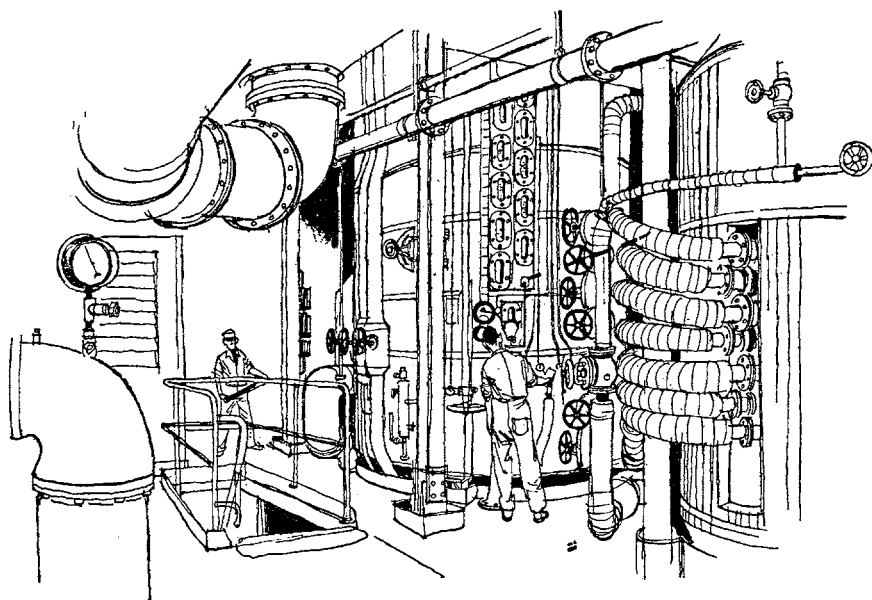




CHAPTER 8

Sugar Refining by C.S.R.

J. VERNON

This chapter describes briefly the physical character and working of the company's refineries, some of the interesting technical aspects of refining, and some of the considerations which govern the economic operation and development of C.S.R. refineries. The transport of raw sugar to the refineries and the marketing of the refined products have already been dealt with.

Dr J. Vernon joined the company to train as a chemist in 1928, obtained his Ph.D. degree at London University, became chief chemist of the company in 1938, and is now one of its two assistant general managers.

December 1955

THE name itself suggests the primary function of a refinery—to refine raw sugar into foodstuffs for human consumption. We have seen that raw sugar contains about 98 per cent of sucrose; it is variable in size of grain, in colour and in composition; it is very susceptible to bacterial action and deteriorates rapidly in humid conditions; furthermore it is not handled under the strict conditions of hygiene which are required for a final food product. This raw sugar has to be turned into refined products which will keep indefinitely without deterioration, which are standard in quality and purity, and which are packed and handled in a manner appropriate to a pure food. The main products of a refinery are white refined sugars of various types, soft brown sugars, golden syrup and treacle. Various specialities, such as tablet or loaf sugar and coffee crystals, are produced in small quantities, while liquid refined has been developed fairly recently for bulk distribution to certain large manufacturers. The main product, ordinary crystallized table sugar, is 99.9 per cent pure sucrose, one of the purest of foodstuffs in every respect.

The other main function of a sugar refinery is to hold the stocks of finished products that retail traders and food processors continuously require in modern communities. The refinery at Pyrmont, serving Sydney and the rest of the state of New South Wales, holds stocks at certain seasons of the year of 50,000 tons of raw sugar and 10,000 tons of refined products, representing a total value of about £2,700,000. Even in a smaller refinery these safeguarding stocks are considerable. The total working capital of C.S.R. refineries, mainly represented by stocks of raw and refined sugar and packaging material, fluctuates during the year but the company has to have approximately £10 million available to carry out the refineries' functions as the main commercial or strategic storehouses of sugar products.

The typical raw sugar used in Australian and New Zealand refineries contains 98.4 per cent sucrose and 0.4 per cent water. To get to the standard of 99.9 per cent sucrose would not appear to be very difficult, but we shall see that it is a complex process. This fact, combined with the large quantities involved, calls for big and highly specialized factories.

The Pyrmont refinery's annual capacity of refined sugar products is 200,000 tons, and it is probably the biggest food processing factory in Australia. Refineries are multi-storeyed buildings, which makes it possible to economize in space on expensive city waterfronts, to utilize gravity feed from operation to operation, and to house individual units of plant which in some cases extend vertically through several storeys. While the main operations in a sugar mill can be seen from

one or two vantage points, a refinery is divided into a number of distinct sections, each with its own function, and it is quite difficult in one visit to get even a general understanding of the successive operations. The characteristic noises and smells of a sugar mill are missing; there is, instead, the quiet of the huge stores of bulk and bagged raw sugar, which may occupy as much as three acres of lofty buildings, or of the big sections where syrups are quietly running from filters or circulating in pans and mixing vessels. There is a complex network of pipes conveying syrups from one section to another and circulating them back and forth through various stages of manufacture. A sugar refinery contains most of the unit processes of a chemical engineering textbook—filtration, clarification, gas absorption, precipitation, evaporation, crystallization, surface adsorption, centrifuging, heat exchange and many others. It also involves a wide range of problems in materials handling. Heat and electric power are important items and the boiler and power stations are major installations.

C.S.R. operates six refineries of which five are in Australia, one in each capital city of the mainland, and one is situated at Auckland and supplies the whole needs of New Zealand. Tasmania's requirements are supplied from Sydney and Melbourne. The six refineries have a total capacity in excess of 600,000 tons of refined products per annum, individually producing in proportion to the populations of the areas they serve. In the company's balance sheet they are valued at about £10 million, representing about 30 per cent of the total value of the company's fixed assets and its investments in subsidiary companies. To build new refineries of this capacity would cost over £20 million.

The Principles of Sugar Refining

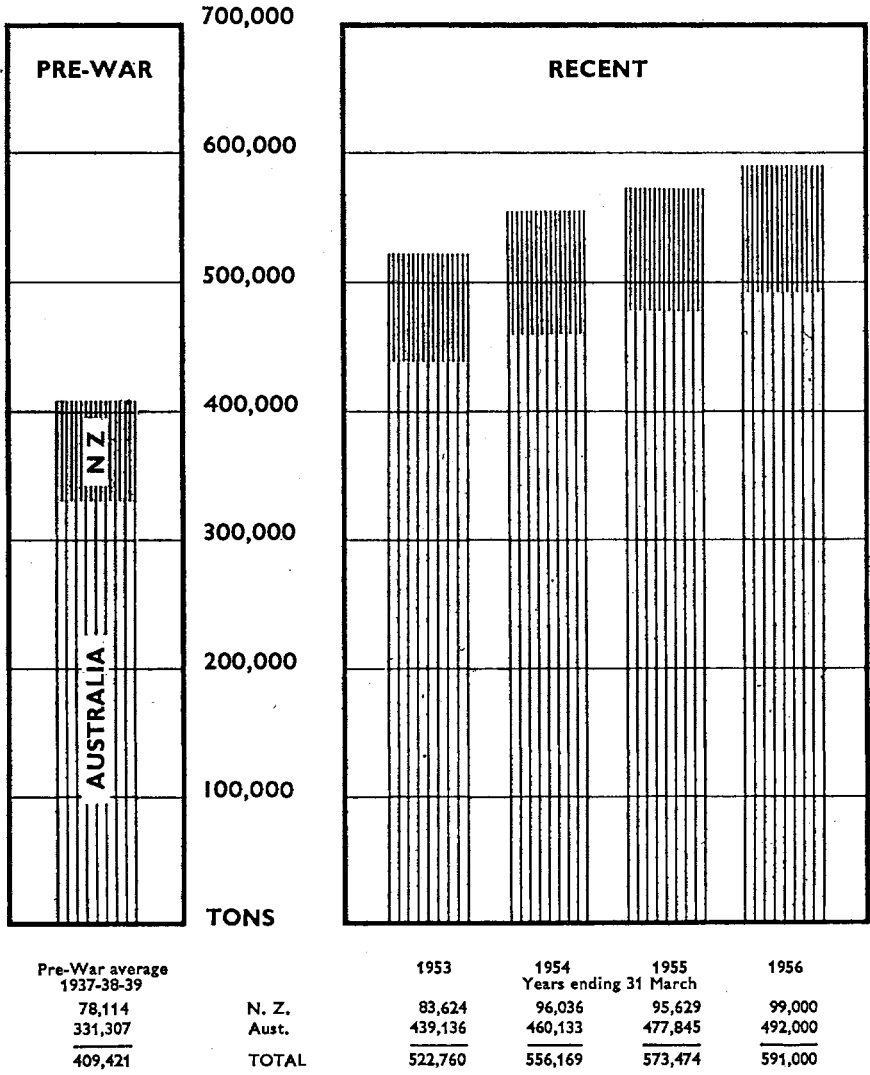
In order to understand the refining process, it is necessary to examine in more detail the composition of raw sugar. We have seen that it contains about 98 per cent of *sucrose*, which is the chemical name for the pure substance which we ordinarily refer to as "cane sugar". The other constituents of raw sugar are called, in sugar refiners' parlance, the "impurities". Many of them are, in fact, as edible and wholesome as the sucrose itself, but a small number of them are impurities in the sense of contaminants or materials unsuitable for consumption as foodstuffs. The refiner's primary task is to eliminate completely these undesirable contaminants, mostly dirt and bacteria, so that every product of a refinery is of a pure food standard. The next task is to produce a sugar which will keep indefinitely, which is attractive in colour, and which is constant in

SOUTH PACIFIC ENTERPRISE

purity, taste and all other respects: and this involves removal of all non-sucrose constituents to make a white granulated sugar.

SALES OF REFINED AND OTHER SUGAR PRODUCTS BY C.S.R.

Refined sugar in Australia is manufactured from raw sugar obtained from C.S.R. Company and other mills in Queensland and northern New South Wales. In New Zealand refined sugar is manufactured from raw sugar obtained from Queensland, Fiji and other world sources. *Source: C.S.R. records.*



SUGAR REFINING BY C.S.R.

Chemically there are various types of sugar, the name being given generally to a group of carbohydrates which are sweet and crystalline. One class of "impurities" in raw sugar consists of two chemically different sugars, glucose and fructose, which are described as *reducing sugars*. Glucose, as sold commercially in the form of glucose syrup and best known in confectionery, is usually made from starch. Fructose is not used to any extent as a commercial product. These reducing sugars are present in raw sugar because they are present in the original sugar cane plant and because sucrose is converted into equal parts of glucose and fructose under mildly acid conditions such as may occur at some stages of the milling process or by the action of certain micro-organisms during storage and transport under tropical conditions.

Another group of "impurities" is referred to as *other organic matter*, an omnibus term which covers a large number of substances such as small pieces of fibre carried through the milling process from the original cane, suspended protein material, gums and waxes, polysaccharides, micro-organisms and their products, and fluff from jute bags. These substances are contaminants, some of which produce turbidity when raw sugar is dissolved in water. Other compounds such as aconitic acid, furfural, amino acids and anthocyanin are included in the organic matter group. There is also the complex substance called caramel, which is formed by the partial decomposition of sugars, particularly at high temperatures, during the milling process. Caramel is mainly responsible for the yellow or light brownish colour of raw sugar which must be removed in making white refined sugar.

Ash (or, as it is sometimes termed, *mineral matter*) is also an omnibus term to include a number of mineral constituents such as the salts of iron, potassium, calcium and magnesium. Some of these come from the original cane juice and from the soil brought into the mill with the cane stalks, while others have been carried over from the purification process at the sugar mills, where lime is added as a partial clarifying agent.

With this introduction, we can now consider the composition of a typical Australian raw sugar such as is handled at one of the C.S.R. refineries. Its analysis would be approximately as follows:

<i>Sucrose</i>	..	..	..	..	98.4 per cent
<i>Reducing sugars</i>	..	..	..	..	0.5 " "
<i>Other organic matter</i>	..	..	..	..	0.5 " "
<i>Ash</i>	..	..	..	..	0.2 " "
<i>Water</i>	..	..	..	..	0.4 " "
					100.0 " "

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Although the proportions of the non-sucrose constituents appear small in relation to sucrose, they nevertheless amount to considerable quantities during a year's operations. For instance, in a refinery handling 200,000 tons of a typical raw sugar per annum the above percentages would represent the following tonnages over the year:

<i>Reducing sugars</i>	..	..	..	1,000 tons
<i>Other organic matter</i>	..	..	..	1,000 „
<i>Ash</i>	..	..	..	400 „
				2,400 „

The non-sucrose constituents can be used to make other products of the refinery. These other refined products, making up about 5 per cent of the refineries' output, are No. 3 brown sugar, golden syrup and treacle. Each of these products requires the presence of selective amounts of the reducing sugars, organic and mineral constituents which have been rigorously excluded from the white refined sugar. The refiner's task also involves, therefore, the separation and selective redistribution of the various non-sucrose constituents into products other than white refined granulated sugar.

