FOOD TECHNOLOGY PROCESSING AND LABORATORY CONTROL

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PREFACE

FOOD TECHNOLOGY has been defined as "the application of science and engineering to the production, processing, packaging, distribution, preparation and utilisation of foods."

The area of this definition is wide and many text books published are concerned primarily with some one branch—for example with cereal, sugar or meat products. There is, however, an underlying unity in the food industries; based on the nature of the chemical components present in many different foodstuffs, on the engineering techniques employed, on common problems of micro-biology, of hygiene and of nutrition.

In this volume some of the more important food processes have been selected for review and in addition to a description of the techniques used in industry, details have been given of analytical and other control methods. The authors all have practical experience in their special fields and have described the analytical methods adopted by their own laboratories.

It is hoped, therefore, that this volume will be of use to chemists engaged in food processing, as well as to students preparing for careers in the food industries.

FRANCIS AYLWARD.

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PART 1.—PROCESSING METHODS

CHAPTER 1

SUGAR REFINING

RAW sugar used for refining in the United Kingdom is derived from sugar cane and sugar beet.

Raw cane sugar is imported from tropical or sub-tropical countries, principally from Cuba, British West Indies, British Guiana, Australia, Natal, Mauritius, Fiji and San Domingo.

Raw beet sugar in pre-war days was purchased from the Continent of Europe but at the present time it is largely produced in the United Kingdom. The appearance of both types of raw sugar is not very different. The colour is light yellow to brown and the size of the crystals is variable. More or less raw syrup or molasses still clings to the surface of the crystals, to which the colour and stickiness are due.

Raw sugar cane smells and tastes quite pleasant, but raw beet sugar, especially when of low purity, is decidedly unpleasant.

The Sugar Cane

The juice in the sugar cane is expressed in roller mills. The cold juice is heated and lime is added, which combines with some of the impurities and coagulates them. After settling, the clear juice is run off. Alternatively, if the juice is limed cold and then heated, the dissolved air is expelled and rises, carrying the impurities to the top as a scum, which is removed, leaving clear juice. The juice is concentrated in evaporators, boiled to form crystals in steam-heated vacuum pans, and the mixture of crystals and mother syrup is spun in centrifugals to separate the raw cane sugar from the cane molasses.

The Sugar Beet Roots

Sugar beet roots that have been topped and tailed in the fields are washed free from earth and stones, sliced into thin chips (cossettes) which are fed into large vessels termed diffusers. Hot water is passed through them causing the sugar contained to diffuse into the water, leaving a large portion of the soluble but non-diffusable impurities behind. The sweet water obtained passes through a series of these diffusers "a battery," becoming increasingly richer in sugar until finally its concentration nearly reaches the concentration of the sugar in the juice of the original root. Various types of continuous diffusers are gradually superseding the older battery system in Europe. Although constructional details vary, the principle is similar, i.e., of cossettes and juice travelling in opposite directions in a sloping cylindrical vessel.

This sugar solution or so-called "juice," is then treated with lime and gaseous carbon dioxide or gaseous sulphur dioxide according to whether the carbonatation or sulphitation process is utilised. A precipitate of carbonate or sulphite of lime is produced which removes some impurities from solution. This precipitate is separated from the clear light-coloured juice by filter presses and the juice is then concentrated in evaporators.

The thick juice is treated in the same way as thick cane juice, but yields in this case raw beet sugar and beet molasses.

THE PURPOSE OF THE REFINING PROCESS

The refining process removes reducing sugars, ash and other organic matter almost completely, thus giving refined white sugar, which is sucrose of a purity above 99·9 % on dry matter.

As so much misconception prevails regarding the various forms of sugar, it is only fitting to describe briefly the objects of refining.

The Raw Sugar

Raw sugar or "brown unrefined sugar" is impure and may contain sugar lice, "Acari," mould spores which cause deterioration of cooked foods, bacteria which produce acidity in milk and the like, and dirt and clay, pieces of wood, string, particles of cane fibre, and sometimes even large insects, beetles and small reptiles.

Raw sugar becomes moist if the atmosphere is moist, as the surrounding film of molasses is hygroscopic. It becomes then an ideal breeding ground for micro-organisms. It is therefore an impure sugar.

