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08416

Distr.
LIMITED
ID/WG. 282/28
29 Sept. 1978
ENGLISH

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

INTERNATIONAL FORUM ON APPROPRIATE INDUSTRIAL TECHNOLOGY

New Delhi/Anand, India 20–30 November 1978

WORKING GROUP No.4

APPROPRIATE TECHNOLOGY FOR THE PRODUCTION OF SUGAR

APPROPRIATE TECHNOLOGY IN PRODUCTION OF CANE SUGAR
Background Paper

id. 78-5884

APPROPRIATE TECHNOLOGY IN PRODUCTION OF CANE SUGAR

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Appendix: Equipment Suppliers

1. Introduction

This paper is set out in the context of the genrally accepted belief that industrialization in many less developed countries (LDC's) has produced disappointing results in terms of attaining developmental goals other than economic growth *per se*.

In the following section alternative sugar production processes, products and their by-products are described. The section also includes some production, trade and consumption statistics to illustrate the likely future importance in the industrialization policies of many LDCs. Section 3 briefly discusses the more important agricultural aspects of sugar cane production, emphasizing the necessarily close relationship with factory operations.

Section 4 identifies alternative techniques at each major sub-process for two technology types viz open-pan and vacuum-pan. The section also includes a brief discussion of sources of equipment for both technologies. Section 5 goes on to evaluate and discuss a number of alternative technologies based on stated assumptions on season length, operating parameters and cost data. Section 6 is a discussion of relevant policy implications and options, drawing from the illustrative evaluation of the previous section.

An appendix to this paper offers a list of suppliers of turnkey packages and specialist equipment for both small- and large-scale technologies and a number of consulting firms.

2. Processes and Products

2.1 Sugar production processes

The processing of sugar cane to produce a form of sweetener has been practised for some 2,000 years. Present day industrial practice, however, can be categorized into basically two methods, each with internal variations. The first of these is the open-pan system, also known as the *khandsari* process, which has been developed and improved for the small-scale production of crystalline sugar, particularly in India. The second is the vacuum-pan process widely used for the large-scale production of raw or mill-white grades of sugar.

The manufacture of crystalline sugar, whether by a vacuum-pan or open-pan method, involves several stages. The first of these is the extraction of the sucrose-rich juice. By the use of vegetable or chemical clarificants, the non-sucrose components are precipitated, settled and filtered leaving clear juice which is then concentrated by boiling. When the thick syrup contains a sufficiently high concentration of sucrose the crystallization process begins. Sucrose crystals are separated from the viscous liquid by centrifugal force and are finally dried, bagged and stored.

2.1.1 Open-pan sugar production

The traditional open-pan method of sugar production dates back several centuries. Cane is crushed by a small animal-powered mill and the juice boiled in an open vessel over a fire. Thick syrup is transferred to moulds or clay pots and left to solidify. Much present day production of *gur* (Asia), *jaggery* (Africa), *panela* (South America) has added very little to the traditional method except the use of power-driven crushers which are more efficient in juice extraction, and the use of vegetable mucillages, lime or other chemical clarifying agents to lighten the colour of the final product. Beyond this, the use of centrifugal machines allows the production of a brownish-coloured crystal sugar commonly known as *khandsari*. In recent years a considerable amount of engineering and chemical research and development effort has been expended on the open-pan system, largely in India.[1/] The improved *Khandsari* or Open-Pan Sulphitation (OPS) process can now be used to produce a sugar comparable in quality and appearance to mill-white sugar. The description of this improved OPS system can be conveniently organized in three parts - covering cane preparation and crushing, juice clarification and boiling, and crystallization and separation from molasses respectively.

<u>Cane preparation and crushing</u>: Sugar cane is normally delivered to the factory by animal-drawn cart or tractor and trailer. For ease of handling cane may be tied in bundles, using cane leaves twisted into a 'rope'. Cane may be fed directly to the one or two 3-roller mills (possibly hydraulic) or may first be passed through a set of rotating knives which helps to improve the juice extraction rate. The first set of machinery is driven by an electric motor or diesel engine. The capacity of a sugar factory can be measured by the quantity of cane which the mills can crush in a given period of time. For an OPS factory this tends to be in the range of 60-250 tonnes of cane per day (tcd); the latter value is normally achieved by two sets of mills running simultaneously. One of the main reasons for this limit is that each set of open boiling pans (see below) cannot be greater than a size which one sugar boiler can handle. Replication would therefore be the only way to increase capacity. Such increase would raise difficult questions for plant lay-out, material handling and effective use of labour.

_/ See for example work by M.K. Garg in *Open-Pan Sulphitation Process of Khandsari Sugar Manufacture*, P.R.A.I., Lucknow, India, 1969.

Juice clarification and boiling: To produce a sugar of a given purity and colour it is first necessary to remove as much of the non-sucrose components of the juice as possible. By adding milk of lime and sulphur dioxide, impurities (which include nutrients, vitamins, proteins etc. from the cane) are separated in the form of a precipitate or surface scum. The efficiency of this process is increased by heating the juice before adding the chemicals. The solids are removed by settling or filtration with the filtrate being returned for re-clarification. Filter mud is commonly disposed of as landfill or spread on cane fields.

Clarified juice is passed to the first of a series of open pans. Usually five in number the pans, with a furnace below, are arranged on a slight gradient. The furnace is fired by bagasse, cane trash if available and firewood. As water is evaporated and the juice becomes thicker, it is transferred from one pan to another in accordance with temperature variations in different parts of the furnace. Without instrumentation for measuring temperature or sucrose concentration (brix) it is difficult to determine the precise moment when the syrup should be transferred. Losses of sucrose are relatively high as boiling at high temperature and the uneven temperature distribution in each pan causes carmelization and inversion of sucrose to dextrose and fructose. The imprecision and dangers of sucrose loss in boiling provide considerable scope for the skills and experience of the sugar boiler under whose supervision it takes place.

As the crystals of sucrose are just about to form, the syrup is transferred from the finishing pan to the crystallizers.

Crystallization and separation from molasses: To allow the full development of sucrose crystals it is necessary to keep the embryo crystals in close contact with sucrose-containing liquid. This is done in a large tank with a mechanically driven, slow moving agitator. The crystallization may take up to 48 hours for the first sugar and up to 3 days for the second. The mixture of crystals and molasses can then be separated by centrifugal force. The crystals are spun and washed to remove as much of the molasses as possible. As the molasses is still very rich in sucrose, it is normally returned to the pans for boiling twice more. Sugar drying methods vary from sun-drying to boxes in a well-ventilated drying room to the use of an electrically-driven rotary drier. The final products from an OPS unit are typically three grades of sugar and final molasses. Thus of the total sugar output the first, second and third grades will represent 65, 25 and 10 per cent respectively; and overall between 45 and just over 60 per cent of sucrose available in the cane would be recovered. The quantity of final molasses is normally too small to warrant further processing so it may be sold to a large or central organization for the production of alcohol (mainly industrial) or cattle feed (see Section 2.3).

2.1.2 Vacuum-pan sugar production

As engineering skill has developed and a greater understanding been achieved in the chemistry of sugar production, a technology has been created with much more control and greater recovery of sucrose from cane than before. This is a relatively capital-intensive technology and it would appear that economies of scale have pushed the so-called 'minimum economic size' up to several thousand tonnes of cane per day. It is again convenient to organize the description of the technology in three parts.

Cane preparation and crushing: After being placed on a moving cane table, the cane stalks are levelled and shredded or chopped to form a dense mass approaching the first mill. A milling train usually consists of four or five sets of 3 or 4 roller hydraulic crushers. The juice extracted by the first set of rollers accounts for about 80 per cent of the total removed and to increase the extraction of the remaining sucrose by the subsequent rollers, water or dilute juice is sprayed onto the fibre. This spraying is known as imbibition or maceration.

The capacity of a milling train is in the range of 1250 to 5000 tcd although there are a few cases of capacities over 20000 tcd. Of the factories in operation throughout the world (excluding Brazil for which no data were available) in 1975, however, some 50 per cent had a capacity of less than 4500 tcd.[2/] The major limiting factor is typically cane supply both in terms of land area and organization. In the factory itself increased scale is normally associated with instrumentation and automation. Vacuum-pan factories are largely self-sufficient in fuel requirements, utilizing bagasse from the mills to fire the boilers

An alternative means of juice extraction is by diffusion but usually after the cane has been passed through one set of rollers.[3/] After being removed from the diffuser, bagasse has to be passed through a de-watering mill before it can be used as a furnace fuel.

Juice clarification and boiling: As with OPS the most commonly used clarification system for the production of mill-white sugar is that of liming and sulphitation although phosphatation and carbonation are alternatives. The vacuum-pan process, however, is much more scientific than the OPS being carried out, as far as possible, in standardized conditions of, for example, temperature and brix. Precipitation of impurities is a continuous process; the mud is filtered through filter presses or rotary vacuum filters and water is added to 'sweeten off' the mud i.e. to wash out sucrose in solution and so reduce losses.

The clear juice is passed to multiple-effect evaporators. This is a steam economy measure using the high temperature vapour from one effect to heat the next. Evaporation continues until the syrup is about 60/65° Brix after which it is transferred to the vacuum-pans along with a proportion of re-cycled molasses. Boiling under vacuum involves lower temperatures than would otherwise prevail and so losses due to inversion and carmelization are considerably

2/ Source: Sugar Y Azucar Yearbook, 1975, edited by Dudley Smith.

3/ Diffusion is a displacement washing process by means of which the relatively strong concentration of sucrose in the bagasse is diluted and hence displaced (extracted) by the addition of water and/or weak juice.

reduced. To encourage sucrose crystals to develop 'seed' or dust sugar is injected; the seed may be sugar from the second or third boiling of molasses.

