
Alternative methods of juice purification and concentration were investigated first. Scaling down the vacuum evaporation technology employed in large sugar factories was ruled out for the time being because at the level of scale contemplated it was likely to result in an unacceptable increase in capital cost per unit of output. Thus, intermediate solutions were sought which would raise the technical efficiency of small-scale manufacture without greatly adding to the cost and complexity of the process. This search resulted in designs for two model core systems adaptable to the requirements of a wide range of scales and products. The first system (figure I) produces non-centrifugal block sugar in plants processing 20–300 tcd. The second system (figure II) produces a washed direct consumption sugar similar to plantation white in plants processing 100–300 tcd.

Liming and phosphating are used to purify the raw juice. To produce plantation white sugar the juice is subjected to further purification by flue-gas carbonation and settling.

Both basic models employ a three-stage flue-gas and vapour system of evaporation. In the first stage juice is concentrated from 18 to 30° Brix (BX) in a vertical short-tube calandria heated by flue gas. Either directly or after carbonation and settling the juice is further concentrated to 80°BX in a vapour-heated Robert-type open evaporator. In the final stage a thin-film evaporator (vertical-cylinder type with scrapers mounted on a central revolving shaft and external steam jacket) is employed to increase concentration to 90 or 95°BX, depending on whether block or granulated sugar is to be produced. To make block sugar the massecuite, after crystallization in an air-cooled crystallizer with revolving helix, is poured into moulds. To make granulated
sugar, the massecuite is discharged into a centrifuge where the sugar is washed with steam and hot water before passing to a vapour-heated dryer. The steam for the second and third stages of the evaporation process and for washing and drying the crystals is supplied by the vapour produced in the first stage.

Although the evaporation equipment described above is more expensive than that used in OP plants, total investment costs are likely to be higher only in the lower part of the capacity range mentioned. This is chiefly because the new design requires only one furnace instead of the multiple furnaces required by all installations except those processing less than 5 tcd. The space saved means substantially reduced construction costs, particularly in regions where local building materials are lacking.

Figure II. Intermediate washed direct consumption sugar technology
The changes in purification methods entail several advantages. There is a net gain in operational simplicity. The cumbersome sulphur burner is eliminated and the drawbacks of using sulphur dioxide are avoided. Carbon dioxide is contained in the flue gas and costs nothing; superphosphate, commonly used as a fertilizer, is relatively cheap and widely available. If the filter cake containing the phosphate compounds is applied to the cane fields, a phosphate cycle is established.

The evaporation system outlined above makes the process semi-continuous. Shorter retention times and less exposure to high temperatures are expected to reduce sucrose loss due to inversion and caramelization during boiling by one half to two thirds as compared with present OP systems. More uniform crystal formation as the result of more continuous operations and greater process control as well as the availability of vapour and clean hot water to wash the sugar during centrifuging improve the quality of product.

This new system overcomes one of the main objections to OP boiling: excessive fuel consumption. The replacement of multiple furnaces by one furnace reduces radiation losses and in combination with the evaporators makes for better heat transmission. The residual heat of the flue gas is utilized in the carbonation. The flue-gas and vapour combination represents a simple form of multiple evaporation. Together these changes reduce fuel requirements by at least one half.

Labour input is reduced by at least a quarter in comparison with customary OP processing but the new system is still considerably more labour-intensive and less skill-demanding than large-scale technologies. The new technology will also permit future increases in labour productivity because the replacement of multiple furnaces by one furnace makes it possible to mechanize the transport and feeding of bagasse as fuel.

The new system also provides greater flexibility in producing different types of sugar. Gur-type sugars can be manufactured by standard OP boiling techniques in plants processing more than 30 tcd. Nevertheless, non-centrifugal sugar production in OP furnaces can only be increased by increasing the number of furnaces. The evaporation system outlined here, employing only one furnace, expands block sugar production capacity to 300 tcd.

The new technology also offers the possibility of converting block sugar plants with a capacity of 60 tcd or more to the production of washed raw and plantation white grade sugars. Initially, with defecation by liming and phosphating only crystallizers and centrifuges need be incorporated in processing to enable a block sugar plant to produce washed raw sugar. At a later stage carbonation can be added to produce plantation white sugar. Conversely, plants designed to produce washed direct consumption sugar can also process molasses to block sugar which is fit for human consumption since it is free of sulphur dioxide.

Figure III illustrates alternative uses of sugar-cane. Depending on local conditions, block sugar may be marketed for direct consumption or for further processing to white sugar. In India so-called neutral gur was made specifically for refining. In Thailand both noncentrifugal "red" sugar and syrup are reprocessed in larger refineries. In Venezuela several small mills now produce...
Figure III. Alternative sugar-cane use
only syrup for further processing. Such practices may be adopted for various reasons: consumer preferences, transport savings effected by shipping a product of higher unit value, the relative perishability of different products, and better utilization of existing sugar refining capacities or higher returns to the sugar-cane growers or both. Similarly, the conversion of molasses I to so-called molasses gur has been a common practice in Indian khandsari factories. The use of relatively high-grade materials, such as molasses I and II, to produce alcohol is based on the consideration that it may be more economical to crystallize and market only the most easily obtainable fraction of the total sugar and utilize the rest for fermentation.

The plant designs described here incorporate several elements of standard modern small-scale sugar technology such as currently available extraction units. These, too, however, are subject to innovation as a result of continuing R and D. One of the main objectives of R and D is to increase the efficiency of extraction in small plants. Suggested possibilities include the following:

(a) A five-roller crusher unit for dry milling which would eliminate the intermediate carrier now located between two three-roller crushers;

(b) Replacing the crushers by hammer mill shredder and screw press;

(c) Using the fibre-pith separation process with subsequent juice extraction by pressure;

(d) Reconsidering wet milling since the development of the flue-gas and vapour evaporation process has removed the limitations imposed by OP boiling on imbibition.

A substantial improvement in the technical efficiency of the evaporation process may well be achieved without departing from the principle of OP boiling and at no greater cost by introducing North American-type maple syrup evaporators. Economically, this equipment appears to be particularly suitable for small plants.

In crystallization better control of crystal formation may be obtained by adapting the seeding procedure used in large-scale factories or by passing the oversaturated syrup through a colloid mill or homogenizer.

The improved heat economy and accelerated evaporation process made possible by the innovations discussed above open two major possibilities for further development of intermediate sugar processing technology. One is juice extraction. As noted earlier, because of the spongy nature of the fibrous residue there is an absolute limit to the extraction efficiency that can be achieved by dry milling. The multiple evaporation obtained by the flue-gas and vapour combination clears the way for the application of imbibition, probably in conjunction with the addition of a third three-roller mill unit. This can be expected to bring a 10 per cent increase in sucrose recovery at the cost of a relatively small additional capital investment.

Secondly, the availability of vapour from the first evaporation stage makes it possible to explore further changes in the boiling process. Without attempting to scale down the entire vacuum boiling system of large sugar factories, there is likely to be considerable advantage in creating a slight vacuum in the crystallization stage by the simple expedient of a steam-jet condenser. In this case, the thin-film evaporator employed in the present designs for the final
concentration would be replaced by cheaper conventional vacuum-pans. The vacuum would permit the final boiling to take place at a lower temperature and result in less sucrose decomposition. Crystal quality would also be improved since more crystal growth would take place in the vacuum-pan where it is more easily controllable.

Possible improvements in the heat economy of the evaporation process do not, however, eliminate the dependence of small-scale sugar processing on an outside supply of fuel or power to generate mechanical energy. This problem could be solved by adapting a producer-gas generator utilizing bagasse to intermediate-level sugar processing. The gas is used to fuel an engine; the heat produced during gas generation and the waste heat from the engine are used to evaporate the juice. This coupling of mechanical and thermal energy generation represents efficient utilization of the energy value of bagasse.

This discussion has shown the wide scope for improvements in intermediate sugar processing technology. With only a fraction of the support now given to R and D on large-scale, capital-intensive technology, it would probably be possible to provide competitive intermediate alternatives.

**Policy conclusions**

Few industries display greater technological pluralism than sugar manufacturing but extensive research has failed to identify one universally appropriate technology. Modern large-scale sugar plants may well be a triumph of technical efficiency but their increasing cost heightens the risk of economic failure, particularly when the technology is transferred from a developed to a developing country. Although the small-scale and intermediate technologies now available are less efficient, they have a strong claim to consideration as profitable alternatives in cases of insufficient or dispersed cane supplies, small domestic markets, inadequate infrastructure, limited capital and high rural unemployment.
Cane-sugar production techniques in developing countries

J. M. Paturau*

The sugar industry has experienced relatively rapid growth during the past decade in many developing countries and is considered to be an instrument for accelerating rural development. A range of operating scales has evolved, ranging from small-scale dispersed plants crushing cane at the rate of 100 tcd to large-scale central plants with a crushing capacity of more than 8,000 tcd. This paper examines the conditions which influence choice of capacity. Both aspects of this agro-industry are considered: the agronomics of cane-sugar production and the technology of sugar manufacture. Several of the options that would increase processing flexibility and stimulate the dispersal of industrial activity are also reviewed.

Sugar-cane production

Sugar-cane can be divided into five species. One of these species, Saccharum officinarum, is rich in sucrose, relatively poor in fibre and is used in sugar production. Varieties of Saccharum officinarum differ in their suitability for a given set of soil and climatic conditions and their productive capacity generally deteriorates with age. Hence most sugar producing countries maintain breeding and selection programmes and many hundreds or thousands of new varieties are screened every year. Selection is based on many characteristics including vigour, sucrose content, disease resistance, ratooning ability, and suitability for mechanical harvesting. No sugar industry can rely on a single cane variety and the import of successful foreign varieties can supplement but never replace local breeding programmes.

Length of the growing season and crop cycle

In most sugar producing countries cane is reaped when it is about 12 months old (16–18 months for plant cane); in only a few countries is cane reaped when it is 22–24 months old. The advantage of the longer growing time is a substantial reduction in the costs of preparation, cultivation and planting in relation to the quantity of sugar produced. This is counterbalanced to a certain degree by higher irrigation costs since more irrigation is needed to ensure prolonged growth.

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In tropical regions subject to severe storms long cropping is not practicable but where climate and soil provide suitable conditions for both short and long cropping, the cropping period should be set after a careful evaluation of all economic factors. Available cane varieties will often determine the cropping period chosen but no hard and fast rule can be given. The crop cycle, that is, the number of ratoons that can be successively utilized, is also difficult to decide unless the more important local factors, especially the cane varieties cultivated, are taken into consideration to determine how the tonnage of cane produced decreases with successive ratooning. Some countries have cycles of plant cane plus two ratoons; others have a cycle of four ratoons or more. When trying to set up a sugar industry, it is generally prudent not to plan on more than four ratoons.

Methods of watering cane

Irrigating cane lands always involves significant costs both as an initial capital investment and as an operating cost, especially when pumping is required. However, the increased tonnage of cane per hectare which results from irrigation will normally cover the higher cost.

Some parts of many tropical countries have relatively dry climates but adequate surface water is available. Such countries can become good sugar producers once an irrigation infrastructure has been set up. Africa, Egypt, the Ivory Coast and the Sudan have demonstrated this, and other African countries will probably follow their example in the future. However, it is not generally possible to predict accurately the increase in cane tonnage that will result from the introduction of irrigation.

Land ownership and labour relations

Land ownership and labour relations are complex questions but one successful response to them appears to be a system which combines individual ownership of medium-sized farms (average size 35 ha) with part ownership of a central co-operative processing plant. The vexing question of sugar allocation between planters and millers does not thus arise.

The share-cropping system has many drawbacks and is not recommended. The plantation system is more difficult to evaluate but some positive effects of large plantations have been noted:

(a) Creation of social and economic infrastructures, including schools, clinics, roads, railways, ports, water supply, electricity and telecommunications;
(b) Expansion of production and income resulting from plantation activity and its multiplier effect;
(c) Contributions to technology through systematic R and D: improved varieties of cane, new processing techniques and efficient utilization of by-products;
(d) The demonstration effect of plantation production methods on the output and income of small-scale producers.

A balanced evaluation of all the pros and cons of plantation economy is not easy to make. However, where there has been no foreign ownership of
plantations—and thus few “metropolitan” directives—and where local government has been able to protect small- and medium-scale growers and labour, the sugar industry and the national economy have benefited from locally-owned large-scale plantations.

