THE INDUSTRIAL UTILISATION OF BAGASSE

by

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INTRODUCTION

There is little doubt that the sugar industry in Trinidad is facing a difficult and uncertain future. Like most sugar producing countries, Trinidad has a gross surplus of labour and few immediate new outlets for this labour. In the interest of maximising employment in the industry, attempts have been made to slow down the process of mechanisation and modernisation but the gradually increasing labour bill could soon render our sugar concerns completely uneconomic. The gradually declining profits which have been derived from the manufacture of sugar during the fifties and sixties have now been replaced by a series of rapidly increasing losses and the entry of the United Kingdom into the European Economic Community has served to cast yet further doubts on the viability of the local sugar industry.

In this context, the future of the Trinidad sugar industry is likely to depend, to a great extent, on its ability to diversify and one way of doing this is to find uses for what today are surplus by-products of the industry. At the outset, however, it should be pointed out that, in point of fact, very few sugar producing countries have been successful in this direction. While it is possible, in theory, to manufacture several important materials from the by-products of the sugar industry, many factors inhibit the commercial production of such products. The major inhibiting factor is, of course, the limited market available. Without an adequate market, no by-product industry stands a chance of being successful and it is true to say that in the production of most sugar by-products, economy of scale is of the greatest importance.

The raw cane sugar factory produces bagasse, molasses and filter mud as its major by-products. The number of products which can be synthesised from these materials is legion. In the interest of brevity, consideration will be limited to those which can be manufactured from bagasse and more specifically to those which appear to have a reasonable chance of commercial success if manufactured in Trinidad.

Efforts to make valuable products from bagasse have occupied many minds for more than a century. The results of all this work are meagre indeed, and even now less than one million tonnes of bagasse, dry basis, are used annually in the world for any purpose other than fuel at the sugar mill. As we will see later, bagasse is composed of cellulose, pentosans and lignin. Essentially, we can say that from cellose we can obtain paper, from pentosans furfural, and from lignin plastics. Other materials such as fibreboard, particleboard, bagasse concrete, alpha cellulose and animal feed have been produced from bagasse while, traditionally, bagasse has been used as a fuel.

The market for bagasse by-products has never been a particularly easy one. Insulation board has, until recently, been one of the more important products while the utilisation of bagasse for paper is slowly building up. A more recent market for particleboard is showing great promise. The versatility of particleboard in its raw material requirements, in its method of manufacture, and in its uses have contributed to its rapid success as an important board material. Perhaps the only other industry which has achieved so remarkable a growth rate over the past two decades is the petrochemical industry. It is expected that this trend in the particleboard industry will continue and, in fact, several new high capacity plants, using mainly wood as raw material, are at present under construction in Europe and the U.S.A. The production of furfural from bagasse is still limited to only two plants - one - in the Dominican Republic and the other, which is much more recent, in Florida.

In the context of the Trinidad situation, the more significant possibilities for the utilisation of bagasse appear to lie in paper and particleboard production together with the manufacture of furfural and animal feeds. One should, however, guard against the optimism which prevails in certain quarters and which appears to suggest that the non-food uses of sugar and the utilisation of the industry's by-products are the panacea for all the ills of the industry.

BAGASSE

Bagasse is the fibrous residue of the cane stalk which is left after crushing and extraction of the juice. It consists of water, fibres and relatively small quantities of soluble solids, mostly sugar. It is not a uniform material. Its physical properties and chemical composition vary according to the variety of the cane, its maturity, the method of harvesting and finally the efficiency of the milling plant. A typical composition might be:

Moisture	50%
Insolubles - true fibre, pith and dirt	47%
Soluble solids	3%

Expressed chemically, the insoluble portion of Trinidad bagasse consists of cellulose (57%), pentosans (22%), lignin (17%) and mineral matter (4%).

Cellulose is a polysaccharide having the general formula $(C_6 H_{10} O_5)_n$ and is the main constituent of vegetable tissue. Cellulose consists of long polymer chains and differences in the properties are due primarily to different degrees of polymerisation (bagasse cellulose has a polymer chain of 2000 - 3000 units). Pentosans are polymeric five - carbon sugars which, under the action of boiling acid, are converted to furfural. Lignin is the name given to a group of high molecular weight substances whose chemical structure is largely aromatic.