TABLE I

ANALYSIS OF RAW SUGARS

	Cuban	*Javan*	*Australian*	*West Indian*	*British Beet*
Sucrose – –	96·70	97·10	98·60	96·50	97·09
Reducing sugars –	0·92	1·24	0·38	1·45	0·04
Ash – – –	0·52	0·35	0·23	0·41	0·54
Organic non-sugar	1·13	0·70	0·48	0·54	1·06
Water – – –	0·73	0·61	0·31	1·10	1·27
	100·00	100·00	100·00	100·00	100·00

TABLE II

ANALYSES OF RAW AND AFFINED CANE SUGARS (DRY SAMPLES)

	Raw	*Affined*
Sucrose . . .	97·54	99·44
Reducing sugars .	·74	·16
Ash. . . .	·68	·10
Organic non-sugar .	1·04	·30
	100·00	100·00

The Refined White Sugar

Refined white sugar is an article of food which is free from impurity to an extent unapproachable by any other foodstuff made in such large quantities. Sugar is not refined solely for colour but to make it a clean, dry, sound food, of exceptional chemical and bacteriological purity. Refining does not deprive sugar of its sweetness or nutritive value. Pure sucrose can only exist in the form of hard, dry, white crystals and in such form it is of maximum sweetness. Whether the refined sugar has been derived from raw beet sugar or raw cane sugar makes no difference. It is impossible to determine the origin from the analysis or sweetness of the refined white sugar.

Cube Sugar

Cube sugar is no sweeter nor less sweet than refined white granulated sugar. It has been produced from the same liquor by boiling, and the sole essential difference in manufacture lies in the centrifuging of the massecuite in special machines which produce thin slabs of moist sugar which, after stoving to dry, are chopped into the familiar cubes. Its higher price is due to this more elaborate manufacture.

STAGES IN THE REFINING PROCESS

Until recently all raw sugar arrived at the refinery in jute bags holding 1 to 3 cwts. For reasons of economy this is being displaced by bulk loading of ships and bulk unloading by power grabs which discharge on to conveyors which deliver the raw sugar to large shed stores or to silos, or directly to the refinery.

The First Process—Mixing With Raw Syrup

The raw sugar is conveyed by travelling bands either direct or from silos to the affination house, where it is mingled with raw syrup to form a fluid "magma" of crystals and syrup. This is passed by means of screw conveyors to centrifugal machines rotating at high speed, where the syrup is thrown off through the perforated metal sides, leaving a wall of sugar which is washed with a jet of hot water to remove adherent syrup.

This affined sugar is of lighter colour, as most of the impurities have been removed.

The Syrup and Washings Are Now Boiled to Grain

Some of the syrup and washings is circulated for making magma, but the excess is boiled to grain in vacuum pans. The resulting mixture of crystals and mother syrup, "massecuite," is centrifuged like raw sugar, and joins the affined sugar in the melter. The mother syrup is boiled again to yield a further crop of recovered sugar and final syrup or molasses. This molasses is a syrup of such a very high non-sugar content that it is uneconomical or impossible to remove further sucrose by boiling.

Removing the Coarse Insoluble Impurities

The affined sugar and recovered sugars are dissolved in hot water in a tank "melter" and passed through a wire mesh strainer to remove coarse insoluble impurities.

Removal of Further Impurities

The strained melted liquor is further purified by one or other of the following methods: Kieselguhr filtration without previous

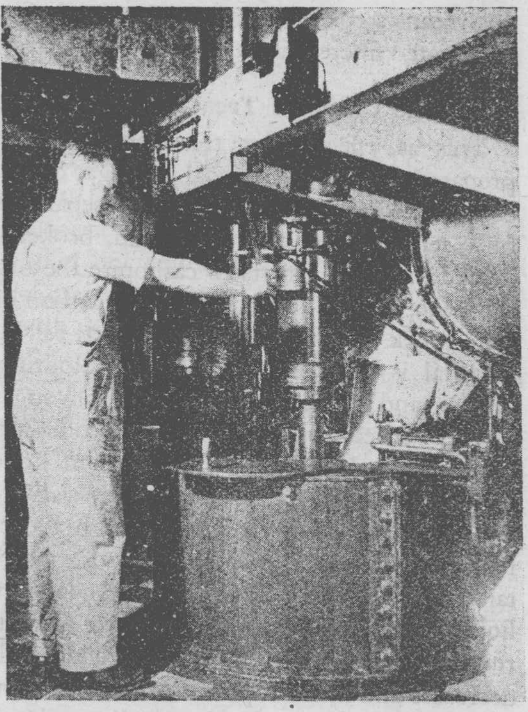

FIG. 1.—AFFINATION MAGMA OF RAW SUGAR AND RAW SYRUP CHARGED INTO A HIGH-SPEED CENTRIFUGAL MACHINE.