If policy is trying to create an agricultural system in which there are only owner-growers and no hired hands, then the large-scale plantation system is unsuitable. However, unless there is much free land, normal population increase will soon force undue parcellization of the land to maintain individual land ownership. Agricultural land is generally a scarce commodity and it would appear more realistic to seek an equitable balance between owner-growers and agricultural labourers rather than insist on universal individual ownership. Further, mechanization and automotive transport are gradually changing the type of jobs available on large agricultural estates. There is less need for unskilled labourers and greater need for semi-skilled operatives. Hence land ownership would no longer seem to have its previous significance as the exclusive index of social and economic status in the community, especially if the estate is the property of a local public company with numerous shareholders.

Harvesting

The sucrose content of the cane increases during ripening and it is important, to obtain the maximum amount of sugar, to harvest the cane at the right time, neither too early when it is immature nor too late when it is overripe. Generally the duration of the harvest should be limited to about 100 days if the maximum amount of sugar is to be obtained. Therefore the capacity of a sugar factory must permit crushing the cane within the optimal period; any significant extension of the harvest would mean a loss of sugar because once cut the cane deteriorates fairly rapidly. This is particularly true if it has been harvested mechanically with a harvester of the chopper type. Ideally cane should reach the factory within 48 hours of harvesting. Cane harvested with a chopper should reach the factory within 24 hours.

Cane can be cut and loaded by hand, cut by hand and loaded mechanically, or both cut and loaded mechanically. When cane is cut and loaded manually, productivity is only 2–2.5 t per man-day, but the cane supplied to the factory is very clean and the cane tops are separated from the millable cane. The cleanly cut whole stick of cane does not deteriorate rapidly and can be crushed even after a delay of two to three days. With mechanical loading productivity rises to 4–5 t of cane cut and loaded per man-day; the grab-loader, with or without push-rake, usually brings in 3–5 per cent of trash with the cane. With a mechanical harvester and loader productivity rises to 20 t of cane cut and loaded per man-day. The amount of trash and extraneous matter varies with local conditions but generally amounts to 8–10 per cent of the net weight of cane. As previously mentioned, the short cane billet (about 30 cm) produced by chopper harvesters deteriorates fairly quickly, especially in hot, moist climates, and should be crushed within 24 hours of cutting.

The average harvester will cut and load at the rate of about 40 tch and consume 20–25 litres of diesel oil per hour. It is difficult to state a hard and fast rule but whenever the cost of cutting and loading cane reaches $2 per tonne, there is an economic incentive to consider mechanizing loading at least.
Mechanical harvesting is a complex operation which requires adequate land preparation and is not adapted to small fields. It should be regarded as the second stage of a sugar-cane development programme which can be adopted when the industry is well established and the local standard of living has risen to a level where it corresponds to an annual per capita GNP of some $500.

Technology of sugar manufacture

Sugar can be manufactured in:

(a) A family-type workshop, producing gur, a primitive type of sugar;
(b) A small-scale open-pan (OP) sugar factory producing brown sugar, generally termed khandsari. Capacity is usually 100–200 tcd;
(c) A large-scale vacuum-pan (VP) sugar factory producing raw or plantation white sugar. Capacity is usually 100–200 tch (2,400–4,800 tcd).

Although gur is produced in very large quantities in India, about 7 million tonnes annually, many experts believe that gur manufacture is not appropriate for agro-industrial development. The alternatives are small-scale OP and large-scale VP production. The seminar held in Nairobi in April 1977 by the United Nations Environment Programme and UNIDO considered this question and some of the participants maintained that from a social and environmental point of view the small-scale OP production model appeared preferable. However, when the equipment required for a 100-tcd OP sugar plant is compared with the equipment required for a 100-tch VP plant, it is by no means obvious that the latter is much more complex than the former. Vacuum pans, juice heaters, evaporators and barometric condensers are fairly straightforward pieces of equipment, mainly of steel, with few moving parts. Once standard designs are available it is relatively easy to adapt them to varying capacities. These items have been successfully manufactured in a number of developing countries.

Modern large-scale sugar plants tend to adopt simplified continuous processes in all departments. It therefore appears questionable whether choosing small-scale production is the best way to promote socio-economic development and whether this supposedly “appropriate” technology would not in fact impede development and accustom its users to a mediocre technology entailing substantial sugar losses and offering few prospects for improvement.

Because of the rapid growth of education in all developing countries the capacity of these countries to absorb a moderately advanced technology such as VP sugar production should not be underestimated.

The recent development of the sugar industry in developing countries has generally followed the large plantation model with a central modern VP plant. Ivory Coast, Kenya and the Sudan exemplify this trend. The creation of a class of planters with small or medium-sized holdings who pool their resources in co-operatives appears to be the main requirement of socio-economic development of the country or region. The factory should be owned by all planters and run by local technicians and managers. During construction and the initial years of operation some foreign specialists will probably be required but
they should have local counterparts with preliminary training in advanced sugar-producing countries who can assume management of the plant after three or four years.

The creation of an agronomic and technological research unit with adequate extension services is essential to ensure the progress of a newly developed sugar industry. The beneficial effect of a few large plantations which demonstrate efficient technology and management should not be underestimated.

Where further development of an existing sugar industry is sought, it is prudent not to change rashly what has been painstakingly established over many years. Where foreign investment now predominates it should be gradually replaced by local investment. However, if the industry is not to be jeopardized, foreign specialists must be replaced by equally qualified local specialists.

Areas for technological improvement

Nitrogen fertilizers

The importance of nitrogen to cane yield and its high cost make it necessary to study its effects in detail. Such studies would provide a better understanding of volatilization, leaching and nitrification losses. The efficiency of nitrogen fertilization leaves much to be desired since the bulk of the nitrogen applied, probably more than 50 per cent, is lost to the plant. Research possibilities include the use of the isotope N15, the action of nitrification inhibitors, the subsoil application of ammonia, and the biological production of nitrogen by bacteria living in or near the root system. This is an area in which industrialized nations can help developing countries and their own agricultural sectors at the same time.

Artificial ripeners

The use of chemical ripeners to increase the sucrose content of cane has been studied in recent years. The economic benefits that can result from successful application of these chemicals are significant and include avoidance of late harvesting when yields tend to be lower and labour is less efficient. The response to ripeners now used commercially depends on the type used, the time of application and the interval between application and harvesting. Maximum response occurs about eight weeks after application; dosage is 3–4 kg/ha. The chemicals are most effective when applied early in the crop season to the immature cane. In some trials poor ratooning has occurred in the subsequent crop; this is a potential drawback which should be closely studied. Generally speaking the use of chemical ripeners is still in its infancy but results to date have been sufficiently encouraging to justify further experimentation.

Inter-row cultivation

The spacing between rows of cane varies from country to country; it averages 1.4 m. However, it has been demonstrated experimentally that with alternate spacings of 1 m and 2 m the sugar yield per hectare is the same as with
constant 1.5 m spacing. The advantage of such differential spacing, especially for countries with long ratooning cycles and few fallow periods between replanting, is that the larger 2 m strip can be utilized, generally up to the fourth ratoon, for growing other crops such as ground-nuts, potatoes, soya beans and dwarf maize. In practice about 30 per cent of the land under cane, for a crop cycle of seven ratoons, can be used for inter-row cropping. For a shorter crop cycle of, say, three ratoons, the usable area increases to 50 per cent. This is an important asset for countries with limited arable land. Further, it enables cane planters to increase income from their acreage and allows a more uniform distribution of the work-load, since other crops can generally be reaped between cane harvests.

**Mixing efficiency in milling**

The extraction efficiency of the standard three-roller mill has hardly improved in the last fifty years but the rate of throughput for a given mill size has increased almost fivefold.

In a modern milling train the first stage is a mill that separates the juice from the cane mechanically; the second stage (four or five more mills) represents a multi-stage countercurrent leaching system to extract part of the solute remaining after the first mill extraction. The overall extraction efficiency of a good milling train can reach 96 per cent, distributed over the mills as follows:

<table>
<thead>
<tr>
<th>Mill</th>
<th>Extraction (%)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

The relatively poor performance of the last four mills is mainly due to inefficient mixing of the solvent with the solute-impregnated bagasse. Theoretically, if mixing efficiency were improved, two mills could achieve 96 per cent extraction. Researchers should pay more attention to solving this economically significant problem.

Work done to prevent the bagasse issuing from the first and succeeding mills from reabsorbing air has ensured better mixing. The device is simple: it submerges the issuing bagasse in a bath of juice. It is said, however, to have increased the total amount of juice extract and this represents a much needed improvement.

**Heat loss**

In sugar production the most important sources of heat loss are flue gases escaping up the chimney stack and warm water issuing from the barometric condensers. Such loss can be appreciably reduced in the following ways:

(a) Mixed juice can be sprayed into the chimney and heated by the escaping flue gases. The juice spray reduces the amount of flyash and the temperature of the flue gases from about 200° C to about 150° C. The heated juice (at about 65° C) is screened, clarified and returned to the normal juice processing cycle;

(b) Cold mixed juice can be used to replace water in the barometric condenser of the evaporation station. The condenser is an efficient juice heater and the usual condenser cooling water losses are thus eliminated.
Bagasse saving

The arrangement of evaporator, juice heater and pans can be substantially improved to reduce the amount of low-pressure exhaust steam required. Since exhaust steam results from the production of live steam, that is, from burning bagasse, a saving in exhaust steam means a corresponding saving in bagasse, which may be used for purposes of greater economic value (see below).

Reducing the power consumption of the milling train would also mean a corresponding reduction of live-steam consumption and hence a substantial bagasse saving.

Continuous vacuum pans

Improvements in the sugar industry have often evolved in the course of replacing batch processing by continuous processing. Thus the industry has moved from filter presses to rotary filters, from decanters to clarifiers and from batch centrifuges to continuous centrifuges.

The continuous vacuum pan is now a reality and many continuous pans are being used in industrial sugar production. This allows simplification of the boiling process, requiring less equipment and less supervisory labour, and permits more uniform and efficient use of exhaust steam. In turn, this improves the steam balance throughout the plant.

The main difficulty of continuous pans is that they tend to produce final sugar with a relatively wide spread of grain sizes. There is, however, reason to believe that this drawback will be eliminated within the next few years.

Electricity generation

The average raw sugar factory should normally produce surplus electrical energy which it can sell during the cropping season. If the national power grid is well developed and the factory can be linked to it, the factory can earn additional revenue while contributing to the general electricity supply. With medium-pressure boilers (60 kg/cm²) and pass-out/condensing turboalternators a modern sugar factory should be able to produce a saleable surplus of 50 kWh per tonne of cane (425 kWh per tonne of sugar). Some producing countries have exploited this possibility.

Using bagasse as fuel to generate electricity does not assign a very high value to bagasse. One tonne of bone-dry bagasse can produce about 900 kWh of electricity worth $18, but if the bagasse were transformed into bleached pulp it would produce about 350 kg of pulp, which is worth about $130. However, local conditions could be such that the production of electricity from bagasse would be more profitable than the highly capital-intensive transformation of bagasse into bleached pulp.

Ethyl alcohol

Because of the recurrent shortages and increasing prices of gasoline, it may be advantageous for developing countries with insufficient foreign exchange to pay for oil imports to use ethanol, which can be produced from molasses as a motor car fuel instead of gasoline, even though 37 per cent more of it would be required to produce the same energy. Engines would have to be modified, of
course, but research on this has reached an advanced stage, for example in the Federal Republic of Germany. Brazil already has an ambitious programme to produce ethanol, initially for mixture with gasoline containing 15 per cent ethanol, but ultimately for use pure.

**Cane tops**

For every 100 t of cane crushed in the factory, some 40 t of cane tops remain in the cane fields and can be used as animal feed. Fresh cane tops have a metabolizable energy of about 680 kcal (2.8 MJ) per kilogram of dry matter. With the addition of some 5 per cent by weight of molasses, it can play an important part in meat production.

The construction of feedlots adjacent to sugar mills has simplified the handling and transport of such feed; at the same time the concentration of animals has rendered feasible the conversion of organic waste into methane and fertilizer. Methane can be used as fuel for household cooking or in modified stationary engines to produce electricity. Under some circumstances systematic exploitation of by-products can increase the turnover of a sugar estate by almost 50 per cent.

**Slack seasons**

One great drawback of a sugar factory is that much capital-intensive machinery is used for only about six months of the year. Little has been published on alternative uses for such machinery. Productive employment for technical personnel during slack seasons also requires consideration.

If a large-scale alcohol industry were to be developed, then the distillery stillage could be evaporated in the evaporator and steam generating stations of the sugar factory. Steam could be generated either with surplus bagasse or fuel oil. The medium-pressure steam could be used to produce electricity with a back pressure turbo-alternator and the exhaust steam could be used in the quadruple-effect evaporation station to concentrate the stillage from 8 to 60 per cent solids. The syrup could then be mixed with cane tops and bagasse pith to produce animal feed.