Structurally, the cane stalk consists of (i) the tough, hardwalled, cylindrical cells of the rind and vascular tissues, or true fibres and (ii) the soft, thin - walled, irregularly shaped parenchymatous cells of the inner stalk tissue, or pith. The true fibre and the pith have about the same chemical composition, but their structure differs widely, and they occur in the ratio by weight of 2.5 : 1 approximately. The true fibres have a fairly high ratio of length to diameter, approximately 70, and a relatively high coefficient of expansion and contraction upon wetting and subsequent drying. This results in close bonding of one fibre with another and accounts for the strength, cohesiveness and ability to felt of bagasse fibres when subjected to pulping processes.

The pith cells are of irregular size and shape and are characterized by their absorbent properties. They do not bond together and so tend to weaken any pulp or board in which they are incorporated. However, they can absorb many times their weight of liquid and can thus find a use, mainly as a carrier for molasses, in the preparation of animal feed.

The average annual production of bagasse in Trinidad is approximately 725,000 tonnes, wet basis, with the two largest mills producing about 75% of this amount. At present the only major use of bagasse is as fuel in the sugar factories. Small amounts are sold to poultry farmers as litter and a certain quantity is committed for the production of particleboard. At present the surplus appears to be of the order of 100,000 tonnes/annum. By making economies in fuelling the boilers with bagasse (which are inadvisable at present because the object of burning the bagasse is to get rid of it), this supply could probably be increased by at least 25%, say, to 125,000 tonnes/annum. If, in addition, the boilers were converted to use oil or natural gas, then all the bagasse produced could be utilised other than for burning.

PULP AND PAPER

Efforts to manufacture paper from bagasse began well over a century ago and the first patent taken dates back to 1838. From then on, and especially after 1850, fairly frequent references can be found to bagasse as a paper-making material. In 1856 bagasse paper on which the 'Baltimore Advocate' was printed was produced. A number of paper mills were planned and built but apparently with little commercial success. One venture succeeded another and, although the number of failures was impressive, experience was slowly gathered and the bagasse pulp industry kept on trying and today there is a steadily increasing number of successful commercial plants.

It is now generally accepted that the presence of pith (+ dirt + soluble matter) is detrimental to pulp and paper manufacture as it tends to lower the quality of the pulp while making the process more costly in chemicals. The better the quality of paper required the more important thorough depithing becomes. The fibre, which remains after the separation of the pith, dirt and fines, is of short to medium length. This length is decreased somewhat by high grinding pressures in the sugar mill but even so, the depithed bagasse has reasonably good papermaking characteristics.

Bleachable pulps from bagasse can be made by the soda, kraft or the neutral sulphite process. Soda or kraft pulping is particularly well suited for producing writing and printing papers. At the present time practically all types of pulps can be produced from bagasse, ranging from a mechanical-type pulp to high-brightness bleached pulp. Bleached and unbleached bagasse pulps have many uses. However, the bagasse fibres are not as long as coniferous wood pulp and thus do not contribute the same degree of strength.

The manufacture of bagasse pulp and paper is essentially a chemical process in which crude cellulosic materials are chemically treated, usually with caustic soda, to remove undesirable components (e.g. lignin and pentosans), admixed with other chemicals (e.g. rosin, alum and clay) that impart desired characteristics, and finally felted from dilute water slurries and dried to form the paper. The minimum economic plant size for the production of bleached bagasse pulp is at present about 40 tonnes per day.

The bleaching of bagasse pulp is an essential step if the production of fine paper or market pulp is considered. A three-stage hypochlorite bleach is the usual solution. The manufacture of pulp and paper from bagasse calls for a plentiful supply of water of good quality, i.e. low turbidity, total hardness and total dissolved solids. The amount of water required depends largely on the end product ranging from about 70 - 80 m^3/tonne pulp for unbleached pulp to 300 - 500 m^3/tonne paper for fine bleached paper.