treatment or with phosphate defecation. Both methods are common in the United States. The Williamson process of forming a floc of precipitated phosphate of lime which is floated off as a blanket of froth caused by aeration is used in Louisiana and is gaining favour elsewhere. Most British refineries and some Canadian and Australian utilise the carbonatation process. The earliest form of this consisted of treating melter liquor in batch carbonatation tanks with lime cream and carbon dioxide gas whilst heating to 90° C. The precipitate of carbonate of lime thrown down adsorbed colouring matter and other soluble non-sugar impurities and also served as a filter aid in pressure filters, yielding a lighter colour liquor, "carbonated liquor" or "brown liquor" entirely free from insoluble impurities.

A development of the batch carbonatation method is that of continuous carbonatation in which liquor, lime cream and carbon dioxide are led simultaneously into a tall tank and the overflow further treated with carbon dioxide in successive tanks. By this means a coarser precipitate easier to filter is obtained. The carbonated filtered liquor is then ready for decolorisation.

The Bone Charcoal Treatment for Decolorisation

This is effected by treatment with bone charcoal. The preparation of bone charcoal for sugar decolorising is not carried out in a refinery, but is an entirely separate undertaking. Carefully selected bones are degreased, broken to correct sizes and heated in closed retorts to carbonise the organic constituents of the bone, leaving about 10 per cent carbon on a porous inorganic framework chiefly composed of tri-calcium-phosphate. This material is capable of adsorbing colouring matters and other organic and inorganic non-sugars from sugar liquors.

Tall vertical cylindrical cisterns containing 30 to 40 tons of bone charcoal are filled from brown liquor tanks through a convenient arrangement of pipes and valves termed an "organ." Brown liquor is slowly run through the cisterns and emerges from a narrow pipe at the bottom of each cistern into a shallow tank called a "rhone." The emergent liquor known as "fine liquor" is water white at first, but after the cistern has been running some time, the decolorising value of the charcoal decreases and tinted liquor is obtained. Finally the liquor is too coloured for use, so that brown liquor has to be shut off at the organ and hot water turned on to displace the liquor and ultimately wash off all traces of sugar.

Water washing is continued until adsorbed impurities are no longer removed.

The Wet Char is Next Removed to the Revivification Kilns

The water supply is then cut off at the organ, the cistern drained and the wet char allowed to run from a manhole at the base on to a belt conveyor, which carries it to the top hopper of revivification kilns. These consist of a number of long vertical pipes passing through a fire of regulated intensity. The pipes stretch through the fire bed to some distance below, to cool the char before it tumbles into the revivified bin.

Newer design of kilns are displacing the old pipe kilns. The Herreshoff multi-bed roasting kiln originally devised for ore treatment and the Stordy kiln, with more uniform heat distribution specially designed for bone charcoal, are both claimed to

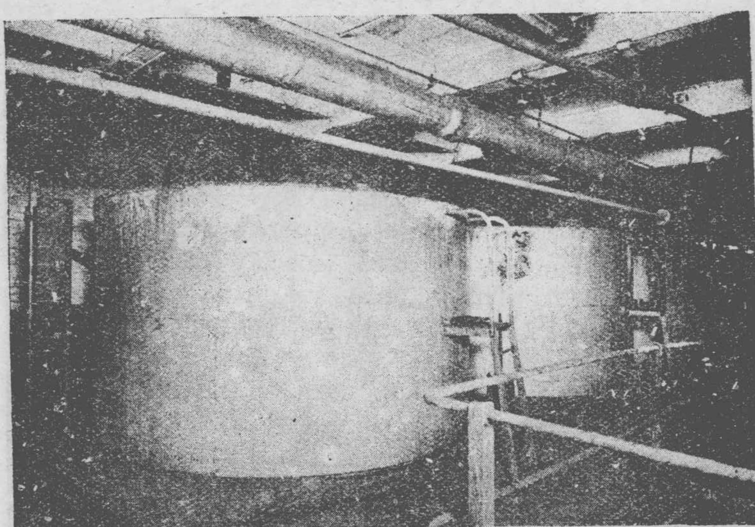

FIG. 2.—BROWN LIQUOR TANKS FEEDING BONE CHARCOAL CISTERNS.

give more uniformly regenerated charcoal with possibly less mechanical breakdown of the particles.

