



SYSTEM OF CANE SUGAR FACTORY CONTROL

Gardens Point.
A22810994B
System of cane sugar
factory control

THIRD EDITION

Edited by J. L. CLAYTON

PUBLISHED FOR THE
INTERNATIONAL SOCIETY OF
SUGAR CANE TECHNOLOGISTS

by
Q.S.S.C.T.
1971

A22810994B



Wholly set up and printed in Australia by
WATSON, FERGUSON AND COMPANY
Brisbane, Q.
1971

PREFACE TO THE THIRD EDITION

The first edition of the book "System of Cane Sugar Factory Control" although published by a Committee of the I.S.S.C.T. was, in fact, written by Dr. F. W. Zerban, and it incorporated not only his style but also certain of his personal opinions.

When I revised the book in 1955 I took pains to alter it no more than necessary though I did not subscribe to some of the claims and policies therein.

After the 12th Congress I set out to perform a further revision but I was so dissatisfied with the results that I abandoned that line of action. I decided that the only satisfactory course was to rewrite the book entirely.

To the 13th Congress I took the major portion of the new text in proof form and distributed it to a panel of technologists representing a wide range of sugar countries. I invited comments from them all, and I here express my thanks to those who were good enough to assist me with their advice. I have done my best to use it constructively.

J. L. CLAYTON.

1971

PREFACE TO THE SECOND EDITION

When the Committee on Uniformity in Reporting Factory Data met during the Eighth Congress in British West Indies in 1953, one of its resolutions was that the booklet "System of Cane Sugar Factory Control of the I.S.S.C.T." be "brought up to date and reprinted".

On the same occasion the resignation of Dr. F. W. Zerban as Chairman of the Committee was accepted with regret, and the writer was appointed to that office, with Mr. J. L. Clayton as Secretary. The major portion of Dr. Zerban's excellent composition in the original booklet remains unchanged in the new edition, the preparation of which is due to Mr. Clayton.

The question of bringing the booklet "up to date" has occasioned considerable thought. Certain revisions had been approved by the Committee as a body but others arose for consideration and it was a question whether they should be included without formal approval. The policy adopted was to select those items which needed revision but were not of a highly contentious nature and to submit proposals to the regional sub-committees. The response was gratifying, the proposals being either approved or commented upon in constructive manner. Our thanks are due to the members of the sub-committee who assisted.

In the current edition two appendices have been included. The first presents data on the units employed in various countries and deals extensively with English-Metric conversions. The second deals with the Tables used in sugar technology. Though there were several requests for the publication of standard Tables it was decided not to print these, for reasons explained in Appendix II.

Thanks are due to the Queensland Society of Sugar Cane Technologists, which body has undertaken the financial responsibility for the printing of this booklet.

It is hoped that the current edition will prove a worthy successor to the first and that its publication will serve to further the good work of the Committee.

NORMAN J. KING,
Chairman.

PREFACE TO THE FIRST EDITION

HISTORY AND AIMS OF THE COMMITTEE

The Special Committee on Uniformity in Reporting Factory Data was created at the Second Conference of the Society, held at Havana in 1927, upon motion made by M. A. del Valle, who pointed out that the confusion of terms used in sugar factory reports, and the multiplicity of control methods employed made it impossible fairly to judge the results obtained and to make mutual comparisons. He urged a study of this question and the establishment of uniform methods by common consent.

The Committee members appointed at the beginning were M. A. del Valle (Puerto Rico), P. C. Tarleton (Cuba), and F. W. Zerbán (U.S.A.), chairman. At the Third Conference (Soerabaja, Java, 1929) E. C. von Pritzelwitz van der Horst (Java) was appointed, vice P. C. Tarleton; he resigned prior to the Fifth Conference (Brisbane, Queensland, 1935), and no new appointment was made to replace him.

The chairman was empowered to co-opt further members. In order to make the Committee truly international in scope, the co-operation of prominent sugar technologists in all the important sugar cane countries was solicited, those connected with official institutions or technical organizations being chosen wherever possible. The response was most gratifying, and the following men have served on the Committee at various times, many of them throughout the entire period during which it has been functioning:

Argentine: W. E. Cross;
Australia: Norman Bennett, W. R. Harman, A. Jarratt, G. S. Moore;
British and French West Indies: Walter Scott, J. G. Davies;
Cuba: A. J. Keller, W. B. Saladin, H. D. Lanier, A. P. Fowler, Jose Santos;
Hawaii: W. R. McAllep, W. L. McCleery, S. S. Peck;
India: Noel Deerr, J. H. Haldane, K. C. Banerji;
Japan: Migaku Ishida, S. Kusakado;
Java: P. Honig, C. Sijlmans, Ph. van Harreveld;
Louisiana: C. E. Coates, A. G. Keller;
Mauritius: Louis Baissac;
Mexico: T. H. Murphy;
Natal: H. H. Dodds, G. C. Dymond;
Peru: Gerardo Klinge;
Philippines: Herbert Walker, E. T. Westly;
Puerto Rico: M. A. del Valle, Jaime Annexy, E. M. Copp;
Santo Domingo: Rafael Cuevas Sanchez.

In some of these countries sub-committees were formed to advise the members of the Committee.

To all these men the chairman again expresses his sincere gratitude because without their willing, sympathetic, and efficient help it would have been impossible to accomplish the large and difficult task allotted to the Committee.

Since the members of the Committee are scattered all over the world it was necessary to undertake the work largely by means of questionnaires and correspondence. The replies to the various questionnaires were analysed, arranged, and summarized by the chairman, who then prepared comprehensive reports for each of the meetings of the Society. These reports were discussed at the Conferences by the Committee members present or their proxies, and all amendments agreed upon were entered in the reports. The revised reports were submitted to the Society as a whole, were adopted by it, and published in the Proceedings. The general terms and definitions, and the system of milling control were thus disposed of at the Third Conference in 1929. The control of the boiling house, and the methods of weighing, measuring, sampling, and analysis were reported at the Fourth Conference in 1932, but since the Committee was poorly represented at that meeting it was decided to resubmit the report to all the members of the Committee by correspondence. The final report was presented at the Fifth Conference in 1935, and was adopted. But the Committee was retained in office in order to keep the methods up to date and to revise them from time to time, in keeping with progress in sugar technology. Accordingly, a report was presented at the Sixth Conference in 1938, but only few changes in the methods were made at that time.

In the present book the reports of the Committee have been rearranged and systematized so that they may be more readily consulted. In some instances the original text has been somewhat condensed, in others amplified, always keeping in mind the intent of the Committee's work. The purpose of this treatise is not to serve as a complete manual of control methods, but rather to explain the principles which guided the Committee in arriving at its decisions, and to emphasize essential points. Those well known methods the details of which may be readily found in any of the generally used handbooks of factory control are not described at length, but simply referred to by name. But the methods recommended by the Committee which are not so widely known, are given in full in Chapter VII. In other words, the book is not meant to replace existing manuals, but to supplement them and to be used as a guide for those countries or associations that desire to bring their control methods in line with those recommended by the Committee, and thus to accomplish the purpose for which the latter was created. It is hoped that the publication of this international system of factory control may be found helpful toward that end.

The Committee accepted for its guidance the following principles enunciated by S. S. Peck: "Your committee should strive for three main objectives, namely, accuracy, clarity, and simplicity; and of these three I consider the last as important as the first two. In striving for greater accuracy, formulas have become so complex that they are practically useless. If the committee stress simplicity of statement which will not conflict with accuracy and clarity, they may be able to do some persuading to an agreement on terms." It was also postulated that wherever direct determinations can be accurately and simply made, they should be preferred to indirect determinations or calculations, and further, that practical considerations should be favoured against theoretical speculations.

CONTENTS

	PAGE
CHAPTER I	
INTRODUCTION AND SOME PREMISES	11
CHAPTER II	
PRINCIPLES OF MILLING CONTROL	13
CHAPTER III	
DETERMINATIONS AND CALCULATIONS FOR MILLING CONTROL	18
CHAPTER IV	
CONTROL OF THE BOILING HOUSE	29
CHAPTER V	
METHODS OF WEIGHING AND MEASURING	39
CHAPTER VI	
METHODS OF SAMPLING	47
CHAPTER VII	
METHODS OF ANALYSIS	55
CHAPTER VIII	
DEFINITIONS AND INTERPRETATIONS	75
APPENDIX 1	
CONVERSION OF UNITS	81

CHAPTER I

Introduction and Some Premises

The manufacture of cane sugar from sugar cane is a distinctive industrial process in that it involves no element of synthesis. Sucrose comes into the factory in the cane, and, subject to some physical losses and some destruction, emerges in the product, crystal sugar. The process is essentially a combination of separation and concentration.