Crystallization and separation from molasses: By a combination of skill and instrumentation the strike is dropped from the vacuum-pan to the crystallizer below. The timing of this operation affects the yield and quality of the sugar produced. After two hours of slow movement in the crystallizer the fully developed sucrose crystals are separated from the molasses in large, batch centrifugal machines. The first purge (wash) is with water and the second with steam, so as not to dissolve too much sucrose and to encourage drying. The sugar is transported along the conveyor with one or more mesh screens for size grading. Drying is completed in a rotary drier or granulator and the sugar is stored in a hopper before bagging. Sucrose recovery is in the range of 80-85 per cent of that available in cane. Molasses is boiled two or three times, usually to produce A and B sugar of saleable quality and C (and D) sugar for re-melting or use as seed.

2.2 Product choice

In its crystalline form, sucrose is a very pure natural product being more akin to a purified chemical than to a form of food. Sugar cane itself may be used as a high yielding, good quality source of cattle feed; for sale as chewing stalks; or crushed to yield cane juice for drinking. There are, however, several types of processed 'sugar' which can be produced using part or all of the technologies described above; and these differ in sucrose content or purity which is measured in degrees of polarization (^{o}pol). A classification commonly used in the industry is that of centrifugal and non-centrifugal sugars, the former being raw/refined sugar and mill- (or plantation-) white sugar and the latter being *khandsari* sugar and solid *gur (jaggery,panela)*. This classification is misleading in that *khandsari* sugar, and particularly the improved OPS sugar, is produced with the use of centrifugal machines. A more useful distinction is that between vacuum-pan and open-pan sugars, with the former comprising what has been traditionally described as centrifugal sugar.

Gur is a brownish, non-crystalline form of sugar which contains 70-75 per cent sucrose plus the minerals, vitamins, proteins and other constituents normally separated in more processed sugars as molasses. The nutritive value of *gur*, therefore, is slightly greater than that of the crystalline sugars but the effect of this on the human diet is negligible. The nutrient components do, however, support the growth of micro-organisms (which sucrose does not) and this can lead to deterioration of the product. Another disadvantage and possible danger of *gur* is that its colour and consistency make it difficult to identify extraneous matter which would be clearly visible in crystalline sugar. A recent trend in *gur* production has been the use of chemical rather than vegetable clarifying agents. The result can be a more attractive looking and probably somewhat cleaner product much in demand as a food and for baking and cooking. The typically small-scale nature of *gur* producing units, however, raises some doubts as to the ability of the operator to use sulphur, for example, without danger to health in the process and from the residual sulphur compounds in the final product. *Gur* is produced and sold at relatively low cost and may be used as a sweetener, as a food, or for cooking and baking (e.g. in Indian sweetmeats). In some parts of the world it is also used as a cheap source of carbohydrates for fermentation and distillation in the production of, usually illicit, alcohol.

Open-pan sugar has often been dismissed as a brown, crystalline form of *gur* which would not sell because of consumer demand for 'white' sugar. Technological advances in the past 20 years, however, have enabled the open-pan system to produce a reasonably white sugar which can compete with the output of vacuum-pan factories; and at its most efficient the OPS sugar is indistinguishable from the product of the vacuum-pan process. OPS sugar should be 98-99^{O}pol with a moisture content of less than 0.5 per cent assuming a reasonable standard of management. The remaining invert sugars and non-sugars are harmless but may give the product an off-white or yellowish coloration with less lustrous crystals than the vacuum-pan sugars. The lack of fine control over the process leads to a considerable degree of variation in the output, mainly in terms of crystal size but some two-thirds of the sugar would sufficiently resemble mill-white sugar as to be an acceptable substitute in normal domestic usage.

Raw and refined sugars must be grouped together as the former is not used directly and must be refined. Raw sugar is commonly produced in the tropics and exported to Europe and North America for refining. By re-melting, further clarification and re-crystallization the sucrose content of raw sugar is increased from about 98^{O}pol to over 99.7^{O}, to give the refined product. The colour of refined sugar is less than 60 ICUMSA (International Commission for Uniform Methods of Sugar Analysis) units. As mentioned before, refined sugar is virtually a pure chemical and as such can be used for any relevant domestic or industrial purpose.

Mill-white (plantation-white) sugar falls between raw and refined sugars in terms of purity, being around 99.5^{O} pol. The process involves a considerable amount of clarification, but not the repetition of the process required when refining raw sugar. The result is a white, crystalline product which is marginally less pure than refined sugar and with a colour which can be less than 150 ICUMSA units. A difference of 100 colour units is barely noticeable to the naked eye so that a good mill-white can be almost indistinguishable from refined sugar, although crystal size tends to be larger and more variable. In practice, mill-white sugar tends to have a colour of several hundred ICUMSA units with the off-white or yellowish appearance of OPS sugar. Mill-white sugar production in developing countries has increased dramatically over recent years.

The chemical differences between OPS, mill-white and refined sugars are very small - from 98-99.9 per cent sucrose. Each increment in purity, however, is achieved by a more sophisticated technology, typically larger in scale and more capital-intensive in character. For this and other reasons, it may be argued - in the light of the distinction to be made between purity in a technical sense (polarization) and purity defined as the absence of health hazard - that in developing countries no great premium need be placed on technical purity. In this regard it is useful to consider the uses of sugar in such countries.

Sugar is used in households for sweetening and for industrial purposes. For domestic use an important influence on choice is colour as seen by the naked eye. The attitude of the consumer may be culturally constrained, influenced (or capable of being influenced), by advertizing. There are circumstances, however, where certain preferences are rational. Thus adulteration of the product is likely to be noticed more quickly in white sugar with uniform crystal size than in other sugars; and cube sugar is easy to store and may keep longer in a humid atmosphere. The question of colour is not restricted to a comparison between the different types of sugar but arises within each of OPS and mill-white sugars, depending on factors such as weather (affecting cane quality), the intentional degree or effort at clarification and centrifugal separation stages and the degree of managerial control throughout the process.

Industrial utilization of sugar may be classified in ascending order of quality requirements, namely: confectionery, soft drinks, canning and pharmaceuticals. The important characteristics here are extraneous matter, filterability, sulphur dioxide content and in certain cases, colour. Industrial use requires sugar to be melted or dissolved in water, so that insoluble solids need to be at a minimum. Colour is important in soft drinks and jams where any cloudiness or discoloration is obvious to a potential buyer. In soft drinks manufacture the requirements of a few international brand names are higher, for purposes of uniformity of product, than those of local manufacturers. The sulphur dioxide content is critical for canning to avoid staining and contamination of the food. The pharmaceutical industry has strict specifications, as does the baby food industry, in terms of non-sugar components, especially sulphur dioxide, heavy metals and micro-biological content. Industry, therefore, has generally higher quality requirements than would normally be needed for domestic consumption sugar.

2.3 Sugar industry by-products

The by-products of the sugar industry - bagasse, molasses and filter mud - can each be processed in a variety of ways. In developing countries, however, there are two important factors which limit the industrial utilization of sugar and its by-products; the relatively small size of internal market demand; and the capital-intensive nature of the production process for many of these goods. There are many examples in the developing world of factories which produce sophisticated products operating well below capacity because they are unable to compete internationally and the domestic market is too small in relation to full capacity production. Bagasse, molasses and filter mud potentially present serious disposal problems and environmental hazards but with adequate forethought and planning in the design of a project these could become valuable raw materials for a range of ancillary industries, helping to generate more wealth, employment and overall diversification of the project area.

2.3.1 Bagasse

Bagasse is the cane fibre remaining after the extraction of juice with a composition of 43-52 per cent fibre; 46-52 per cent moisture; and 2-6 per cent soluble solids. The composition is affected by efficiency of milling, cane variety and maturity, and cane deterioration since harvesting. Production of wet bagasse can be assumed to be 30 per cent in the vacuum-pan technology from a cane of 15 per cent fibre. In the open-pan technology, differences in milling efficiency would cause bagasse production to be around 35 per cent on cane.

The most natural use of bagasse is as boiler fuel to power the vacuum-pan factory or to heat the furnaces in an open-pan unit. While an OPS unit requires supplementary fuel an efficient vacuum-pan factory should be self-sufficient in its fuel requirements provided the fibre content of cane is not too low; discussion of potential uses for bagasse implies that either an alternative fuel is to be provided or that the quantity of bagasse available is surplus to factory requirements. Substitution of bagasse assumes an alternative fuel source is available at low cost; theoretically 1 tonne of furnace oil can replace 5 tonnes of bagasse. In practical terms, however, this assumption is not valid except perhaps where cheap hydroelectric power is available. In any case, with the present plights of developing countries facing rapidly increasing fuel import costs, and the global problem of the depletion of non-renewable resources, it is unlikely that a valid case could be made for complete substitution of a material which represents a valuable and annually renewable source of energy.

In general terms a modern vacuum-pan factory should have a surplus of bagasse of say 1 per cent on cane. With a low bulk density of around 160 kg per m^3 and its inflammable nature, bagasse is a costly material to store and transport and consequently a bagasse-using industry such as paper or board production would require to be situated close to the sugar factory. This has the additional saving of access to workshop facilities and perhaps the use of electricity generated in the sugar factory. The scale of operation of the ancillary industry would depend on the daily capacity of the sugar factory, the actual surplus and the length of the crushing season; for example a 200 tch factory with 1 per cent on cane as surplus bagasse gives 48 tonnes per day but the annual supply could be based on as little as 100 days per year hence reducing the daily capacity to say 12t for all year round operation.

An interesting alternative to the utilization of surplus bagasse in a secondary industry is its use in the sugar factory to generate surplus electricity. Typically bagasse is used as a fuel to fire boilers for the production of steam and hence to electrical power. By careful planning and design of the factory's steam economy system, steam and thus electricity can be generated surplus to the factory's needs and be made available to a national grid or to the immediate area including employees housing. Again season length is critical as the longer the season the less dependence there will be on alternative sources of supply such as diesel generators or, where available, links to the national grid.

2.3.2 Molasses

Final or blackstrap molasses is the viscous liquid remaining after repeated crystallization and centrifugal separation of sugar. Molasses commonly contains 30-40 per cent sucrose and other non-crystallizable sugars and is produced at a rate of about 3.5 per cent on cane in the vacuum-pan technology and 4.25 per cent on cane in the OPS technology. As with bagasse, potential buyers of molasses as a raw material would tend to deal with the larger sugar factories although a central collecting system may be possible where several OPS units are in existence.