This makes clear the answer to a question which is sometimes asked, "Why bother to refine raw sugar at all when it already contains over 98 per cent of sucrose?" The answer is that raw sugar would be quite useless for many food and drink manufacturers, and that the contaminants, although small in volume, have most undesirable characteristics. They impart off-flavours, after-tastes and odours which people find unpleasant. For some foods and many drinks, the brown coloration of raw sugar is unacceptable. The hygroscopic film around the raw sugar crystals is an excellent medium for the growth of bacteria and moulds so that the sugar would not keep in the warehouses, the grocers' shops and the home. The bacterial count is high and precludes the use of raw sugar in a great many bottling and canning processes; and raw sugar slowly deteriorates into a fermenting, sticky mess. Raw sugar is too variable a product to be accepted for use in standardized manufactured foodstuffs. Overriding all considerations is the fact that raw sugar is not a pure food product, prepared, handled and transported under conditions which must be applied to a foodstuff for consumption. These are the basic factors which account for the fact that nowhere in the world do advanced communities eat raw sugar.

The Refining Process

The modern refining process has been developed and improved over a long period of years. The process is a complicated one and in order to give a simple picture it is necessary to eliminate much of the detail, particularly of the way in which syrups of varying concentration and degrees of purity are recirculated through the process. For the purposes of this book, however, we can describe the main features of the successive steps shown on the coloured flow diagram.

Raw sugar, as received from the mills in bulk or in bags, consists of crystals of fairly pure sucrose, surrounded by a film of syrup which contains the greater part of the non-sucrose constituents whose elimination is the prime task of the refiner.

The first refining process is aimed at removing as much as possible of the syrup film from around the sucrose crystals. This is done by "washing" the raws with hot water in high-speed centrifugal machines. To do this the crystals of raw sugar and a hot sugar solution of lower purity and high concentration are mixed into a slurry, in which the film on the crystals is softened and diluted without appreciably dissolving the sucrose crystals themselves. The slurry is fed into centrifugal machines which are, in effect, perforated baskets capable of being revolved at high speed; the syrup is spun off, and the crystals are washed with hot water which carries with it much of the film surrounding the original crystals. This process removes about three-quarters of the non-sucrose constituents originally in the raw sugar and concentrates them in the form of a low-grade solution which can be more efficiently handled in a separate recovery system.

The "washed" sugar, noticeably lighter in colour than the original raw sugar, is next dissolved in hot water to give a concentrated, turbid syrup which is then subjected to the "carbonatation" step of the refining process. This is a method which is not widely used by other cane sugar refiners, except for Tate and Lyle Limited. The latter, in the United Kingdom, and C.S.R., in Australia, have carried out considerable research to develop the method, which consists essentially of the addition of lime to the concentrated sugar solution and the precipitation of this lime by bubbling carbon dioxide through the solution. The carbon dioxide is obtained cheaply by extracting it from the flue gases of the boiler station. During the precipitation and growth of the fine calcium carbonate (chalk) crystals many complex organic impurities are coagulated and trapped, or adsorbed, by the precipitate. The calcium carbonate thus formed becomes the filter medium in the subsequent filtration stage.

After carbonatation is completed the solution is filtered through cotton cloth in pressure filters which remove the precipitate, with the coagulated impurities, bacteria and micro-organisms which it contains, leaving a sparkling, straw-coloured sugar solution known as "raw liquor".

The next purification step eliminates most of the colouring matter and dissolved minerals. The transformation from yellowish raw liquor to colourless, sparkling syrup, known as "fine liquor", is a striking change achieved by the action of bone charcoal, a black granular material made by heating beef bones to a high temperature in closed retorts. Even to the chemists specializing in this work, the actual mechanism by which bone charcoal effects the change is still something of a mystery, although the basis of the mechanism is that the bone charcoal particles consist of a highly porous framework of calcium phosphate completely covered with a thin layer of carbon. Because of its multitude of pores, each small granule of bone charcoal presents a relatively enormous area of the carbon layer and it is generally believed that this carbon is in a sufficiently activated state to adsorb large quantities of colouring matter and mineral matter from any solution.

The raw liquor from the filters is run through large vertical cylindrical tanks filled with bone charcoal, and the fine liquor emerges at the bottom containing only a trace of the original organic and mineral impurities.

At the next stage of the process the sucrose in the liquor gets back to the solid crystalline form. Fine liquor is run into vacuum pans where it is boiled under high vacuum; this allows water to be evaporated off at about 140°F. thus avoiding the use of high temperatures and minimizing the destruction of sucrose and the formation of colouring matter. As evaporation proceeds, a point is reached where the solution becomes supersaturated and, by use of a special technique, a cloud of microscopic crystals is made to form suddenly throughout the solution. The rate of evaporation and the rate of addition of fresh fine liquor are controlled so that the solution is kept just supersaturated and the grains of the original crop of microscopic crystals are made to grow gradually without any new crop forming. At the finish of boiling the vacuum pan is full of a heavy mixture of crystals of the required size plus residual syrup; this mixture is discharged and run into centrifugal machines working on the same principle as those used in the "washing" stage. The residual syrup is spun off through the perforated baskets and the pure crystals are retained. A light spray of water aids the removal of traces of adhering syrup.

The crystallization process does not stop after one boiling. Although



New Farm Refinery, Brisbane.



Entrance to Yarraville Refinery, Melbourne. Employees' amenities block on right.

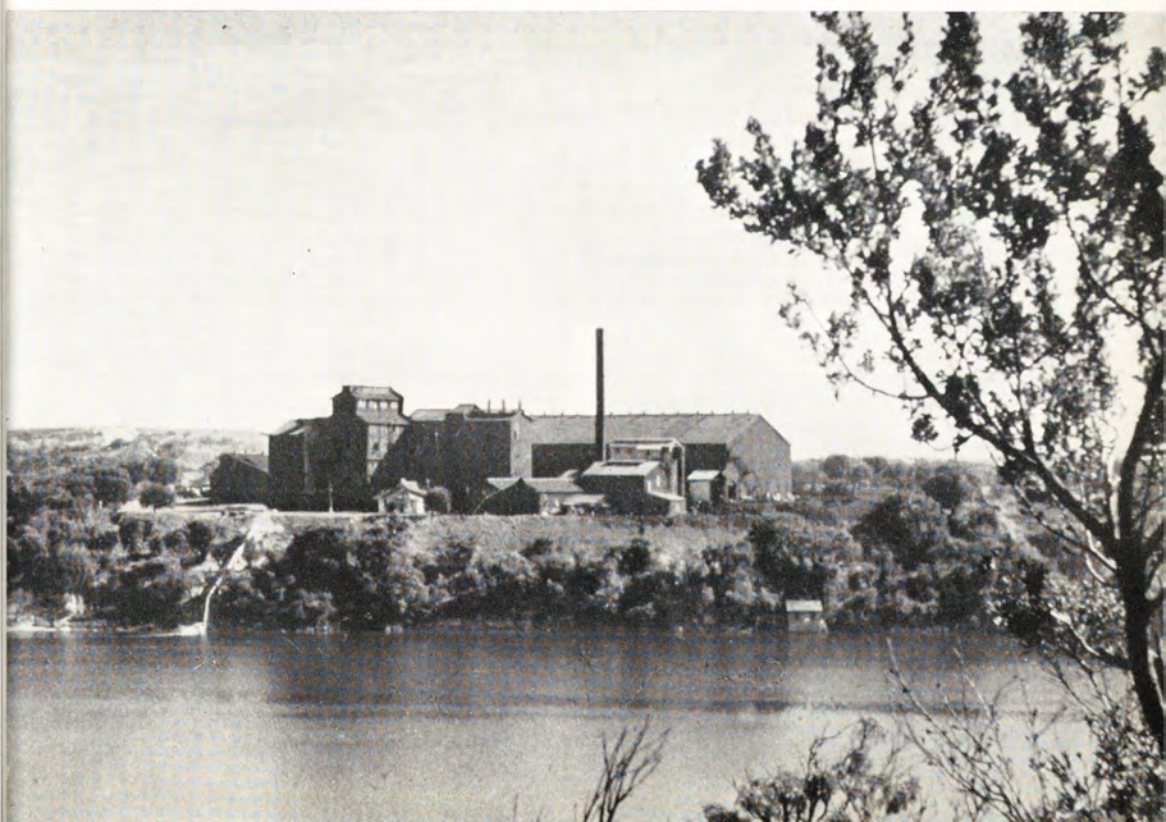
Inspecting the canteen kitchen at Yarraville Refinery. At left: Messrs E. Thatcher, amenities supervisor, and A. G. Stokes, refinery manager.

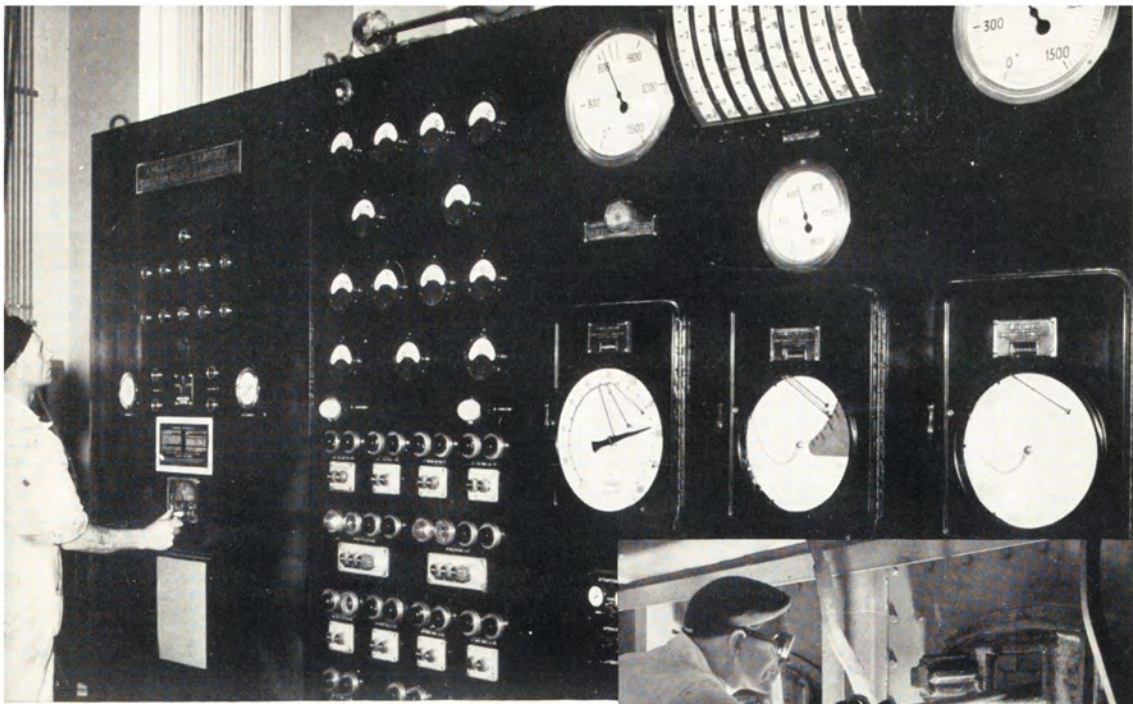




Glanville Refinery, Adelaide.

Cottesloe Refinery, Perth.