One of the more interesting possibilities for Trinidad appears to be the manufacture of corrugating medium for cartons. At the present time the principal sources of corrugating board are hardwood pulps and straw pulps and it is significant that about 40% of the total pulp and paper plant capacity in the world is engaged in producing paper board for use in the manufacture of boxes and shipping containers. Bagasse, in all essential respects, is a highly suitable material for the manufacture of corrugating board. Its fibre structure and high pentosan content give it an inherent advantage of rigidity, obviously a very important property for boxes, and for the fluting of corrugated cardboard. Unbleached bagasse pulp can be used in corrugating medium. Wrapping papers represent another possibility but in order to obtain the required tear resistance, it is necessary to blend the bagasse pulp with at least 40% of long fibres, i.e. rags, waste paper, etc., which of course increases the cost of the final product.

The world pulp market has strengthened over the past two years and there is now an acute shortage of wood pulp available to paper manufacturers. It is likely, however, that this situation will be reversed and the next five years will see a considerable weakening in the pulp market. This will affect the attractiveness of any bagasse pulp project since it is generally considered to be inferior to the hardwood pulp for which it would be a substitute. It might be useful to review the whole question of the feasibility of creating a paper making industry in Trinidad and Tobago using bagasse as raw material.

The line of approach so far has been principally that of the manufacture of bleached bagasse pulp for export mainly to Europe. This might appear to be a misconceived approach because

a) Bagasse pulp at its best is inferior to coniferous wood pulp for most paper and board manufacturers.

b) Bagasse pulp would have to be sold on the world market at appreciably lower prices than wood pulp in order to compete with it; this despite the extra freight charges it would have to bear.

Such competition would be difficult against the numerous wood pulp mills having very large production capacities. An integrated mill, making bleached pulp and a range of paper products, would therefore seem to be more feasible. An attractive short term possibility is the manufacture of unbleached pulp for use in corrugating medium.

One of two things has to happen before bagasse can be utilized effectively. The most likely development would be that technology and machinery improves, enabling bagasse to be processed economically at low throughputs. This has not yet occured but paper making experts are optimistic. The other factor is the increase in total market requirement in Trinidad and Tobago so that 40 or more tonnes per day of pulp could be utilised. Probably both technology will improve and market demand will increase, so that the installation of bagasse equipment becomes economically justifiable. At this stage modern pulping facilities can be installed.

It is important to realise that only a restricted number of grades of paper can be made on one particular paper machine, even if it is constructed to be as versatile as possible. The selection of the papers which, from the market point of view can be made to the best advantage, is therefore, a very important matter. It would seem that the following grades could be made - corrugating medium, wrapping and bag papers, toilet and tissue paper and writing and printing papers.

In order to obtain a picture of the long-term possibilities for an integrated pulp and paper industry in Trinidad, it can be assumed that the paper market of the country will, in 1978, be able to support a mill making 40 tonnes/day of various types of paper from bleached bagasse pulp with a proportion of imported wood pulp. The former would involve a complete pulping and bleaching plant, with soda recovery process, lime burning equipment and a plant for the preparation of chlorine and caustic soda by the electrolysis of brine, the excess caustic soda being sold locally. The amount of imported wood pulp would average about 10 tonnes/day. Both pulp and paper manufacture would be on conventional lines and the total capital cost has been estimated at approximately $50 million. Bagasse would obviously be the potential raw material for a scheme of this kind, but equally bamboo and pinus caribaea could be used. This also assumes that only those types of papers that can be made on one paper machine will be manufactured.

With rising costs of plant and machinery, and a tendency for pulp and paper prices to fall (in the long term) due to even larger manufacturing units in the traditional producing countries, it may well be that such a mill may even be too small to be profitable.