The Revivification Kilns

The function of the kilns is firstly to dry the char, and secondly to burn off adsorbed organic colouring, etc., which has not been removed by the wash water. The revivified char, after passing over sieves to remove fine char dust, is refilled into cisterns for further decolorisation of liquor. The char dust which has been removed is a useful by-product and is used as a source of phosphate of lime for mineral feeding of animals, for fertilising the soil, or as a pigment.

How Refined Sugar is Obtained from the Fine Liquor

Returning to the fine liquor from the char cisterns, we will follow its course towards its end, namely refined white sugar.

It is pumped from the rhone to tanks on the pan floor and there drawn into steam-heated vacuum pans, where it is boiled at low temperature to evaporate water without damaging or colouring the liquor.

The Formation of the Sugar Crystals

Whereas this operation was formerly due solely to the skill of the pansman in operating his valves, it is now generally achieved

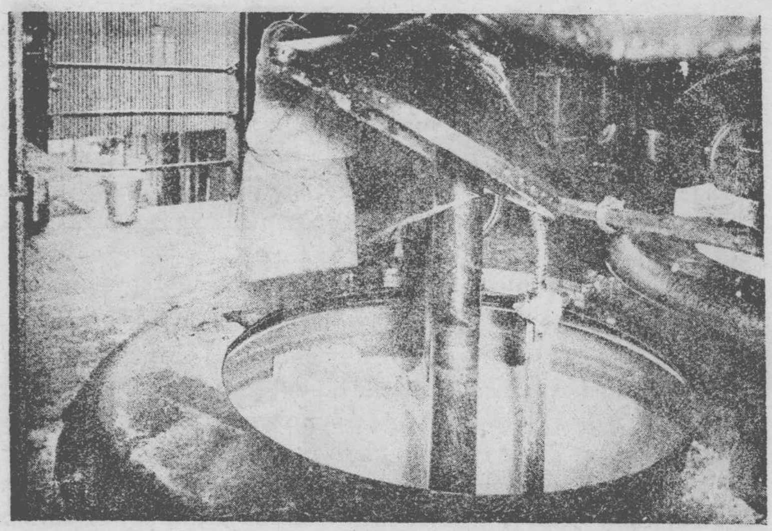

FIG. 3.—DISCHARGING SUGAR FROM CENTRIFUGAL MACHINE.

by instruments which enable him to control the degree of supersaturation within the limits suitable for crystal growth and also to inspect the size of the crystals whilst boiling is in progress.

When the pan contains its maximum working capacity load of "massecuite," i.e., crystals and mother syrup, the steam is shut off, the vacuum broken and the contents of the pan discharged through troughs into large tanks containing stirring gear, which keeps the massecuite in movement until it is drawn into centrifugal machines.

Here the mother syrup is spun off through the perforated wall of the centrifugal basket; a jet of boiling water is used to wash the face of the wall of white sugar left lining the basket, and when these washings have been spun off, the machine is stopped and the sugar ploughed out through the circular opening at the bottom, which previously is kept closed by a bell-shaped cover.

The Rotating Dryers

The hot and moist white sugar falls into a conveying trough, which quickly carries it to the granulators, which are long cylindrical rotating dryers arranged at a slight angle to the horizontal. The sugar is fed into the raised end, a series of vanes in their rotation lift the sugar to the top position and allow it to fall continuously in a cascade, whilst heated air is passing through the granulator, carrying away moisture with it. This operation continues until finally the sugar arrives at the lower end and falls as dry crystal granulated sugar on to a belt conveyor which carries it on to grading sieves and thence to the filling house.

Before consideration of the packing, a return will be made to the mother syrup and washings from the refined sugar centrifugals.

Treatment to Produce Further Yields of Sugar

As this mixture of mother syrup and washings contains 40 to 50 per cent of the sugar originally contained in the fine liquor from which it was boiled, a further boiling is necessary to recover another crop of white sugar. The syrup and washings from this second crop are decolorised in char cisterns to remove some of the colour and non-sugars that have become concentrated in these mother syrups, together with the small amount of colour that has been produced in boiling in vacuum pans.