A distillery with an annual capacity of 120,000 hl of alcohol would produce 1,850,000 hl of stillage, that is 185,000 t. To evaporate this stillage in a quadruple-effect unit would require some 40,000 t of exhaust steam.

If we assume that 2,400 hours (about four working months) are available between sugar-cane crops, then about 17 t of exhaust steam would be required per hour. This is well within the capacity of a 100-tch factory. Given a turbo-alternator with a steam rate of 10 kg/kWh, then the total amount of electricity generated during the four months would be approximately 4 million kWh.
Mini sugar technology in India

M. K. Garg*

Introduction

The terms "mini sugar technology" and "mini sugar-mill" as used in this paper denote open-pan (OP) khandsari sugar technology and OP khandsari sugar mill respectively.

The first detailed comparative study of mini sugar technology and large-scale sugar technology was made in 1973 by the International Labour Organisation on the basis of data collected in India. It established the economic viability of mini sugar technology.

Since then many planners, economists and technologists from other countries have studied these Indian units in operation. The latest study, made by a French government team, reported that mini sugar technology is economically almost at par with large-scale technology and that even slightly improved sugar yield will give mini sugar technology an economic advantage over large-scale sugar technology.

The Planning Commission of India studied mini sugar technology in 1977 and included the following policy decision in the Indian draft five-year plan for 1978–1983:

"The alternative technologies available for the production of sugar consistent with desirable capital employment parameters show that future demand for sweetening agents, after allowing for fuller utilization of the existing and licensed sugar-mills, can be met by necessary expansion through OP khandsari plants. It is proposed to work out the policy framework for the further expansion of the sugar industry in the light of these studies. For the time being, therefore, no new sugar-mills will be licensed, although expansions of existing units may not be ruled out where this is necessary for maintaining their viability."

Some comparative economic data on large-scale and mini sugar technology under Indian conditions 1977/78 are shown in table 1.

The data show that mini technology would produce 2.37 times more sugar and create 10.3 times more jobs for the same capital cost than would large-scale technology. However, experience indicates that the efficiency of large-scale sugar technology improves if the unit working periods are extended.

A comparative analysis of the productivity of the two technologies is presented in table 2.

*Director (Projects). Appropriate Technology Development Association (ATDA), Lucknow, India.
TABLE 1. COMPARATIVE DATA ON LARGE-SCALE AND MINI SUGAR TECHNOLOGY

<table>
<thead>
<tr>
<th>Item</th>
<th>Large-scale</th>
<th>Mini</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total capital available for investment (Rs million)</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Capital required for installation of one unit (Rs million)</td>
<td>60</td>
<td>1.3</td>
</tr>
<tr>
<td>Number of units which can be set up with available investment capital</td>
<td>1</td>
<td>46</td>
</tr>
<tr>
<td>Working days</td>
<td>120</td>
<td>100</td>
</tr>
<tr>
<td>Total sugar output (t/a)</td>
<td>14,550</td>
<td>34,500</td>
</tr>
<tr>
<td>Persons employed</td>
<td>900</td>
<td>9,292</td>
</tr>
</tbody>
</table>

TABLE 2. COMPARATIVE ANALYSIS OF THE PRODUCTIVITY OF THE TWO TECHNOLOGIES

<table>
<thead>
<tr>
<th>Item</th>
<th>Large-scale</th>
<th>Mini</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working days</td>
<td>160</td>
<td>120</td>
</tr>
<tr>
<td>Cost of 100 quintals</td>
<td>1,250</td>
<td>1,250</td>
</tr>
<tr>
<td>of cane (Rs)</td>
<td></td>
<td>1,250</td>
</tr>
<tr>
<td>Cost of processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 quintals of cane (Rs)</td>
<td>1,032</td>
<td>585</td>
</tr>
<tr>
<td></td>
<td>2,282</td>
<td>1,835</td>
</tr>
<tr>
<td>Total sugar produced (quintals)</td>
<td>9.6</td>
<td>7.5</td>
</tr>
<tr>
<td>Cost of sugar per quintal (Rs)</td>
<td>238</td>
<td>243</td>
</tr>
</tbody>
</table>

*1 quintal = 100 kg.

To produce one unit of sugar mini technology is superior to large-scale technology in all respects but cane consumption. To produce one unit of sugar mini technology requires 13.33 units of cane as against 10.4 units for large-scale technology but this difference will be minimized when recent technological innovations are put into commercial use. The development of an expeller for increasing crushing efficiency will increase yield by 0.7 per cent to 8.2 per cent and manufacture of liquid sugar out of khandsari molasses will raise it to about 9.2 per cent. It should also be emphasized that the sugar produced by mini technology is of identical quality with the sugar produced by large-scale technology. Mini sugar units now crush 10 per cent of the total cane grown in India and produce about one million t/a.

The socio-economic benefits to India of mini technology include:

(a) Capital amounting to Rs 800 million has been invested by the unorganized sector, primarily in rural areas;

(b) Potential employment for 150,000 persons in the rural sector has been created in the agricultural slack season when these persons formerly migrated to cities in search of work;

(c) Tax revenues to federal and state governments have increased by Rs 40 million;
(d) A manufacturing industry producing mini technology components has developed whose annual turnover has reached almost Rs 100 million;

(e) Mini sugar equipment requires only about 60 per cent of the iron and steel needed to fabricate large-scale equipment producing the same quantity of crystal sugar. This saves 40 per cent on iron and steel;

(f) More than 60 per cent of the cane for large-scale units is transported by vehicles consuming fossil fuel. Practically no fossil fuel for transport is utilized by mini units. They are near the cane growers and cane is transported by bullock carts;

(g) Mini units provide repair services for other mechanical agricultural equipment;

(h) Centralized large-scale technology draws capital away from rural areas. This weakens the rural capital base and makes the introduction of improved agricultural technology difficult. Rural mini units help build up local capital resources;

(i) Mini sugar equipment can be manufactured and maintained by small workshops in rural and semi-urban areas;

(j) Mini units employ about 2 1/2 times as many labourers for the same capacity as those employed by large-scale units;

(k) The capital required to manufacture an equivalent quantity of crystal sugar by mini technology is only 42 per cent of the cost of doing so by large-scale VP technology;

(l) The price mini units pay for cane is at par with that paid by large-scale units. This price is at least 25 per cent higher than small-scale traditional farmers, who grow cane as a cash crop, can obtain from other cane buyers; it can be said that the establishment of dispersed mini units has added about Rs 400 million to agricultural income;

(m) Some mini technology innovations have filtered through to the gur and khandsari industries. The introduction of power crushers to gur manufacture, crystallization in motion, and improved boiling furnaces, for example, have improved the output and efficiency of these traditional industries.

Product selection

The question is often asked why mini sugar technology should be introduced rather than improving the traditional technologies for gur or khandsari sugar. These traditional technologies are low-cost and the skills needed to operate them are already available in rural India. The answer is that mini sugar technology is more economical to operate and that its product is more acceptable to consumers.

Operational economics

Gur is a concentrated product of the whole cane juice. It contains about 80 per cent sucrose and other substances having nutritive value. It is used by the
rural population more as a food than as a sweetening agent. The gur yield is 10 per cent on cane processed, that is, to manufacture one quintal of gur, 10 quintals of cane are required. The standard price of 10 quintals of cane fixed by the Government for large-scale mills is Rs 125–135. The market price of gur fluctuates sharply; during the last five years it has ranged from Rs 80–150 per quintal. Even at the peak price of Rs 150, a margin of only Rs 15–25 is left to cover processing. This means that gur manufacturers cannot pay the standard cane price and that returns to cultivators who must sell to them will be low. Any improvement in the technology will raise the manufacturing cost of the product and its marketability will be reduced. Improved technology has in fact been tested but was given up because the gur although of higher quality did not find buyers at higher prices. Attempts to increase the yield of gur from cane necessitated higher investment which again affected the cost of the product and defeated the purpose of trying to keep gur manufacture as a cottage industry.

Khandsari sugar is a creamy white powdery sugar containing 94 to 98 per cent sucrose. Nutritively it is said to be superior to white crystal sugar. The price range is Rs 200–300 per quintal. Its recovery is 5.5 per cent, that is, to produce one quintal of khandsari sugar, 18 quintals of cane are required. The price of cane to large-scale units is Rs 225–245 per quintal; this leaves very little margin to pay for technological improvements.

Market acceptability

One present strength of large-scale technology is that its standardized products are acceptable to Indian society. On the other hand, consumer acceptance of gur and khandsari produced by traditional low-cost technologies has declined. This fact is usually not given enough weight in schemes for reviving and improving traditional technologies. Most research agencies try to improve the productivity of traditional technologies by introducing new equipment and techniques; governments have concentrated on providing marketing and financial aid. These efforts, however, have not succeeded in putting low-cost technology on its feet.

For example, gur production and consumption are gradually declining. In 1930, 65–70 per cent of the total cane crop in India was made into gur; currently only 45–50 per cent of the cane crop is being processed in this way. The manufacture of traditional khandsari sugar has also been declining; at present the khandsari industry utilizes barely 2 per cent of cane grown in India.

The declining production of gur and khandsari sugar reflects the demand for white crystal sugar, a product of large-scale technology. At present the output of large-scale sugar technology in India is 5–6 million t/a. Mini sugar technology, which was introduced as a pilot project in 1956/57, is now producing 1 million t/a. The potential market for white crystal sugar can be judged from the fact that annual per capita consumption is only 6 kg in India, while in developed countries the annual per capita consumption averages 50 kg. Therefore from the point of view of product selection the only alternative was the development of a suitable small-scale technology for manufacturing white crystal sugar.
Technology

The manufacture of sugar can be divided into the following processes:
(i) Extracting the juice from sugar-cane;
(ii) Clarifying the juice;
(iii) Evaporating and concentrating the juice into massecuite;
(iv) Forming and separating crystals from the massecuite to obtain the final sugar product.

Juice extraction

In large-scale technology juice is extracted by a crushing unit which consists of a tandem of five mills of three rollers each. Other equipment also used to increase juice extraction includes:
(a) Cane preparation devices;
(b) Extra hydraulic pressure on the rollers;
(c) Imbibition or maceration, that is, adding water and diluted juice to the crushed cane and re-pressing it;
(d) Increased compression by working a number of mills in tandem.

For gur manufacture bullock-powered crushers are used. Traditional khandsari sugar technology uses (a) three-roller bullock-powered vertical crushers; (b) three-roller motor-powered horizontal crushers; or (c) five-roller motor-powered crushers.

The efficiencies of sugar extraction in the gur, khandsari and large-scale VP sugar technologies are compared in table 3.

<table>
<thead>
<tr>
<th>Efficiency Basis</th>
<th>Gur</th>
<th>Khandari</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(bullock</td>
<td>Three-roller</td>
</tr>
<tr>
<td></td>
<td>crusher)</td>
<td>power crusher</td>
</tr>
<tr>
<td>Juice</td>
<td>55–60</td>
<td>58–62</td>
</tr>
<tr>
<td>Sugar content of juice</td>
<td>67–68</td>
<td>68–70</td>
</tr>
</tbody>
</table>

*The figure given is the juice extraction, i.e. the ratio of the weight of juice to the weight of cane.

*bThe figure given is the milling efficiency, i.e. the ratio of the sugar content of juice to the sugar content of cane.

To cut sugar loss during evaporation, a new six-roller crusher has been developed which incorporates cane preparation by means of two sets of cane knives and extra hydraulic pressure on the rollers. In large-scale crushing cane is usually subjected to 10 pressings but this has been reduced to 4 pressings by use of two three-roller mills in place of five. This was done because a greater number of pressings is effective only when imbibition or maceration is used. Introduction of imbibition required 12–18 per cent more water; this diluted the juice too much and increased fuel consumption during evaporation. Higher fuel consumption could probably be compensated by higher yield but the diluted juice when evaporated in an OP furnace loses too much sucrose.
Inversion is a process by which the sucrose in cane-sugar, which is a disaccharide, is converted to monosaccharide, that is, dextrose, which does not crystallize and is lost in the molasses. The inversion rate increases rapidly if the juice is boiled above 60–70°C. VP technology lowers the boiling point to 60–70°C and thus checks the sucrose loss through inversion. In OP furnaces juice starts boiling at 100.5°C and as the concentration increases, the boiling point goes up to 110–112°C. Inversion is also increased by the duration of boiling. Diluted juice takes much more time to boil than pure juice fresh from the cane. The additional sugar obtained by imbibition and increased pressing is lost because of accelerated inversion in OP boiling.