The materials other than sucrose in the cane are collectively known as impurities, and may be classified as dissolved and insoluble respectively. The first step is the separation of sucrose and the impurities in solution from the insoluble impurities, together called fibre. This is the function of the milling plant, and the process is commonly called extraction. The second step is the treatment of the extracted juice for the removal of some insoluble and some dissolved impurities, and this is known as clarification. A considerable proportion of the water present is then removed in the process called evaporation. The further stages constitute the separation of impurities by crystallization of the sucrose. The processing of juice to crystal sugar takes place in the boiling house, and the separation of sucrose is called recovery. The overall separation of sucrose from cane is also known as recovery.

The proprietor of a sugar factory is naturally interested in knowing how much of the sucrose in the cane he purchases is present in the sugar he sells, and he also wishes to know how good or how bad is the achievement. This demands a series of measurements, analyses and calculations which constitute the system known as chemical control.

The main purposes of chemical control are threefold—

1. To ensure that the various unit operations in the process of manufacture are conducted at the highest efficiency. This is the most important function of chemical control—to provide "live" data for the immediate guidance of the plant operators. As this book does not pretend to be a manual of instruction for operators, it touches lightly on this function of chemical control.
2. To provide a quantitative account of materials and their components entering the process, in transit, in stock, and leaving the process. From the basic data convenient measures of performance—such as sucrose extraction or overall recovery—may be derived, but most of such records are dispassionately factual.

3. To assess the merits of performances achieved. Sugar technologists realized long ago that it is not reasonable to judge sugar factory results against the standard represented by perfection. Other things being equal, an extraction of 96 is better than an extraction of 94; but in practice other things are commonly not equal, and the 94 may represent a more meritorious performance than the 96.

The system commonly adopted is to compare the actual result with an arbitrary standard result—a standard result which tempers perfection by recognition of the prevailing circumstances. Since the formulation of a standard involves speculation, none of the arbitrary standards is above reproach, and different lines of speculative reasoning can lead to different standards for the same operation. This book discusses many of these standards and attempts to select the best for common usage.

Not all the "figures of merit" involve a comparison against a standard. Some are purely factual, and express merit only by virtue of an accompanying assumption; for instance, lost absolute juice per cent fibre is a statement of fact but it is regarded as a figure of merit by those—and there are many—who accept as a general truth that lost absolute juice is an index of milling efficiency.

Sucrose and Pol.

Although the material of primary importance in the sugar factory is sucrose and the accounting for sucrose should constitute the main material balance, this is not generally so. The determination of sucrose as such is laborious and more prone to error than the measure of apparent sucrose by direct polarization, known as pol.

There is no doubt whatever that pol is used more generally than sucrose as the basis of chemical control, and, until there is some significant change, pol must be the common basis. It is all very well to point to the superior merits of sucrose, but, if the sugar industry of a country will not adopt sucrose in its own interests, it is hardly likely to do so for others.

In plain fact, the normal relationships between pol and sucrose are gratifyingly stable and most of the time chemical control on a pol basis is entirely satisfactory. If suspicious results are recorded at any time, the pol-sucrose relationships can be checked for abnormality.

For every pol and every derivative from pol there is a sucrose equivalent. This should be kept in mind, because, to save wearisome repetition, this book deals primarily in pol. Those who prefer the alternative, sucrose, as a basis of control, are welcome to adhere to it, but should qualify reports accordingly.

There is one important exception. The concentration of optically active impurities in final molasses is so high that the pol and apparent purity of final molasses are practically meaningless. Those figures should be used, as required, for purpose of calculation, but only purities based on sucrose have any absolute significance.

CHAPTER II

Principles of Milling Control

The chemical control over the operation of milling involves accounting for four materials—cane, bagasse, mixed juice and water—and their components. Before procedures may be discussed some features of the materials are due for consideration.

Cane.

Cane may be taken to comprise fibre, being the aggregate of all components in the solid phase, juice, being the aggregate of all components in the liquid phase, and, possibly, hygroscopic water, being water physically adsorbed by some of the fibre.

At this stage it is pertinent to mention that terms like "solid" or "insoluble" or "undissolved" have to be accepted with some reservations. In many ways Nature does not deal in clear distinctions, and the technologist who studies the structure of cane in minute detail will find components to which classification as solid or liquid cannot be applied with certainty. For ordinary purposes fibre is a solid or insoluble component, but in finer degree fibre has to be distinguished as a "non-liquid" component, and even this distinction is not absolute.

The component called juice is really a heterogeneity of juices—the rich juice of the pith cells, the poorer juices of the rind and the internodes, and the watery content of the fibro-vascular bundles.

In earlier years there seems to have been some doubt about the existence of the third component "hygroscopic water". It can now be stated categorically that hygroscopic water exists and that when cane fibre has been steeped in dilute juice or water, the hygroscopic water which it adsorbs is somewhat variable in quantity, but is of the order of 25 per cent of the weight of fibre.

Hygroscopic water was referred to as a "possible" component of cane because, although its existence in bagasse is beyond question, its existence in cane is not proven, and there is substantial evidence that if it is at all part of cane it is present in a very small proportion.

Undiluted Juice.—Probably in order to avoid the complexity of allowing for the variations within the true juice of cane, the technologists of the Java sugar industry adopted a concept that the juice left in cane after dry crushing had the same Brix as the juice expressed by dry crushing, i.e., primary juice. The whole juice of the cane, computed on this basis, was termed undiluted juice.

In general the Brix of the residual juice is lower than that of the primary juice, so if the residual juice is credited with a higher Brix

than it possesses, its quantity is less than the true juice. This leaves a deficiency in the materials balance, and the term "undetermined water" was applied to the closure. Cane was presumed to consist of fibre, undiluted juice and undetermined water. It can be reasoned that this undetermined water must consist of water which is part of the true juice but not part of the undiluted juice, together with any hygroscopic water.

A weakness of this concept for practical purposes is that the Brix, and therefore the quantity, of undiluted juice depends on the Brix of primary juice which is subject to external influences, specifically, the crushing conditions.

Absolute Juice.—To provide a more stably based quantity than undiluted juice the concept of absolute juice was adopted. The assumption is the ultimate in simplicity—that cane consists entirely of fibre and absolute juice. If there is any hygroscopic water, it is regarded as part of the absolute juice.

Absolute juice was not presumed to exist as such, and it certainly does not in bagasses, but its existence in cane may be closer to reality than is generally imagined.

It is well known that the milling factor—that is, the factor converting the Brix of first expressed juice to the Brix of absolute juice, is of the order of 0.975. This factor may be regarded as the product of two subsidiary factors, one to convert the Brix of first expressed juice to the Brix of true juice, and one to convert the quantity of true juice to the quantity of absolute juice (that is, to allow for hygroscopic water). If the first of these two factors were unity, that is, if the factor 0.975 were solely to correct for hygroscopic water, the correction would represent 17.5 per cent hygroscopic water at 12.5 fibre in cane; but it is invariably found that the Brix of the true juice is below that of the first expressed juice, and therefore the hygroscopic water allowed for is less than stated above. Actually the factor to convert Brix of first expressed juice to Brix of true juice is of the same order as the overall factor, 0.975, and therefore the second factor is approximately unity.

It is not proposed to pursue this subject exhaustively but evidence from practical milling results, from press tests, and from alternative methods of determination of fibre in cane all leads to the one conclusion that, for practical purposes, there is no hygroscopic water in cane as cane. There is a suggestion that the adsorption of hygroscopic water begins when cells are disrupted and proceeds at a quite moderate rate. This can explain why cane pieces crushed in a press yield juice of declining Brix; but when the pressing is interrupted and resumed later, the Brix of the juice jumps to a new level and declines again. Whatever be the explanation, experimental results suggest that hygroscopic water should not be allowed for in original cane, but must be allowed for in bagasses and disintegrator slurries.