Molasses is commonly used for fermentation and distillation to industrial alcohol, often after exportation to Europe and North America. In most LDC's the domestic market for industrial alcohol is small but there is an increasing interest in the production of power alcohol from molasses. This product can be used in a blend with petrol hence saving on expensive fuel imports. A major proponent of this is Brazil[4/] which has a large sugar industry and collects molasses from several factories to a central distillery; very recently, with sugar

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4/ Al Hammond, "Alcohol: A Brazilian Answer to the Energy Crisis", *Science*, Vol.195, p.564, February 1977.

fetching a low price on the world market, sugar has been used for power alcohol production.

Should an alcohol industry be considered full account must be taken of the spent mash, a very highly polluting material if disposed of by discharge or dumping. As a raw material, however, it is high in recoverable potash, or can be dried and processed to produce cattle feed yeast.

Another use of molasses which is gaining interest in LDC's is as a high-energy cattle feed. With the necessary nutrient supplementation, small quantities of molasses can be mixed as a feed for intensive cattle production or as a seasonal addition to the fodder supply of traditional cattle rearing.

2.3.3 Filter mud

Filter mud contains the non-sucrose components of sugar cane juice, both organic and inorganic, which are precipitated out of the juice in the settling/clarification process. Mud is normally 60-80 per cent moisture depending on the type of filter used and amounts to 4-5 per cent on cane.

Although cane wax can be extracted by chemical means, the most common use of filter mud or means of its disposal is as a fertilizer/soil conditioner spread over the cane fields. On a dry basis, filter mud contain 1-4 per cent CaO; 1-3 per cent P_2O_5; and 0.5-1.5 per cent MgO. The fertilizing effect, especially of phosphate, is due to the very large quantities applied to the fields usually between uprooting and replanting. Possibly the more significant effect is due to a fibre content of up to 30 per cent which has a beneficial conditioning effect on both heavy clay soils and sandy soils.

The major problem with filter mud is the cost of transport for its disposal. In a 200 tch vacuum-pan factory it is produced at a rate of some 200 tonnes per day. In small factories, local farmers may be invited to collect the mud at no cost except for their own time and means of transport.

2.4 Production and trade statistics

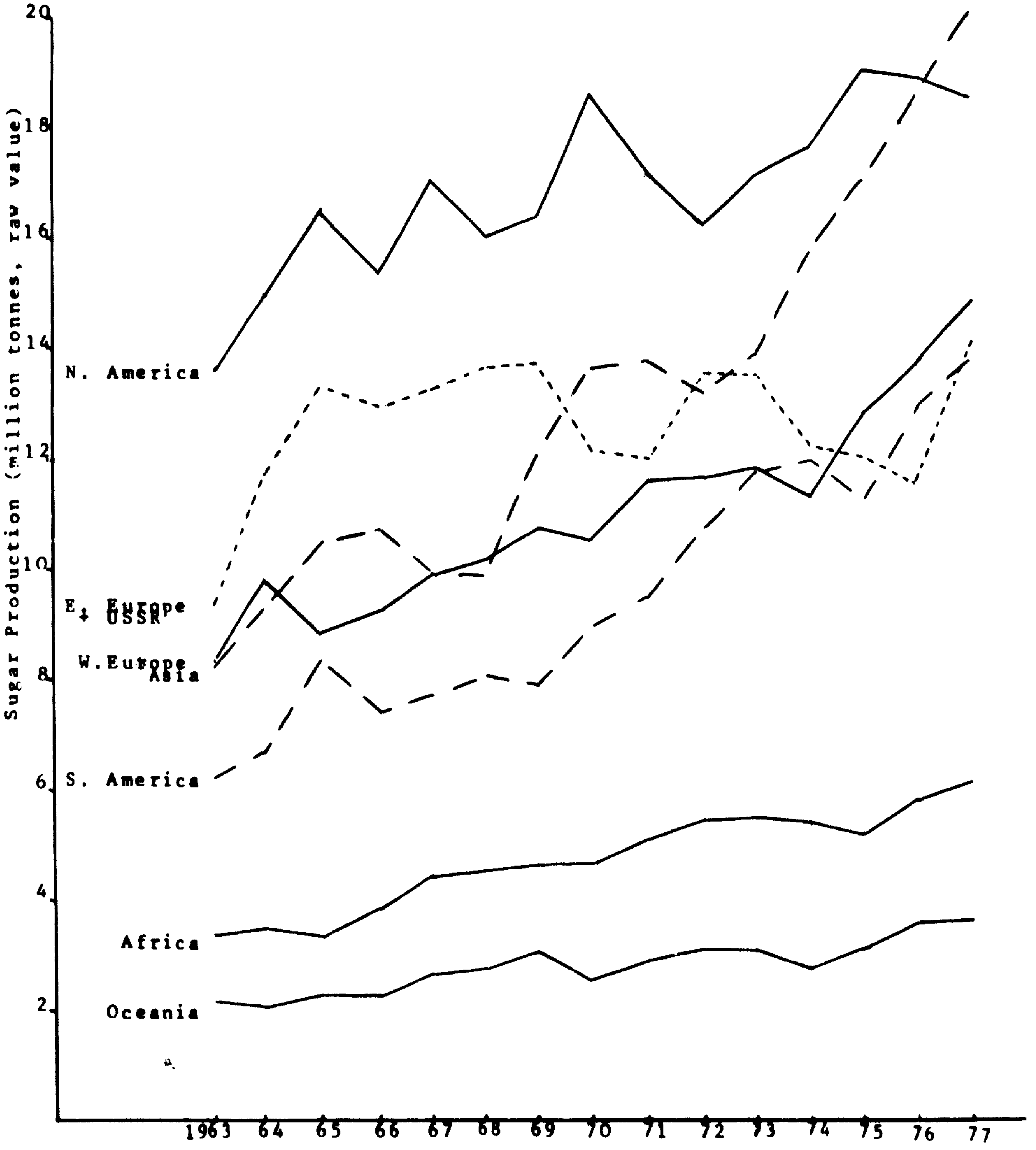
The growing of sugar cane is carried out to some extent in the majority of developing countries and also in a few developed countries with suitable conditions. Its processing into crystalline sugar whether by vacuum-pan or open-pan methods, however, has recently become much more widespread after having been associated for generations with a few concentrated areas such as the West Indies. The importance of sugar as an energy-giving part of the human diet may be unduly great in North America and Western Europe for example but in most developed countries sugar consumption is relatively low but with a high income elasticity of demand. Fluctuations in world market price for sugar has, in recent years, caused severe difficulties for importing developing countries with foreign exchange restrictions and without the apparent benefits of bi-lateral sugar agreements as obtained by many developed countries.

As a result of these factors the production of cane sugar has undergone significant expansion, often being placed high in the priority list for import-substitution industries; many developing countries have longer term plans to become net exporters of sugar.

Figure 1 illustrates the growth of the sugar industry since the early 1960's in the major regions of the world. Figure 2 shows minimum, maximum and mean annual import prices for raw sugar (cif New York), clearly indicating the wide fluctuations in recent years.

Table 1 presents production, import, export and consumption data for over 100 countries, for 1975-76 with the addition of estimated per capita consumption.

FIGURE 1: Centrifugal Sugar Production, 1963-77

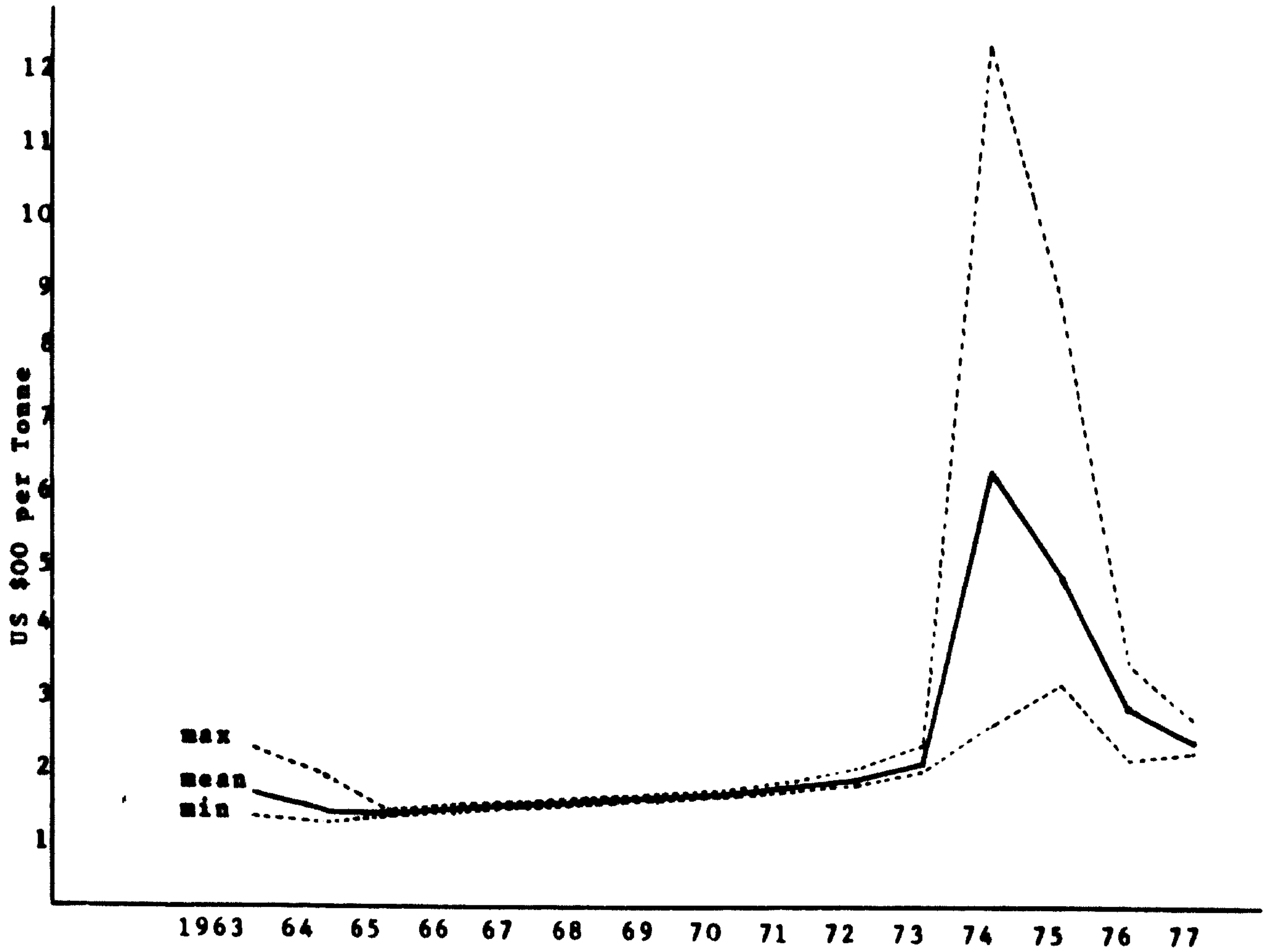


Sources: 1963-65 - Growth of World Industry, Vol II, 1972 edition;

1966-74 - Yearbook of Industrial Statistics, Vol II, 1975 edition; and

1975-77 - FAO Monthly Bulletin of Statistics, Vol I, April, 1978.