Initially a 13×18-inch crusher was developed by the Indian Planning, Research and Action Institute with the help of the National Sugar Institute. Later a 16×24-inch crusher was developed by the Appropriate Technology Development Association. The operational data of 13×18 inch and 16×24 inch six-roller hydraulic crushers are similar:

| Juice extraction | 66–68 per cent |
| Milling efficiency | 80–82 per cent |
| Crushing capability | 5 tch or 100 tcd for 13×18 inch |
| | 10 tch or 200 tcd for 16×24 inch |

Sugar loss is cut from 30 per cent to 20 per cent; thus the yield is 0.8 to 1 percentage points higher than with traditional khandsari technology.

A sugar expeller is now being developed which on a dry crushing basis will give a primary juice extraction rate of 72 per cent and a milling efficiency of 87 per cent.

**Juice clarification**

Clarification in large-scale technology is carried out by chemical agents, principally lime alone or lime in combination with sulphur dioxide or carbon dioxide. There are three types of clarification:

- Lime defecation: to produce raw sugar for further refinement by carbon filtration
- Lime sulphitation: to produce direct consumption white crystal sugar
- Lime carbonation: to produce direct consumption white crystal sugar

In India lime sulphitation is the most widely used process in large-scale VP technology. In traditional technology clarification is carried out by means of mucilage prepared from vegetable barks.

The barks are soaked in water and the resulting solution is added to the boiling juice. The impurities rise as scum to the surface of the juice and are ladled out.

The comparative efficiency of the various clarification methods is as follows:

<table>
<thead>
<tr>
<th>Method</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime defecation</td>
<td>60</td>
</tr>
<tr>
<td>Lime sulphitation</td>
<td>35–45</td>
</tr>
<tr>
<td>Lime carbonation</td>
<td>50–55</td>
</tr>
<tr>
<td>Bark mucilage clarification</td>
<td>10–15</td>
</tr>
</tbody>
</table>
Sugar-cane juice contains about 2 per cent of non-sugar insolubles. This non-sugar component retards crystallization and its elimination from the juice to the highest possible degree is necessary to produce white crystal sugar.

Since the primary object is to manufacture crystal sugar, mini sugar producers have no choice but to use the lime sulphitation method which produces sugar similar to that produced by large-scale technology.

**Evaporation and concentration of juice**

In large-scale technology cane juice is evaporated after clarification in a multiple-effect evaporator and then concentrated into massecuite in a vacuum pan. Heating is done by steam.

In traditional khandsari technology cane juice is evaporated and concentrated in an OP furnace fuelled with bagasse. The VP process entails a sugar loss of 2 per cent; the OP process, of 15 per cent.

Large-scale VP boiling is too complicated and too capital-intensive to be adopted in mini sugar technology; scaling the process down was found to be difficult and uneconomic.

The OP furnace is essentially a long inclined tunnel containing a sequence of pans of increasing diameter. Bagasse is burnt directly below the smallest pan. Draught is provided by a small chimney placed at the end of the last pan. The juice is fed into the large pan and gradually transferred manually from the highest to the lowest pan where concentration is completed. The massecuite is ladled into a small tank. This design can be used for a low-capacity unit producing about 50–90 kg of massecuite per hour or a high-capacity unit producing 130–150 kg per hour.

Since the low-capacity furnace did not fit the requirements of mini-plant design, a new furnace was developed with a juice capacity of 800 kg and a massecuite capacity of 180 kg. Discoloration and caramelization were reduced and sugar loss was cut to 5–7 per cent.

In large-scale technology bagasse is burnt wet, that is, as it leaves the crusher but in an OP furnace bagasse is generally dried before burning. However, attempts to burn wet bagasse in OP furnaces are being made. Recently the author designed a heat recovery device which reduces fuel consumption. Both forced and induced draught fans are provided and concentration capacity has been increased to 180 kg/h.

**Crystallization**

In large-scale processing the massecuite is poured into a U-shaped vessel in which it is slowly rotated for 24–36 hours while crystals develop and grow. In traditional processing crystallization takes place in earthen vessels where the massecuite is stored for two to three weeks. The large-scale process is called crystallization in motion; the traditional process, static crystallization. Crystallization in motion entails a sugar loss of about 1 per cent; static crystallization, of 4–6 per cent.

This deficiency of traditional processing has been overcome to some extent in mini technology through new seeding and cutting techniques but the sugar loss in molasses is still higher than in large-scale processing.
Crystal separation

In large-scale technology crystals are separated from the massecuite with a centrifuge.

In traditional technology crystals were separated initially by micro-biological action. After static crystallization, the massecuite was poured into woollen bags which were stacked to a height of 8–10 ft; a heavy stone was placed on top of the stack to exert pressure. In the course of a week some of the molasses would flow out. The yellowish syrpy mass was then taken out of the bags and put in masonry tanks with perforated bottoms. A layer of sewer grass, which grows profusely in still waters, was placed on top. The heat developed by the micro-biological action of the grass caused some of the molasses to drain off, leaving a powdery white to creamy sugar below the sewer grass layer. This layer of sugar was then removed and replaced by another layer of sewer grass until all the sugar in the tank was free from molasses. By 1960, this traditional separation technique had completely disappeared.

The centrifuges used in large-scale VP technology are of very high capacity and fully automatic; mini technology employs a batch-type centrifuge and the main operations of feeding, washing and sugar removal are done manually. However, manually operated centrifuges are economical in mini technology because of the low capital investment per unit of sugar centrifuged.

Organizational pattern

Mini sugar operations are usually organized on a producer-owner basis. Ownership is vested in one producer or in a partnership of producer, artisans and small entrepreneurs. Required capital investment is low and management simple. This kind of organization can operate and survive at a low level of efficiency. Mini sugar units have been standardized in capacities of 100 and 200 t/d with three work shifts.

However, mini sugar technology as it now exists cannot be scaled down to village entrepreneur level and a larger-scale ownership is necessary.

In India units organized on a co-operative basis to date have not succeeded. Nevertheless, the author believes that the mini sugar industry could be organized on a co-operative basis if:

(a) Co-operative membership were limited to a group of cane growers who would use the unit to process their own crops;

(b) The major part of the required investment capital were provided by the cane growers or, if the group must borrow investment capital, repayment should be scheduled to permit payment of an annual dividend to the shareholders;

(c) An institution were set up to provide technical and managerial support to co-operative units until their economic viability were firmly established and management could be taken over by the cane growers themselves.

Annexes I and II give details about the capital investment required for the standardized 100-t/d and 200-t/d mini sugar plants, and annex III is a profitability analysis.
Annex I

CAPITAL INVESTMENT REQUIRED FOR A 100-T/D MINI SUGAR PLANT
(Thousands of rupees)

LAND AND BUILDINGS

| Land (3 acres) | 30 |
| Buildings     | 410 |
| Worked shed, 14,400 ft² at Rs 25 | 350 |
| Office        | 20 |
| Quarters      | 20 |
| Boundary wall | 20 |
| Other construction | 60 |
| Molasses tank and drying platform | 20 |
| Masonry foundation of machinery and bel construction with chimney | 25 |
| etc. including fire-brick | 25 |
| Tube-well with overhead tank | 15 |
| Total         | 500 |

PLANT AND MACHINERY

1. Crushing unit
   Cane-crushing unit, 13 x 18 in. 6-roller, hydraulic loaded, complete with cane carrier, double cane-cutter and intermediate carrier | 125 |
   Electric motor, 70-75 hp, 960 rpm, with starter and switch | 30 |
   Electric motors (2), 10 hp, 1,440 rpm | 6 |
2. Raw-juice tank 8 x 2 x 1 1/4 ft, 10-gauge mild steel | 0.8 |
3. Juice strainer, 2-mm aperture | 6 |
4. Automatic juice-weighing machine | 5 |
5. Juice pumps (2), 2 in., open impeller | 12 |
6. Hot-juice pump, 3 in. | 7 |
7. Rotary positive blowers (2), 36 cfm with motor, starter and switch | 9 |
8. Sulphur furnace, tray area 2 ft², water-cooled | 1.5 |
9. Scrubber, 18 x 48 in., double-walled, water-cooled | 0.5 |
10. Sulphitation tanks (2), 3-ft diam., 8-ft high, with lime-addition tank, parabolic circulation baffle and operating valves, 5-mm mild steel | 6.4 |
11. Sulphitation bels (2) | 24 |
12. Lime solution-making equipment | 2 |
13. Settling tanks (12), 4 x 4 x 2 ft | 12 |

*If electricity is not available, one 100-kVA and one 35-kVA diesel generator will have to be installed for an additional cost of Rs 150,000 + Rs 60,000 = Rs 210,000.
14. Filtration equipment with mud pump. 2 x 2 in.
   Bag filters (10) or filter presses (2)\(^ {b} \)
   Filter press. 18 x 18 x 3-in. plates
   Bag filters. 4 x 4 x 2 ft
   Refiltration filter press. 18 x 18 in., with 24 plates 10

15. Juice-boiling bels (7)
   Round pan, 54-in. diam., 40–50-mm thick, mild steel
   Round pan, 42-in. diam. 40–50-mm thick
   Channel pans (3), 6 x 2 ft 70
   Wet-bagasse burning equipment for two furnaces only.\(^ {c} \)
   Complete with step grates, recuperator, forced-draught fan 2,000 cfm at 4 in.
   WG and induced-draft fan 4,000 cfm at 4 in. WG 24

16. Molasses bels (5), each with three cast-iron pans. 42 x 7 1/2 in.,
    and 30 x 7 1/2 in. 9

17. Crystallizers (8), 8 x 5 x 5 ft made from 3-mm and 8-mm plate 40
   Crystallizers (10), 6 x 4 x 4 ft made from 3-mm and 6-mm plate 40
   Countershaft, complete 6
   Electric motors (6), 5 hp, 960 rpm, with switch and starter 12
   Seed crystallizers (4), 5 x 3 9/4 x 3 1/2 ft made of 3-mm and 6-mm plate 12
   Electric motor, 3 hp, 960 rpm, with switch and starter 2

18. Centrifuges (2). 12 x 24 in. 22

19. Magma pump, motor 5 hp, 960 rpm 6

20. Rab feeding equipment with drive 6

21. Gear-pump for molasses, motor 5 hp, 960 rpm 3

22. Hopper-dryer, 50-ft long in two 25-ft parts, separately driven,
    with sugar classifier, complete with driving motor, air-heater
    and fan of 2,000 cfm at 4 in. WG 25
   Motors (2), 5 hp, 960 rpm
   Motor, 4 hp, 1,440 rpm

23. Weighing bridge, 20 t 40

24. Platform balances (2) 6

Total 590

---

**WORKSHOP AND FITTINGS**

*Workshop* including 12-ft lathe, 1 1/2-in, drill, welding set, tools 25

*Fittings*

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe</td>
<td>10</td>
</tr>
<tr>
<td>Electric</td>
<td>35</td>
</tr>
<tr>
<td>Mill stores</td>
<td>10</td>
</tr>
<tr>
<td>Contingencies, freight and other charges</td>
<td>10</td>
</tr>
<tr>
<td>Erection charges</td>
<td>15</td>
</tr>
</tbody>
</table>

Total 105

---

\(^ {b} \)Filter presses would add Rs 15,000 to the cost of plant machinery.