Bagasse.

Bagasse here means final bagasse, the end product of the milling train. It comprises fibre, juice and hygroscopic water. The fibre is almost the whole of that originally present in the cane from which the bagasse was derived. Losses are negligible, but a proportion approximating 0.5 per cent on cane passes out of the milling tram with the mixed juice. In strict accounting this quantity has to be allowed for, but for general purposes it is assumed that the fibre in cane all becomes fibre in bagasse.

The juice is a mixture ranging from virtually water to original juice still enclosed in a few inaccessible cells. The fibre contains hygroscopic water in quantity usually assumed to be 25 per cent of the weight of fibre.

Since a final bagasse contains some 50 per cent of fibre which in turn holds some 25 per cent of hygroscopic water, the quantity of this last item is substantial—12.5 per cent of the bagasse. This makes an appreciable difference between the true residual juice, 37.5 per cent, and the absolute residual juice, 50 per cent. If the bagasse contains 4 per cent Brix, then the concentration of the absolute residual juice is 8 Brix, but the concentration of the true residual juice is about 10.7 Brix.

There is rarely occasion to consider the average composition of the residual juice. Residual juice is commonly regarded as a mixture of some standard juice and water; the most popular standard juice was undiluted juice, first expressed juice has been used by many, but the recommended choice is absolute juice. If the Brix of the absolute juice of the cane was 20, then the bagasse referred to previously may be said to comprise 50 per cent fibre, 20 per cent absolute juice and 30 per cent water, the water being made up of 12.5 per cent hygroscopic water and 17.5 per cent imbibition water. The proportion of absolute juice was derived on a Brix basis, and this is the standard practice; but it can be derived on a pol basis, and such a procedure is inherent in the Reduced Extraction formula of Noel Deerr.

The standard method of analysis of bagasse at present involves the determination of dry substance and pol. The Brix is generally derived from the pol using the purity of last expressed juice or last mill juice. For generations it has been acknowledged that neither of these purities is even close to the purity which is really involved—the purity of the residual juice in bagasse.

In earlier years the direct determination of Brix in bagasse was known to be possible but was considered to be too exacting for routine use. Nowadays the high speed wet disintegrator provides a ready means of releasing the Brix into an extract, and a precision refractometer serves to determine the Brix of the extract. Direct analysis for Brix is still not recommended in relation to every sample,

but it is practicable to analyse a sufficient number of extracts for pol and Brix to maintain an adequate measure of the prevailing purity of residual juice in bagasse.

Mixed Juice.

Mixed juice is the main liquid product of the milling train. It incorporates all the extracted juice of the cane together with the major part of the imbibition water. It also contains a solid component made up of soil, particles of fibre, and other minor items. Cane of a high standard of cleanliness yields about 0.3 per cent insoluble matter in mixed juice, and when the cane is dirty this figure may rise well over one per cent.

This insoluble matter is technically fibre, not juice, and it should be taken into account accordingly. When the mixed juice is weighed, a sample should be analysed for insoluble matter, and the gross weight of mixed juice should be apportioned between fibre in mixed juice and clean mixed juice. Not only is this correct as regards accounting for materials, but also it relates the analysis of the mixed juice to the material actually analysed.

The pol of mixed juice will normally be determined by the dry lead method. The pol thus measured is the pol of the liquid phase, the clean mixed juice. The Brix should be determined on filtered mixed juice, because, if the juice is not filtered, the inflationary effect of the suspended matter is interpreted as extra dissolved solids which do not really exist.

Water.

The water referred to in this context is the net quantity of water which is added in the milling process. Most of it is, of course, applied as imbibition, and a little may come in through hoses or steam lines. On the other hand, a substantial quantity is lost by evaporation, particularly when hot milling is practised.

The Mass Balance.

According to the previous edition of this book "the fundamental equation for the weights of the products entering and leaving the mill states that cane plus water equals mixed juice plus bagasse". This is a dangerous over-simplification, for it fails to specify that the term "water" has to mean the net balance of added water.

More precisely, the fundamental equation is:

$$\text{Cane} + \text{water added} = \text{juice} + \text{bagasse} + \text{water lost.}$$

In earlier days it was not practical to weigh bagasse, and the quantity thereof was calculated by subtracting the weight of mixed juice from the combined weights of cane and added water. The result is not truly the weight of bagasse but the combined weights of bagasse and water lost. The loss of water is mainly by evaporation from the milling train. Extensive tests on a milling train working under hot conditions have disclosed a loss of water by evaporation

representing 3 per cent of the weight of incoming material. Under these conditions, the weight of bagasse calculated by difference will be inflated by 18 per cent. The example may be extreme, but in any case the error due to evaporation is serious enough to discourage the use of the simple mass balance to determine the weight of bagasse. Furthermore this method is cumbersome, and the ban on the use of unmetred water at the mills has a high nuisance value.

Nowadays the weighing of bagasse can be carried out as a routine operation and the statement that "the best way to determine the weight of bagasse is to weigh it" is no longer facetious.

The weights of mixed juice and bagasse, individually and directly determined, represent a powerful combination. The weight of added water can be dispensed with, and even the weight of cane is unnecessary if one key component—fibre or Brix or pol per cent cane—can be determined.

When it is impossible or inconvenient to determine the weight of bagasse the best procedure is to weigh the cane and determine its fibre content. The weight of fibre in cane, less the weight of fibre in mixed juice, is the weight of fibre in bagasse. This leads to the weight of bagasse and its components. This system was originally accepted by the International Society with some misgivings as to sampling cane for fibre. It is sufficient to state here that reliable sampling can be achieved and the scheme works well in practice.

A very important contribution to factory control—an innovation since the previous edition of this book—has been the development of the direct analysis of cane using the wet disintegrator. This operation has now been established as practical and reliable subject to the normal demands on diligence and maintenance. Its success depends upon the provision of reliable samples of cane but this requirement can generally be met.

If the weight of cane is known, and the analysis of that cane is determined, most of the purposes of the more complicated systems are achieved. Fibre in cane, corrected approximately for fibre in mixed juice, gives fibre in bagasse, hence the weight of bagasse and its components. Pol in cane less pol in bagasse gives pol in mixed juice, hence the weight of mixed juice and its components. If the weight of cane is unknown, then the weight of mixed juice should be determined and the above procedure applied with the necessary modifications.

The previous editions of this book listed five other bases of control. Each of them incorporates an arbitrary factor or a questionable assumption, and none was formally approved for use. There is no point in re-stating them here.

It remains only to add that, in some factories, cane, water, bagasse and mixed juice are not the only materials entering or leaving the milling train. Any other material involved, such as decant fluid from mud treatment, must be accounted for as to quantity and composition and taken into the materials balances.

CHAPTER III

Determinations and Calculations for Milling Control

In Chapter II the general basis of milling control was discussed, and several schemes were outlined broadly. It is now desirable to classify these schemes, express them in more detail, and go on to derive all the items of a full control programme.

For this purpose a system of symbols has been devised, as follows. The materials and components are represented by letters—

Cane	C, c	Brix	B, b
Bagasse (Ampas)	A, a	Pol	P, p
Net Added Water	I, i	Fibre	F, f
Mixed Juice (actual)	M, m	Water	W, w
Mixed Juice (clean)	J, j	Purity	Q

Excepting purity, the capital letters are used to refer to quantities, and the reference material is identified by a lower case subscript letter. Hence A_c is the amount of bagasse obtained from the original weight of cane, and F_a is the weight of fibre in that bagasse. Lower-case letters are used to express one item as a proportion of another, and, for simplicity, a unit basis has been adopted. Hence p_c is pol per unit cane and f_a is fibre per unit bagasse. Two subscripts are occasionally necessary as in p_{fw} pol per unit fibre in bagasse.

It follows, for example, that—

$$A \times p_a = Pa$$

$$\text{and } F_c \div f_c = C$$

Preliminary Data.— When cane is analysed the items determined directly are water, w_c , Brix, b_c , and pol p_c . Fibre is determined by difference, $f_c = 1 - w_c - b_c$

Bagasse is analysed directly for water, w_a , and pol, p_a . Brix is determined from pol and the purity of the residual juice, here expressed as Q_a (again on a unit basis). Hence $b_a = pa \div Q_a$. Fibre is then determined by difference, $f_a = 1 - w_a - b_a$.