FIGURE 2: World Market Price of Raw Sugar (cif New York), 1963-77



Source: FAO Monthly Bulletin of Agricultural Economics and Statistics (various dates).

TABLE 1: Production, trade and consumption statistics for crystalline cane and beet sugar, 1975-76

Country	Sugar Production cane	(000t)	beet	Imports (000t)	Exports (000t)	Consumption (000t)	Per Head (kg)
Federal Republic of Germany			2540	206	314	2292	37.0
France			3239	363	1482	2136	40.3
Benelux			716	65	297	390	38.7
Netherlands			915	62	149	786	57.5
Italy			1442	532		1780	31.8
Denmark			423	3	158	275	54.3
UK			697	1981	257	2536	45.3
Ireland			203	65	115	165	52.7
Austria			512		158	330	43.8
Sweden			277	94		360	43.9
Yugoslavia			483	250		679	31.8
Greece			306	75	35	280	30.9
Switzerland			65	199		260	40.6
Finland			88	102	19	207	43.9
Turkey			986	5	1	997	25.4
German Democratic Republic			665	184	70	730	43.3
Czechoslovakia			780	75	186	640	43.2
Hungary			331	178	9	500	47.4
Poland			1840	50	274	1620	47.6
Albania			18	18		36	14.5
Rumania			561	100	36	615	28.9
Bulgaria			157	213	50	330	37.8
USSR			7702	3852	76	11300	44.4
Iceland				9		9	41.2
Norway				151		140	34.9
Portugal				336	42	255	29.1
Malta/Cyprus/Gib.				40		40	41.4
Spain	19		917	20	12	1045	29.4
Canada			133	982	69	1010	44.2
USA	1657		3646	5223	64	9785	}
Puerto Rico	279				188	124	}46.5
Hawaii	953				904	34	}
Cuba	6279				5724	550	57.8*
Trinidad	205				}	45	40.9*
Barbados	106				}538	13	53.0
Jamaica	369				}	108	53.2
St. Kitts	36				}		..
Dominican Rep.	1302				583	180	38.3
Mexico	2724	(65)				2662	44.2
Martinique	14				3	11*	30.3
Guadeloupe	96				88	8 *	22.5
Haiti	60				10	50	10.9
Guatemala	549	(54)			248	199	36.1*
El Salvador	267	(16)			115	122	30.4
Belize	63				64		..
Honduras	90				8	82 *	27.0
Nicaragua	246	(10)			144	103	47.7
Costa Rica	174	(40)			53	121 *	61.4
Panama	142	(3)			71	71 *	41.4
Argentina	1353				170	967	38.0
Brazil	6180	(200)			841	5084	47.4
Peru	956	(13)			387	584	37.3

TABLE 1 (cont/d.)

Country	Sugar cane (000t)	Production beet	Imports (000t)	Exports (000t)	Consumption (000t)	Per Head (kg)
Guyana	343			284	34	42.9
Uruguay	30	100		38	98	31.9
Surinam	11		4		12	28.4
Venezuela	483 (38)		30		591	49.2
Bolivia	209			85	136	24.1
Ecuador	287 (40)			65	245	36.3
Colombia	935 (687)			151	829	35.2
Paraguay	56		20	10	60	22.6
Chile		319	105	20	326	31.7
Other N. & C. America			30		296	..
Egypt	626		190		780	20.9
Sudan	125		201		325	43.9
Ethiopia	134			30	120	4.2
Somalia	35		15		50 *	15.7
Mauritius	496			552	38	42.2
Reunion	226			240	12	23.9
South Africa	1934		2	814	1217	47.7
Swaziland	224			206	18 *	36.4
Mozambique	240			90	135	14.6
Angola	40			7	40	5.9
Kenya	173		50		202	15.0
Uganda	21				15	1.2
United Rep. Tanzania	106		12	18	110	7.1
Madagascar	121			42	79 *	11.2*
Rhodesia	260			130	130 *	20.6
Malawi	69			36	33 *	6.5
Zambia	85		5		90 *	18.3
Congo	34			30	4 *	2.9
Zaire	69				69 *	2.7
Nigeria	35		142		177 *	2.8
Ghana	13		49		62 *	6.2
United Rep. Cameroon	30		2		32 *	5.0
Mali	14		20		34 *	5.9
Madeira	2				2 *	..
Ivory Coast	23		38		61 *	12.4
Morocco	4	255	237	9	525	30.3
Algeria		8	321		340	20.2
Tunisia		9	140		142	24.6
Azores		7	10		17 *	..
Mauritania			21		21 *	15.2
Chad			20		20 *	4.9
Senegal			60		60 *	14.5
Guinea			12		12 *	2.7
Togo			5		5 *	2.2
Upper Volta			12		12 *	1.9
Benin			8		8 *	2.5
Gambia			3		3 *	5.7
Central African Empire			2		2 *	1.2
Burundi			2		2 *	0.5
Rwanda			2		2*	0.4
Canary Is.			32		32*	..
Libya			100		100*	40.9

TABLE 1 (cont/d.)

Country	Sugar Production cane	(000t)	beet	Imports (000t)	Exports (000t)	Consumption (000t)	Per Head (kg)
Sierra Leone				26		26*	9.6
Other Africa				50	6	1233	..
India	[1200] 4630	(6200)			1164	3923	[2.0] 6.5
Indonesia	1126	(200)		170		1330	9.7
Pakistan	641	(1445)	27			663	9.4
Nepal	12					12*	0.9
Burma	80	(135)				80*	2.5
Philippines	2930	(54)			1179	840	19.7
China	2650	(820)	960	500	30	4080	4.8
Iran	89		625	584		1250	37.8
Iraq	10		10	365		400	35.9
Malaysia	47			317	35	325	27.3
Afghanistan	2		8	47		57*	2.9
Bangladesh	95					95*	1.2
Thailand	1757	(370)			1049	572	13.6
Japan	223	(12)	244	2401	35	3092	27.8
Sri Lanka	25			49		75	5.3
Israel			39	103		142*	42.1
Syria			25	187		212*	28.8
Lebanon			4	44		48*	16.7
Vietnam		(10)					..
S. Korea				336	120	216*	2.1
Hong Kong				96		96*	..
Jordan				48		48*	17.7
Arab Peninsula				350		350*	..
Singapore				122	20	90	40.0
Other Asia	817	(27)		313	512	2050	..
Australia	2933				2120	780	57.7
Fiji	283				261	29	50.6
New Zealand				166		163	52.8
Other Oceania				30		30	..

* Authors estimates or extrapolation

( ) Non-centrifugal cane sugar production expressed in raw sugar equivalent

[ ] Khandsari sugar production in India

.. Complete details not available

Source: F.O. Lichts, International Sugar Economic Yearbook and Directory, 1977

Statistical Yearbook, UNESCO, 1976

The production figures in Table 1 show a total world production of centrifugal sugar of 82.24 million tonnes for 1975/76; this can be broken down into approximately 50 million tonnes cane sugar and 32 million tonnes beet sugar. These totals represent an increase of 16 per cent from the 1970/71 season for cane sugar and 6 per cent for beet sugar. Estimated production for 1976/77 is 53 million tonnes cane sugar and 33 million tonnes beet sugar; that is a further increase of 6 per cent in cane sugar in one year and only 2 per cent in beet sugar. This trend is indicative of the general differences in the agricultural sectors of developed countries - producing most of the beet - and developing countries - producing most of the cane.

In addition to the production of centrifugal sugar there is a total of 10.4 million tonnes of non-centrifugal or non-crystalline sugar, such as *gur*, *jaggery* or *panela*, from 21 countries and a further 1.2 million tonnes of *khandsari* or open-pan sugar from India; the latter is a crystalline sugar produced with the use of centrifugal separation.

The last column in Table 1 shows approximate per capita consumption of centrifugal sugar based on total consumption and population estimates for 1975. On the whole, developed countries have a relatively high per capita consumption while developing countries have a relatively low consumption; the range is very wide from over 50 kg per capita to less than 1 kg per capita per annum. There are a few exceptions, however, to this general trend; the poorer of the developed countries have a low consumption e.g. Portugal and the richer of the developing countries have a high consumption e.g. Brazil, Libya and; traditional developing country producers have a high consumption e.g. Cuba, Fiji. These figures give no indication of the distribution of sugar consumption by end use but analysis of industrial and domestic uses would again reveal a major distinction between developed and developing countries. In USA in 1973 approximately 70 per cent of sucrose and other sweeteners was delivered as industrial sugar[5/], that is for use in processed foods and beverages. This can be compared with figures for the USA in 1910 when industrial uses accounted for

5/ S.M. Cantor, *Patterns of Use*, National Academy of Sciences Forum, "Sweeteners: Issues and Uncertainties", Washington DC, 1975.

only 25 per cent of the total. In 1975 sugar used for industrial purposes amounted to 4.3 per cent of total consumption in Kenya and 6.1 per cent in Ethiopia.[6/]

The generally low level of consumption in developing countries in association with the importance of domestic consumption or voluntary intake sugar, rapid population increase, and gradual improvement in the spending power of many leads inevitably to a significant upsurge in the demand for sugar. FAO projections[7/] 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, the increases in demand are heavily concentrated in the developing regions; in 1985 demand is project to increase by 69 per cent over 1975 levels in Asia, 57 per cent in Africa, 58 per cent in Near East, 55 per cent in Far East and Oceania, and 41 per cent in Latin America.