\(^ {c} \)In the initial stage. The remaining five furnaces should be fitted with wet-bagasse burning equipment as required.
### SUMMARY

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land and buildings</td>
<td>500</td>
</tr>
<tr>
<td>Plant and machinery</td>
<td>590</td>
</tr>
<tr>
<td>Workshop and fittings</td>
<td>105</td>
</tr>
<tr>
<td>Working capital</td>
<td>123</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1318</strong></td>
</tr>
</tbody>
</table>

Annex II

CAPITAL INVESTMENT REQUIRED FOR A 200-T/D MINI SUGAR PLANT
(Thousands of rupees)

LAND AND BUILDINGS

| Land (5 acres) | 50 |
| Buildings      | 565 |
| Working shed. 18 000 ft² at Rs 25 | 450 |
| Office         | 30  |
| Quarters       | 50  |
| Boundary wall  | 35  |
| Other construction | 95 |
| Molasses tank and drying platform | 40 |
| Masonry foundation of machinery and bel construction with chimney and other miscellaneous works including fire-bricks | 35 |
| Tube-well with overhead tank | 20 |
| Total           | 710 |

PLANT AND MACHINERY

1. Crushing unit
   Cane-crushing unit, 16 × 24 in., 6-roller, hydraulic loaded, complete with cane carrier, double cane-cutter and intermediate carrier
   Electric motor, 100 hp, 960 rpm, with starter and switch | 60 |
   Electric motors (2), 15 hp, 1,440 rpm | 15 |
2. Raw-juice tanks (2), 8 × 2 × 1½ ft, 10-gauge mild steel | 1.6 |
3. Juice strainer, 2-mm aperture | 6 |
4. Automatic juice-weighing machine | 8 |
5. Juice pumps (2), 2 in., open impeller | 12 |
6. Hot-juice pumps (2) 3 in. | 14 |
7. Rotary positive blowers (3), 36 cfm with motor, starter and switch | 13.5 |
8. Sulphur furnaces (2), tray area 2 ft², water-cooled | 3 |
9. Scrubbers (2), 18 × 48 in., double-walled, water-cooled | 1 |
10. Sulphitation tanks (4), 3-ft diam., 8-ft high, with lime-addition tank, parabolic circulation haffle and operating valves, 5-mm mild steel | 12.8 |
11. Sulphitation bels (2) | 24 |
12. Lin.2 solution-making equipment | 3 |

*If electricity is not available, three diesel generating sets will have to be installed as follows: 150 kVA (Rs. 250,000), 35 kVA (Rs 65,000) and 25 kVA (Rs 50,000); total additional cost Rs 365,000.*
13. Settling tanks (16), 4 × 4 × 2 ft
14. Filtration equipment with mud pump, 2 × 2 in.
   Bag filters (16) or filter presses (2).¹ one with 24 × 24 × 3-in. plates. one
   with 18 × 18 × 3-in. plates. Refiltration filter presses (2)
15. Juice-boiling belts (7)
   Round pan, 54-in. diam., 40–50-mm thick, mild steel
   Round pan, 42-in. diam. 40–50-mm thick
   Channel pans (3), 6 × 2 ft
   Wet-bagasse burning equipment for two furnaces only.² Complete with
   step grates, recuperator, forced-draught fan 2,000 cfm at 4 in. WG
   and induced-draft fan 4,000 cfm at 4 in. WG
16. Molasses belts (8), each with three cast-iron pans, 42 × 7½ in.,
    and 30 × 7½ in.
17. Crystallizers (16), 8 × 5 × 5 ft made from 4-mm and 8-mm plate
    Crystallizers (18), 6 × 4 × 4 ft made from 3-mm and 6-mm plate
    Countershaft, complete
    Electric motors (6), 5 hp, 960 rpm, with switch and starter
    Seed crystallizers (6), 5 × 3¾ × 3½ ft made of 3-mm and 6-mm plate
    Electric motor, 3 hp, 960 rpm, with switch and starter
18. Centrifuges (3), 12 × 24 in.
19. Magma pumps (2), motor 5 hp, 960 rpm
20. Rab feeding equipment with drive (2)
21. Gear-pumps for molasses (2), motor 5 hp, 960 rpm
22. Hopper-dryers (2), one 75-ft long in three 25-ft parts, the other 50-ft long
    in two, separately driven, with sugar classifier, complete with driving motor,
    air-heater and fan of 2,000 cfm at 4 in. v/G
    Motors (3), 5 hp, 960 rpm
    Motor, 3 hp, 1,440 rpm
23. Weighing bridge, 20 t
24. Platform balances (3)

Total

WORKSHOP AND FITTINGS

Workshop, including 12-ft lathe, 1½-in. drill, welding set and tools
Fittings
Pipe
Electric
Mill stores
Contingencies, freight and other charges
Erection charges

Total

---

¹Filter presses would add Rs 40,000 to the cost of plant machinery.
²In the initial stage. The remaining five furnaces should be fitted with wet-bagasse burning equipment as required.
## SUMMARY

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land and buildings</td>
<td>710</td>
</tr>
<tr>
<td>Plant and machinery</td>
<td>888</td>
</tr>
<tr>
<td>Workshop and fittings</td>
<td>185</td>
</tr>
<tr>
<td>Working capital</td>
<td>180</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,963</strong></td>
</tr>
</tbody>
</table>
Annex III

PROFITABILITY ANALYSIS OF A 100-T/D MINI SUGAR PLANT
UNDER INDIAN CONDITIONS
(Thousands of rupees)

DETAILED OPERATING COSTS

*Cane 10,000 t at Rs 125 per q.t (average) 1250

Stores

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime, 20 t at Rs 300</td>
<td>6</td>
</tr>
<tr>
<td>Sulphur, 5 t at Rs 1,300</td>
<td>6.5</td>
</tr>
<tr>
<td>Castor seed, 2.5 t at Rs 1,800</td>
<td>4.5</td>
</tr>
<tr>
<td>Gunny bags, 7,500 at Rs 6</td>
<td>45</td>
</tr>
<tr>
<td>Lubricants</td>
<td>10</td>
</tr>
</tbody>
</table>

Electricity and fuel

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity and diesel fuel</td>
<td>120</td>
</tr>
<tr>
<td>Extra fuel, 3%, 300 t at Rs 200</td>
<td>60</td>
</tr>
</tbody>
</table>

Staff

<table>
<thead>
<tr>
<th>Position</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manager, 12 months at Rs 600</td>
<td>7.2</td>
</tr>
<tr>
<td>Accountant/cashier, 12 months at Rs 400</td>
<td>4.8</td>
</tr>
<tr>
<td>Weigh-bridge clerk/accountant, 12 months at Rs 200</td>
<td>2.4</td>
</tr>
<tr>
<td>Assistant mechanic (3), 5 months at Rs 150</td>
<td>2.25</td>
</tr>
<tr>
<td>Storekeeper, 12 months at Rs 300</td>
<td>3.6</td>
</tr>
<tr>
<td>Mechanic, 12 months at Rs 450</td>
<td>5.4</td>
</tr>
<tr>
<td>Head karigar (rab), 5 months at Rs 600</td>
<td>3</td>
</tr>
<tr>
<td>Assistant karigar (bel) (8), 5 months at Rs 250</td>
<td>10</td>
</tr>
<tr>
<td>Karigar for molasses (6), 5 months at Rs 250</td>
<td>7.5</td>
</tr>
<tr>
<td>Sulphitation mate (3), 4 months at Rs 300</td>
<td>3.6</td>
</tr>
<tr>
<td>Centrifugal operator (6), 5 months at Rs 200</td>
<td>6</td>
</tr>
<tr>
<td>Electrician, 12 months at Rs 250</td>
<td>3</td>
</tr>
<tr>
<td>Settling mate (3), 4 months at Rs 150</td>
<td>1.8</td>
</tr>
<tr>
<td>Night guard (3), 12 months at Rs 150</td>
<td>5.4</td>
</tr>
</tbody>
</table>

Daily labour (73, 45, 45)*

<table>
<thead>
<tr>
<th>Activity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading and unloading (4, -, -)</td>
<td>98</td>
</tr>
<tr>
<td>Crushing section (15, 15, 15)</td>
<td></td>
</tr>
<tr>
<td>Sulphitation section (5, 5, 5)</td>
<td></td>
</tr>
<tr>
<td>Settling section (4, 3, 3)</td>
<td></td>
</tr>
<tr>
<td>Juice bel etc. (14, 14, 14)</td>
<td></td>
</tr>
<tr>
<td>Molasses bel (8, -, -)</td>
<td></td>
</tr>
<tr>
<td>Crystallizer section (2, 2, 2)</td>
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</tr>
<tr>
<td>Centrifuge (3, 3, 3)</td>
<td></td>
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<tr>
<td>Bagasse drying (8, -, -)</td>
<td></td>
</tr>
<tr>
<td>Sugar drying (6, -, -)</td>
<td></td>
</tr>
<tr>
<td>Reserve labour (4, 3, 3)</td>
<td></td>
</tr>
</tbody>
</table>

*Figures in parentheses are number of labourers per shift. Wages are calculated as Rs 5 per day for 120 days.
### SUMMARY OF OPERATING COSTS

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Amount (thousands of rupees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane</td>
<td>1 250</td>
</tr>
<tr>
<td>Stores</td>
<td>72</td>
</tr>
<tr>
<td>Electricity and fuel</td>
<td>120</td>
</tr>
<tr>
<td>Staff</td>
<td>66</td>
</tr>
<tr>
<td>Daily labour</td>
<td>98</td>
</tr>
<tr>
<td>Contingencies</td>
<td>10</td>
</tr>
<tr>
<td>Excise duty, Rs 2 950 per week per centrifuge for one centrifuge for 18 weeks</td>
<td>53</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1 669</strong></td>
</tr>
</tbody>
</table>

### Direct processing cost per 100 quintals of cane (Rs)

<table>
<thead>
<tr>
<th>Direct processing cost per 100 quintals of cane (Rs)</th>
<th>63</th>
</tr>
</thead>
</table>

### INCOME

<table>
<thead>
<tr>
<th>Product</th>
<th>Yield from 10,000 t cane (quintals)</th>
<th>Price (Rs)</th>
<th>Amount (thousands of rupees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First sugar</td>
<td>4 750</td>
<td>300</td>
<td>1 425</td>
</tr>
<tr>
<td>Second sugar</td>
<td>1 750</td>
<td>270</td>
<td>472</td>
</tr>
<tr>
<td>Third sugar</td>
<td>700</td>
<td>220</td>
<td>154</td>
</tr>
<tr>
<td>Fourth sugar</td>
<td>300</td>
<td>190</td>
<td>57</td>
</tr>
<tr>
<td>Molasses</td>
<td>3 000</td>
<td>15</td>
<td>45</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>2 153</strong></td>
</tr>
</tbody>
</table>

### GROSS PROFIT

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount (thousands of rupees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income</td>
<td>2 153</td>
</tr>
<tr>
<td>Costs</td>
<td>1 669</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>484</strong></td>
</tr>
</tbody>
</table>

### OTHER COSTS

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Amount (thousands of rupees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depreciation</td>
<td>95</td>
</tr>
<tr>
<td>Buildings, 470 at 5%</td>
<td>25</td>
</tr>
<tr>
<td>Machinery, 698 at 10%</td>
<td>70</td>
</tr>
<tr>
<td>Repairs and maintenance</td>
<td>37</td>
</tr>
<tr>
<td>Buildings, 470 at 2%</td>
<td>9</td>
</tr>
<tr>
<td>Machinery, 698 at 4%</td>
<td>28</td>
</tr>
<tr>
<td>Overhead</td>
<td>29</td>
</tr>
<tr>
<td>Auditors expenses</td>
<td>2</td>
</tr>
<tr>
<td>Other statutory charges</td>
<td>5</td>
</tr>
<tr>
<td>TA</td>
<td>10</td>
</tr>
<tr>
<td>Office expenses</td>
<td>8</td>
</tr>
<tr>
<td>Entertainment</td>
<td>2</td>
</tr>
<tr>
<td>Insurance</td>
<td>2</td>
</tr>
</tbody>
</table>
Purchase tax, 50 paise per quintal of cane
Interest on additional capital of Rs 400,000 required during the season to
be arranged as cash credit limit or short-term loan at 14% for 6 months
Interest on capital investment of Rs 1,300,000 at 10%
Total

PROFITABILITY

<table>
<thead>
<tr>
<th>Gross profit</th>
<th>484</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other costs</td>
<td>369</td>
</tr>
<tr>
<td>Net profit</td>
<td>115</td>
</tr>
</tbody>
</table>

Net return on investment 8.8%
Appropriate technology for production of sugar and other sweetening agents

K.K. Gupta, N.C. Jain and N.A. Ramaiah*

The per capita annual consumption of sugar in the developed countries is more than 40 kg, whereas in developing countries it is less than 10 kg. Promotion of sugar production in developing countries would help increase their per capita consumption, and appropriate technology would ensure that sugar is produced in adequate measure and at low cost. This paper discusses the various technologies used in India for production of sugar and other sweetening agents and the criteria for choosing them for use elsewhere.

Sugar-beet and sugar-cane are the most important raw materials for the manufacture of sugar. Sugar-beet is grown abundantly and profitably and is used for making sugar in countries of the temperate zone. In 1975 beet-sugar production was about 40 per cent of total world sugar production (81.6 million tonnes).

In warmer climates, sugar-cane is grown and used to make not only sugar but also other sweetening agents. Examples are Australia, Brazil, Cuba, India, Mauritius, Mexico and the Philippines. Since most developing countries are situated in such climates a technology using cane-sugar is more appropriate for them, and the technologies described in this paper are based on sugar-cane only.