Mixed juice is analysed for fibre, f_m , and it follows that $J = M - F_m$ or $j_m = 1 - f_m$. The clean mixed juice is analysed for Brix, b_j , and pol, p_j . It is assumed that, in all cases, b_a , p_a , f_a , w_a , f_m , p_j and b_j are known.

Basic Control Schemes.

Class I—When the weight of cane is known.

Scheme A—Cane weighed and analysed.

Calculations:

- (1) $C \times b_c, p_c, f_c, \text{ resp.} = B_c, P_c, F_c, \text{ resp.}$
- (2) Assume (for this purpose only) that $M \div C$.
 $C \times f_m = F_m$
- (3) $F_c - F_m = F_a$
- (4) $F_a \times p_a \div f_a = P_a$
 Similarly B_a, W_a and A
- (5) $P_c - P_a = P_j$
- (6) $P_j \div p_j = J$
- (7) $J \div F_m = M$
- (8) $M + A = C - J$

Scheme B—Cane and mixed juice weighed.

Cane analysed for fibre.

Calculations:

- (1) $C \times f_c = F_c$
- (2) $M \times f_m = F_m$
- (3) $F_c - F_m = F_a$
- (4) from F_a and bagasse analysis calculate A, P_a, B_a .
- (5) $M - F_m = J$
- (6) from J and analysis of clean mixed juice calculate P_j and B_j .
- (7) $P_a \div P_j = P_c$
 $B_a \div B_j = B_c$
 hence p_c and b_c
- (8) $M + A = C - J$

Scheme C—Cane, Mixed Juice and Bagasse weighed.

Calculations:

- (1) $A \times p_a, b_a, f_a, \text{ resp.} = P_a, B_a, F_a, \text{ resp.}$
- (2) $M \times f_m = F_m$
 $M - F_m = J$
- (3) $J \times p_j, b_j \text{ resp.} = P_j, B_j \text{ resp.}$
- (4) $P_a \div P_j = P_c$
 $B_a \div B_j = B_c$
 $F_a \div F_m = F_c$
 hence p_c, b_c, f_c
- (5) $M + A = C = J$

Scheme D—Cane, Mixed Juice and Added Water weighed.

This is the familiar "mass balance" method. The derivation of results usually starts with the assumption that the actual weight of water added equals the net weight J . This is a dubious assumption but, in the absence of knowledge regarding incidental gains or losses of water, it has to be made.

Calculations:

- (1) $C - I - M = A$
- (2) $M \times f_m = F_m$
- (3) $M - F_m = J$
- (4) $A \times b_a, p_a, f_a \text{ resp.} = B_a, P_a, F_a \text{ resp.}$
- (5) $J \times b_j, p_j, f_j \text{ resp.} = B_j, P_j \text{ resp.}$
- (6) $B_j + B_a = B_c$
- (7) $P_j + P_a = P_c$
- (8) $F_m + F_a = F_c$
- (9) $B_c, P_c, F_c, \text{ resp.} \div C = b_c, p_c, f_c \text{ resp.}$

This scheme should not be utilised unless none of the others A, B or C can be.

Class II—When the weight of cane is unknown.

Scheme E—Mixed Juice weighed.

Cane analysed.

Calculations:

- (1) $M \times f_m = F_m$
- (2) $M - F_m = J$
- (3) $J \times p_j, b_j \text{ resp.} = P_j, B_j \text{ resp.}$
- (4) Extraction $e = 1 - \frac{p_a \times f_c}{f_a \times p_c}$
- (5) $P_j \div e = P_c$
- (6) $P_c \div p_c = C$
- (7) $P_c - P_j = P_a$
- (8) $P_a \div p_a = A$
- (9) $M \div A - C = I$

Scheme F—Mixed Juice and Bagasse weighed.

Cane analysed for fibre.

Calculations:

- (1) $M \times f_m = F_m$
- (2) $M - F_m = J$
- (3) $J \times p_j, b_j, \text{ resp.} = P_j, B_j, \text{ resp.}$
- (4) $A \times p_a, b_a, f_a \text{ resp.} = P_a, B_a, F_a, \text{ resp.}$
- (5) $P_j + P_a = P_c$
 $B_j + B_a = B_c$
 $F_m + F_a = F_c$
- (6) $F_c \div f_c = C$
- (7) $M + A - C = I$

This listing of schemes may not be exhaustive but it should cover all the cases likely to be encountered in practice and amenable to absolute calculation. Conspicuous by its absence is the case where nothing is known of the cane—neither its weight nor any of its components quantitatively. In such a case the weight and composition of the cane cannot be determined by any absolute method; some empirical factor or arbitrary assumption must be invoked.

The procedures above outlined lead to full knowledge of the weight and composition of each of the materials involved, and it is possible to draw up mass balances for Brix, pol, fibre, etc., as desired. Certain transitions from one material to another have been based on pol where Brix might have been used instead. The reason is that the main goal is considered to be a pol balance; the consequence is that the Brix may not, and probably will not, balance exactly but the error should be tolerable. If, for a particular purpose, it is desired that the Brix balance be exact, then let Brix be used instead of pol for the transitions.

Having pursued the subject so far, the reader should not need to be instructed in the derivation of such obvious quantities as mixed juice per cent cane or pol in bagasse per cent fibre; however a few terms are worthy of some explanation.

Absolute juice, as explained in Chapter II is that part of the cane which is not fibre. If b_c is the Brix per unit cane, then the Brix per unit absolute juice is $b_c \div (1 - f_c)$; likewise the pol is $p_c \div (1 - f_c)$. These are used to find quantities of absolute juice in other materials, usually on a Brix basis, but optionally on a pol basis. The quantity of absolute juice relative to fibre in bagasse is an important criterion of milling performance.

For reporting purposes the net added water is called Imbibition, which explains the symbol I. Part of the imbibition water added appears in the mixed juice, and this part is known as Dilution; the rest emerges as Imbibition Water in Bagasse. For the purposes of determining the division of the imbibition it is assumed that the original juices extracted into the mixed juice were the same as those left in the bagasse; both are treated as absolute juice, and calculation has traditionally been on a Brix basis. However, the milling performance figures which will be recommended for reporting are on a pol basis, and such a basis might well be adopted here.

Since the absolute juice in the mixed juice is regarded as being identical with the absolute juice of the cane, it follows that the extraction of absolute juice equals the pol extraction. The quantity of clean mixed juice is known from the mass balance; the quantity of absolute juice therein is the quantity of absolute juice in cane multiplied by the pol extraction (unit basis). The remainder of the mixed juice is the dilution, which can then be expressed relative to cane or absolute juice in cane.

That quantity of absolute juice not accounted for in the mixed juice is in the bagasse, and the difference between this absolute juice and the absolute residual juice in the bagasse is counted as imbibition water in bagasse—a figure of doubtful accuracy. The assumption that the original juice left in the bagasse has the same pol as absolute juice in the cane may be expected to be appreciably in error.

Figures Used for Judging Milling Results.

Extraction (sucrose, pol, Brix, juice) is purely a quantitative statement of fact. If all canes were of one composition then extraction would also be a figure of merit—but cane is not uniform, and to the extent that it departs from uniformity so extraction becomes deficient as an index of the performance achieved.

Recognizing this, technologists have sought criteria which would take account of variations in the composition of the cane and allow for them in assessing milling results. The three significant variables in cane (the only three that can be considered) are fibre, Brix and pol. The various criteria which have been proposed for indicating milling efficiency differ fundamentally in the assumptions made regarding the effects of these variables.

It is a feature of all the criteria that, either in the first instance or entirely, they regard milling efficiency as independent of fibre in cane; in other words, at a constant order of merit, the loss of pol or Brix or juice in milling is expected to vary directly with fibre in cane. Efficiency is judged either by expressing the loss relative to fibre, or by "reducing" the loss to what it would have been at a standard fibre in cane.