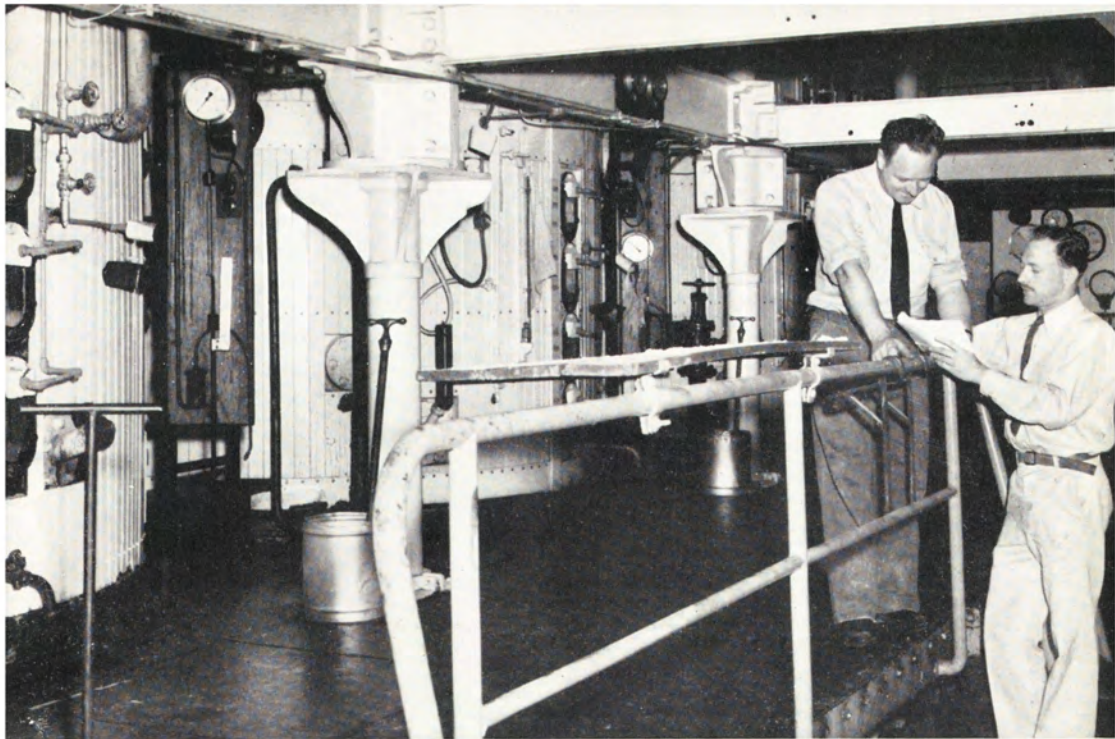


Above, control panel of new high pressure boiler station, Pyrmont Refinery. Right: Inspecting furnace.



New electric power station, Pyrmont Refinery. The turbines are driven by high pressure steam from the boiler station. Low pressure exhaust steam from the turbines is used in the refinery. At left, Mr C. F. Rigby, chief engineer, Pyrmont Refinery.

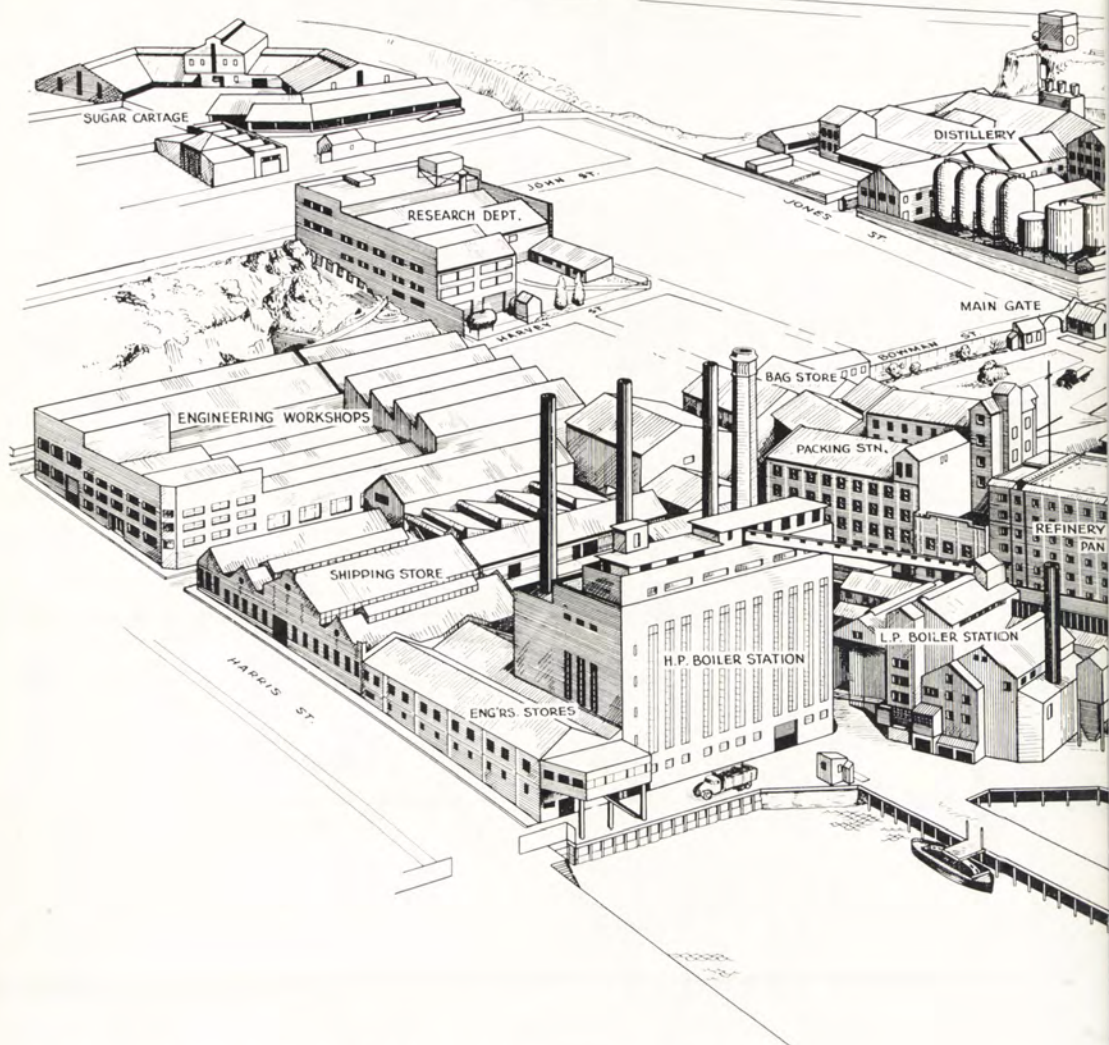




On the pan floor, Yarraville Refinery. Where major technological change does not occur old plant like this, when well maintained, gives efficient results. At right: Messrs T. Kennison, process foreman, and G. W. Watson, shift chemist.

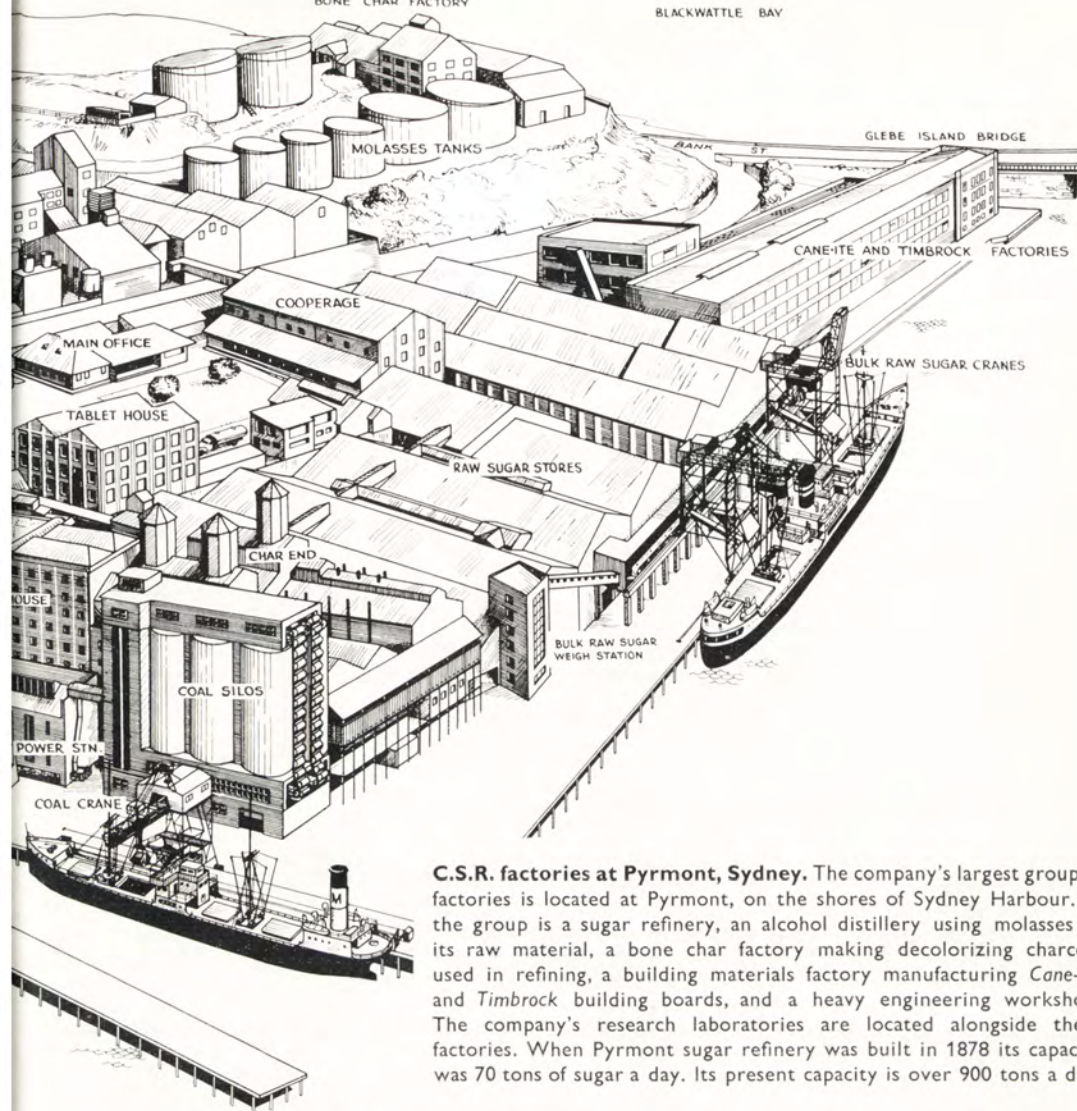
Refinery laboratory, Yarraville. From left: Messrs W. Opstelten, R. Zindler seated, P. J. Noble, J. P. Moulding and Miss M. Vitolins.





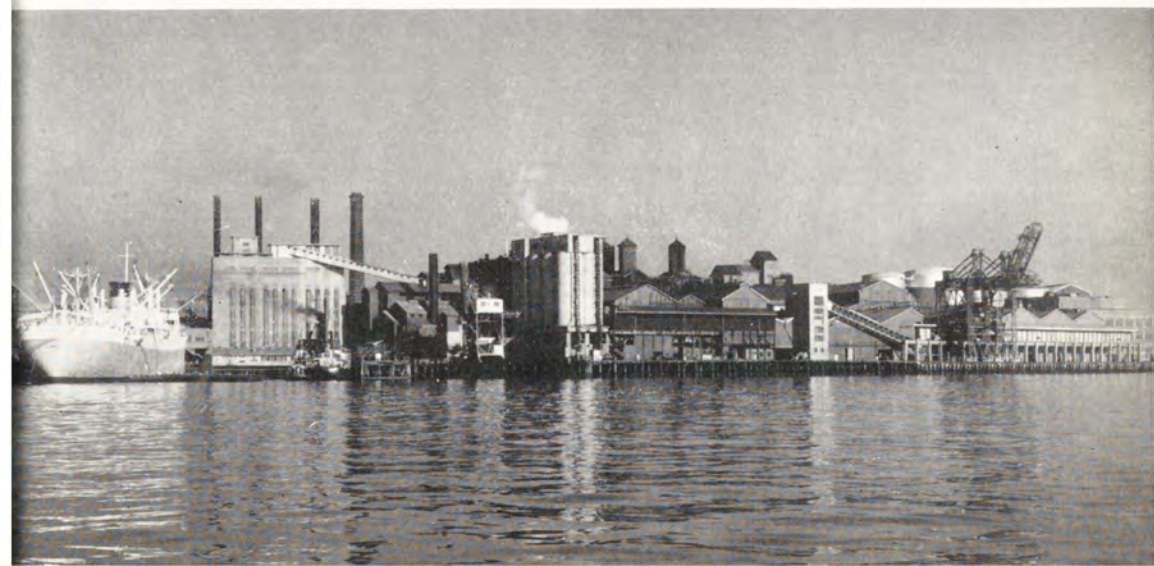
Below: Pyrmont Refinery, 1878, shortly after it commenced operations.