PARTICLE BOARD

The term 'particle board' is used to describe all boards produced from lingno-cellulosic particles and bonded together with a synthetic resin adhesive. Patents had existed before 1900 for gluing together particles of wood into board, but the industry was only made commercially feasible by the develpment of economical thermosetting resin adhesives. The first plant was built in Germany in 1941 and operated on wood chips with phenolic resin binder. The annual world production of particle board is probably now some 15 million tonnes representing a 1200% increase over the past ten years. End uses include furniture, shelving, flooring, roof lining and decking and wall elements and door construction. In general, particle board is 'self supporting' so that framing or supporting reinforcements are not normally required. Particle board is usually classified as follows:

Low-density (insulating type)	240 - 400 kg/m^3	(15 - 25 lb/cu. ft)
Medium-density	400 - 800 kg/m^3	(25 - 50 lb/cu. ft)
High - density (hardboard type)	> 800 - Kg/m^3	(50 - 75 lb/cu. ft)

MANUFACTURING PROCESSES

There are three main processes of manufacture, namely:

The multi-platen hot press process, where the board is flat pressed between the platens of a hot press.

The extrusion process, and

The continuous pressing or Bartrev process.

The multi-platen hot press process will be described since this method is being employed in the plant which is at present in operation. Three basic types of board can be produced by this method.

i) Single-layer boards, which consist of a homogeneous mass of particles throughout their structure.

ii) Three-layer boards (also called sandwich boards or Behr boards), which have two outer layers, about 1-3 mm thick, of fine particles and a core of larger particles, this core being of a lower density - and frequently with a smaller proportion of resin. They are especially suitable for furniture construction and have a relatively high bending strength. The main advantages of three-layer boards are their high density fine surface for painting, veneering, etc. and their saving in weight.

iii) Graded-density boards (often called Bahre boards) in which the particles are distributed through the thickness in such a manner that they gradually increase in size from the surface to the centre of the board. In all types, fungicides and insecticides can be added and the boards may be surface treated to resist spread of flame or veneered.

The bagasse used as raw material is hammer milled and screened, generally in two stages, before entering the storage bin. It is then dried and further screened for pith separation. If a three-layer board is to be produced, the bagasse is classified into coarse and fine fibres, which are then processed through two separate but parallel channels. The fibres are thoroughly mixed with metered quantities of urea formal-dehyde resin and sent to the spreading station for the mat-forming operation. Moulding cases or cauls pass underneath the spreader where they receive, in the case of a three-layer board, in sequence one thin layer of fine particles, then one layer of coarse particles, and finally another thin layer of fine particles.

The mat of resin coated particles which is initially about four times thicker than that of the finished board is then consolidated by pressing.

It progresses along a conveyor to the multi-platen hot press via its press loader. The press loader is equipped to receive a number of boards equal to the number of openings in the hot-platen press, which may range from 1 to 20, or more. When the press loader has received a full charge, the press opens and, upon discharge of the cured boards, the full uncured load is injected into the press. So called 'caul-less' systems have been developed by a number of manufacturers and a number of advantages are claimed, e.g. a smaller sanding allowance on thickness, which results in a saving in material. The 'Tray Belt' system uses deckle boxes which are equipped with a bottom-belt. The tray-belt deckle box serves for matforming and loading of the press. One forming frame is required for each day light of the press. The forming frames, filled with mats, are stacked in the loader. The frames then move into the press simultaneously during loading and place the mats on to the hot plates by means of the unreeling of the bottom belts.

At the end of the pressing cycle, the boards must be quickly removed to avoid too great a loss of moisture. The hot boards are taken from the press, via the unloader, and piled flat, and left for several days to cool, and finally condition. This is an important part of the manufacturing process, since after the boards are removed from the press, they must be cooled gradually to ensure the moisture content is distributed uniformly through the thickness, while the resin must cure completely. After conditioning the boards are trimmed to specified dimensions by travelling saw, and finally sanded on both faces to the required thickness.

The function of the resin is firstly to act as an adhesive and, secondly, to impart a certain degree of moisture resistance to the boards by creating a water resistant glued bond, dependent upon the proportion of resin to fibre. Urea formaldehyde resins are lower in cost and render the finished board clean and attractive in appearance and for these reasons are widely used with wax added as a water repellent. Phenolic resins are more expensive and improve water resistance, rendering boards suitable for exterior usage. They have, however, been manufactured with only very limited success. The weight of resin used varies between 6 - 9% of the dry fibre weight.