The decolorised material is then cropped again and again yielding further white sugar until finally the sugar obtained is no longer white and is remelted and once more put through the refining process or is sold as refinery soft sugar or pieces.

Packing the Sugars

The combined yields of white sugars, granulated and graded, arrive at the fill houses, and a portion diverges to the bulk filling, where it is automatically filled and weighed into 1 or 2 cwt. bags and machine sewn. A modern development for the special benefit of food manufacturers is the delivery of loose sugar in road tanks. The remainder is conveyed by travelling belts to a series of hoppers, arranged above ingenious machines, which convert rolls of thin blue cardboard into open cartons labelled ready for filling, on one section, and are quickly and automatically transferred to the other section in which 1, 2 or 4 lb. of sugar are automatically weighed and delivered into the cartons, which the machines then close and seal and pass to tables where they are parcelled ready for supply to grocers and thus to the consumer.

At no stage, from the pan boiling to final carton, is the refined sugar touched by the hand, so that its final cleanliness and purity is assured.

H. C. S. de W.

CHAPTER 2

SUGAR CONFECTIONERY

In this chapter no attempt will be made to cover all the many aspects of sugar confectionery, but examples will be given to illustrate methods of manufacture.

HIGH BOILINGS

This section will be treated more fully than the others, not only because boiled sweets form the major part of confectionery production, but because the behaviour of the sugars is common to many other products which follow later.

Hard boilings may be made by boiling sugar and water to such a temperature that practically no water remains—on cooling, the mass remains in a vitreous state. The result is actually a very supersaturated solution of sugar, since at room temperature a saturated solution of sucrose contains only about 66·5 per cent of sugar. Ordinary granulated sugar (sucrose) is not capable of being made into boilings by itself—it crystallizes out of solution, or "grains", far too easily.

However, sucrose may be converted into other sugars by a process of hydrolysis—usually called the "inversion" of sugar:

$$\underset{\text{sucrose}}{C_{12}H_{22}O_{11}} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\substack{\text{dextrose}\\ \text{(d-glucose)}}}{C_6H_{12}O_6} + \underset{\substack{\text{levulose}\\ \text{(d-fructose)}}}{C_6H_{12}O_6}$$

These two sugars, dextrose and levulose, are produced in equal amounts and are together called "invert sugar."

Invert sugar has the property of stabilising the supersaturated solution of sucrose and so reducing the tendency to grain. Sufficient invert sugar must be produced during manufacture, but this must be carefully controlled because the levulose in invert sugar is very hygroscopic: too little invert sugar and the sweet will grain, too much and it will pick up moisture very quickly. 10 to 15 per cent of invert sugar has been found to be the optimum figure. Here is a case where laboratory control is necessary to achieve uniformity.

The original method of making boilings was to add sucrose to water and to boil the resulting syrup on coke or gas stoves until less than 2 per cent water remained (300° F. to 330° F.). In order to catalyse the inversion of the sucrose an acid must be added—usually a very weak one, such as cream of tartar. The exact amount depends on many factors—in particular the hardness of the water used and the exact time at which it is added to the syrup during the boiling period—the weight can only be determined by trial and error but is of the order of 0·15 to 0·25 per cent (in terms of sugar). Once a given procedure has shown that the correct amount of inversion takes place (about 10 to 15 per cent), that procedure must be rigidly adhered to—even to the extent of using the exact amount of water each time. Often more than half the cream of tartar is used in neutralising the hardness of the water.

It is unfortunate that it is not possible to calculate the amount of invert sugar which should be produced under given conditions. Undoubtedly the hydrogen ion concentration (pH) is one of the most important considerations but information is lacking on the pH of acids at high temperatures and in the presence of high concentrations of sugar—particularly as temperature and concentration are increasing all the time. It is essential therefore to institute regular checks on the invert content.

From what has been said above the obvious question may seem to be—why not add a measured amount of invert sugar, previously prepared, to the batch before cooking? It is not easy to give an answer to this but two points may be made:

(*a*) A certain amount of invert sugar is produced from sucrose by the action of heat and the mineral matter present. This will occur in any case and so not much improvement in standardisation will occur.

(*b*) The levulose in invert sugar is susceptible to heat and over a period of time will break down. This results in an appreciable deepening of the colour.