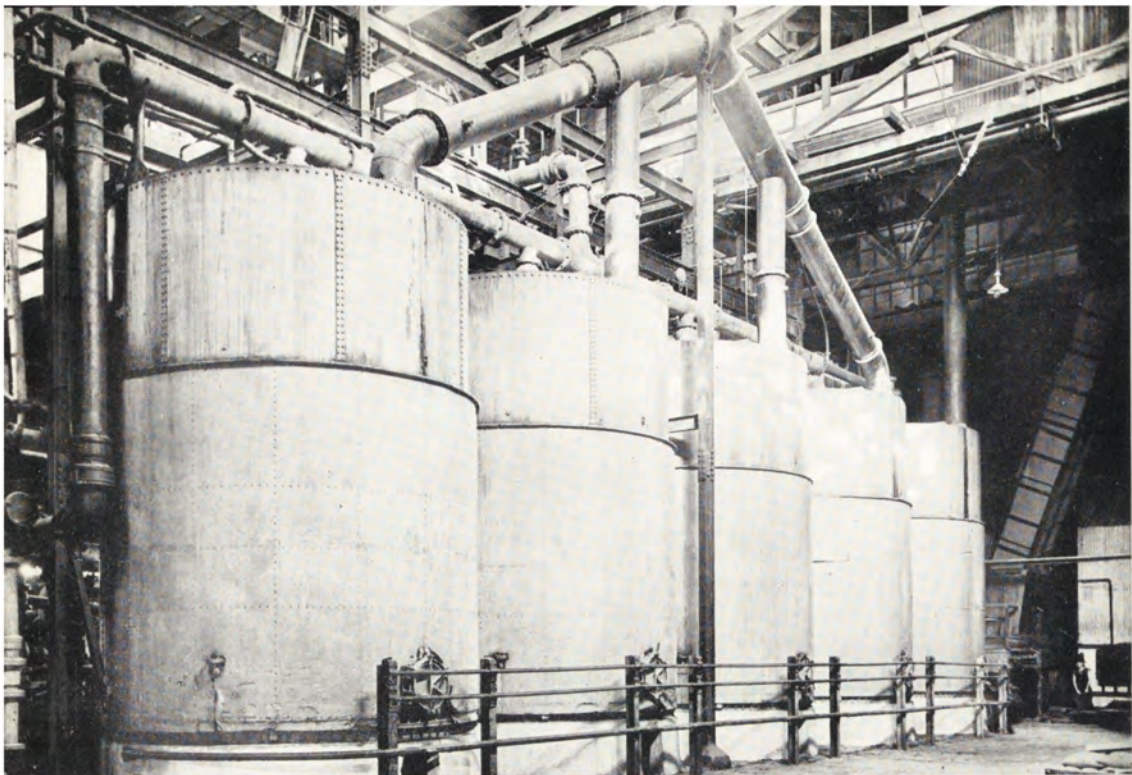




C.S.R. factories at Pyrmont, Sydney. The company's largest group of factories is located at Pyrmont, on the shores of Sydney Harbour. In the group is a sugar refinery, an alcohol distillery using molasses as its raw material, a bone char factory making decolorizing charcoal used in refining, a building materials factory manufacturing *Cane-ite* and *Timbrock* building boards, and a heavy engineering workshop. The company's research laboratories are located alongside these factories. When Pyrmont sugar refinery was built in 1878 its capacity was 70 tons of sugar a day. Its present capacity is over 900 tons a day.

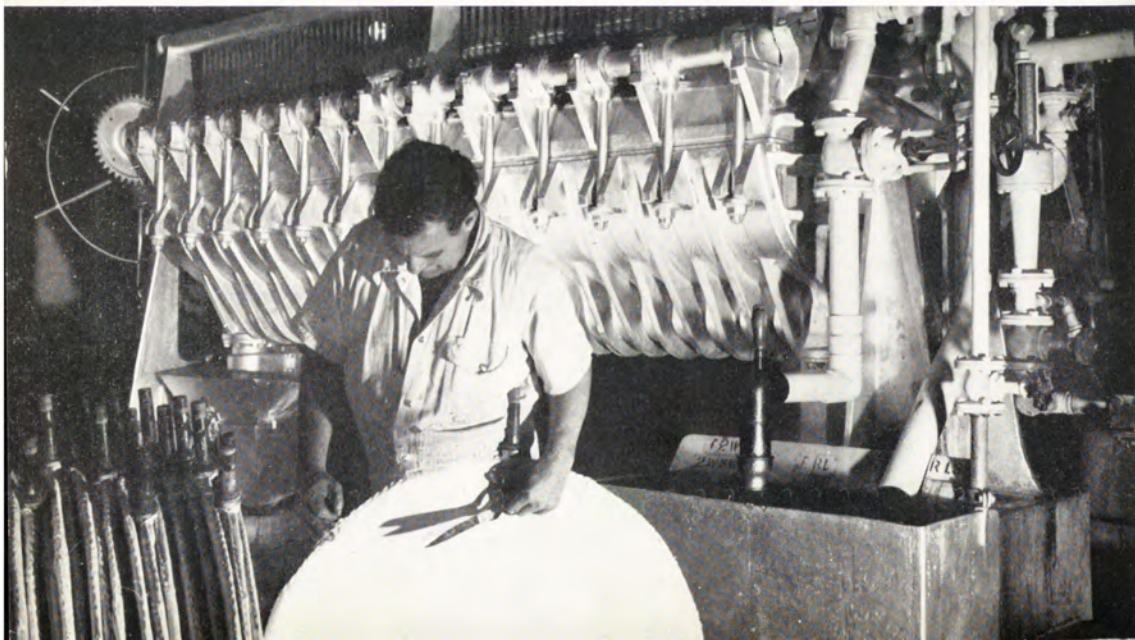
Below: Pyrmont Refinery, 1955, from the same viewpoint as the old photograph opposite.





Carbonatation tanks, Pyrmont Refinery. Milk of lime is added to a solution of "washed" raw sugar in these tanks (see text) and carbon dioxide from waste flue gases bubbled through to precipitate calcium carbonate. The fine calcium carbonate adsorbs a large part of the coagulated impurities and also acts as a filter aid in the subsequent filtrations. The successful operation of the carbonatation process depends on the correct choice of conditions such as temperature, initial alkalinity, final alkalinity, temperature of reaction, and also on the maintenance of such conditions within close limits. The process is automatically controlled by instruments.

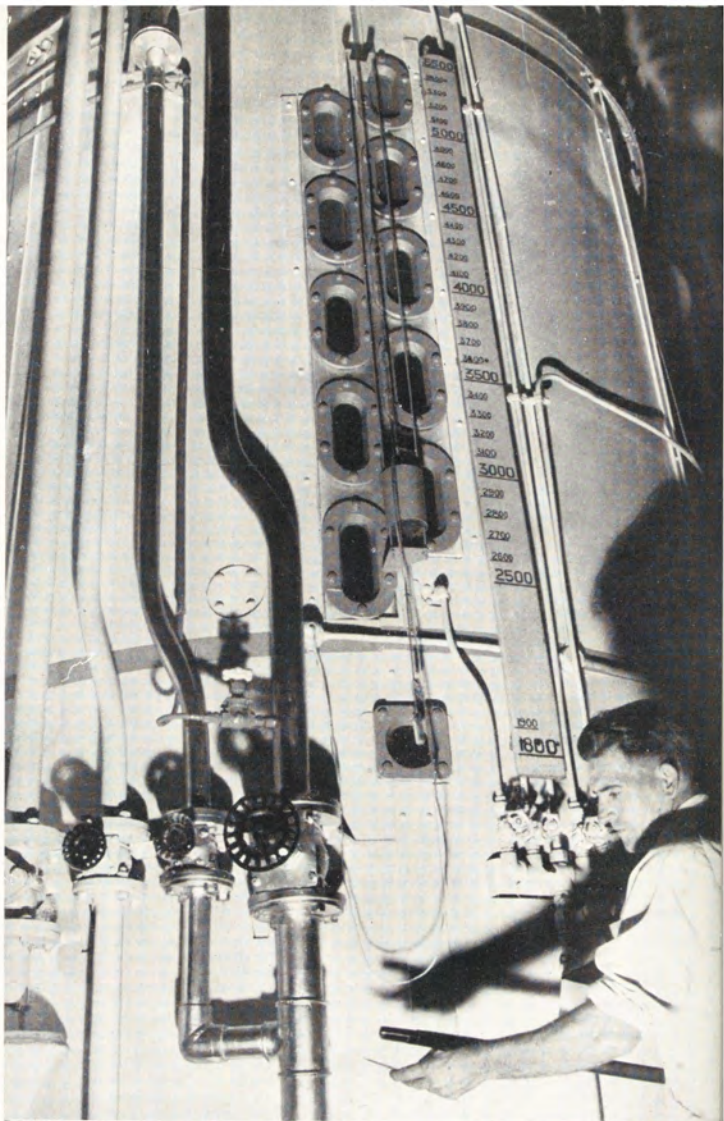
Filter press, New Farm Refinery. *Foreground:* Operator fitting new filter cloth. The solution from the carbonatation process, containing suspended calcium carbonate and coagulated impurities, is forced under pressure through cotton cloths. A clear honey-coloured "raw liquor" emerges from the filter presses.



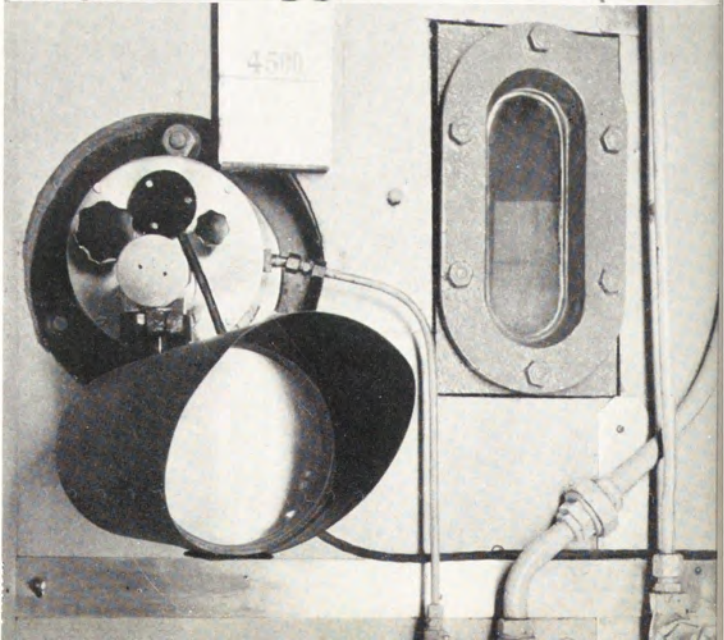


Char cisterns, Cottesloe Refinery (*from a retouched photograph*). Filtered "raw liquor" is run through cisterns containing granular bone char, which removes colouring matter and mineral constituents. The char is made by heating bones in closed retorts at high temperatures. It consists largely of calcium phosphate in the form of a porous "skeleton" coated with active carbon. A large surface area of carbon is thus available to adsorb colouring matter and mineral salts from sugar solutions. After use the char is washed, regenerated by heating—which decomposes adsorbed organic material—and used again.

Sugar boiler drawing a sample from a vacuum pan, New Farm Refinery. Sugar is sensitive to excessive heat, which tends to destroy the sugar itself and to colour it. If sugar solutions were boiled in open pans the temperature would reach 240°F, but similar solutions will boil at 140°F under vacuum with little danger of loss or discoloration by heat. To make crystals of white refined sugar a clear sugar solution of high purity called "fine liquor" is run into a vacuum pan (see text and colour diagrams). The solution is heated and, as it boils, water is evaporated off until it becomes supersaturated. At this stage crystals of sugar form and continue to grow as boiling continues. The crystallization process must be precisely controlled so that the requisite number of microscopic crystals are formed initially, and grow to the required uniform size as quickly as possible. Control instruments help the sugar boiler in his work, but the process still demands skill and experience.



A microscope on a vacuum pan. A magnified image of crystals forming and growing in the pan is projected on a screen.