It can be seen, therefore, that major increases in cane sugar production capacity will be required to meet future demand. This should be hand in hand with agricultural developments and improved factory operation to increase the overall efficiency of existing capacity.

6/ Alpine, Barclay, Duguid and Pickett, *Development and Application of Appropriate Technology for the Sugar Industry in Africa*, Glasgow 1977.

7/ F. Pignalosa - *A Statistical Analysis of Sugar Consumption and Future Demand*, Monthly Bulletin of Agricultural Economics and Statistics, December 1977.

3. Agricultural Characteristics of Sugar Cane Production

3.1 Introduction

The sugar cane plant (*Saccharum officinarum)* is a member of the grass family, similar in appearance to bamboo and reaching a height of 4m or more. Sugar cane contains about 70 per cent water; from 11-15 per cent sucrose; and 9-17 per cent fibre. Agronomically sugar cane is a very tolerant crop being capable of producing reasonably high yields in a wide range of soil and climatic conditions.

The commercial crop is grown from setts (short sections of cane stalk) and after harvesting of the first or plant crop the root stock continues to grow and a ratoon crop is produced. Several ratoons may be allowed to grow before the yield falls sufficiently to warrant complete uprooting and replanting. The growing season for sugar cane depends largely on rainfall and/or irrigation and temperature and to a lesser extent on cane variety and ranges from less than one year to over two years.

Rainfall and temperature also affect the length of the crushing season. The factory can only operate when cane can be harvested and transported to the cane yard. In the rainy season or during periods of heavy, unseasonal rain field operations, especially the use of machinery, have to be suspended. Where irrigation is used there is more control over the harvesting and transport operations. Extremely high daily temperatures can cause intolerable working conditions for field and factory labour and also severe deterioration of cut cane. Depending on rainfall and temperature, the average crushing season can vary in different locations from as little as three months to as much as eleven months in a year.

3.2 Alternative agricultural systems

In the production of sugar cane there are a number of basic operations in common with any crop. The techniques used, however, vary considerably depending on the scale of production and the system of organization. The two extremes - plantation or smallholder (outgrower) systems in combination with varying degrees of mechanization give considerable scope for choosing a system most suited to a project in a particular location.

In order to supply cane to an OPS factory some 2-700 hectares of cane must be grown, depending on factory capacity and length of season. This relatively small area of land may be organized on a factory farm basis or may be subdivided into plots of a few hectares in line with the existing land use system. A large vacuum-pan factory obviously requires a much greater cane area, say around 10,000 hectares, again depending on factory capacity, season length and whether or not the cane is irrigated hence determining annual yields. Once more the cane land may be in plantation or under the ownership of outgrowers; it is becoming increasingly common to have a combination of the two systems, with the factory retaining a measure of control over the agricultural operations on the outgrower plots.

The level of mechanization is also variable although very broadly small-scale production tends to be more labour-intensive than large-scale. In developed countries where cane is grown such as USA and Australia, mechanization has virtually replaced all manual operations. In LDC's many cultivation operations are done by tractor and implements but planting, weeding and harvesting of green or burned cane remain manual operations. The nature of the work involved in cane cutting, rising wage costs and some local shortages of labour are forcing the, possibly premature, implementation of mechanical harvesting. Sophisticated mechanical harvesters now available are of very high cost, require highly skilled operators and more significantly require a specially designed field lay-out and carefully levelled land for efficient operation.

Cane begins to deteriorate as soon as it is cut; this is even more true of burned cane in which the protective rind of the stalks is damaged by burning. As a result a factory will plan its cane cutting and transport operations on a daily basis in order to have the cane crushed within 24 hours of cutting. This organization is obviously easier with a plantation or factory farm than with outgrowers; in the latter case there is the extra job of allocating each load to its owner for payment.

The transport system is usually organized by the factory, large or small, in order to maintain a reasonably even flow of cane to the crushers. A small factory may rely on the farmers own trailers, possibly animal-drawn, or may supply a tractor and trailer. Large-scale factories usually operate a fleet of tractors and trailers, in some cases running 24 hours a day from a plantation to the factory.

3.3 Social implications

The growth of a sugar industry opens up a great deal of potential for integrated rural development. There is the introduction of a cash crop to the traditional subsistence agricultural sector, employment in field and factory operations, and the consequent multiplier effect of the cash injection into the local economy. This should be true for both large- and small-scales of operation.

There are dangers, however, of the displacement of the local population, and traditional tried-and-tested forms of agriculture and the creation of a one-crop economy employing landless labourers on a seasonal basis. The incorporation of an outgrower system in many new projects has gone some way to alleviating these difficulties.

The choice of system, however, depends greatly on the type of land and population in a proposed project area. For example, the Kenyan sugar industry, with increasing dependence on outgrowers, is concentrated in an area of high population density and intensive cropping. On the other hand, the Ethiopian industry has been built up in an area of low population density used as extensive grazing land; the need to install an irrigation network also points towards a plantation system.

It should be clear from the foregoing that the physical and social environment and the factory operations are very closely related. It follows that any economic evaluation of factory operations has explicitly or implicitly to take account of climatic, agricultural and social factors.

4. Alternative Technologies

4.1 Introduction

In general, the choice presently available to a sugar mill investor is between the open-pan and the vacuum-pan process. Within the vacuum-pan process itself, however, further choice includes:

(i) variation in the number of machine units for a given sub-process. Although there are no technological differences *per se*, there are differences in the input requirements and possibly output achieved;

(ii) differences in technology with differences in input requirements and perhaps in output (quantity and/or quality); and

(iii) differences in technology but no (or marginal) differences in input requirements. This can arise where there are small differences in machine design, for instance, between different manufacturers of the same type of machine and can be ignored in economic evaluation of alternative techniques except where there are large differences in machine prices.

An example of the first type of differences in 'techniques' is the use of, say, 4 evaporator vessels with smaller unit capacity rather than 3 with larger unit capacity. For higher capital and operating costs greater flexibility with regard to breakdowns is obtained and a higher actual output could be achieved. The benefits of this flexibility vary with local conditions being greatest, for example, where there is a scarcity of repair engineers and a short crushing season.

The main concern in evaluating alternative technologies is firstly between the OPS and vacuum-pan technologies and secondly within the two processes. In the rest of this section a list of alternatives available, in principle, at each sub-process is first set out for both the OPS and vacuum-pan plants.

4.2 Open-pan sulphitation process

4.2.1 Cane intake

Sugar cane is usually delivered to OPS factories in trailers, weighed on a weighbridge and unloaded manually.

4.2.2 Cane preparation

Cane is not always prepared prior to crushing, but when it is, a cane cutter is employed. Usually crushing units that have a cane cutter also have a cane carrier (a slat conveyor) to feed the cane into the cutter and then the crusher. The cane carrier itself is fed manually. Preparation of the cane prior to crushing improves juice extraction.

4.2.3 Juice extraction

Juice is extracted from the cane by passing it through a 3 or 5 roller crusher which is usually power driven, except at very small levels of scale. Animal-driven crushers have a capacity of up to 200 kg of cane per hour.

4.2.4 Clarification

After sieving, the raw juice is clarified by means of the open-pan sulphitation technique described in Section 2. Raw juice is stored either in masonry or cast iron tanks. Although the former are lower in capital costs, sucrose losses are higher. Filtration of the muddy juice can be carried out either by means of bag filters or filter presses. In general, bag filters are less capital-intensive and require more labour.

4.2.5 Evaporation

The cane juice is evaporated in a series of standard boiling bels. Heat is obtained from a furnace designed to burn either wet bagasse straight from the crusher or bagasse which has been left to dry for several days. The wet bagasse furnace is usually preferred as the moisture content of the bagasse fed into the furnace can be expected to vary.

4.2.6 Crystallization

Crystallization is carried out in standard crystallizers which are lagged in order to maintain a uniform temperature.

4.2.7 Centrifugal separation

Separation of the sugar crystals from the molasses is carried out in manually-controlled batch centrifugal machines.

4.2.8 Drying

The sugar can be dried either in the open-air on trays or in a mechanical drier. Losses can be higher with the former, although it is less capital- and energy-intensive.

4.3 Vacuum-pan process

4.3.1 Cane weighing

The cane delivered to the factory gate is usually weighed on a weighbridge. Although recording of the weight can be done manually, an automatic printer is more reliable from the security aspect.

4.3.2 Unloading of cane and its transport to the crusher/ mills (or cane preparation area)

Cane is unloaded from the trucks/trailers that deliver it to the factory either by a tipping mechanism or by a crane.

4.3.3 Feeding of cane to crusher/mills (or cane preparation area)

The standard technique of feeding cane is to use a cane carrier, a slat conveyor which is itself loaded either directly or via a cane table. The slats making up the apron may be either of wood or metal. They can be driven either by electric motors, or by steam engines. With the former, automatic control of the carrier speed and, thus, the feeding rate is possible; with steam drive, the carrier speed is controlled manually. In addition, men may be required to regulate the cane flow on the carrier.

4.3.4 Cane preparation

The preparation of cane prior to juice extraction involves shredding and cutting which ruptures the cane cells and thus improves the extraction of juice. In addition, it is easier to mill shredded cane because of its more uniform bulk density. It also renders the juice more readily available for the action of imbibition.