One may argue that when the fibre in cane rises, a mill grinding at a constant *cane* rate is operating at a higher *fibre* rate and may be expected to incur higher losses of pol per unit of fibre. The argument is sound enough, but it encroaches into the field of performance per unit of equipment, which is beyond the present considerations. Even so, it is well to keep in mind that milling performance criteria envisage a constant fibre rate rather than a constant cane rate.

Whereas in respect of fibre in cane the various criteria are virtually at one, this is not so as regards pol in cane. Here there are two fundamental propositions—one, that the ratio of pol to fibre in bagasse is independent of pol in cane; the other, that the ratio is directly proportional to pol in cane, or pol in juice.

It is convenient at this point to discuss various criteria of milling performance.

1. *Extraction*: The word alone normally signifies pol extraction; it is possible to calculate also the extraction of sucrose or Brix or absolute juice, in which case the term should be suitably qualified.

The formula for calculation of pol extraction (here expressed on a unit basis) is:

$$e = 1 - \frac{p_a \times f_c}{f_a \times p_c}$$

but, when a mass balance is taken out, pol extraction is normally calculated as $P_j \div P_c$.

The last expression in the formula is the complement of extraction, that is, the proportion of pol lost in bagasse. It may be rendered into the form—

$$\frac{\text{ratio of pol to fibre in bagasse}}{\text{ratio of pol to fibre in cane}}$$

Mill engineers in general maintain that the response of this term, and therefore the response of extraction, to the ratio of pol to fibre in cane is a false index of milling performance. Extraction is a statement of fact and an inevitable product of quantity accounting, but it is universally acknowledged to be a poor figure of merit.

2. *Milling Loss*: Milling loss is the ratio of pol to fibre in bagasse, usually expressed as a percentage. It is a simple expression of the contention that, regardless of the pol and fibre in cane, milling performance is best when the pol lost per unit of fibre is least. It has the advantage of simplicity and the disadvantage that as performance improves it decreases.

3. *Whole Reduced Extraction*: In a paper presented before the International Society in 1962, B. L. Mittal introduced the term Whole Reduced Extraction which he defined as:

$$\text{W.R.E. (unit basis)} = 1 - \frac{p_c \cdot m_c}{Jc}$$

This expression probably had an eye to the availability of the data, pol in bagasse per cent cane and fibre per cent cane. Its significance is more readily appreciated when it is converted to the form:

$$\text{W.R.E.} = 1 - \frac{p_a}{Jc}$$

This shows that W.R.E. is the complement of Milling Loss. Through the reversal of the sign of the variable, the result rises, with improving performance, towards a limit of 1 (100 per cent). Like milling loss, it ignores the composition of the cane.

4. *Extraction Ratio*: Extraction ratio is normally defined as the percentage ratio of (100 — extraction) to fibre per cent cane. Mathematically, on a unit basis:

$$E.R. = \frac{JL}{Jc}$$

This is more readily understood when rendered into the form:

$$E.R. = \frac{p_a}{f_a \times p_c} = \frac{\text{Milling loss}}{p_c}$$

This is the first of those criteria based on the contention that higher pol in cane means higher loss of pol in bagasse. W.R.E. eliminates both fibre and pol in cane from the extraction formula; E.R. eliminates only fibre in cane. According to this criterion the milling loss is expected to vary with pol in cane, and allowance is made accordingly.

5. *Reduced Extraction (Mittal)*: On the same occasion as he introduced W.R.E., Mittal also proposed a Reduced Extraction which he defined as:

$$e^1 \text{ (unit basis)} = 1 - \frac{0.125 \times p_{ac}}{f_c \times p_c}$$

Here again the appearance is deceiving. Simple substitutions lead to the form:

$$e^1 = 1 - \frac{p_a \times 0.125}{f_a \times p_c}$$

which will be recognised as the extraction formula with a fixed value of 0.125 for f_c (12.5 per cent fibre in cane). R. E. (Mittal) can also be expressed in the form:

$$e^1 = 1 - 0.125 \times E.R.$$

This shows that R.E. (Mittal) has the same premises as Extraction Ratio, but yields results in a more familiar numerical range, rising as performance improves.

6. *Absolute Juice in Bagasse per cent Fibre*: The concept of milling as a process of opening and emptying discrete cells in cane naturally suggested that the best milling would leave the fewest unopened or unemptied cells. As these cells were presumed to contain juice of the same Brix as the juice expressed without dilution, it followed that the best milling would leave the least equivalent juice per unit of fibre in the bagasse.

The reference juice adopted for many years was undiluted juice as defined in Chapter II, and the quantity determined was Undiluted Juice in Bagasse per cent Fibre. Absolute juice is now perhaps a more popular but not a better standard of reference.

The criterion Lost Absolute Juice (for short) has much in common with Extraction Ratio and R.E. (Mittal) in that it allows for a loss proportional to the fibre content of the cane, but whereas the last two also expect the loss to vary with pol in cane, Lost Absolute Juice expects it to vary with the Brix or pol of absolute juice.

When the fibre in cane is constant, pol in cane and pol in absolute juice are tied to each other, but if the fibre varies they become independent of each other. Lost Absolute Juice is traditionally derived on a Brix basis, but it may be derived on a pol basis and in another connection to be mentioned, the latter basis is used.

If e_b is the Brix extraction (unit basis) then $1 - e_b$ is the Brix in bagasse per unit in cane. Assuming uniformity of absolute juice, $1 - e_b$ is also the absolute juice in bagasse per unit absolute juice in cane. The factor $\frac{1-f_c}{f_c}$ converts this to absolute juice in bagasse per unit fibre in cane, and a unit of fibre in cane is a unit of fibre in bagasse. Hence, representing Absolute Juice in Bagasse per cent Fibre by v :

$$v = 100 \times \frac{(1 - e_b)(1 - f_c)}{f_c}$$

A common alternative form is:

$$v = \frac{10,000}{\text{Brix abs. juice}} \times \frac{b_a}{f_a}$$

It may be somewhat sounder to base expected losses in bagasse on the concentration of Brix or pol in juice rather than in cane, but it is not established beyond doubt that the proportionality is valid in either case.

Absolute Juice in Bagasse per cent Fibre is a criterion highly regarded by many and is probably the most favoured for intensive studies of milling.

7. *Reduced Extraction (Deerr)*: Noel Deerr adopted the principles of Lost Absolute Juice for the formulation of a less pretentious, but more attractive criterion, Reduced Extraction. His procedure was to take the Actual Lost Absolute Juice per cent Fibre of a milling train, calculate what the loss would be at a standard fibre, and convert this loss into an extraction. He adopted the pol basis for juice, and a standard fibre of 12.5 per cent.

The traditional derivation of R.E. (Deerr) is neat but not lucid and the following may be more readily understood. If v is the Absolute Juice in Bagasse per cent Fibre then, when the cane contains 12.5 per cent fibre, 100 parts of cane will yield 12.5 parts of fibre in bagasse and cause the loss of $0.125 v$ parts of absolute juice. This cane contained 87.5 parts of absolute juice, so the loss of absolute juice per cent absolute juice is $\frac{12.5v}{87.5}$, that is $\frac{v}{7}$

By the assumption of uniformity of pol of absolute juice, the absolute juice in bagasse per cent absolute juice in cane equals pol

in bagasse per cent pol in cane. Hence the extraction in this special case, that is the Reduced Extraction, e_m , may be expressed:

$$e_m = 100 - \frac{v}{7}$$

As established earlier:

$$v = \frac{(100 - e)(100 - f_c)}{f_c}$$

(here e and f_c represent percentages)

hence:

$$(100 - e_m) = (100 - e) \times \frac{100 - f_c}{7f_c}$$

This is the form of expression for practical use. The complement of the pol extraction multiplied by the fibre factor yields the complement of the reduced extraction.

Mittal, referred to earlier, has criticized R.E. (Deerr) on the ground that the results are not independent of fibre in cane. Perhaps the best answer is that the results do not pretend to be independent of fibre in cane. This criterion presumes that, when fibre in cane changes, the loss of absolute juice per unit of fibre will not change; but when fibre in cane changes and pol in cane is constant, the pol of the absolute juice changes and so a constant loss of absolute juice does not represent a constant loss of pol. R.E. (Deerr) responds to fibre in cane through the secondary influence of fibre in cane on the pol of absolute juice.

Discussion.