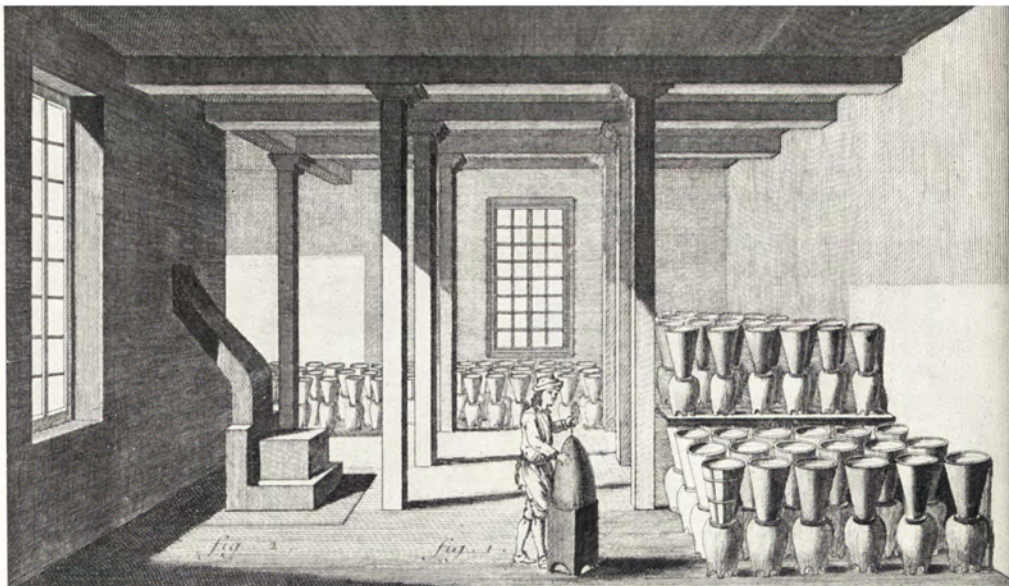
Above: Operator and centrifugal machine, Yarraville Refinery. Centrifugal machines, which separate crystals from syrup, make possible the manufacture of free-flowing granulated sugar. Before the introduction of centrifugal machines, about the middle of last century, sugar in the form of separate small crystals could not be made commercially.

A mixture of syrup and crystals, called *massecuite*, from the vacuum pans is poured into perforated baskets in the centrifugal machines. The baskets are revolved at high speed and the syrup is flung off (see colour diagram). In recently-developed forms of the machine all operations are done automatically.

After discharge from the centrifugals the crystals of refined sugar are dried, graded and packed.



Left: Packing refined sugar in 70 lb. bags, Pyrmont Refinery.



Until the middle of last century, when the development of the centrifugal machine enabled loose, dry crystals to be made, refined sugar was made in conical loaves formed by pouring a mixture of crystals and syrup into moulds. The syrup drained off through a hole in the apex of the mould. The sugar set hard, and had to be broken up with a mallet before using. From *Agriculture et Économie Rustique*, 1762-1772.



Left: The old-fashioned sugar loaf, still made in some European refineries for the Asian and African trade. *Right:* The modern descendant of broken-up loaves—rectangular tablets of refined sugar still popularly referred to as “loaf sugar”.



a substantial proportion (about 55 per cent) of the sucrose in the fine liquor has been obtained in crystalline form, the residual syrup still remains. This is collected and subjected to a similar boiling process to give a further yield of crystals, and this is repeated a number of times. The effect of all this is to remove and recover the greater part of the sucrose in pure crystalline form, and to concentrate the non-sucrose constituents in the residual syrup which becomes lower and lower in purity. The end is reached when the residual syrup contains such a high ratio of "impurities" to sucrose that the syrup is heavy and viscous and further treatment becomes uneconomical. This last syrup is molasses, into which have been concentrated all the non-sucrose constituents not removed or destroyed earlier in the process.

Damp refined sugar from the centrifugal machines (the "fugal station") is passed through revolving drum driers where moisture is reduced to less than 0.1 per cent by warm air. It is then sieved to give grades of uniform crystal size, passed to the storage bins, and thence is packed in bags for delivery to consumers.

This account of the refinery process has necessarily been greatly simplified. Some syrups, for instance, are run through the char cisterns a second time to raise purity and improve colour before proceeding further. Again, at a certain stage in the crystallization sequence the syrup becomes too high in non-sucrose constituents to produce crystals of the required purity. Some of this syrup is used for making special products such as golden syrup, treacle, and soft brown sugar, while the remainder goes to the "recovery" or "boil-out" house. Here it is mixed with the syrup made from the original washing of the raw sugar and is crystallized in vacuum pans in three controlled stages to yield crystals whose purity is equivalent only to that of a low-grade raw sugar. These crops of crystals are returned to the beginning of the whole refining process, and again pass through carbonatation, filtration and all subsequent steps.

All the unwanted impurities gradually accumulate in the syrups of the "boil-out" section. The rate of crystallization in these syrups is very low and a point is reached where the rate is retarded so much by the impurities present that further attempts to extract the remaining sucrose are not worth while. This point must be decided by a carefully balanced determination. The resultant black viscous syrup, molasses, is the residual product of the refinery.

It is difficult to convey an impression of the complexity associated with the large number of syrups of different purities circulating in the various sections of the refinery. At Pymont refinery, for example, there are, at any instant, about 1,000 tons of materials, made up of some

fifty different grades and types, circulating throughout the plant, each strictly directed along its own particular course of pipelines and tanks. There are also over 1,000 tons of decolorizing charcoal slowly moving through a continuous cycle in the decolorizing and regenerating plants.

Check and Counter-Check

Throughout the day and night sampling and analysis go on continuously in order to keep each section of the process under close control. Continuous sampling devices collect samples of all the different grades of liquors and syrups. Every second or third bag of the raw sugar entering the refinery is sampled by means of a steel prong which is poked into the bag to extract about a dessertspoonful of sugar. Syrups, refined sugar, bone charcoal, filter mud, coal, coke, and lime are all sampled at a planned frequency. The water circulating in process is also sampled continuously at various check points. This includes water from the condensers, heat exchangers and vacuum pans, washing water from char cisterns and filters, water from sugar dust scrubbers, boiler feed water, and all water leaving the refinery via refinery drains.

The laboratory staff analyses this constant flow of samples, and supplies a running bulletin of temperatures, densities, colours, ash, reducing sugar, and sucrose contents. The supervisory staff can thus detect and quickly correct any trend away from standard at any point in the process.

One of the most important controls is the *pH* figure which is a measure of acidity. In acid solution cane sugar is converted into reducing sugars, the reaction being more rapid the more acid the solution. Care must be taken not to allow any of the solutions circulating in the process to become even slightly acid, otherwise some sucrose will be destroyed. In critical sections of the process, recording instruments are used to give an automatic and continuous record of *pH* values.

The ash content and reducing sugars content of the various liquors and syrups are determined every eight or twenty-four hours so that the chemist in charge of the shift can ensure that the required degree of purity is being reached in each operation. For instance, by the time the sugar solution has been carbonatated, filtered, passed through the decolorizing stage and made ready for crystallizing in the vacuum pans, about 90 per cent of all the impurities and colouring matter should have been removed. Once having diverted these impurities into lower-grade syrups care must be taken to see that they do not contaminate the

higher-purity syrups again, otherwise some of the work already performed would be undone. The reducing sugar content of each material also indicates to the shift chemist whether destruction of sucrose is occurring. This may be the result of bacterial action or of an increase in acidity.

Since all water added in the refinery process must eventually be evaporated, the aim is to use as little water as possible. Densities, or specific gravities, of solutions provide an index of the proportion of dissolved solids to water, and therefore serve as important control figures. A small percentage reduction in density of any of the materials in process can produce a noticeable increase in the weekly coal bill.

The decolorizing section of the refinery is virtually a chemical plant complete in itself and requiring specialized control. Bone charcoal is an expensive material and must be handled carefully, firstly to prevent loss by abrasion into useless dust and secondly to prevent oxidation and other changes in its chemical composition during regenerations at high temperatures in the kilns. Its decolorization and ash adsorption properties are very sensitive to the time and temperature of revivification. It can also be a great harbourer of micro-organisms which destroy cane sugar, and in this respect needs close supervision. The bone charcoal must therefore be analysed frequently for carbon content, decolorizing power, *pH* and volatile organic matter. A full chemical analysis is carried out at regular intervals to see that no slow change in chemical composition is taking place and a sieve analysis is done at the same time to see whether the particles are suffering physical breakdown.

In addition to supplying the supervisory staff with the hour-to-hour information necessary for the efficient running of each section of the process, the laboratory also carries out at regular intervals a complete chemical balance of each and all of the constituents of the sugar products going into and out of the refinery.

For the main constituent, sucrose, a typical sucrose balance would be:

<i>Sucrose introduced</i>	..	..	..	<i>100.0 per cent</i>
<i>Sucrose in refined products</i>	..	..	..	<i>98.4 " "</i>
<i>Sucrose in molasses plus</i>	}	..	..	<i>1.6 " "</i>
<i>Sucrose lost in process</i>				
				<i>100.0 " "</i>

The figure of 1.6 per cent is divided approximately equally between molasses and process loss. This proportion and the total figure itself,

however, vary considerably according to circumstances. The main causes of variation are the purity of the raw sugar entering the refinery and the quantity of golden syrup and treacle produced.

The importance of controlling process losses is seen when it is realized that in the refining of 600,000 tons of sugar per annum an increase in loss of 0.1 per cent during processing would amount to 600 tons of sugar which at raw sugar value represents an increase in monetary loss of approximately £24,000.

A balance of the non-sucrose constituents is made in exactly the same way. Each constituent, i.e., the reducing sugars, the organic matter, and the ash, is considered separately. Each of the impurity balances serves as a counter-check on losses and efficiency. For instance, the reducing sugars balance might sometimes show a gain of reducing sugars and this would indicate chemical breakdown and loss of sucrose, a state of affairs requiring immediate investigation and correction. The ash balance also could show a gain of ash, indicating excess addition of lime in the process or some deterioration in the ash removal efficiency of the char plant.

Not all refiners in other parts of the world carry out a balance of the impurities, but C.S.R. has found that it is a most useful guide and a sensitive means of detecting undesirable trends in the process.

Technical Control

In the operation of its refineries the company has progressed, firstly by having an experienced technical operating and management staff; secondly by keeping in close and continual touch with refiners in other parts of the world to exchange experiences; and thirdly by having an active research and development organization. No one method would be adequate of itself; the interplay of ideas is an essential part of a large manufacturing organization and ideas can arise from any one of a number of sources. Management can make them effective by providing the right "climate" and by seeing to it that the necessary finance is available for improvement and expansion.

The technical control of process, both chemical and engineering, has long been a tradition in the company. The control of the refinery process has a number of facets, but the basic principle is the precise sampling and chemical analysis of incoming raw sugar, materials in process, discarded materials, and outgoing refined products, as already described. From these analyses, it is possible to standardize products, to minimize losses and to achieve maximum economy in the handling and direction of the syrups and other materials in the process itself.

The most important tool in the chemical laboratory is an optical instrument termed a saccharimeter, used for determining the amount of sucrose in products of all kinds. Developed over a hundred years ago, the saccharimeter depends on the fact that when a beam of light is passed through a specially-shaped prism of Iceland spar it is split into two rays, the ordinary ray, which is refracted sideways and lost, and the polarized ray, which passes on through the prism. A polarized ray is one in which the light is vibrating only in one plane. If this polarized ray is passed through a sucrose solution its plane of vibration is rotated about the axis and the number of degrees of rotation can be measured optically and used to calculate the sucrose content of the solution.

A diverse series of analytical techniques is used to determine the other constituents of sugar products. Apart altogether from the chemical analysis of sugar-containing materials, the essence of efficient process control is measurement of all kinds; boiler efficiencies, the steam usage of various processes, the consumption of water, lime, filter cloth, bone charcoal and so on. Labour utilization and efficiency is checked by the calculation at weekly intervals of the man-hours used per ton of throughput.

The engineering control of operation and maintenance is an important factor in the smooth and efficient running of refineries. There is no "slack" season as with a mill; production continues throughout the year for twenty-four hours a day for five days a week. Therefore maintenance, reconstruction and the installation of new plant must be carried out while production is going on. The result is a continuous challenge to the skill and ingenuity of the engineering personnel.

Good maintenance by the engineers is the more important because a refinery is essentially a series of closely interdependent stations; a breakdown in any one of them can have serious repercussions throughout the plant for it is not possible to stockpile the output from one station.

Another factor affecting the engineers' task is the trend towards the use of new plant designed to operate at greater throughput per unit; new centrifugals, pumps and turbines operate at higher speeds and there are higher pressures and temperatures in boiler stations; new metals and materials require special working techniques; and complex instruments and electronic controls are being introduced in the constant drive for ever-more automatic operation. Such factors have made more exacting the responsibility of the refinery engineers and call for a high standard of technical skill and organization.

The company's research and development activities in sugar refining cover too wide and specialized a field to be dealt with adequately

in a book of this nature. As with most industrial research, there are two main types of investigation: first, the improvement of existing processes in order to lower costs and, secondly, the search for new processes which give economically better performance than those now in use. Much of the work of both types starts on the laboratory bench but, if promising, may be fairly quickly translated to the pilot plant stage where operating characteristics can be determined under conditions more closely approaching the factory scale.