Moreover, the laevulic acid produced is able to invert more sucrose and this effect will be magnified if the invert sugar is added all at once at the beginning of the boil, instead of being produced continuously as boiling proceeds.

Starch Syrup

Fortunately another material has been found to replace invert sugar. This is a syrup produced by the hydrolysis of starch (using enzymes or acids) and consists of the sugars dextrose and maltose together with dextrins.

This product is known as *starch syrup* or *corn syrup* or *glucose syrup* and is often referred to as *confectioners' glucose.* In view of the fact that the term glucose refers to a definite chemical compound, it seems preferable to use the name *starch syrup* for the mixture obtained by hydrolysis of starch.

By careful control during manufacture the syrup is supplied as a standardised product, and a typical analysis is:

dextrose	16 per cent
maltose	27 per cent
dextrin	40 per cent
water	17 per cent

By adding starch syrup to sucrose in the boil (about 30 to 40 per cent) graining is hindered. As the syrup does not contain the hygroscopic and heat-labile levulose, it can be added in a measured amount to produce a standard product. Three

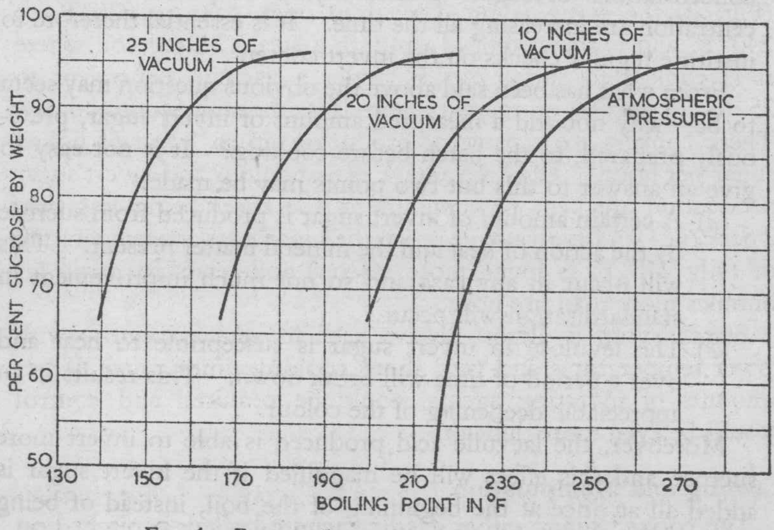

FIG. 1.—BOILING POINTS OF SUCROSE SOLUTIONS.

differences in its effects may be noted: (1) It is less sweet than sucrose and invert sugar; (2) The dextrin present imparts a toughness to the sweet; (3) Inferior starch syrup sometimes gives a slight cloudiness on boiling. For these reasons it is generally held that sucrose-invert sweets (commonly called "all sugar" boils) are superior to those from sucrose-starch syrup.

Methods of Cooking

When cooking is carried out on gas stoves, the batch sizes are limited to about 30 to 40 lb., and thus the rate of production is low. Although the best work is still done in this way, cooking by steam has now become the usual process.

Unfortunately an open steam pan is impracticable as, with the highest steam pressure usually available (120 p.s.i.), the highest temperature which can be reached is in the region of 280° F. to 290° F. depending on the pan, and this may take 30 to 60 minutes.

An answer was found, however, in cooking under reduced pressure (Fig. 1). There are two types of vacuum cooker—batch and continuous. In the *batch type* the syrup is boiled to about 260° F. to 270° F. under atmospheric pressure and is then subjected to reduced pressure for a given time. The exact details depend on the type of machine. In the *continuous type* (Fig. 2) the syrup is pre-cooked in open pans to 230° F. to 240° F. and is then pumped through a steam heated coil where it is cooked to about 240° F. under a vacuum equivalent to 25 to 28 inches of mercury and is withdrawn continuously. These cookers are capable of producing up to 1 ton of boiled sugar per hour. Their advantage is that colour and invert sugar production are kept to a minimum, the latter being less than 2 per cent. A disadvantage is that the sugar mass at a temperature of only 240° F. is much more viscous and tends to retain air bubbles more than fire boils.

Starch syrup is almost always used in vacuum work—with lower temperatures and very short cooking times much larger amounts of inverting agents would be required and control would be even more difficult.

Cooling and Manipulation

The cooked sugar, either gas or vacuum boiled, is pitched on to an oiled and heated slab, and colour, flavour and acid are