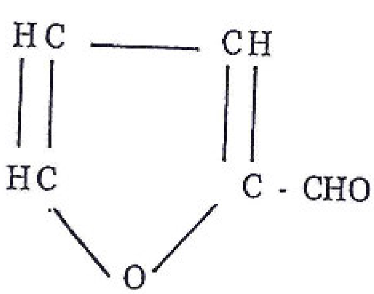
The pressing time varies with the moisture content and shape of the particles, and the nature of the hardener. A pressing time between ½ and 1 minute per mm of the total thickness is usually sufficient at a temperature of 140C. About 15 minutes is therefore normal for a 19 mm board.

The local plant has a design capacity of 36 tonnes/day of finished product based on a board size of 1830 x 4100 mm (6' x 13½'), a density of 600 kg/m^3 (37.5 lb/ft^3) and a thickness of 19 mm (¾"). The board thickness can, however, be varied between 6 and 45 mm (¼"-1-¾") and the density between 300 and 750 kg/m^3 (19-47 lb/ft^3).

The bagasse coming from the mill is depithed and the fines returned to the sugar factory. The bagasse is dried to reduce the moisture content to about 5% and then distributed to the two preparation lines for the surface layer and core layer particle preparation. The preparation includes refining to reduce and classify the size of the particles. The particles are then glued and conveyed to the spreading machines and then to the Tray belt press installation. The press is 4-opening. After pressing, the boards are trimmed and resized and then sanded on both sides. Veneering equipment and processing machines are available. This includes a high speed press designed for the application of thin wood and artificial veneers (impregnated papers).

FURFURAL

Furfural, when freshly distilled, is a colourless, inflammable, volatile, aromatic liquid. It is the aldehyde of the compound furan so that furfural has the formula



or $C_5H_4O_2$

Furfural may be produced from a number of plant materials containing pentosans (polymeric five-carbon sugars) - in the case of bagasse more than 90% being xylan. On acid hydrolysis the xylan yields xylose, which subsequently loses three molecules of water to form furfural. The overall reaction can therefore be written as follows:

$$\underset{xylan}{C_5H_8O_4} + H_2O \xrightarrow{H+} \underset{xylose}{C_5H_{10}O_5} \xrightarrow{H+} \underset{furfural}{C_5H_4O_2} + 3H_2O$$

In practice, several side reactions which occur simultaneously with the main reaction shown above detract from the furfural yield. To a small extent furfural is destroyed by the high temperature and acidic media, but a more important reason for not attaining quantitative yields is the reaction of furfural with some precursor. Thus a fundamental objective in obtaining reasonable yields is to remove the furfural from the reaction zone as soon as it is formed, and steam is the agent utilized. This important fact provides the basis for the well known Quaker Oats Process which has been responsible for nearly all of the world's commercial production of furfural.

USES

Furfural has a number of uses in the chemical industry but the market position is rendered difficult by the fact that established markets have been shifting to more competitive products. One of its major uses is as a selective solvent in the refining of high quality lubricating oils (20,000 tonnes/year world wide). Furfural is also used as a chemical intermediate in the preparation of a wide variety of commercial products. For example, furfural has been used in the manufacture of Tetrahydrofuran (THF) from which Nylon 66 is made. This, however, is a declining market where furfural has to compete against lower cost processes and, in fact, the main consumer, the du Pont Company, has already switched to a cheaper alternative petrochemical route.

Hydrogenation of furfural yields furfuryl alcohol, from which resins can be produced. These resins are inexpensive, heat-stable and corrosion resistant. They have been widely used in foundry applications (ca. 50,000 tonnes/year) and this represents a rapidly growing market with excellent prospects. During the last few years furfuryl alcohol based foundry resins have shown an extraordinary growth rate, the demand having doubled repeatedly within spans of 2 to 5 years in the U.S.A., U.K. and Europe. This was due to two factors, the growth of the foundry industry and, more important, a change in the technology of making cores and moulds. The old high pressure liquid-phase hydrogenation process is not competitive with the newer low pressure vapour-phase process based on a modified Nickel catalyst as now used by Quaker Oats.