Other Refined Products

There are three well-known refined sugar products in addition to white sugar; these are brown (or No. 3) sugar, golden syrup and treacle.

Brown sugar, especially beloved by children for their breakfast cereals, is a small-grained, rather moist sugar with a characteristic flavour. It is made to the following standard composition:

<i>Sucrose</i>	..	..	..	..	91.5	<i>per cent</i>
<i>Reducing sugars</i>	..	..	..	..	2.5	" "
<i>Other organic matter</i>	..	..	..	..	1.9	" "
<i>Ash</i>	..	..	..	..	1.4	" "
<i>Water</i>	..	..	..	..	2.7	" "
					100.0	" "

It is manufactured by utilizing the fact that as successive boilings are carried out in the crystallization process the residual syrup has a higher and higher content of non-sucrose constituents. When the appropriate composition has been reached, the syrup is boiled and crystallization is specially controlled to give "brown sugar". The crystals are handled through the centrifuges in a special way and are not sprayed with water, as is done with white sugar, so that the adhering film of the residual syrup is left on the crystals to impart the golden-yellow colour and the characteristic flavour.

Golden syrup is a standardized refined product containing a high proportion of the reducing sugars, glucose and fructose. Its composition is approximately as follows:

<i>Sucrose</i>	..	..	..	..	27.0	<i>per cent</i>
<i>Reducing sugars</i>	..	..	..	..	47.4	" "
<i>Other organic matter</i>	..	..	..	..	4.4	" "
<i>Ash</i>	..	..	..	..	3.2	" "
<i>Water</i>	..	..	..	..	18.0	" "
					100.0	" "

It will be noted that sucrose and reducing sugars together amount to 74.4 per cent of the weight of golden syrup. If attempts were made to prepare a syrup containing this percentage of sucrose alone, the syrup would be supersaturated and sucrose would crystallize out. Similarly, if all the sugar content was in the form of reducing sugars glucose would crystallize and give a product similar in appearance to "candied" honey. The proportion of sucrose and reducing sugars in golden syrup (approximately $1\frac{3}{4}$ parts reducing sugars to 1 part of sucrose) are precisely controlled so that the syrup is stable. At these proportions, neither sucrose nor glucose will crystallize from solution.

In the refinery process none of the syrups in process has the high reducing sugar content required for golden syrup and it is necessary to prepare special batches of "invert syrup", using the fact that if a sucrose solution is heated under acid conditions it is converted completely into equal parts of glucose and fructose. The invert syrup is neutralized and filtered, and then added to other syrup of known composition, to give a mixture of the analysis shown above.

Treacle is a similar product of darker colour and stronger flavour.

Steam and Electricity

Every process in refining is carried out with heated sugar solutions and the heat is supplied by steam. The biggest single use of steam is in the eventual evaporation of water from these solutions. It will be remembered that at an early stage in the refinery the incoming sugar is dissolved in water while the end products are largely dry crystalline sugar, so that virtually all water added initially or throughout the process must be evaporated off. The whole process is therefore a large steam user. Temperatures are never very high, since destruction of sucrose must be avoided, so that steam pressures from 10 lbs. to 30 lbs. per square inch are mainly required.

There is also a substantial demand for mechanical power to drive the pumps, belt conveyors, centrifugal machines, driers, graders and many other machines. This demand for power, coupled with a heavy usage of relatively low-pressure steam, has enabled the development of a convenient and efficient steam-power balance. Whereas a railway engine exhausts its steam to the atmosphere after using it for generation of mechanical power, in a refinery the exhaust steam, remaining after passing through turbines or steam engines to generate power, can still be used for the entire heating requirements of the process.

The most recent steam and power installations at Pyrmont, Sydney, are illustrated in photographs and diagrams. Steam is produced at 650

lbs. per square inch, and power is produced from electric alternators driven by high-speed turbines. The entire boiler and power station equipment when finally completed will have cost about £2½ million and serves not only the refinery but also the distillery and the "Cane-ite" and "Timbrock" factories. It burns about 2,000 tons of coal per week. There is enough electric generating capacity to supply the electricity requirements of a city of 30,000 people, such as, say, Bendigo or Broken Hill, and if all the steam produced were used to drive electric generators it would be enough to supply a city of 100,000 people, such as Hobart.

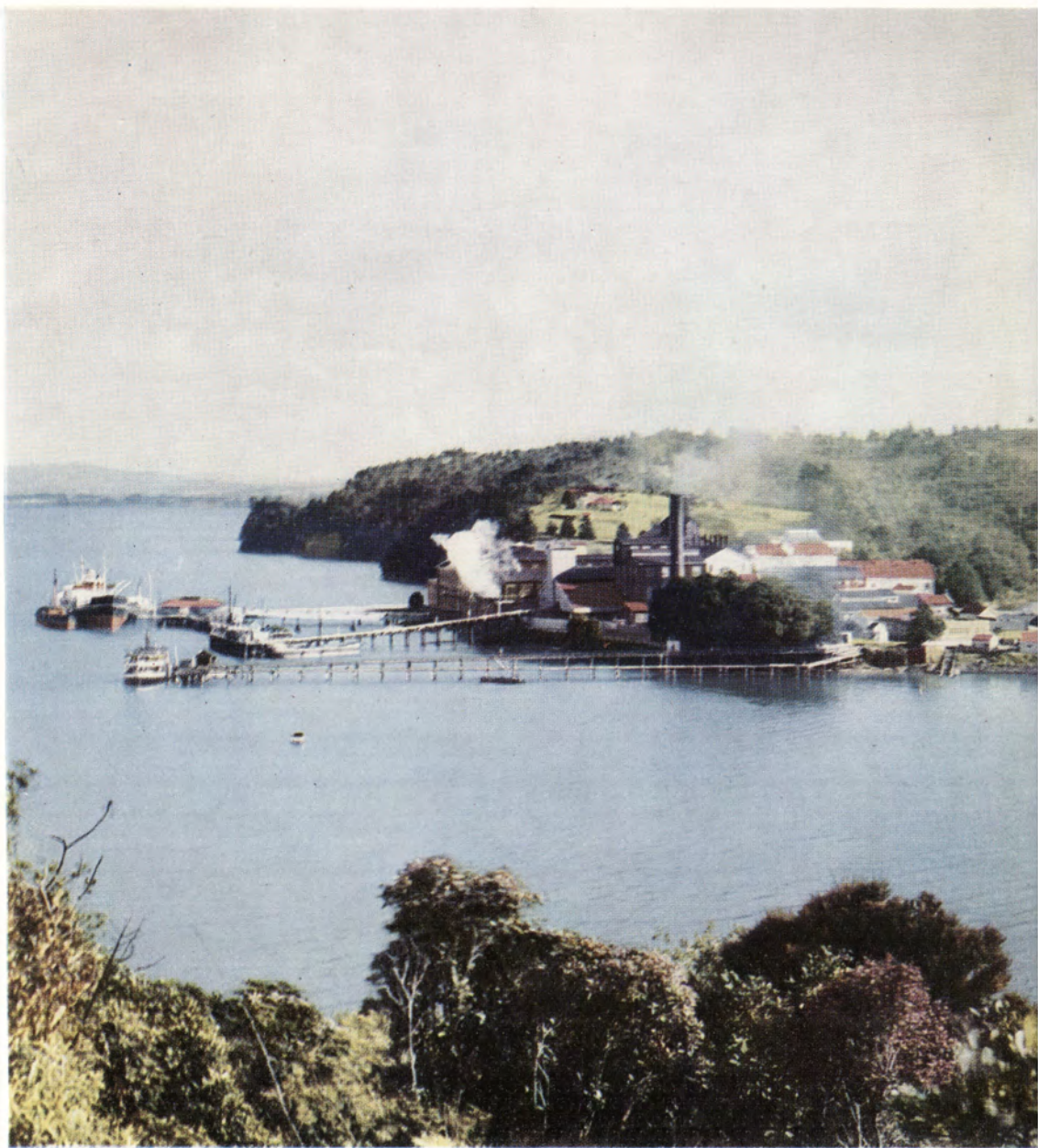
The economy inherent in the steam-power balance of a refinery can only be achieved by continuous and painstaking attention to every detail of steam and power usage. Coal, because of its greatly increased price, has become a major item in the cost of refining and much technical effort has been devoted to ways and means of decreasing the steam usage of the process. Success in this direction gives rise to power problems, for reduction in the quantity of steam required for evaporation of syrups must be followed by a corresponding reduction in the quantity of steam passing through all engines unless steam is to be blown to waste. There is, therefore, a constant demand for increased efficiency in both production and usage of power.

This continuous struggle that has been proceeding in the refinery process has been made more difficult by the fact that refineries, in common with most factories today, are steadily increasing their power demands as automatic, labour-saving equipment is installed. For these reasons a "steam account", akin to the "sucrose balance", is kept and watched.

Seasonal Variations in Demand

The demand for refined sugar varies throughout the year, showing a pronounced seasonal pattern with higher deliveries in the summer months, when consumption of beer and cordials is high and jam making and other preserving take place. The intensity of the seasonal fluctuation varies, due to such things as changes in the fruit crop for canning. The accompanying graph shows the delivery curve of one refinery throughout a full yearly period.

The refiner who has to meet these varying seasonal demands can either install sufficient plant capacity to meet the peaks and so be able to increase his production as needed or can have capacity equal to the average demand and use storage to cope with the variations. Under the latter arrangement, the refiner would accumulate stocks of refined



Chelsea Refinery, Auckland, New Zealand. Refineries are large-scale industrial establishments, situated close to the market they supply. They generally have a deepwater berth alongside to unload cargoes of raw sugar and coal. They also require large quantities of fresh water.



Interior of boiler house, Pyrmont Refinery, Sydney. The boilers provide high pressure steam for electric power generation and for operating machinery. The low pressure exhaust steam from the power station is used for heating. The boiler furnaces are mechanically fed with coal, and the whole station is automatically controlled and operated.

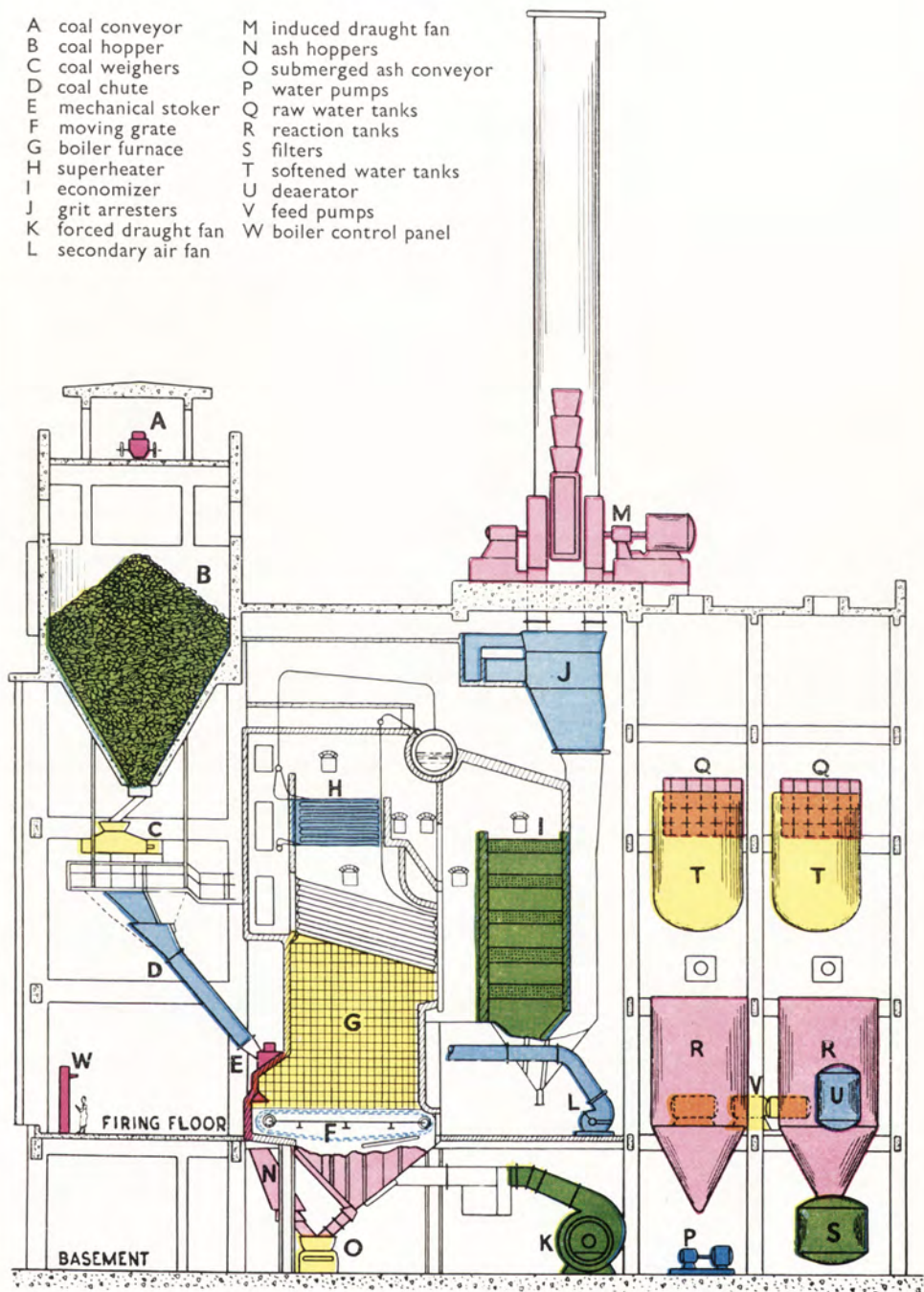
Above: Firing floor, with coal chutes feeding to mechanical stokers. See D and E on diagram opposite. Note comparative size of man.