There are basically three types of preparation equipment and these are commonly used in combination

(i) Crushers, which consist of a pair of heavy rollers with deep grooves, rotate slowly with the ridges of one roller meshing with grooves of the other. This is the only type of preparatory equipment which actually extracts juice from the cane.

(ii) Knives - these consist of rotating knives fixed radially on a shaft across the carrier. They enable the cane to be supplied to the mills in small pieces and assist juice extraction by breaking the waxy rind of the cane. Several designs of knives are available and they can be driven either by a steam engine, an electric motor or a steam turbine. The last, although technically the best, is usually considered only at large levels of scale because of the considerably higher capital and operating costs.

(iii) Shredder - this is usually employed at the final stage of preparation and involves the tearing or shredding of the cane into finer pieces.

The choice of which arrangement/combination to use is, to a large extent, related to the physical characteristics of the cane. With softer canes, the shredder can be omitted while with the harder canes (having a higher fibre content) a shredder is necessary. However, even with softer canes, the addition of a shredder to a knives/crusher arrangement can improve extraction. When combined milling and diffusion is employed for juice extraction, cane knives usually suffice.

4.3.5 Juice extraction

Although some amount of juice may be extracted at the cane preparation stage, that is not the primary purpose of the operation. Extraction of sugar cane juice can be carried out solely by milling or by diffusion or a combination of both. Imbibition can increase the extraction of available juice.

(i) Milling tandem

Milling makes use of pressure in expressing juice from the fibre. Several sets of rollers are used in a tandem, usually arranged horizontally in threes. The number of rollers in a tandem ranges from as few as 5 to as many as 20; 11-14 is the most popular range. The number of rollers in the tandem influences the extraction obtainable and the capacity of the tandem.

The mills are driven by either:

(a) electric motors;
(b) steam engines; or
(c) steam turbines.

The advantages of an electric drive over the steam engine are better control (which can improve extraction), easier speed regulation and easier starting and stopping, lower operating and maintenance costs and greater safety. It has, however, a higher net capital cost than the steam engine drive. The steam turbine offers the same advantages over the steam engine as the electric drive and can save on net energy consumption.8/

Hydraulic or pneumatic systems are used to increase roller pressure and to maintain uniform pressure.

The cane is usually force fed into the mill and rotary, reciprocating or continuous pressure feeders are used.

Apart from general engineering improvement in mill design, two labour-saving innovations have taken place: the use of central controls to regulate mill speeds individually or collectively and central lubrication systems for the mills.

Intermediate carriers are used to move the bagasse from the delivery of one mill to the feed of the next. These are of three main types.

(a) apron carriers - a steel slat conveyor or a heavy rubber band conveyor (which has a higher capital cost, but a longer working life);
(b) rake conveyor; and
(c) fixed chute conveyor.

When imbibition is used (as in almost all vacuum-pan plants), the first two are preferred for proper mixing of the bagasse with imbibition fluid. The fixed chute is, however, attractive from the point of view of cost (capital and operating).

8/ Most large sugar mills generate their own electricity; so one needs to take into account any energy saving on account of not having to double transform from steam to electricity to mechanical work.

Imbibition is usually only carried out in vacuum-pan factories. Even after repeated application of heavy pressures, the bagasse retains a quantity of juice approximately equal to the weight of the fibre. Therefore, in order to extract the maximum possible juice, it is necessary to dilute the juice remaining in the bagasse and this is done over several milling stages after the first mill. Normally compound imbibition is practised which involves the use of juice from each mill for imbibition before the preceding mill and the addition of water only before the final mill. Sometimes imbibition is replaced by maceration which involves steeping the bagasse in the dilute juice and/or water. This involves the use of a maceration bath intermediate carrier and provides more complete penetration. The gain in extraction is reported to be not worth the complications involved with feeding a saturated bagasse.

(ii) Diffusion

Diffusion in the case of sugar does not strictly involve diffusion of the cane juice through the cell walls - it is a displacement washing process and requires that the cane cells be ruptured. The capital costs of a diffusion plant are lower than that of a milling plant and power consumption marginally lower. A higher extraction than with a milling train is also obtained and there is some saving in costs downstream because of the somewhat lower dilution. But diffusion calls for greater skills in operating the plant. Combined milling (for the first 70 per cent of the juice) and diffusion has been suggested as a more efficient method than either straight milling or straight diffusion.

4.3.6 Juice screening

The juices are screened in two stages: first through a mesh size of approximately 1 mm. and then through a mesh size of 0.2-0.8 mm.

The juice is weighed (usually by means of automatic scales) in order to facilitate chemical control.

2.3.7 Clarification

The purpose of the clarification process is to remove impurities from the juice before evaporation. This involves the formation of a flocculent precipitate which entraps most of the fine suspended extraneous matter.

There are two types of process used for clarification proper:

(i) sulphitation where lime and sulphur dioxide gas are added to give a precipitate of calcium sulphite;

(ii) carbonation where carbon dioxide gas is also added to give a precipitate of calcium carbonate.

In sulphitation, the sulphur dioxide is produced in a sulphur furnace, passed through a scrubber to remove dust and other impurities and then passed through hot limed juice. Heating is carried out under pressure in tanks made of steel or cast iron.

Settling of the mixture to separate the clear juice from the precipitate is effected in either:

(i) a conical subsider; or

(ii) a multi-tray clarifier.

The former is available at lower unit capacities than the latter but is reported to be less efficient. Several versions of the multi-tray clarifier are available; no comparative tests have been reported. Instrumentation at various levels (from manual through to automatic) is available to monitor and control the pH (acidity or alkalinity).

4.3.8 Sugar/mud separation

Since the subsider mud contains sucrose, it is necessary to recover this by washing and filtering the mud. There are three types of filters available:

(i) Filter presses;

(ii) Mechanical or leaf filters; and

(iii) Rotary vacuum filters.

Filter presses make use of a fabric enclosed in a frame through which the clear liquid passes. The cakes are then washed to reduce the amount of sucrose loss. Labour is employed for the operations involved including cleaning the cloth. Mechanical or leaf filters are a modification which have a higher capital cost but require less labour and consume less filter cloth.

The rotary vacuum filter is an even less labour-intensive alternative and makes use of bagacillo on a metallic screen as the filtering medium. This requires equipment to separate the fine fibres from the final bagasse. An alternative uses a cloth of felted dacron with bagacillo. The filter consists of a segmented drum rotating through a mud tank with vacuum applied to the drum chambers. The cake is discharged automatically by the breaking of the vacuum and mechanical scraping. One disadvantage is that the filtrate is not as clear as that from fabric filters and has to be returned to the liming tank rather than being sent on to the evaporator. Vacuum filters using cloth are available which eliminate this problem - these would be more labour-intensive.

4.3.9 Evaporation

Evaporation of the cane juice is carried out in multiple effect evaporators. The main alternatives are with regard to the level of automatic control provided.

Scale is deposited inside the evaporator body and this needs to be removed. This is carried out either:

(i) mechanically - (a) by hand operated scrapers
(b) by power operated scrapers; or

(ii) chemically.

Generally, a combination of both mechanical and chemical methods is used.

4.3.10 Boiling

Sugar boiling which is part of the process of crystallization is carried out in vacuum-pans. The variants here are with regard to the level of instrumentation and control over the process.

4.3.11 Crystallization

Crystallization of sugar from the original syrup is carried out by cooling and agitation in a crystallizer. There are basically two types - (i) air cooled; and
(ii) water cooled.

Water-cooled crystallizers lead to a higher sugar recovery but have a higher capital cost.

4.3.12 Centrifugal separation

Centrifugal force is used to separate the sugar crystals from the molasses. The alternatives available are:

(i) batch centrifugal machines which may be

- (a) manual
- (b) semi-automatic or
- (c) automatic; and

(ii) continuous - which can only be used to handle the lower quality strikes, usually the last one.

The different batch centrifugals differ in the number of machine operations that need to be effected manually.

4.3.13 Drying

Two types of sugar driers are available:

(i) vertical cylindrical drier; and

(ii) rotary drum drier.

4.3.14 Bagging

Bagging of sugar and stitching of bags can be carried out by either semi-automatic or automatic machines. As it would appear, the former are more labour-intensive and less capital-intensive than the latter.

4.4 Hybrid technologies

Because of the very large differences in scale associated with the OPS and vacuum-pan technologies respectively, the number of hybrid technologies actually available is much more limited in practice than in principle. The use of cane preparation, cane carriers, filter presses and mechanical driers in OPS factories is borrowed from vacuum-pan plants. The use of small rotary vacuum filters (which would reduce sucrose losses in the `ilter cake and save on liming costs in some cases) in OPS plants is also feasible. More generally, however, the use of vacuum-pan equipment in small factories would be seriously uneconomic because the equipment would be used well below its maximum operating capacity (which determines its capital cost).

In principle, OPS equipment could be used to produce any amount of sugar. If, however, this were to be done in single locations serious problems of organization and efficiency (particularly of labour) would arise.

4.5 Machinery supply

A brief review of possible sources of equipment for the OPS and vacuum-pan technologies is given below.

(i) Open-pan sulphitation technology

At present, the only sources of equipment for the OPS technique are in India. Turnkey arrangements, including training of local personnel, has been offered by several Indian manufacturers to investors in other developing countries. However, machines are also sold on an individual basis and several of the other less developed countries have the inherent technical capability to manufacture at least the simpler pieces of equipment, e.g. clarification tanks, boiling bels, etc.

(ii) Vacuum-pan technology

The supply of machinery for the vacuum-pan process tends to be strongly organized on a turnkey basis, especially from European sources. These sources generally manufacture most of the equipment specific to the sugar industry and procure the equipment that they do not manufacture from specialist manufacturers. Although the individual specialist manufacturers are prepared to supply direct to potential investors in developing countries (and thus widen the potential choice beyond the turnkey package), at present, they appear to supply the replacement market mainly in developing countries. As mentioned earlier, the main choice of technique within the vacuum-pan process is between the use of milling and milling plus diffusion at the juice extraction stage. The equipment for the latter is manufactured by at least two West European sources, one of whom, in effect, merely markets the design and knowhow. Thus, this diffuser has been manufactured in at least two less developed countries, India and Mauritius apart from France and the U.S.A. This means there is a wide variation in the installed machine price, depending on the place of manufacture, although it is supplied by the same source, and this offers the possibility of saving on capital costs.