Survey of the Indian sugar industry

India is the world's largest producer of sugar-cane, regularly accounting for over 20 per cent of world production. In 1977/78 India produced 160 million tonnes of sugar-cane, 35 per cent of which was used to make plantation white sugar and 55 per cent to make gur and khandsari. (The remaining 10 per cent was used for seed.) There are 8,000 small khandsari units having crushing capacities of 5–300 tonnes of cane per day (tcd).

Plantation white sugar is produced in about 290 factories at the rate of 5–6 million t/a. The crushing capacities of the factories range from 1,250 to 6,000 tcd, the average being about 1,800 tcd. India ranks third in the world in crystal sugar production.

Technical efficiency

The technical efficiency in the plantation white sugar factories is very high, as can be seen from the following figures:

*National Sugar Institute, Kanpur, Uttar Pradesh, India.
Reduced mill extraction 93
Reduced boiling-house extraction 90
Reduced overall extraction 84
Total sugar losses (per cent cane) 2.3–2.7
Fuel consumption in terms of bagasse 26–28
Capacity utilization based on 24 hours operation 95.0

Sugar machinery manufacture

There are a number of manufacturers in India that supply complete sugar plants. India is not only self-sufficient in this respect, but has surplus capacity. Large amounts of sugar machinery are exported, and four factories have been set up in other countries.

Exports

Until 1957 India had to import sizeable quantities of sugar to meet its requirements. Since 1957, however, India has been an exporter of sugar and imports have been completely stopped. In 1975 India exported almost a million tonnes of sugar; plans are to export more than a million tonnes annually in future.

Research and development

India is well equipped for the R and D needs of the sugar industry. There are three research institutions financed and administered by the Government, the Sugarcane Breeding Institute (Coimbatore), the Indian Institute of Sugarcane Research (Lucknow) and the National Sugar Institute (Kanpur). In addition, there are the Deccan Sugar Institute (Poona) and the Planning, Research and Action Institute (Lucknow). The former mainly gives advice to co-operative VP sugar factories. The latter does extension work in collaboration with the National Sugar Institute for the khandsari sugar industry.

The Sugarcane Breeding Institute develops varieties of cane suitable for different parts of the country. The Coimbatore (Co) varieties of cane are world famous and are used in many countries.

The Indian Institute of Sugarcane Research develops the various cultural practices required for different cane varieties and agro-climatic conditions. The governments of individual states also maintain a large number of cane research stations; their main purpose is to provide guidance and healthy cane seed to cultivators.

The National Sugar Institute, which is over 50 years old, deals with all the technological and engineering aspects for the establishment of new sugar factories and the rehabilitation, modernization and expansion of existing units. The Institute also does R and D on gur, khandsari sugar, raw sugar and refined sugar.

Improved crushers were developed for improving the juice extraction in the gur and khandsari industries. Methods of clarification of cane juice for producing good quality gur were also developed. For khandsari, hydraulic crushing units were designed, a liming and sulphitation process for juice
clarification was developed, furnaces with better fuel efficiency were designed, and boiling techniques for producing better quality sugar were promoted.

One of the important functions of the National Sugar Institute is to train personnel for the sugar industry, including khandlsari production. Many of the trainees come from other developing countries. About 50 technicians and 20 engineers are trained every year, the total number trained up to 1977 being 2,524.

Technical assistance to other countries

Technical experts have been sent from India to many other countries to help their developing sugar industries. In some cases these experts take on the entire job of developing an area, establishing new plants and operating them (e.g., in Malaysia and the United Republic of Tanzania). Know-how on khandlsari sugar has also been furnished, particularly to African countries.

Technologies used in India for the production of sweetening agents

In India, the following sweetening agents are obtained from sugar-cane:

- Gur (jaggery)
- Khandlsari sugar
- Plantation white sugar
- Raw sugar
- Refined sugar
- Cube sugar

The technologies for producing them are described below:

**Gur**

Gur is solidified clarified cane juice; molasses do not appear as a by-product when it is made. It is hard, crystalline and has a colour ranging from golden yellow to brownish yellow. The range of composition of gur is as follows:

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>65–85</td>
</tr>
<tr>
<td>Invert sugar</td>
<td>10–15</td>
</tr>
<tr>
<td>Ash</td>
<td>2–5</td>
</tr>
<tr>
<td>Moisture</td>
<td>3–6</td>
</tr>
<tr>
<td>Protein</td>
<td>0.25</td>
</tr>
<tr>
<td>Insoluble matter</td>
<td>5</td>
</tr>
</tbody>
</table>

The juice is extracted from the cane by crushers consisting of two or three vertical or horizontal rollers. Crushers with a capacity of 3–5 tcd are normally driven by bullocks, sometimes by camels. Those of higher capacity are driven by electric motors or diesel engines. The juice is strained through coarse cotton cloth and heated in shallow iron pans, in which it is clarified by vegetable mucilages such as deola (*Hibiscus ficulentus*), bhindi (*Hibiscus esculentus*) and sukhlai (*Cadia calyccina*). In some cases small quantities of lime water, crude sodium carbonate, sodium hydrosulphite, soda ash or superphosphate are used.
to achieve better clarification of juice and impart greater lustre to the product, but the effect of such chemicals is not permanent. The scum is scooped out and the juice concentrated to the striking temperature (116°C). Some emulsion of castor seed is also sprinkled in just before the striking temperature is reached to eliminate foam and bubbles. The mixture is then transferred to a cooling pan where it is vigorously stirred. The semi-solid mass that results is cut up and made into lumps or moulded in different shapes and sizes. The yield is 8–12 per cent on cane, depending on the quality of cane and the time of crushing.

**Khandsari sugar**

Khandsari sugar is finely granulated, crystallized sugar manufactured by the open pan (OP) system on a cottage industry scale. Neither a vacuum evaporator nor a vacuum pan is employed. Clarification is either by vegetable mucilaginous extracts or by the modern sulphitation process. The specifications of khandsari sugar clarified by the latter method are as follows:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polarization (%)</td>
<td>99.4–99.9</td>
</tr>
<tr>
<td>Reducing sugar (%)</td>
<td>0.10–0.40</td>
</tr>
<tr>
<td>CaO (mg/100 gm)</td>
<td>45–80</td>
</tr>
<tr>
<td>SO2 (ppm)</td>
<td>5–25</td>
</tr>
<tr>
<td>Colour (400–550 nm)</td>
<td>0.04–0.15</td>
</tr>
<tr>
<td>Viscosity (cp)</td>
<td>20–30</td>
</tr>
<tr>
<td>Conductivity (10⁶ mho/cm²)</td>
<td>50–200</td>
</tr>
<tr>
<td>Turbidity (%)</td>
<td>40–70</td>
</tr>
<tr>
<td>Filtrability (F₁)</td>
<td>50–400</td>
</tr>
<tr>
<td>Shape of crystal</td>
<td>Flattened</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>0.15–0.50</td>
</tr>
</tbody>
</table>

This sugar compares favourably with the crystal sugar produced by VP factories; in fact it is sometimes difficult to tell them apart without an analysis. However, khandsari sugar can be distinguished from VP sugar by careful observation of the crystals: khandsari contains more fine crystals and the crystals can be crushed between the thumb and forefinger.

For extraction, power-driven crushers containing three or six rollers, with or without hydraulics, are usually employed. To improve extraction, experiments are being conducted by the National Sugar Institute on the use of an expeller. The capacity of khandsari units ranges from 5 to 300 tcd. The extraction rate is 60–70 per cent, depending on the equipment. The low-capacity units (less than 20 tcd) employ vegetable mucilages for clarification, the larger and newer units use the sulphitation process.

In the units using vegetable mucilages, the extract is added to the heated juice before it starts boiling, and the scum rising to the surface is removed from time to time with a perforated ladle. In the modern units using the single sulphitation process, 1.2 per cent by volume of milk of lime of 15° Bé is added and the juice is treated with SO₂ until a pH of 7.0 is reached. The result is a heavy coagulation of impurities. The juice is then heated to 100°C (the "cracking" point). After settling, the clear juice is decanted. The muddy juice remaining at the bottom of the settling tanks is either filtered through bag filters (now out of date) or through cloth filter-presses.
After clarification (by either process) the juice is concentrated in a standard bel to form rab (massecuite), which has a striking temperature of 108°C. The mass is agitated in crystallizers and the crystals are separated by centrifuging. The separated crystals are dried and bagged. The molasses obtained after separation of crystal is often boiled to another rab, cooled and centrifuged to obtain a second crop of sugar crystals. These are also dried and bagged. The molasses are again boiled into a third rab, which is cooled and allowed to crystallize for 4–6 weeks. This third crop of sugar crystals is brown and is usually reprocessed the next season.

In the older system, using mucilage clarificants, the overall yield averages 6 per cent. When the sulphitation process is used for clarification, it is possible to obtain a yield of 7.5 per cent (about 5 per cent in the first crop, 1.7 per cent in the second and 0.8 per cent in the third). The yield of molasses is about 4.5 per cent.

**Plantation white sugar**

Plantation white sugar is defined as sugar in crystal form, manufactured by VP factories directly from sugar-cane, with a minimum sucrose content of 99.5 per cent and moisture content of less than 0.08 per cent. In India the sugar is clarified by double sulphitation or by a combined double carbonation and double sulphitation process. The specifications for plantation white sugar are as follows:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polarization (%)</td>
<td>99.5 min</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>0.08 max</td>
</tr>
<tr>
<td>Reducing sugar (%)</td>
<td>0.10 max</td>
</tr>
<tr>
<td>Conductivity (10⁶ mho/cm²)</td>
<td>100 max</td>
</tr>
<tr>
<td>Insoluble matter (%)</td>
<td>0.01 max</td>
</tr>
<tr>
<td>SO₂ (mg/kg)</td>
<td>70.0 max</td>
</tr>
<tr>
<td>Arsenic (mg/kg)</td>
<td>1 max</td>
</tr>
<tr>
<td>Copper (mg/kg)</td>
<td>2 max</td>
</tr>
<tr>
<td>Lead (mg/kg)</td>
<td>2 max</td>
</tr>
</tbody>
</table>

The juice is extracted by a power-driven milling tandem of 12–18 hydraulically loaded rollers. The extraction juice is about 78–80 per cent. When the double sulphitation process is used for clarification, the juice is treated as described above for khandsari sugar. When double carbonation is used, the juice is treated with lime and carbonation twice, filtered twice, then treated by the sulphitation process. The clarified juice is concentrated in multiple-effect evaporators and finally massecuites are made in vacuum pans. Normally, the three- or four-massecuite system of boiling is used and the sugars marketed are first and second grade. The yield of sugar is 8–13 per cent, depending on the quality of cane, processing, time of crushing and plant efficiency.

**Raw sugar**

India does not normally produce or consume raw sugar. It was produced for export from 1962 to 1973, according to the requirements of importing countries. The specifications for raw sugar are:
For the production of raw sugar, the plantation white sugar factories, especially the sulphitation factories, use the defecation process with minor modifications for juice clarification. The process involves the treatment of cane juice with lime only and leads to a coloured or brown sugar. The other steps in its manufacture are the same as for plantation white sugar except that single curing is used for raw sugar. The raw sugar produced usually has a thin layer of molasses over the crystals. The yield obtainable for raw sugar in the same VP factory that normally produces plantation white sugar is about 0.2 of a percentage point higher than for plantation white sugar.

**Refined sugar**

Refined sugar is produced in India in very limited quantities by two factories at Daurala and Tilaknagar. The amount produced by these factories is only a small fraction of their total sugar production.

The refined sugar produced in India mostly conforms to the following specifications:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polarization (%)</td>
<td>99.8 min</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>0.05 max</td>
</tr>
<tr>
<td>Reducing sugars (%)</td>
<td>0.03 max</td>
</tr>
<tr>
<td>Conductivity (10^6 mho/cm^2)</td>
<td>15 max</td>
</tr>
<tr>
<td>Colour (ICUMSA units)</td>
<td>50 max</td>
</tr>
</tbody>
</table>

Plantation white sugar of D or E grain size is melted in hot condensate at 60–70°C. The melt is treated with milk of lime and phosphoric acid and filtered in two filter presses in series or treated with activated carbon and filtered twice. The clear water-white liquor is boiled to form refined massecuite, which on purging gives refined sugar. The yield of refined sugar is 40–50 per cent of the melt. This process can only be used for producing small quantities of refined sugar in units producing plantation white sugar, since more than 50 per cent of the refinery molasses obtained after separating 40–50 per cent refined sugar has to be returned to the plantation white sugar or raw sugar process.