Left: Boiler control panel. See W on diagram opposite.



SECTION THROUGH ONE OF THREE STEAM GENERATING PLANTS AT C.S.R.'s PYRMONT REFINERY

- | | |
|----------------------|--------------------------|
| A coal conveyor | M induced draught fan |
| B coal hopper | N ash hoppers |
| C coal weighers | O submerged ash conveyor |
| D coal chute | P water pumps |
| E mechanical stoker | Q raw water tanks |
| F moving grate | R reaction tanks |
| G boiler furnace | S filters |
| H superheater | T softened water tanks |
| I economizer | U deaerator |
| J grit arresters | V feed pumps |
| K forced draught fan | W boiler control panel |
| L secondary air fan | |

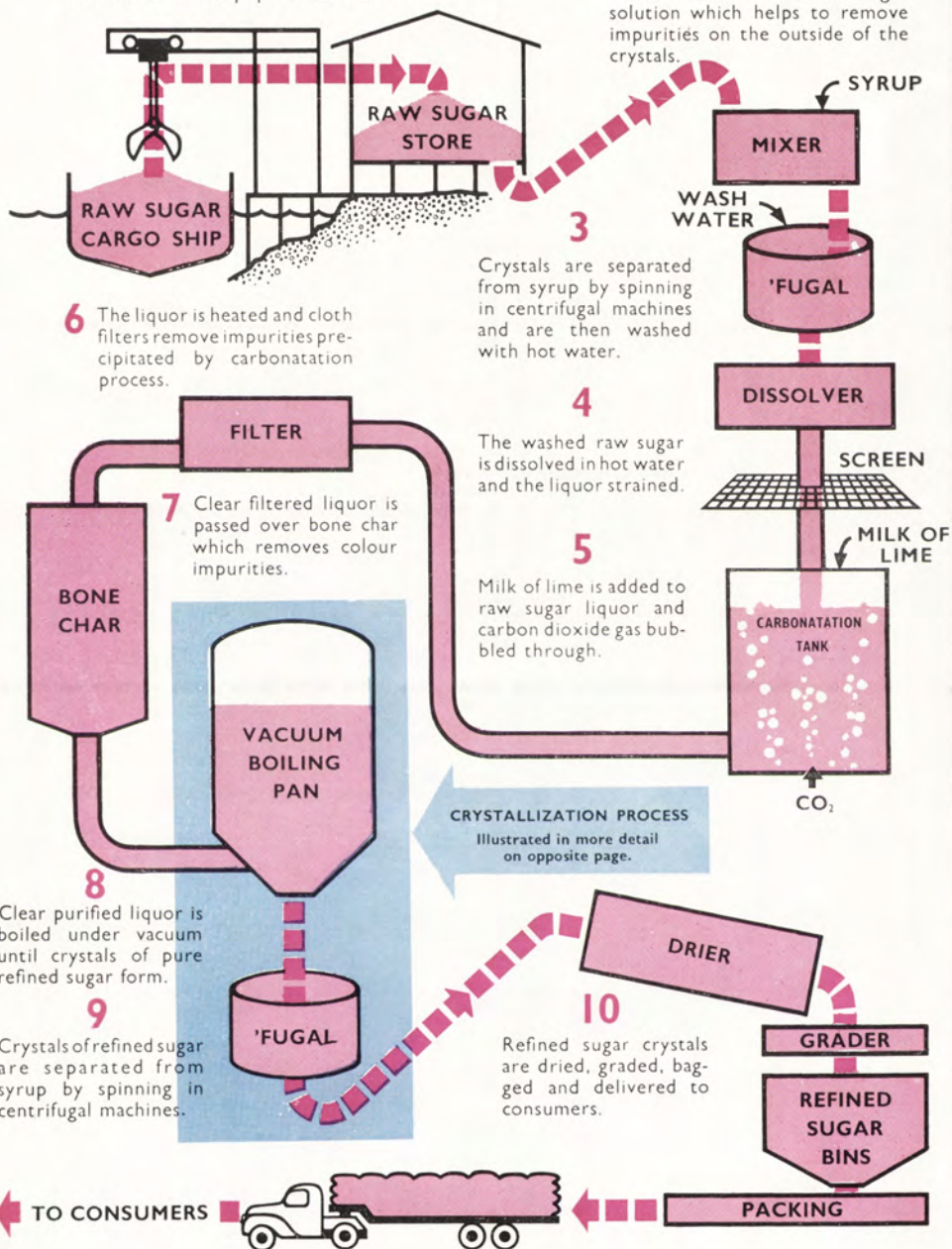


REFINING OF RAW CANE SUGAR

This diagram is not to scale and gives only a general indication of the main processes and items of plant. Portion of the process is shown in more detail on the opposite page.

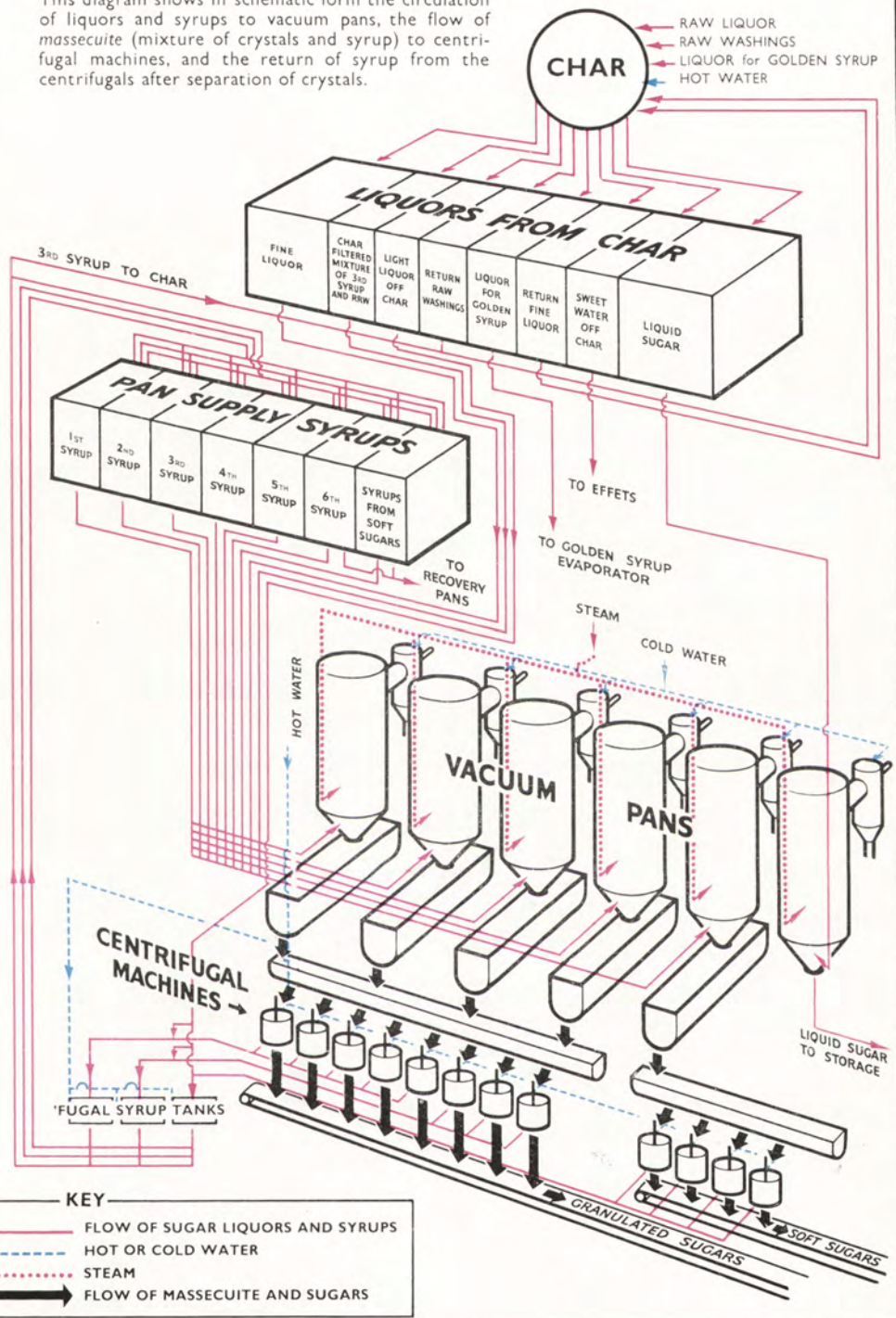
- 1 Raw sugar made at mills in the cane-growing areas is received in bulk or in bags at refineries in the population centres.

- 2 Raw sugar is fed into the first stage of the refining process, and mixed with a concentrated sugar solution which helps to remove impurities on the outside of the crystals.



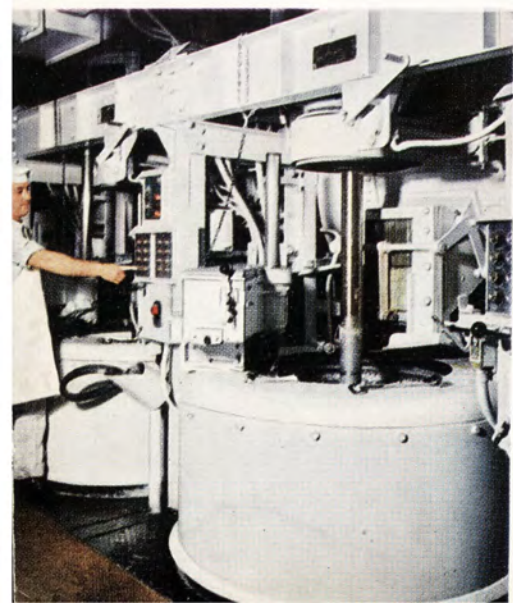
CRYSTALLIZATION OF REFINED SUGAR

This diagram shows in schematic form the circulation of liquors and syrups to vacuum pans, the flow of massecuite (mixture of crystals and syrup) to centrifugal machines, and the return of syrup from the centrifugals after separation of crystals.