TECHNOLOGY

There are only three known processes for the manufacture of furfural with reference plants, namely the Quaker Oats Process, the Agrifurane Process and the Sävö Process. However, there have been and are numerous processes under development, the most notable being the Two-Stage process.

Until recently, almost the entire world production of furfural was in the hands of the American Quaker Oats Company, which owns furfural plants at Cedar Rapids, Memphis and Omaha. Corn cobs constitute the major source of raw material, but oat hulls, cotton seeds, olive pits and rice hulls are also used. In 1955, a furfural extraction plant started operating at Central Romana in the Dominican Republic. It is a joint venture of the South Puerto Rico Sugar Company and the Quaker Oats Company, and the plant uses bagasse as raw material. It was reported, in 1966, that the Quaker Oats Company was building another furfural plant, using bagasse as raw material, at Belle Glade, Florida.

The conventional semi-batch process used by Quaker Oats in its mainland plants is as follows: corn cobs or other agricultural residues, along with dilute sulphuric acid, are fed into a series of large spherical digesters. When fully charged the digester is closed, set in rotation and steam at about 700 kPa introduced through a large number of orifices until the desired reaction temperature is reached. A vapour outlet valve is opened and additional superheated steam blown through the digester to permit removal of the furfural as soon as it is produced. Steaming is continued for 6 - 8 hours until the furfural content of the vapours decreases below the optimum economic level, i.e. where the gain in yield can no longer compensate for the increased steam consumption. The furfural-laden vapours are led into fractionating and dehydrating columns where approximately 99% furfural is finally obtained. Yields of 33 - 38% based on pentosan content are commonly obtained in industrial plants.

Each digester in itself operates as a batch reactor and the required continuous feed to the distillation unit is achieved by the operation of many digesters on a prescribed timing cycle. This necessarily results in a large number of digesters in order to simulate a continuous system. These digesters represent a very high capital investment per tonne of product and are by far the most expensive equipment item in the entire plant.

Disposal of the residue left after extraction is by itself a problem as this residue represents about 70% of the initial weight of raw material. This is mainly lignin and cellulose and is primarily used as fuel for the boilers. Precise data on the industrial production of furfural from bagasse is rather scanty. Steam consumption, which can be as high as 25 kg/kg of furfural, is a major item of cost.

One alternative process for furfural manufacture is the Sävö process developed in Sweden. It is utilised in Italy, Finland and the Soviet Union, mainly with wood residue from tannin extraction. No catalyst is used, since the acid catalyst necessary for the hydrolysis of the pentosans is generated continuously in the process. Sulphur dioxide may, however, be used. It is claimed that steam consumption is only about half that in the conventional process. It is also claimed that the residue is neither carbonised or degraded and could be used in paper and board manufacture.

The inefficiencies of the single stage system have stimulated investigations into other methods of furfural production. A large share of this work has concentrated on a 2-stage type of process. That is, prehydrolysing the raw material to extract the pentosans into solution as pentose followed by a converstion of the solubilized sugar to furfural. The basis for this type of scheme lies in the fact that conversion of the pentosan to mosaccharide (e.g. xylose) is almost quantitative and proceeds much more rapidly than the subsequent dehydration step to furfural. Thus,by properly staging the temperatures and acid concentration it is possible to effectively stop any degradation of the monosaccharide while obtaining a high yield (about 90%) of the available five-carbon sugars. This should prove to be technically feasible and relatively straightforward but no industrial examples of prehydrolysis are known although it is rumoured that the new Quaker Oats plant in Belle Glade operates on this principle. In any event, a great deal of research and development work needs to be carried out before the process can be commercialised.

Because of the extraction step the final dehydration to furfural can be quite simply effected. With due attention to fouling problems the homogeneous reaction can take place at 260 C with yields approaching 65% of theoretical. The high temperature and presence of acid (effectively 0.1 N) produce very rapid reaction rates so that the residence time is reduced to approximately 10 seconds. If the prehydrolysis step is carried out at 120 C, total hold up time in the two stage process is of the order of 30 minutes. The short residence time allows the use of a tubular reactor with very high flow rates and correspondingly large shear forces at the wall to help prevent fouling.