Of the seven criteria listed some can be dismissed easily. Pol extraction finds no favour because of the general agreement that the influence of fibre in cane, at least, should be eliminated. Milling Loss is inherent in and better expressed in W.R.E. and Extraction Ratio is inherent in and better expressed in R.E. (Mittal). For routine reporting the significance of Absolute Juice in Bagasse per cent Fibre is expressed adequately in R.E. (Deerr).

Three criteria remain for consideration, the three reduced extractions, and they represent three schools of opinion. The supporters of W.R.E. maintain that the original composition of the cane as to pol does not affect the milling loss; the supporters of R.E. (Mittal) claim that when the pol in cane rises, the milling loss may be expected to rise in proportion; those who support R.E. (Deerr) believe that the pol of the absolute juice affects the milling loss.

Unfortunately the difference of opinion cannot be resolved. B. L. Mittal, who proposed two of the criteria, clearly prefers W.R.E., and Alfred L. Webre of Florida is on his side. On the other hand, the great significance attached to Lost Juice figures for

many years indicates that they must have some element of realism. It is suggested that the truth, if there be any, lies between the two. The absolute juice theory depends upon the assumption that, if the average juice of Cane A has twice the Brix or pol of the juice of Cane B, then the same ratio applies to the juices of the last few cells in bagasse. Tests suggest that there is a trend towards uniformity (at a level well above zero, by the way). If the end result were uniformity, then W.R.E. would be the best choice.

In a factory report pol extraction will be either recorded or readily available by reference to the loss of pol in bagasse. R.E. (Mittal) is easily calculated from the loss of pol in bagasse or from W.R.E. It is recommended that the milling performance figures for reporting be Whole Reduced Extraction and Reduced Extraction (Deerr).

Imbibition

Milling performance is so responsive to the proportion of water used in the process that a milling result cannot be properly assessed without an accompanying expression of imbibition.

When the actual weight of imbibition water can be measured or deduced, the intensity of imbibition is best expressed as parts of imbibition water per 100 parts of fibre in cane, commonly called imbibition per cent fibre.

It is sometimes convenient, but somewhat less satisfactory to relate the added water to cane, rather than fibre in cane, hence the terms added water resp. imbibition per cent cane.

Lack of data may make it necessary to relate the added water to the weight of a juice, such as absolute juice, undiluted juice or first expressed juice. The calculation requires only the Brixes of the original juice and the diluted juice (mixed juice) but the result has significant limitation. Technically the "original" juice is the extracted juice as it would be if undiluted, but this juice is not available, nor is its Brix; however, any one of the three juices specified above will serve. The second point is that the mixed juice does not contain all the imbibition water, some of which passes out of the milling train in the bagasse. In an earlier example a final bagasse was found to contain 17.5 per cent imbibition water. This bagasse contained 50 per cent fibre so that the imbibition per cent fibre was 35. This is a substantial quantity to ignore in a total of the order of 200, but at least the discrepancy is fairly constant. A third point is that the mixed juice must be the unadulterated product of the milling train, for if it contains filtrates or any other additives its Brix no longer reflects the dilution due to imbibition.

Despite its limitations, dilution per cent "undiluted" juice is a useful criterion, certainly worth reporting if imbibition per cent fibre or cane is not available.

Milling Plant Performance.

It is reiterated here that the performance figures discussed represent attempts to compensate for variations in the cane not the equipment. The only feature related to plant is the inherent assumption of a constant fibre rate. As most of the mills of a train are affected more by fibre rate than cane rate, the basis is reasonable, and accords well with plant capacity formulae which are usually based on fibre rates.

CHAPTER IV

Control of the Boiling House

Mixed Juice.

Though mixed juice is the raw material of the boiling house, it is better regarded as an end product of the milling process, since most of the interest in mixed juice is related to milling. In the boiling house, the mixed juice is about to be supplemented by filtrates, limed, perhaps treated with phosphoric acid or sulphur dioxide or special additives, then boiled and settled. In these processes and operations the components of the mixed juice are so thoroughly re-shuffled that the original composition hardly matters.

The weight of mixed juice is known from the milling records, and the juice should be analysed for suspended matter, and pol and Brix of filtered mixed juice. The densimetric Brix of mixed juice as weighed is a false figure that gives rise to an erroneous purity and a purity rise on clarification that is mostly spurious. Previous editions recommended the determination of reducing sugars and ash in mixed juice but these would not seem to provide information of any use.

Clarification.

In the clarification process pH at various points is kept under control or observation but the only figure of record is the pH of clarified juice. The phosphate and starch contents of mixed juice may be of local significance from time to time, and clarified juice may be analysed for sulphur, calcium, phosphorus, starch, turbidity and suspended matter, but the results are not for publication.

It has been customary to report the amount of lime used for clarification, nominally as available calcium oxide per 1,000 parts of cane. This quantity is responsive to so many features of material, process and conditions that it has only local significance.

The clarification process yields primary mud which nowadays is usually supplemented by bagacillo and additives and passed to the rotary vacuum filters. Other types of filter may be used, and the alternative process of extracting sugar by decantation survives to a limited extent, but in any case there is a filter cake or mud leaving the factory, and filtrates or decant fluids returning to process.

The waste product, which is referred to as filter cake, contains a quantum of sucrose lost from the process, and therefore the weight and sugar content of the filter cake are essential components of the chemical control. Dry substance and bagacillo content may be of interest in relation to filter performance, and the purity of the liquid component serves to check on deterioration, but only the

quantities of cake and pol in cake are of external interest. There is a technical point that some of the loss of pol in filter cake, being associated with its bagacillo content, has already been accounted for as pol in bagasse. It is possible to make allowance for this, but not too precisely, and, as the error is of the order of 10 per cent of the pol in cake, it is usually ignored.

Clarified Juice.

From a chemical point of view, clarified juice is the raw material of the boiling process, and, where mixed juice is not weighed, sometimes the analysis of clarified juice is used as the analysis of mixed juice for milling control. Its Brix is important in judging the performance of the evaporators, and, as mentioned earlier, it may be analysed and tested extensively, but only its pH and purity are commonly reported. Its weight is usually determined from the weight of mixed juice, with allowance for the pol lost in filter cake.

Syrup.

Syrup is a comparatively unimportant intermediate product. Its Brix is important in reference to the performance of the evaporators and the provision of suitable material for the pans; its purity is of interest as the starting level for the sugar boiling process, and these two items, Brix and purity are normally reported. It is not normally weighed, and its weight is rarely of concern.

Pan Products.

Various grades of massecuites and molasses are involved in the sugar boiling system, and their purities and Brixes are under constant observation or control in the interests of the process. A full report will normally include the average purity of each grade of massecuite and molasses. The purity of magma should also be reported.

Sugars.

Several grades of shipment sugar may be turned out, and each should be accounted for separately as to weight and analysis. The standard data for a sugar are pol (corrected to 20°C) and water. Optional extras are reducing sugars, ash and other organic matter. Sugars may also be tested for grain size, starch content, filterability, colour, etc., but such data are not usually published.

Sugars returned to process in the factory are of internal interest only.

Final Molasses.

As final molasses contains one of the major losses of sucrose in process, its weight and analysis are important. The weight should be determined directly, and if this is not possible, a densimetric basis

must be adopted. Pol should be determined for the pol balance, and apparent purity for the general record. As the apparent purity of final molasses may be very deceptive, true purity should also be determined and reported, together with reducing sugars, ash and sucrose, so that exhaustion formulae may be applied.

Recoveries and Performances.

Introduction. -That proportion or percentage of the pol in cane which passes into the mixed juice is referred to as the extraction. That proportion of the pol in mixed juice which passes into the sugar manufactured is referred to as boiling house recovery. The product of the two represents the proportion of pol in cane "recovered" as pol in sugar, and is known as overall recovery. Like extraction, these two recoveries are purely quantitative statements and do not necessarily constitute measures of efficiency. Let the purity of the mixed juice decline, the boiling house recovery will normally do the same when the standard of performance in terms of merit remains unchanged.

In the case of extraction, there was only one variable to consider—the cane. The counterpart in respect of recovery is the mixed juice; but there is another variable to consider also—the quality of the sugar produced. Pour some of the final molasses over the sugar before the latter is weighed and analysed and the recovery will rise, but the performance of the factory has certainly not improved. Hence, in attempting to assess the merits of a recovery figure, one has to take account of both the mixed juice and the sugar.