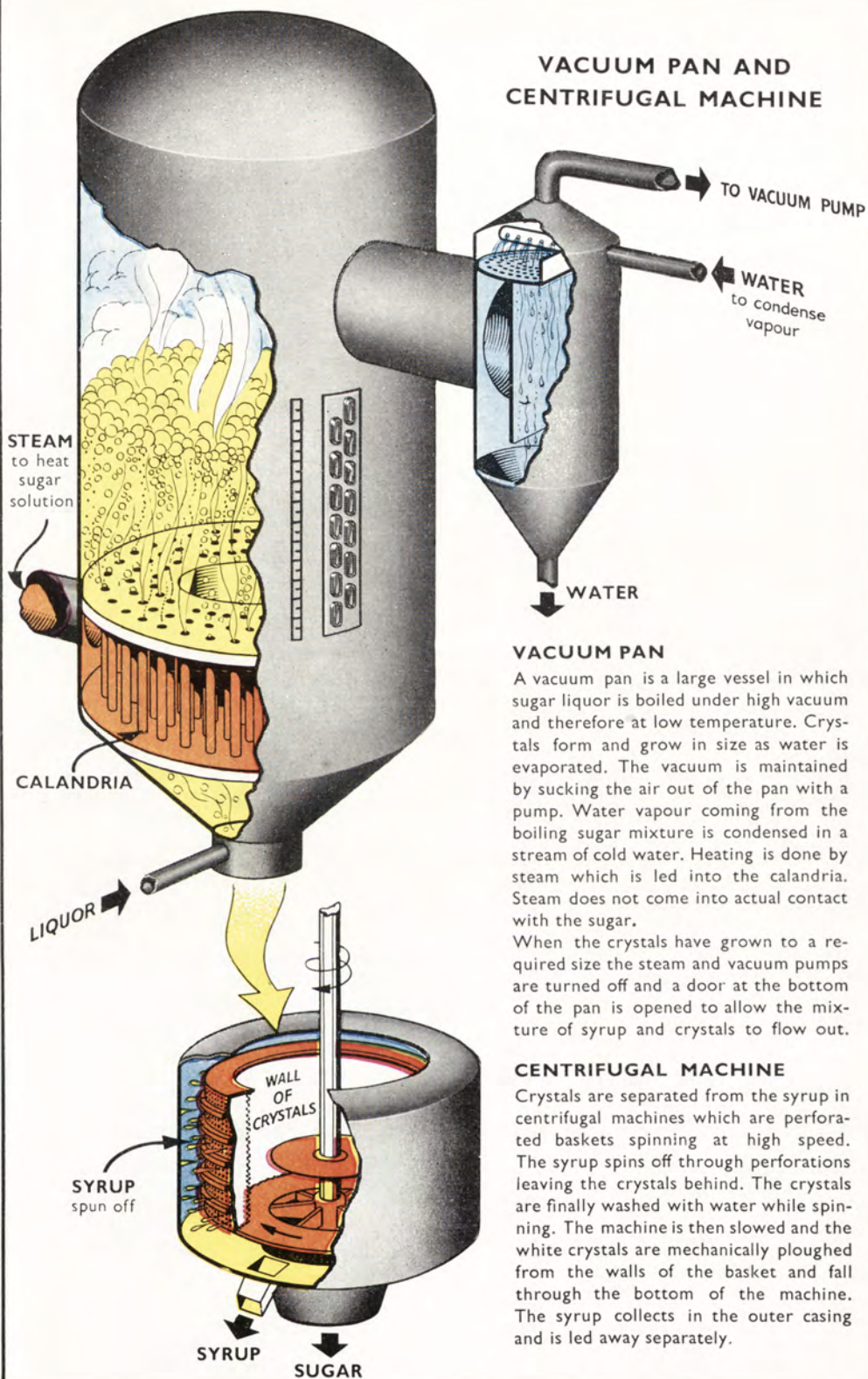


Above: A 14,000 gallon vacuum pan at Pymont Refinery. Instruments assist in the control of the process of concentration, formation and growth of crystals, but the art and knowledge of skilled sugar boilers are necessary to make crystals of the right size and uniformity. The sugar boiler above has removed a sample from the pan and is inspecting the crystals on a small plate of glass.



Left: Semi-automatic centrifugal machines at Pymont Refinery. A mixture of crystals and syrup, called *massecuite*, is fed from the vacuum pans to the centrifugal machines which spin off the syrup and leave damp-dry crystals.

VACUUM PAN AND CENTRIFUGAL MACHINE



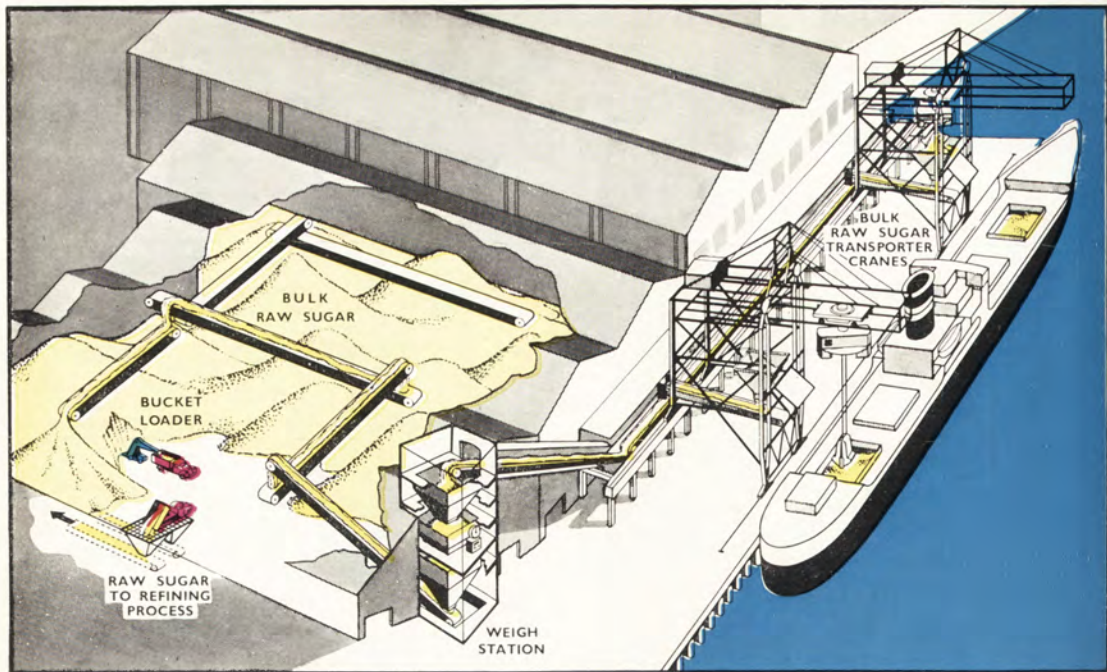
VACUUM PAN

A vacuum pan is a large vessel in which sugar liquor is boiled under high vacuum and therefore at low temperature. Crystals form and grow in size as water is evaporated. The vacuum is maintained by sucking the air out of the pan with a pump. Water vapour coming from the boiling sugar mixture is condensed in a stream of cold water. Heating is done by steam which is led into the calandria. Steam does not come into actual contact with the sugar.

When the crystals have grown to a required size the steam and vacuum pumps are turned off and a door at the bottom of the pan is opened to allow the mixture of syrup and crystals to flow out.

CENTRIFUGAL MACHINE

Crystals are separated from the syrup in centrifugal machines which are perforated baskets spinning at high speed. The syrup spins off through perforations leaving the crystals behind. The crystals are finally washed with water while spinning. The machine is then slowed and the white crystals are mechanically ploughed from the walls of the basket and fall through the bottom of the machine. The syrup collects in the outer casing and is led away separately.

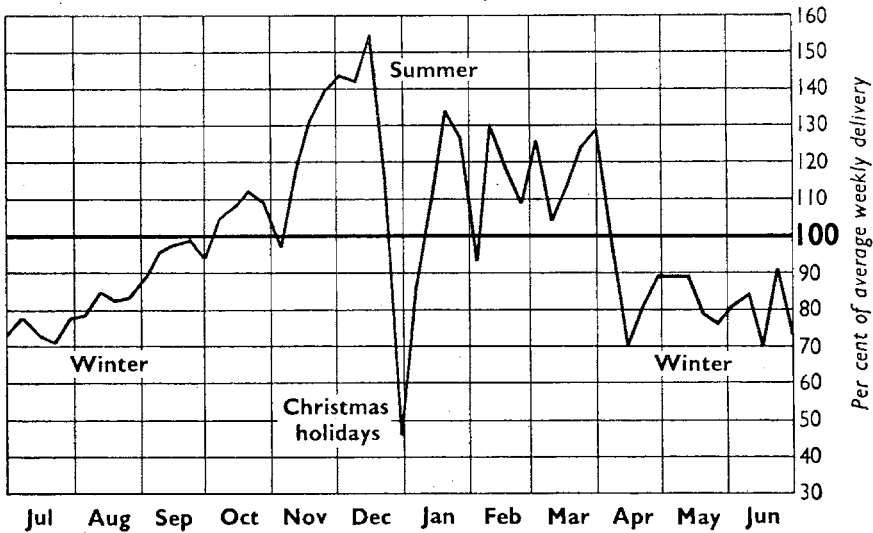


Installations for unloading raw sugar in bulk at Pymont Refinery. The diagram shows how belt conveyors carry unloaded raw sugar from the cranes on the wharf and after weighing distribute it in the bulk stores.

Unloading installations are designed to get raw sugar out of the ship and into store rapidly. Raw sugar is fed to the refining process at a slower rate, using six-ton trucks which are filled by a mobile bucket loader and discharge their loads through a grille to an under-floor conveyor system.



DEMAND FOR SUGAR, VICTORIA



Demand for sugar fluctuates over the year. It is lowest in winter and highest in summer, when manufacturers require larger quantities for fruit processing and beverages. Deliveries from Yarraville Refinery, Melbourne, averaged for the corresponding weeks of the years ending 30th June 1954 and 1955, have been expressed as a percentage of the average weekly deliveries for the two years and plotted on the graph above for 52 weeks.

sugar during the slack winter months and would deliver these during the peak summer ones. In actual practice the company's refineries aim at a compromise: production is increased during the peak months, but only to a relatively small extent, and substantial use is made of refined sugar drawn from reserve storage.

A number of considerations govern the relation of storage capacity and refining capacity. The economic balance between the two can be calculated and is given due weight, but an important consideration is that it is difficult and undesirable for a refinery or any other plant to vary its output by substantial amounts over a period of a year. To do so would involve increasing and decreasing employment which would have an unsettling effect on the very important human side of operations. Stability of employment and the benefits which flow from it are powerful arguments in favour of using storage to even out fluctuations in demand.

Refinery Expansion and Modernization

The company is at present engaged in a major programme of refinery development. Working conditions and employees' amenities are being improved. New plant is being installed and new processes introduced to increase technical efficiency and reduce cost of manufacture. Capacities of refineries are being expanded to keep ahead of demand for sugar from increasing populations. For the last five years expenditure on fixed assets has averaged about £500,000 annually, and is currently at the rate of about £1 million per annum.

Many problems have been and are still being encountered. Perhaps the greatest single problem has sprung from the fact that most of the company's refineries were built many years ago. Buildings and plant were provided on quite a handsome scale and stood the company in good stead in the ensuing years. Between the two world wars, the company made good use of its chemical control skills, and major technical advances were achieved in the refinery process and its control which increased effective capacities far beyond the limits thought possible in earlier years. Additional production was obtained with relatively modest capital expenditure, and costs for processing and for maintenance and depreciation were kept down. Under the pricing system in operation in the Australian sugar industry all the savings were passed on to the raw sugar industry.

The limit was reached during World War II and some ten years ago the first steps were taken in the major expansion programme that is still in progress. In these old factories on congested sites, the task has proved difficult and has taxed the ingenuity of the development and design staff to the utmost, while engineers have had to face the task of constructing buildings and installing new machinery in the middle of other plant operating under full production schedules.

The Employees

Although advances have been made technologically and large sums of money have been spent on improving equipment, the success of sugar refining still depends to a great degree on the people, from the manager down, who operate the refining plant.

The six refineries in Australia and New Zealand employ about 2,500 men and women. Two-thirds of them are employed on day-time duties in maintenance, packing, stacking, clerical, chemical, engineering and administrative tasks. These include a wide range of trades and skills—fitters, turners, boilermakers, draughtsmen, carpenters, riggers, packers, bagmakers, cleaners, electricians, storemen,

clerks, typists, chemists and engineers. The other third comprises the operating personnel who work on shift and operate the plant and process throughout the day and night. These are the fugalmen, firemen, filter hands, sugar boilers, engine drivers, liquor runners, supervising chemists and engineers.

In the years following World War II there has been an influx of migrants, many of whom have been initially unable to speak English. The proportion of these New Australians in some sections of the refineries has been high and the language difficulty has added to the burden of the supervisory staff, the leading hands, foremen, supervising chemists, engineers and managers. Despite these difficulties the absorption of New Australians has proceeded satisfactorily and already a number have been appointed leading hands.

Individual sense of responsibility, skill and reliability of our employees is of high importance in the efficient working of our factories. To gain the best contribution of individuals in these respects is the age-old problem of management and leadership. "Technical know-how" is of little value unless it can be applied to the hour-to-hour running of machines and the handling of materials by men on the job. Efficient production has several components: active management, the provision of proper plant and equipment and the existence of a solid core of reliable men to work the factory—men who know their work, understand the jargon of the plant and who really care whether their own work is good or bad. The social relationship and the economic climate are always changing, but we hope that the good relations established over 100 years between C.S.R. employees and management will continue.