The other important area of choice is in the equipment source for a basically similar technique, between developed and less-developed countries. Some, but not all, machines are manufactured in developing countries under licence from a developed country manufacturer. The lower price of equipment from less developed country sources may, however, be offset by a higher maintenance cost. At least two Indian manufacturers offer turnkey packages built around their own equipment.

5. Evaluation of Alternative Technologies

5.1 Introduction

As already noted, the choice of sugar technology cannot be made independent of a consideration of a variety of socio-economic and climatic factors. In what follows a comparison is made of techniques and scales in two broadly different agricultural regimes: a long season of 270 days and a short season of 150 days of cane crushing per year excluding downtime and; at two cane prices, the lower one broadly representative of a plantation regime and the higher one approximately corresponding to an outgrower regime.

Firstly, alternative technologies are evaluated for the long season. Five of these are vacuum-pan technologies and three are OPS technologies. Some characteristics of these are shown in Tables 2 and 3. The vacuum-pan technologies relate to two levels of scale, two generically different techniques and two sources of equipment. The first is a factory capable of crushing 200 tonnes of cane per hour (tch); and the remaining four factories are each capable of crushing 100 tch. The largest vacuum-pan factory and the first factory with a capacity of 100 tch are assumed to use European equipment with milling (rather than diffusion) at the juice extraction stage. The second 100 tch factory uses the same technology but Indian equipment, and the third and fourth 100 tch factory use European and Indian equipment respectively with milling plus diffusion introduced at the juice extraction stage. The diffusion equipment is of European origin. A comparison among the four 100 tch factories can be taken as applying to a corresponding comparison among 200 tch factories.

Three scales of OPS technologies are considered: 90 tonnes of cane per day (tcd), 150 tcd, and 220 tcd.

In the vacuum-pan 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

TABLE 2: Some Characteristics of Alternative Sugar Technologies - Long Season

Technology / Characteristic	VP European/mill	VP European/mill	VP Indian/mill	VP European/diff.	VP Indian/diff.	OPS	OPS	OPS
Scale	200 tch	100 tch	100 tch	100 tch	100 tch	90 tcd	150 tcd	220 tcd
Output (tsa)	110,000	55,000	55,000	55,600	55,600	1,182	1,970	2,888
Utilization @ 24 hr/day	216 days of 270 day season					202 days of 270 day season		
Initial fixed investment:								
absolute ($000)	49,060	29,440	17,470	28,590	16,460	188	243	302
per tsa ($)	446	535	318	514	296	159	123	105
Working capital ($000)	8,950	4,560	4,560	4,560	4,560	45	74	109
Employment								
(i) total	856	657	657	657	657	178	275	332
per 100 tsa	0.78	1.19	1.19	1.18	1.18	15.06	13.96	11.50
(ii) unskilled	286	260	260	260	260	125	205	255
per 100 tsa	0.26	0.47	0.47	0.47	0.47	10.58	10.41	8.83
Annual operating costs: ($000)	20,337	11,012	11,642	10,979	11,579	359	563	788
(i) cane	12,960	6,480	6,480	6,480	6,480	227	379	555
(ii) wages & salaries	1,174	1,027	1,027	1,027	1,027	79	100	113
(iii) materials	3,994	2,146	2,146	2,143	2,143	43	71	104
(iv) repairs & maintenance	2,208	1,359	1,989	1,329	1,929	10	13	16

TABLE 3: Some Characteristics of Alternative Sugar Technologies - Short Season

Technology / Characteristic	VP European/milling	VP Indian/diffusion	OPS
Scale	200 tch	100 tch	220 tcd
Output (tsa)	61,100	30,550	1,601
Utilization @ 24 hr/day	120 days of 150 day season		112 days of 150 day season
Initial fixed investment			
absolute ($000)	49,060	16,460	302
per tsa ($)	803	539	189
Working capital ($000)	8,950	4,560	109
Employment			
(i) total	856	657	332
per 100 tsa	1.40	2.15	20.73
(ii) unskilled	286	260	255
per 100 tsa	0.47	0.85	15.93

TABLE 4: Profitability of Alternative Sugar Technologies - Long Season

($ per tonne of sugar per annum)

1. Vacuum-pan Technology / Discount Rate	200 tch European/milling		100 tch European/milling		100 tch Indian/milling		100 tch Indian/diffusion		100 tch European/diffusion	
	High[a]	Low[b]	High[a]	Low[b]	High[a]	Low[b]	High[a]	Low[b]	High[a]	Low[b]
5 per cent	577	862	272	557	350	635	384	667	315	598
10 per cent	118	284	-104	53	17	184	31	196	- 72	93
20 per cent	-190	-115	-441	-366	-197	-122	-191	-117	-421	-348

2. OPS Technology / Discount Rate	90 tcd				150 tcd				220 tcd			
	High[a]		Low[b]		High[a]		Low[b]		High[a]		Low[b]	
	c/	d/	c/	d/	c/	d/	c/	d/	c/	d/	c/	d/
5 per cent	-975	-156	-517	212	-696	69	-230	448	-503	227	- 38	605
10 per cent	-670	-178	-398	42	-493	- 7	-221	214	-374	63	- 86	297
20 per cent	-404	-170	-281	-70	-309	-92	-187	7	-248	-42	-126	57

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.

TABLE 5: Profitability of Alternative Sugar Technologies - Short Season
($ per tonne of sugar per annum)

Technology / Discount Rate	220 tch VP European/milling High[a]	220 tch VP European/milling Low[b]	100 tch VP Indian/diffusion High[a]	100 tch VP Indian/diffusion Low[b]	220 tcd OPS High[a] c/	220 tcd OPS High[a] d/	220 tcd OPS Low[b] c/	220 tcd OPS Low[b] d/
5 per cent	32	302	154	426	-738	4	-305	356
10 per cent	-337	-187	-196	- 44	-599	-184	-356	119
20 per cent	-500	-438	-358	-296	-307	-117	-206	15

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.

diffusion increases the recovery of sucrose but as this equipment may be unfamiliar to the operators, it has been assumed that the recovery rate remains the same as that for milling for the first five years of production before rising to 82 per cent. This is a conservatively prudent assumption as recovery rates of 84-85 per cent have been reported from at least two African developing countries and from India. In the OPS system, the highest reported rate (from India) is about 62 per cent. Since the OPS technology is relatively untried elsewhere, two recovery rates have been used in the evaluation - 50 per cent and 61.5 per cent.

Each of the technologies are evaluated at wage rates which are roughly those prevailing (for different levels of skill) in East Africa and at three *real* rates of discount - 5, 10 and 20 per cent. A project life of 25 years of production with build-up corresponding broadly to reported rates in Africa has been assumed. A selling price for sugar of $300 per tonne has been assumed. Although this is substantially higher than current world market prices, it broadly corresponds to the situation in domestic East African markets. It has been further assumed that 65 per cent of OPS sugar could command the same price as that produced in a vacuum-pan factory; that the next 25 per cent would sell at $270 per tonne; and the remainder at $225 per tonne.

The profitability as measured by the net present value per tonne of sugar per annum (NPV per tsa) of the alternative technologies is set out in Tables 4 and 5. It must be borne in mind that these results (and indeed all the data in this section) are illustrative rather than definitive.

5.2 Long season (Table 4)

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

At a discount rate of 10 per cent, the larger vacuum-pan technology is the preferred choice only at the higher cane price. At the lower cane price, the 220 tcd OPS technology with higher sucrose recovery rate is the most profitable; under these conditions the 150 tcd OPS technology is superior to each of the 100 tch vacuum-pan technologies.

At the highest discount rate all vacuum-pan and the smallest OPS technologies become loss-making although the losses are smaller than those of all the lower recovery OPS variants. However, at the lower cane price and higher sucrose recovery rate both the 150 and 220 tcd OPS technologies will make profits.

5.3 Short season (Table 5)

For the short season, the three more efficient technologies from Table 3 have been selected for evaluation: the 200 tch European milling, the 100 tch Indian diffusion and the 220 tcd OPS.

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 4 that a higher scale Indian milling plus diffusion technology would be even more profitable. The OPS technology with the higher recovery rate is superior to the 200 tch European milling technology.

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

At the highest discount rate, again the only profitable technique is the higher recovery rate variant of the OPS technology. It is interesting to note that even at the lower recovery rate this is superior (less loss-making) to both vacuum-pan technologies.

6. Policy Implications

In this section we discuss some policy implications that emerge from the economic evaluation. 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.

6.1 Financial and social Profitability

In the economic evaluation of the previous section a measure of the surplus expected to be generated by 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 to the 'market' discount rate while the highest, 20 per cent, as an approximation to the 'social' discount rate.[9/]

At the lowest discount rate, for both the long and short season regimes, the vacuum-pan technologies are superior. At the 'social' discount rate of 20 per cent the only profitable technologies are variants of the two larger OPS units. In the short season situation, at discount rates of 10 20 per cent, the higher recovery 220 tcd OPS technology is superior to the two vacuum-pan technologies, although it is only profit-making with the lower cane price; at 20 per cent even the lower recovery variant is superior (less loss-making) to the others.

6.2 Capital rationing

Another measure of profitability which considers the possibility of capital rationing is the NPV per unit of capital

9 / This reflects the general view that capital is relatively scarce, compared to labour, in LDC's and that, for a variety of reasons, the 'market' rate does not reflect this scarcity.

invested. On this basis, the rank orderings of the three more efficient technologies are shown in Table 6.

TABLE 6: $NPV \div K$[a/] of Alternative Sugar Technologies

Technology	200 tch VP European/milling	100 tch VP Indian/diffusion	220 tcd OPS b/	220 tcd OPS c/
Long season				
high cane price	1.09	1.02	-3.54	1.60
low cane price	1.64	1.76	-0.27	4.26
Short season				
high cane price	0.03	0.22	-2.88	0.02
low cane price	0.32	0.62	-1.19	1.39

a/ NPV per tsa; fixed plus working capital per tsa, discounted at 5 per cent

b/ lower sucrose recovery rate.

c/ higher sucrose recovery rate.