Although the procedures described above are technically simple and require minimum capital investment, it is not possible to use them for producing large quantities of refined sugar. Moreover, recovery of sugar from refinery molasses poses a serious problem. The cost of production would naturally be high if refined sugar is produced in small quantities in a unit attached to a plantation white sugar factory.

If refined sugar is desired on a large scale it is necessary first to produce raw sugar by the process described earlier. The raw sugar is melted, treated with phosphoric acid and neutralized with milk of lime. The liquor is then heated to 95°C, aerated and sent to the continuous flotation clarifier, where the scum floats and clear liquor is drained off. The clear liquor is heated with activated
carbon and filtered. This is the most modern clarification process being used. The clear water-white liquor is then boiled by a three-massequeite system of boiling. Three grades of refined sugar are obtained in curing and the final refined molasses are returned to the raw-sugar house to be used in high-grade boiling. The refined sugar so obtained is dried in rotary dryers, cooled, graded and packed.

*Cube sugar*

Most of the small amount of refined sugar produced by the Daurala and Tilaknagar factories is converted into sugar cubes, mostly for hotels and export. Another part is used in syrups for pharmaceuticals and beverages.

Cube sugar is made by simple moulding of refined sugar with water under pressure, followed by drying in hot-air chambers and packing in wrappers or cartons.

**Cost analysis of the technologies**

Because of the different yields of the different technologies the costs computed in this section are per tonne of sweetening agent instead of per tonne of cane crushed. The table gives comparative data on output, costs and employment potential for three of the technologies described above, gur, khandsari and plantation white sugar, the last in two sizes, large and mini. For the large plant, a 1,250-tcd factory is taken as standard, since that capacity is considered to be economically viable. For a mini VP factory, 100 tcd is considered economically viable.

*Mini VP technology*

After discarding its old 34-tcd VP plant, which had been set up in the 1930s, the National Sugar Institute installed a 100-tcd mini VP sugar factory. The technological operations in the mini factory are exactly the same as in a standard 1,250-tcd or larger VP factory. The operational efficiencies such as milling extraction, boiling-house extraction etc. are also the same. The unknown losses due to inversion, spillage etc. cannot however be precisely assessed at such a low level of cane crushing.

The capital investment for producing raw sugar is practically the same as that for plantation white sugar; yield is slightly higher, and there are savings in chemicals, fuel, capacity in boiling house etc., with the result that the cost of conversion is about Rs 3.70 per quintal less.¹

The capital investment required for a 1,250-tcd sugar factory capable of producing about 16,000 t of refined sugar annually by the process described above is estimated to be about Rs 75 million, compared to about Rs 60 million for a plantation white sugar factory. The cost of large-scale production of refined sugar is about Rs 291 per quintal, compared to Rs 211 for raw sugar.

Cube sugar costs about Rs 100 per quintal more to make than refined sugar.

---

¹1 quintal = 100 kg.
### TABLE. COMPARATIVE DATA FOR DIFFERENT TECHNOLOGIES

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Gur</th>
<th>Plantation white sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bullock driven</td>
<td>Diesel driven</td>
</tr>
<tr>
<td>Cane-crushing capacity</td>
<td>tcd</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Yield</td>
<td>% on cane</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Production</td>
<td>t/d</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Capital investment</td>
<td>Million Rs</td>
<td>0.005</td>
<td>0.012</td>
</tr>
<tr>
<td>Unit cost of production</td>
<td>Rs per quintal</td>
<td>130</td>
<td>132</td>
</tr>
<tr>
<td>Cane</td>
<td>Rs per quintal</td>
<td>101.50</td>
<td>101.50</td>
</tr>
<tr>
<td>Conversion</td>
<td>Rs per quintal</td>
<td>28.50</td>
<td>30.50</td>
</tr>
<tr>
<td>Employment potential per unit of production</td>
<td>Person per t/d</td>
<td>12</td>
<td>6.7</td>
</tr>
<tr>
<td>Capital investment per person</td>
<td>Rs</td>
<td>833</td>
<td>1200</td>
</tr>
<tr>
<td>Project cost per unit of production</td>
<td>Million Rs per t/d</td>
<td>0.010</td>
<td>0.008</td>
</tr>
<tr>
<td>Total employment</td>
<td>Persons</td>
<td>6</td>
<td>10</td>
</tr>
</tbody>
</table>

*1 quintal = 100 kg.*
In spite of their high cost of sugar production (the highest in the table), the khandsari factories operate successfully for the following reasons:

(a) Khandsari units pay a low excise duty, 17.5 per cent of actual sale price or on a compounded basis, taking into account the size and number of centrifugal machines employed;

(b) While the VP factories are governed by a sugar policy of 65 per cent levy and 35 per cent free, khandsari units sell their entire product in the free market;

(c) VP factories sell their molasses at a controlled price of Rs 60 per tonne, while khandsari units sell theirs at much higher prices.

Choice of appropriate technology

The technology to be chosen depends primarily on the availability of cane and market preference. It also depends upon investment capability and government policies on excise and other taxes. A detailed study of the existing conditions must be made before a technology is chosen. In what follows an attempt is made to give broad outlines of the conditions governing the adoption of each of the above technologies.

Gur

The technology of gur manufacture could only be adopted where sugar-cane is produced. Large scale production is not feasible because of the manual operations involved. Furthermore, gur has poor keeping qualities and is highly hygroscopic. Its sale value decreases considerably with time. The technology of manufacture wastes a considerable amount of the sugar present in cane. It should, therefore, be adopted only on a limited scale, preferably by farmers for their own domestic consumption.

Khandsari sugar

Khandsari production has been adopted in India in areas where cane is available in limited quantities and large sugar factories cannot be set up because of shortage of either raw material or finance. White crystalline sugar (khandsari sugar) can be produced by the modern sulphitation open-pan technology. Of the technologies compared in the table it has the highest employment potential. However, this technology is very inferior not only because of low yield and poor quality of product, but also because it involves manual operations that limit the size of factories and hence increase the cost of production. Nevertheless, khandsari units survive because of a government policy of granting an excise tax rebate. India produces 140–150 million tonnes of sugar-cane annually. The 300 existing VP sugar factories can handle hardly 60–65 million tonnes. The rest of the cane, 80–35 million tonnes, has to be used. It is not possible to set up within a reasonable period (10–20 years) enough new VP factories to consume another 65–70 million tonnes of cane. Until they are set up, inferior technologies have to be employed and have to be supported by fiscal concessions, such as excise
rebate etc. Similar circumstances may not exist in other countries. Even when the supply of cane is limited, inferior technology of khandsari should not be adopted and mini VP technology should be preferred to the inferior khandsari technology. Where cane is a scarce commodity, technologies that give maximum yield of sugar should be adopted, even if capital requirements are higher.

Plantation white sugar

The technology for manufacture of plantation white sugar is the cheapest and most efficient of the technologies. The quality of sugar is much superior to khandsari and compares favourably with that of refined sugar. The sugar produced has market acceptability and has good keeping properties. The technology involves a minimum of manual operations. Capacity of any size—from 100 to 10,000 t/d—can be achieved. The technological efficiency is the highest. Low-capacity factories can also be expanded to higher capacities as more cane becomes available. During the 1930s and 1940s, many mini factories of 100–300 tcd operated in India. In the course of time capacities increased to as high as 6,000 tcd. A few factories are attempting to expand up to 10,000 tcd. The cost of production is the lowest amongst all the technologies. Even in VP technology, the cost of production varies inversely with factory size. For all these reasons, the adoption of VP sugar technology should be encouraged in developing countries, even though the capital investment is high.

Raw sugar

The technology for raw sugar is the simplest but should only be adopted if there are plans to set up refineries. Raw sugar is not acceptable for direct consumption because of its colour and poor keeping quality.

Refined sugar

The technology for manufacture of refined sugar is the costliest and should only be adopted for sophisticated application in the food and beverage, pharmaceutical and other industries.

Conclusions and recommendations

1. Cane is the cheapest raw material for the production of sweetening agents in developing countries.

2. Gur can be produced by individual farmers for their own consumption. The poor keeping quality of gur and storage difficulties set a limitation for its commercial production on a large scale.

3. Khandsari sugar, which is white and crystalline, can be manufactured in mini factories with capacities ranging from 50 to 300 tcd using modern sulphitation OP technology. The yield of sugar is extremely low (6–7 per cent). Use of this technology should not be encouraged except under limited
conditions and should be considered only in areas where superior technologies cannot be adopted because of lack of finance or technical skill.

4. Plantation white sugar (VP) technology is the cheapest and the most efficient. The quality of the product is superior to OP khandsari sugar and is roughly equivalent to refined sugar. This technology is the one most suited for both developing and developed countries. The size and capacity of the factory will depend on the availability of raw material. Factories with capacities ranging from as little as 100 tcd to as much as 10,000 tcd can be designed and set up with ease. The cost of production is inversely proportional to the capacity of the factory.

5. Raw-sugar technology is the simplest of all; it is actually the first stage in manufacture of refined sugar. The high colour content of raw sugar leads to low market acceptability for direct consumption.

6. Refined sugar technology is the costliest.
Technology planning factors in the cane-sugar industry

M. H. Tantawi*

Sugar represents roughly 10 per cent of world food energy consumption. In general, the sugar consumption pattern of each country reflects its level of industrialization and its per capita income. In highly industrialized countries 50 to 60 per cent of total sugar consumption is channelled to industrial uses; in developing countries most sugar is consumed as food.

Factory size and location

It is difficult to generalize about the most economic factory size. The availability of high-capacity equipment can make it feasible to build a cane-sugar factory capable of processing up to 20,000 tcd. But to estimate the most economic size for a given factory in a given location, these factors must be taken into consideration:

(a) The expected crop within 20 to 30 km of the factory;
(b) The duration of the crushing season;
(c) Whether production is intended for local consumption or for export.

When selecting the location of a sugar factory, these factors are decisive:

(a) Proximity to the cane fields to avoid excessive transportation costs;
(b) Availability of an ample water supply;
(c) Accessibility to the national network of roads or railways to facilitate transportation to domestic markets and export centres.

Technical options

To unload cane several mechanical solutions are available: tilting, dumping or gantry crane; choice depends on the size of the cane yard and the feeding table or of the feeding conveyors. The sequence of processing operations is as follows:

- Juice extraction and bagasse disposal
- Juice purification and mud disposal
- Juice concentration
- Crystallization
- Condensation

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Juice extraction: Extraction by crushing the cane between massive rollers was the only process used by the sugar industry until the 1960s when extraction by lixiviation was introduced. This process has the following advantages over straight milling:

(a) Lower investment cost since one cane lixiviation unit replaces three to four rollers;
(b) Lower maintenance costs;
(c) The juice has a lower starch content;
(d) Higher extraction efficiency.

Juice purification: Depending on the grade of sugar to be produced one of the following processes is adopted:

(a) Lime defecation, which is a simple process universally used in sugar factories to produce raw sugar;
(b) Sulphitation, which is the cheapest process to produce white cane sugar;
(c) Carbonation, which is only rarely used to produce white sugar from cane.

Juice concentration: Multiple-effect evaporation is the only technique used in the sugar industry to concentrate the clear juice.

Crystallization: In general all raw cane sugar factories follow a three boiling scheme.

Condensation: two condensing systems are widely used:

(a) The counter-current condenser, which uses a vacuum pump to extract the air and non-condensable gases from the top of the condenser;
(b) The jet condenser, which is a co-current type condenser. This system eliminates the vacuum pump as well as the air piping between the condenser and the last evaporating vessel or the vacuum pans.

When the water supply is limited and the condenser cooling water is recycled through a cooling tower, the counter-current condenser and an air pump are indicated.

The jet condenser can only be used when an ample water supply is available.

Choice of capacity

The optimum size of a factory under given conditions is determined by the duration of the crushing season. Small factories of 2,500 tcd would be justified if the crushing season lasts for seven to eight months a year. Large sugar factories processing one million tonnes or more of cane per season, however, could provide the core for an industrial complex to diversify the agricultural basis of a given region. In addition, such large factories could easily use their surplus bagasse to manufacture paper, molasses, alcohol and fodder yeast, since collecting surplus bagasse and molasses from small, isolated plants for processing in a central factory is often difficult. Newsprint mills with a capacity of 90,000 t/a based on bagasse are at an advanced stage of construction in Mexico and Peru.
Investments in the sugar industry

The sugar industry often faces very low prices because production is greater than demand. For example, the considerable escalation of sugar prices in 1974 induced many countries to increase production but sugar prices have now declined to a level where the cost of investment per tonne of sugar would hardly attract investors unless the sugar was to be consumed by a local market or sugar exports were subsidized.