The simplicity of the system and continuous operation result in the advantageous combination of high throughput capacity at very low investment. In contrast to the single stage process where as much as three-quarters of the equipment investment is due to reactors, the tube type reactor is practically expendable, amounting to about 5% of the equipment cost.

One possible process alternative lies in the depithing of the whole bagasse. Under this alternative,the whole bagasse is separated into a pith fraction and a fibre fraction. The pith would be utilised for furfural production and the fibre upgraded to another product. An analysis of Trinidad bagasse has shown it to contain 24 - 26% pith by wet screening methods and roughly two-thirds of the pith can be removed by simple mechanical means. There is very little difference between the chemical composition of the pith and that for the remaining fibre with the pith containing slightly more gums or xylans.

Since the pith does not substantially differ in composition from the rest of the stalk, the potential furfural amounts to less than one-quarter of that obtainable from the whole bagasse. In addition to this disadvantage of smaller scale of production there is the cost of pith separation. There are, however, several factors which tend to counterbalance these unfavourable aspects. A potentially very attractive advantage in processing pith to furfural in contrast to whole bagasse is the likely large reduction in reactor volume necessary to accomplish the conversion. The difference in physical characteristics of the pith and fibre accounts for this possible process simplification.

One of the more obvious possibilities for upgrading the value of the residual fibre lies in the conversion of the fibre into pulp. It is conceivable that by operating a furfural plant in conjunction with a pulp plant, a reduction in raw material cost could be obtained by sharing the depithing costs between both plants. Hopefully, both the furfural and pulp plants would become viable by such a manoeuvre. An important consideration in order to achieve maximum benefits from plant combination is the necessity for integrating the fibre utilisation capacity to the pith requirements of the furfural plant. It does appear that a prima facie case can be made out for a combination type process.

MARKET CONDITIONS

The world market conditions appear to indicate that the price of furfural is the key to the market. Thus, if furfural could be produced in Trinidad at an ex-plant cost of US 7 cents/kg, it is reasonable to believe that the production could be marketed without difficulties. If, on the other hand, the costs were above US 9 cents/kg, it would be extremely difficult for Trinidad to market any significant quantities. The local consumption in Trinidad for the lube oil refining process is relatively small (ca. 430 tonnes/year).

The crux of costing furfural production lies in the raw material situation since, with conventional processing techniques, the cost of the raw material is the item of major expense (approximately 45%) in the manufacture of furfural. This is due to the low yields (generally less than 10%) that can be practically obtained and the handling costs associated with the necessity for moving large quantities of low bulk density material. Bagasse in Trinidad is produced in two large sugar mills and some smaller ones, with the large mills releasing approximately 130,000 long tonnes each of bagasse, dry weight.

Another valid approach appears to be to produce furfural at one of the two large sugar factories, using total bagasse from the two large mills, together with all other available cheap pentosaniferous materials (e.g. coconut bass, pigeon pea shells, etc.). This would be a relatively large venture, involving conversion of sugar mills to alternative fuels and handling, transportation and storage of bagasse - a low bulk density material - in large quantities. Such a project appears to be marginally profitable. Although it is certain that such a project would be economic from the national standpoint (addition to the G.D.P., employment, incomes earned in transporting bagasse, sale of fuel, etc.), it may not be so from the standpoint of its independent commercial viability in a market economy.

The viability of a furfural project in Trinidad would be enhanced considerably if a substantial fraction of the furfural output were converted to furfuryl alcohol. This is mainly because furfuryl alcohol represents the largest, most widely dispersed and fastest growing sector of the market. Moreover, Trinidad, in contrast to many potential furfural producers, has an available supply of hydrogen for furfuryl alcohol manufacture.

From a market standpoint, a plant capacity of 10,000 tonnes per year of furfural appears ideal and well within the range of the potential market. This is also the largest plant size which can be accommodated by raw material availability at either of the two major sugar factories.

Of this amount, about 6,000 - 7,000 tonnes should be converted to furfural alcohol. The alternative of producing furfural only is much less promising. Since the market for furfural as such will not grow enough, entry could presumably be gained by price cutting only.