Actual recoveries, standard recoveries and various performance figures to be discussed are almost invariably expressed as percentages, but it simplifies mathematical expressions and derivations greatly if the terms are referred to the basis of unity rather than 100. The former basis has been adopted.

All the terms can be, and ideally should be, based on true analyses—sucrose and dry substance—but pol and Brix are accepted as the working standards and the terms, unqualified, are taken to be based on these apparent measures.

Actual Recoveries:

Boiling House Recovery.—As previously stated, Boiling House Recovery is pol in sugar as a proportion of pol in mixed juice.

Overall Recovery.—As previously stated, Overall Recovery is pol in sugar as a proportion of pol in cane.

Standard Recoveries.

The S-J-M Formula.—When a raw material containing sucrose and impurities is processed into a final product, rich in sucrose and a waste product containing most of the impurities, all components being accounted for, there is a mathematical relationship

between the materials and their components. The most familiar expression of this is the s-j-m formula of Noel Deerr, which pictures a notional juice being processed into sugar and molasses only. If the purities of the materials respectively be j, s and m, then the recovery, r, i.e., that proportion of the sucrose in the juice which is contained in the sugar is determined by the formula:

$$j (s - m)$$

This is mathematically true when s, j and m are literally true and there is no loss of any material. When apparent values are used for s, j and m, the formula is no longer correct in general. The large disparity between the true and apparent purities of final molasses might suggest that the use of apparent purity would yield absurd results, but there is a significant measure of compensation. The difference between the two purities for mixed juice is appreciably less than for molasses, but the formula is much more sensitive to j than to m. A difference of 3 units of purity in juice is equivalent to about 7 units of purity in molasses, and these figures are not too remote from the real differences between true and apparent purities in the two cases.

Given values of s, j, m and r from the records, and adopting the s-j-m formula, it is possible to compare the actual recovery with the ideal figure. The former result will be the lower because of the known and unknown losses of sucrose other than in molasses. The ratio of the two recoveries would be a figure of merit, taking account of the purity of mixed juice, showing up losses other than in molasses, but accepting the purities of sugar and molasses at their actual values.

The Winter Formula.—Before 1900, Winter and Carp independently concluded that the yield of commercial sugar to be expected from a mixed juice could be predicted by deducting from the pol in the mixed juice 40 parts for every 100 parts of impurities. This is expressible in the form:

$$r = 1.4 - \frac{0.4}{J}$$

where r was, originally, the recovery of commercial sugar per unit of pol in mixed juice of purity j (unit basis).

When the s-j-m formula was devised it was soon recognized that the s-j-m formula would yield the same values of r when s was fixed at 1 (100 per cent) and m at 0.2857 (28.57 per cent). The formula of Winter and Carp, generally called the Winter formula nowadays, is generally regarded as a special case of the s-j-m formula, but this is mathematical rather than historical.

Regardless of its origin, the Winter formula is commonly used to provide a standard recovery for the boiling house, designated Basic Boiling House Recovery. It recognizes the purity of the

mixed juice, it allows no losses of pol except in molasses, it provides for a molasses of 28.57 purity, and it takes no account of the purity of the sugar made.

Equivalent Standard Granulated Sugar.—It has been mentioned that the quality of the sugar is a factor in recovery. Not all of the sucrose in a commercial sugar is truly "recovered" because, in the ultimate removal of the remaining impurities, some sucrose will inevitably be lost. Hence the sucrose content of any commercial sugar has to be discounted for potential loss if recovery is to be truly assessed.

Many standards of comparison of sugars, e.g., raw value, net titre, titrage, and many standard sugars, e.g., 96 degree, Standard Muscovado—have been or are used in practice, but most of them have a local and usually a commercial significance.

Noel Deerr suggested that the sugar itself was as good a subject for the assessment of a process recovery as any other factory product. He proposed the use of the Winter formula, and to the material expected to be recovered he gave the name Equivalent Standard Granulated, usually abbreviated to E.S.G. The Winter recovery, being a recovery of pol, is applied to the pol of the sugar to yield the E.S.G. factor. Hence:

$$\begin{array}{l} \text{pol of sugar} \times \text{Winter recovery} = \text{E.S.G. factor} \\ \text{tons sugar} \quad \times \text{E.S.G. factor} \quad = \text{tons E.S.G.} \end{array}$$

The actual recoveries referred to earlier are of pol in actual sugar; the Basic Boiling House Recovery is of pol in pure sugar. For comparison purposes either the actual recoveries might be adjusted to pure sugar, or the basic recovery to actual sugar.

Conventionally the first choice is adopted; comparisons are made in terms of pure sugar, that is, E.S.G.

Criteria of Performance.

Boiling House Efficiency.—The ratio of Actual B.H.R. to Basic B.H.R. is frequently worked out (as a percentage) and reported as Boiling House Efficiency. As a criterion it compensates for the purity of the mixed juice and it responds to losses, but it takes no account of the quality of the sugar produced, and it postulates a standard purity of 28.57 for final molasses.

Boiling House Performance.—The neglect of sugar quality in B.H.E. can be rectified by expressing the actual recovery as E.S.G. instead of pol. The result can then be matched against Basic B.H.R. which, being a recovery of pure pol, may legitimately be entitled Basic B.H.R.E.S.G. Thus B.H.P. is the ratio (usually as a percentage) of Actual B.H.R.E.S.G. to Basic B.H.R.E.S.G.

By previous specifications, the term B.H.P. was to be associated only with sucrose and gravity purities. No name was specified for

the equivalent result based on apparent analyses, though it might be termed B.H.E.E.S.G. It is time there was an end to this use of different names to distinguish between pol and sucrose bases of control. It creates unnecessary confusion. Pol is the norm, and the use of the term B.H.P. alone should automatically indicate a pol/Brix basis. If a B.H.P. is reported on a sucrose/Brix basis, it can easily be qualified as B.H.P. (suc./Brix). The same attitude has been adopted towards all the criteria discussed.

B.H.P. is a refinement of B.H.E. but it still has limitations and is not regarded as the best available criterion.

Reduced Recoveries.—The performance criteria so far discussed have assessed merit by matching an actual recovery against a standard recovery. One of the more subtle defects of the terms mentioned is that, if the purity of the mixed juice changes and the factory works at the same "efficiency" the actual recovery will change, and so will the standard recovery, but not in the same proportion; the relationship between the two changes. The word efficiency used above warrants interpretation, but this will be deferred until later.

Recognizing the influence of the purity of mixed juice on recovery, the ubiquitous Noel Deerr considered that useful information would be provided by "reducing" the purity of mixed juice to a standard which he set at 85. In other words, from the actual recovery at purity j he attempted to nominate what the recovery would have been at purity 85.

To achieve this Noel Deerr invoked the "virtual" purity of molasses, by which he meant that value of m which satisfies the $s \cdot j - m$ formula—

$$r = \frac{s(j - m)}{j(s - m)}$$

when r is the B.H.R.E.S.G., s equals 1 (100 purity) and j is the purity of mixed juice. The above equation may be solved for m , which is now specifically m_v , yielding:

$$m_v = \frac{j(1 - r)}{1 - jr}$$

This mysterious virtual purity is no more than the purity of an imaginary molasses containing all the unrecovered pol and all the impurities. The unrecovered pol per unit pol in juice = $1 - r$. The

impurities per unit pol in juice = $\frac{1}{j} - 1$

Hence:

$$\begin{aligned} m_v &= \frac{1 - r}{\left(\frac{1}{j} - 1\right) + (1 - r)} \\ &= \frac{j(1 - r)}{1 - jr} \end{aligned}$$

On the assumption that v is constant—

$$r_{85} = \frac{0.85 - m}{0.85(1 - m)} - v$$

Substitution for v leads to the equation—

$$r_{85} = r + \frac{m}{1 - m} \frac{0.85 - j}{0.85j}$$

This is not the traditional final form, but it is convenient and it serves to demonstrate that when the purity of mixed juice is 85 ($j = 0.85$) the expression on the right vanishes and $r_{85} = r$. For purities above 85 the correction applied to r is negative.