6.3 Employment

From Tables 2 and 3 it can be seen that the OPS technology offers greater employment potential than the vacuum-pan technology. For example the 220 tcd OPS units would employ about 14 times and 9 times as many workers as the 200 tch and 100 tch vacuum-pan factories respectively, for any given quantity of sugar produced. The OPS technology, however employs a much smaller proportion of skilled and semi-skilled people than does the vacuum-pan technology.

6.4 Dispersal of industry

A sugar industry based on the OPS 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 comprising only a small number of large vacuum-pan factories. Because of the lower sucrose recovery rate achieved by the OPS technology, however, the aggregate land requirement for sugar cane cultivation to reach a target sugar output is higher than that of the vacuum-pan 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, adding a cash crop to the traditional system rather than replacing it with a *de facto* mono-culture; and minimal, localized displacement of population as a result of cane cropping.

By virture of its small-scale, it is possible to envisage situations where OPS sugar production may be the only way to produce sugar at all. For example, this technology is actively being considered for outer islands of Indonesia to which importation of the small quantities of sugar required from centralized areas of production may be difficult and/or costly.

As can be seen from Table 1, there are many developing countries involved in the production of non-centrifugal sugar. At the very least this means that sugar cane is grown; that simple crushers are being used; and that some degree of knowledge and expertise has been acquired of the crushing and boiling operations. In such circumstances this could, potentially, form the basis of the development of the OPS technology and hence its integration with any existing national sugar industry.

6.5 Effect of machinery sources on technology and policy options

As already noted, the primary source of equipment for the vacuum-pan technology, at least for many African developing countries, has been the West European turnkey suppliers. This situation has arisen for a variety of reasons, partly historical and partly because alternative developing country sources have only recently entered the export market. It has been shown that, with prudent assumptions as to their relative efficiency, developing country sources of vacuum-pan technology offer a large measure of capital-saving and in some cases greater profitability. Furthermore, the milling plus diffusion variant appears to be more efficient than milling alone; as yet diffusion is not readily offered as part of the standard European package. This technique also offers secondary employment possibilities if manufactured in local workshops as has been done in Mauritius and India.

6.6 Conclusions

From the foregoing it would appear that in some circumstances there may be a conflict between surplus (NPV) maximization and other developmental goals. In order to plan a national sugar policy (which has to be set firmly in the context of the overall development policy) a judgement has to be made as to which trade-offs are acceptable. Table 7 illustrates three factors which would have to be considered for the production of, say, 110,000 tonnes of sugar per annum, the output of the largest scale and long season, (the lower cane price and 5 and 10 per cent discount rates are assumed).

TABLE 7: Investment, NPV and Employment in the Production of 110,000 tsa

	200 tch VP European/milling		100 tch VP Indian/diffusion		220 tcd OPS Higher Recovery	
Long Season:		a/		a/		a/
Total Investment ($'000)	58,010	100	41,586	72	15,274	26
NPV ($'000) @ 5 per cent	94,820	100	73,370	77	66,550	70
@ 10 per cent	31,240	100	20,570	66	32,670	105
Total Employment	856	100	1,298	152	12,650	1480
Short Season:						
Total Investment ($'000)	104,437	100	75,686	72	27,552	26
NPV ($'000) @ 5 per cent	33,220	100	46,860	141	39,160	118
@ 10 per cent	-20,570	100	-4,840	176	13,090	264
Total Employment	1,540	100	2,365	154	22,803	1481

a/ Figures on an index basis.

In the long season situation, choosing 38 OPS factories in preference to one 200 tch vacuum-pan factory will lead to the creation of 11,794 more jobs at the sacrifice of $28.3 million in NPV at a discount rate of 5 per cent. Thus, the cost of creating each additional job (by choosing the OPS technology) would be equivalent to a once and for all expenditure of about $2400. As this is much lower than the discounted value of annual wages paid to an unskilled worker ($3600 at 5 per cent), it might appear as a feasible method of reducing unemployment. It should, however, be noted that this is of the order of 10 times the GDP per capita of several LDC's. At the discount rate of 10 per cent, the OPS option would clearly be superior although it is worth stressing that this is on the assumption that the higher sucrose recovery rate can be attained.

In the short season situation, choosing 69 OPS factories rather than four 100 tch vacuum-pan factories to produce 110,000 tsa would create 20,438 more jobs at the sacrifice of $7.7 million at a discount rate of 5 per cent. The cost of creating each additional job would be $380 which is substantially lower than in the long season situation. Again at 10 per cent, the OPS alternative is superior; it is also superior to the 200 tch variant at both 5 and 10 per cent.

It has been seen that in the sugar industry, at least under some situations, there need be no conflict between economic efficiency and other developmental goals (in particular, employment and widespread distribution of industry). This however strongly hinges on the efficiency that can be attained with the improved OPS technology. It has also been shown that even within the modern vacuum-pan sector it is fruitful to examine a wider range of technologies even if, because of exigency, it is only within a wider range of turnkey proposals than that hitherto considered.

<u>Appendix</u>: Equipment Suppliers

OPS Technology

India:

Kay Kay Engineering, Jagadhri Road, Yamuna Nagar, U.P. (Turnkey)

Kirloskar Consultants Ltd., Post Box 803, Poona 411009 (Consultants)

National Sugar Industries, Opp. Block Development, Delhi Road, Meerut 2, U.P. (Turnkey)

National Sugar Institute, Kanpur, U.P. (Design, Operator Training)

Planning Research and Action Dept., Government of U.P., Kalakankar House, Lucknow (Research Institute, Process Development)

Rohilkhand Industries P. Ltd., P.O. Izatnagar, Bareilly, U.P. (Turnkey)

United States of America:

Technoserve Inc., 11 Belden Avenue, Norwalk, Conn. 06852 (Consultants)

Vacuum-Pan Technology

(a) Turnkey suppliers and consultants

Brazil:

Tecomil S.A., C.P. 76, 14160 Sertaozinho, Sao Paulo

Medini S.A. Metallurgica, Av. Mario Dedini, 201, Piracicaba - Est. de Sao Paulo

France:

Technip Compagnie Francaise d'Etudes et de Construction, 232 Av. Napoleon Bonaparte, 92500 Rueil-Malmaison (Consulting Engineers)

India:

Buckau Wolf New India Engg. Works Ltd., Pimprie, Poona

K.C.P. Ltd., P.B. 2278, Madras 600019

Triveni Engineering Works Ltd., 16 Kasturba Gandhi Marg, 1107 Ansal Bhavan, New Delhi-1

Walchandnagar Industries Ltd., Construction House, Walchand Hivachand Marg, Ballard Estate, Bombay 400038

Jamaica

Kingston Industrial Construction Ltd., P.O. Box No. 138, Kingston 11

Japan:

Japan International Cooperation Agency, 1-1 Nishi Shinjuku, 2-chome, Shinjuku, Tokyo

Netherlands:

HVA International bv., P.O. Box 10328, Amsterdam (Consultants)

Stork-Werkspoor Sugar B.V., P.O. Box 147, Hengelo (O.V.)

United Kingdom:

Bookers Agricultural and Technical Services Ltd., 83 Cannon Street, London EC4N 8EJ (subsidiary - Fletcher and Stewart, Derby)

Tate & Lyle Technical Services Ltd., 1 Bromley Common, Bromley BR2 9NA (subsidiary - A & W Smith, successors to Mirlees Watson).

United States of America:

Hawaiian Agronomics Company (International) P.O. Box 3470, Honolulu, Hawaii 96801

F.C. Schaffer and Associates Inc., 185 Bellewood Drive, Baton Rouge, Louisiana 70806 (Consultants)

Federal Republic of Germany

BMA Braunschweigische Maschinenbauanstalt,
Postfach 295, 33 Braunschweig

Buckau R. Wolf, Postfach 100460,
4048 Grevenbroich 1

(b) Specialist manufacturers

Belgium:

N.V. Extraction de Smet, S.A.,
Prins Boudewijnlassn 265, B-2520 Edegem
(Cane preparation, diffusion, clarification)

UCMAS, rue de Trone 4, 1050 Brussels
(Diffusion)

France:

Filtres S.S.A.E. Vernay, av. de lettre de
tassigny, b.p. 68 z.i., 69330 Mayzieu
(Rotary Filters)

Sucatlan Engineering, 18 av. Matignon,
Paris 8e (Diffusion)

India:

Binny Ltd., P.O. Box No. 1111, Madras-600061
(Milling)

Garlick Engg., Bapuras Jagtap Marg,
Sant Gagde Mahraj Chowk, Bombay-400011
(Boilerhouse equipment)

Larson & Toubro Ltd., P.O. Box 278,
Bombay 400001 (Diffusion)

Sikka n Sikka Engg. Pvt. Ltd., D-1 Shivsagar Estate,
Dr.Annie Besant Road, Worli, Bombay-400018
(Milling)

Italy:

Reggiane Officine Meccaniche Italiane spa,
Casella Postale n. 331, 42100 Reggio Emilia
(Milling, clarification, evaporation, boiling
crystallization, drying)

Jamaica:

Caribbean Casting & Engg., Ltd.,
P.O. Box 163, Kingston 11,
(Cane preparation, milling)

Sweden

Asea, S-72183 Vasteras (Batch centrifugals)

United Kingdom:

Babcock & Wilcox Ltd., 165 Gt. Dover Street,
London SE1 4YB (Boilers)

United States of America:

Dorr-Oliver Inc., 77 Havemeyer Lane,
Stamford, Conn. 06904 (Juice screens,
multi-tray subsider, rotary vacuum filters)

Farrel Co., Division of USM, Ansonia,
Conn. 06401 (Cane preparation, milling)

Brill Equipment Co., 35-65 Jabez St. Newark,
N.J. 07105 (Secondhand equipment)

West Germany:

KKK, Postfach 265, D6710 Frankenthal/Pfatz
(Steam turbines)

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