Two main factors directly influence the cost of investment per tonne of sugar: plant size and duration of the crushing season at full capacity. The latter is the more crucial consideration.

For example, a plant with an average crushing rate of 10,000 tcd and a season of 150 days, producing 160,000 t per season, would require an investment of about $600 per tonne representing:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost (Dollars per tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant and equipment</td>
<td>450</td>
</tr>
<tr>
<td>Plant infrastructure</td>
<td>50</td>
</tr>
<tr>
<td>Cane transport</td>
<td>50</td>
</tr>
<tr>
<td>Community development facilities</td>
<td>50</td>
</tr>
</tbody>
</table>

At such a high investment cost per tonne of sugar, efficient operation is important. The sharp rise in the price of equipment and fuel in recent years has reduced the profit margin in the sugar industry considerably.

Efficient operation requires attention to these factors:

(a) Sugar cane is a perishable crop and must be processed within 24 hours of harvesting. This requires careful planning of harvesting transport operations and very tight co-ordination between field and factory;

(b) New sugar factories should be carefully designed. The capacity of the pan and centrifugal stations should be calculated on the basis of the highest expected molasses yield. Such equipment may be expensive but it allows the factory to crush at full capacity regardless of fluctuations in cane quality;

(c) A factory should operate at full capacity and crush at a regular rate to avoid losses and delays;

(d) A high level of maintenance is needed to avoid shut-downs or crushing at a reduced rate because of malfunctioning equipment;

(e) Steam and lubricating oils should be used as economically as possible.
By-products of the sugar industry in Cuba

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It has become increasingly clear in recent years that the future of the sugar industry depends on its successful development of sugar by-products. This paper discusses the current situation and plans for the future of the sugar industry of the Republic of Cuba. The by-products considered are bagasse, molasses, single-cell protein, ethyl alcohol, and dextran.

Bagasse

A sugar mill processing 1,500–2,000 tonnes of cane per day (tcd) can produce a bagasse surplus of 10–15 per cent beyond its own fuel requirements. With higher thermal efficiency, surplus bagasse production could rise as high as 25 per cent of the total. This bagasse can be used as fuel within the sugar industry and to produce chemical pulps, paper products and furfural.

Paper from bagasse

Currently a plant with an output of 45,000 t/a of writing and printing paper and 15,000 t/a of tissue paper costs about $75–80 million. The world market price for writing and printing paper is about $600/t; production costs about $350/t.

A 300 t/d newsprint plant presently costs some $40–45 million. Newsprint is selling at some $400/t and costs about $260/t to produce.

More than one million t/a of paper are being produced globally with bagasse as the raw material. Cuba has three paper plants in operation using more than 100,000 t/a of bagasse:

(a) “Technica Cubana” (Matanzas province), erected in 1957 has a capacity of 20,000 t/a of writing and printing paper;

(b) “Pulpa Cuba” (Sancti Spiritus province), erected in 1959, has a capacity of 18,000 t/a of writing, printing, and industrial papers;

(c) “Sergio Gonzalez”, in operation since 1958, has a capacity of 15,000 t/a of cardboard and industrial paper.

A new factory for the production of 60,000 t/a of printing and writing papers is planned to start operations between 1981–85. This new investment

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will be complemented by an extensive programme to modernize and expand existing factories.

Cuba is also devoting special attention to the development of technologies for producing newsprint paper and dissolving pulps (more than 90 per cent cellulose) for textile fibres, cellophane and other cellulosic derivatives.

In new-plant production, Cuba's main efforts have been centred on obtaining mechanical pulps from bagasse with the same quality and economic efficiency as those obtained from wood. Such mechanical pulps from bagasse will allow production of many types of paper which can only be manufactured today by expensive chemical processes. These efforts are part of the Cuba-9 Project which is being implemented with the co-operation of the United Nations Development Programme (UNDP), the United Nations Industrial Development Organization (UNIDO), and with financial support from the Governments of Canada and Finland.

**Particle and fibre boards from bagasse**

The technology for boards from bagasse is simple and plants can be installed in locations with modest water resources. Furthermore, production consumes only 3 t of bagasse per tonne of board. A 120 t/d plant with a production cost of $180/m³ currently costs about $13.5 million.

Cuba is now using some 150,000 t/a of bagasse for its board industry, and plans to use 170,000 t/a by the end of 1980. There are two particle board factories based on bagasse in Cuba, an 18,000 t/a plant in Cienfuegos and a 12,000 t/a factory in Havana. A 7,800 t/a fibre board plant has been established in Las Tíenas. Four new plants are planned.

**Furfural**

Furfural is used as a selective solvent for production of lubricants, furfurilic alcohol, and certain pharmaceuticals and pesticides. World demand is expected to reach 315,000 t/a by 1980 while existing and planned production capacities will only be 308,000 t/a. Since capacity in the industry has historically operated at some 75 per cent efficiency, actual global output in 1980 might amount to only 235,000 t/a or 80,000 t/a less than estimated requirements.

Cuba is considering creating the capacity to manufacture 10,000–15,000 t/a of furfural during 1980–85. Furfural production requires the following amounts of material and energy per tonne of output:

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagasse</td>
<td>12.5 t</td>
</tr>
<tr>
<td>Water</td>
<td>60 m³</td>
</tr>
<tr>
<td>Electricity</td>
<td>1,200 kWh</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>5 t</td>
</tr>
</tbody>
</table>

**Molasses**

Molasses, the liquid residue from the process of sugar crystallization, is a source of carbohydrate, which can be used to produce animal feed, single-cell protein, ethyl alcohol or dextran.
Animal feed

Cuba is currently using about 1 million t/a of molasses as feed for cattle, and is extending the programme to swine and poultry.

Single-cell protein

Since 1965, Cuba has been operating a 9,000 t/a fodder yeast plant. Ten new 40 t/d yeast factories are planned. The cost of a 12,000 t/a plant is presently estimated at $9 million. Assuming a molasses price of $5/t, yeast containing 50 per cent raw protein costs $170/t to produce.

Ethyl alcohol

There are currently 18 distilleries in Cuba with a total capacity of 200 million litres per year. The production of alcohol by fermentation also permits recovery of yeast from the mash before distillation. The yeast recovered in this way amounts to some 9,000 t/a.

A new plant to produce 100,000 litres of alcohol per day for beverages is under construction, and includes facilities to produce 6,000 t/a of yeast.

Dextran

Dextran is a glucose polymer obtained by a microbiological process from refined or raw sugar. Since 1963, Cuba has been operating a plant in Matanzas province with a capacity of 300 t/a of technical dextran in the form of a highly hygroscopic white powder. Dextran production requires the following material and energy per tonne of output:

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>4.0 t</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>1 700 l</td>
</tr>
<tr>
<td>Steam</td>
<td>50 :</td>
</tr>
<tr>
<td>Electricity</td>
<td>700 kWh</td>
</tr>
</tbody>
</table>

Conclusion

Cuban experience has demonstrated that the by-products of the sugar industry can be used to manufacture valuable products. The sale of these products is especially important when the sugar price is depressed.
Annex 1

SELECTED DOCUMENTATION PUBLISHED OR COMPILED BY UNIDO RELATING TO THE SUBJECT


Cane molasses fermentation alcohol industry in Fiji. Paper prepared by R. Karan for the Workshop on Fermentation Alcohol for Use as Fuel and Chemical Feedstock in Developing Countries, Vienna, Austria, 1979. 1979. 12 p. tables, map. (ID/WG.293/18)


Cost control factors in the production of ethanol from sugar-cane. Paper prepared by F. Kelly for the Workshop on Fermentation Alcohol for Use as Fuel and Chemical Feedstock in Developing Countries, Vienna, Austria, 1979. 1979. 21 p. figures. (ID/WG.293/15)


Technologies from developing countries. Development and transfer of technology series no. 7, 1978. 35 p. (ID/208)

Sugar industry, p. 8.

High fructose corn syrup production. p. 108.


ID/WG.191/1 Tender documents to be prepared on the results of a feasibility study and technical data for plant specifications in the sugar industry. 66 p.
R. Hulpiau

ID/WG.191/2 Unit operations and unit processes for beet and cane sugar production. 66 p. tables, diagrams.
G. Aumuller

ID/WG.191/3 Technical and technological processing considerations for beet and cane sugar production. 103 p.
G. Morvai

ID/WG.191/4 Questions for nomenclature of the sugar industry. 10 p.
F. Kelly

ID/WG.191/5 Process flow in the sugar industry. 14 p.
F. Kelly

ID/WG.191/6 Unit operation in the sugar industry. 17 p.
F. Kelly

ID/WG.191/7 Safety and sanitary requirements in the sugar industry. 9 p.
F. Kelly

ID/WG.191/8 Water, steam, gas and energy supply for a sugar factory. 9 p.
F. Kelly

ID/WG.191/9 Thermo-technical evaluations of the sugar production process. 14 p.
F. Kelly

ID/WG.191/10 Quality control requirements of the sugar industry. 15 p.
F. Kelly

ID/WG.191/11 Sugar production equipment characteristics and spare parts. 8 p.
F. Kelly

ID/WG.191/12 Industrial feasibility calculations in the sugar industry. 14 p.
F. Kelly
ID/WG.191/13 Offers and quotations for sugar production equipment and complete plants. 12 p.  
F. Kelly

ID/WG.191/14 Test runs and take-over certificates of sugar production plants. 14 p.  
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L. Nesvadba

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M. Tantawi

ID/WG.191/17 Repair and maintenance problems experienced in the sugar industry. 21 p. 
S. Gundu Rao


ID/WG.247/1 Sociological issues in the design of cane-growing systems. 8 p. diagram. 
A. Barclay

ID/WG.247/2 The impact of sugar technologies on social change and development. 18 p. 
A. Barclay

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S. Ohingo

ID/WG.247/4 Environmental implications of different sugar technologies with special reference to India. 36 p. tables. 
B. Behari

ID/WG.247/5 Australian cane-growing and sugar milling—Some implications of the technology employed. 18 p. 
G. Ferguson

ID/WG.247/6 Potentials and impact of by-products of the sugar-cane industry. 31 p. tables. 
O. Almazán del Olmo

ID/WG.247/7 The long-term agricultural implication of cane-growing. 41 p. tables. 
Z. Menshawi

ID/WG.247/8 Recent developments in the world sugar industry. 18 p. tables. 
R. Robson

ID/WG.247/9 Impact of different sugar technologies on the economic environment. 20 p. tables. 
R. Alpine

ID/WG.247/10 Economic viability in African conditions of the large-scale vacuum pan sugar technology. 26 p. tables. 
R. Alpine and F. Duguid
ID/WG.247/11 Economic viability in African conditions of the small-scale open pan sugar technology. 21 p. table, annexes.
   R. Alpine and F. Duguid

ID/WG.247/12 Environmental and economic impact of alternative agricultural sugar technologies. 24 p. tables.
   J. Pickett and F. Duguid

ID/WG.247/13 Energy consumption in the sugar industry. 26 p. annexes.
   R. Alpine and F. Duguid

ID/WG.247/14 Measuring the environmental and economic impact of alternative technologies. 20 p. flow-chart.
   J. Pickett

ID/WG.247/15 The sensitivity of sugar technology performance to changes in technical and economic parameters. 15 p. tables.
   R. Alpine

ID/WG.247/16 Possibilities for the further processing of sugar industry by-products. 18 p. tables.
   F. Duguid and R. Alpine

ID/WG.247/17 Recent developments in large-scale vacuum pan sugar technology with particular reference to developing countries. 30 p.
   A. MacGillivray and G. Wood

ID/WG.247/19 Present and potential sugar production and consumption in Africa. 77 p. tables, graphs.
   T. Gedamu

ID/WG.247/20 Economy of scale in the sugar industry. 33 p. tables, diagrams, graphs.
   J. Paturau

ID/WG.247/21 Pollution control in sugar industry. 31 p. tables, diagrams, map, graph.
   P. Kiravanich and Y. Unkulvasapaul

*Technical information compiled by the Industrial Inquiry Service (IIS) and the Industrial and Technological Information Bank (INTIB)*

Copies of these compilations are available to requestors from developing countries only. The reference number must be quoted.

Alcohol from sugar-cane molasses. (IIS file no. 7992)

Mini sugar plants. (IIS file no. 8651)

Torula yeast and lysine (amino acid). (IIS file no. 7882)

Sugar-cane wax. (IIS file no. 5415)
Annex II

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