At the Twelfth Congress of the Society in 1965 the Committee decided that R.B.H.R.E.S.G. Gundu Rao was more soundly based than the corresponding formula of Noel Deerr, and should be the term officially endorsed.

R.B.H.R.E.S.G., though by no means perfect, is as complete a criterion as can be based on the data s , j , m and r . It puts factories on a common basis of mixed juice purity and it corrects for the purity of the sugar produced.

A residual weakness is that it regards factories as competing on equal ground for molasses purity. Gundu Rao proposed a Boiling House Performance which matched R.B.H.R.E.S.G. against Basic B.H.R. at 85 purity, but, as the latter is a constant, no further discrimination is achieved. The effect is merely to set a common target of 28.57 for molasses purity instead of zero.

No more can be achieved without invoking more data; more data are available, but the problem has always been —how to use them.

Expected Purity of Molasses.—The most significant contribution to the future of boiling performance criteria has been the development of formulae predicting the purity of final molasses at a common standard of performance. Probably the most famous formula of this type was derived by Douwes Dekker—

$$\begin{aligned} \text{Expected purity} &= 35.886 - 0.08088 R + 0.26047 A \\ \text{where } R &= \text{reducing sugars per cent non-sucrose} \\ A &= \text{ash per cent non-sucrose.} \end{aligned}$$

This was used for many years in Queensland and to a limited degree elsewhere purely as a standard of reference for the actual *true* purity of molasses. Of recent years in Queensland it has been replaced by the Sugar Research Institute formula:

$$\text{Expected purity} = 40.67 - 17.80 \log. R.S./\text{Ash ratio.}$$

It is not suggested that either of these formulae is the ultimate, but it is suggested that the molasses purity determined by either of them is more realistic and indicative than 28.57. If an acceptable formula for expected purity can be devised, then the best indicator

of boiling house performance would appear to be the ratio of R.B.H.R.E.S.G. to Basic B.H.R. (s 100, j 85, m expected purity). For the pol basis of reporting, the expected purity would need to be adjusted from true purity to apparent purity according to the prevailing local difference.

Overall Performance......With the performance of the milling station expressed in one figure, and the performance of the boiling house expressed in another, it was natural to think of combining the two into one overall performance figure for the factory. This was done originally by combining the two Noel Deerr criteria, R.E. and R.B.H.R.E.S.G. as Reduced Overall Recovery E.S.G.

In view of the preference for Gundu Rao's recovery formula Reduced Overall Recovery E.S.G. may now be defined as the percentage product of R.E. (Deerr) and R.B.H.R.E.S.G. (Gundu Rao). It is not as significant a term as might be expected at first thought, because the milling department and the boiling house are so distinct that the expression of their performances together in a single result gives little satisfaction.

In the consideration of overall performance there is a strong tendency to go back to a cane basis. The Overall Recovery E.S.G. multiplied by pol per unit cane gives the Yield of E.S.G. and the Reduced Overall Recovery E.S.G. treated similarly gives Reduced Yield of E.S.G. These are not performance criteria at all, but, as actual or corrected yields of pure sucrose they are commonly matched against expected yields and so efficiency is judged. Technically the venture is bold because the meagre data available in respect of the cane are inadequate for the prediction, within reasonable limits, of a standard yield; economically the comparison is well and truly justified when the price of the cane purchased is based upon the projected yield of sucrose. Various formulae have been devised and are in regular use for the derivation of a standard yield of sucrose from cane according to the composition of the cane, but these are mainly commercial formulae and are not recognized for technical evaluation of performances.

Recapitulation.—In the consideration of terms to be adopted to express the performance of a sugar factory, for the purposes of International comparisons, it is necessary to subordinate precision in detail to the wide range of conditions to be catered for. Various criteria discussed in previous editions have been ignored here, not so much on the grounds of lack of merit as on the contention that they belong in a different field—the continuing study of the performance of one factory. This applies particularly to the many formulae based on detailed accounting for impurities.

Given as data the purity of mixed juice, the purity of sugar and the actual boiling house recovery, it does not seem possible to derive any better criterion of the work of the boiling house than R.B.H.R.E.S.G. (Gundu Rao). The most obvious avenue for im-

provement lies in using the composition of the molasses to nominate a target purity for that material, and using that purity to provide a value for m in the formula, instead of the traditional and indiscriminate figure of 28.57.

There is probably no need to depart from the Winter formula for the purpose of determining E.S.G. The effect of a change of molasses purity is very slight, the relationships between impurities in the sugar are not necessarily the same as in the final molasses, and one can find some virtue in a common formula for all sugars.

CHAPTER V

Methods of Weighing and Measuring

Chemical control necessarily involves the determination of weights of material, either directly or inferentially. The variations in layout and procedure within factories and the range of equipment available make it necessary to restrict the discussion of weighing and measuring to general principles of operation and types rather than specific brands or equipment.

Weights and Measures.

Whilst the universal adoption of an international decimal system of weights and measures is the ultimate goal, the fact remains that the local systems are strongly entrenched and most of them are not likely to be supplanted in the foreseeable future.

Fortunately the great majority of data in a record of chemical control are relative within themselves and thus independent of units. International trade and communications have fostered the adoption of one or other of the major systems of units in preference to minor local systems in many countries, and the cane sugar world may be said to be divided between the British and the metric systems, with minor local variations. The adoption of either one of these would appear to be the most that one can ask for at this juncture. The tendency to express parts of a major unit in decimals is developing and is to be encouraged, for this is a positive step towards ultimate uniformity.

Weight of Cane.

Cane is almost invariably weighed on a platform weighbridge designed to accommodate the vehicle by which a load of cane is carried.

As a weighing machine used for trade purposes, the cane weigher often comes under the jurisdiction of the Authority controlling weights and measures within the Country, and, if so, calibration and certification are performed by that Authority. If not, the procedures for testing, which are too lengthy to be set out here, are readily available from any recognized testing Authority. The operation of testing and calibrating is usually performed annually.

Certain routine checks are called for. The practice of testing the zero regularly should be observed; this is readily achieved by making it the first task of each weighbridge operator coming on duty. He should also check the tare counterweights for identity and position. There should be a mobile test weight on the premises, weighing about the same as the average commercial load. Correct

recording of the weight of the test load should be verified at least weekly, and for preference, daily.

Cane normally loses weight from the time it is harvested until it is crushed, and therefore it is desirable to minimise the storage of weighed cane. Apart from the normal loss by evaporation, there may be a significant gain if rain falls on the stored cane; the effect in either case is to create an uncertain difference between the cane as weighed and the cane as milled and analysed.

It goes without saying that the accuracy of the net weight—the weight of cane—is no better than the accuracy of the tare of the transport vehicle. Circumstances vary so widely that only a general word of caution is appropriate.

Weight of Field Trash.

The total amount of field trash cannot be weighed directly and must be estimated by determining the proportion of field trash in representative samples of cane as received. Sampling is not easy because the distribution of trash is far from uniform; this applies particularly to soil. Undoubtedly the best sample unit is a whole car of cane, but the stripping of such a quantity is a formidable task. It is more common practice to resort to partial unloading, aiming as far as possible to leave a section undisturbed. A convenient residual weight is from 100 to 200 lb, 50 to 100 kg. The sample is stripped and the original weight accounted for as field trash and clean cane. In order to gain an acceptable average for the whole supply this operation should be carried out not less than twice every shift.

The determination of field trash is not an absolute measure for there is no clear line of separation between clean cane and trash, particularly at the top of the stalk. A team instructed in standard procedures and arbitrary working rules can turn out consistent results, but all reported measures of field trash have to be accepted with reservations.

Weight of Mixed Juice.

As the factory control is largely based on mixed juice, particular care must be taken to ascertain its weight correctly. It is normal to weigh the mixed juice as expressed, filtrates, lime or additives being introduced after the weighing. If any of these must be added before the weighing, the weight of added material must be determined and allowed for.

Various types of scale are available for the weighing of mixed juice (or other liquids). They are all batch weighers, mostly of the beam balance type, but the hydrostatic pressure principle is also used.

The original juice weighers were essentially steelyard scales and were manually operated. A tank of juice was isolated, weighed,

emptied and tared, and the cycle repeated. Many of these have been automated; the filling is halted at a predetermined gross weight, and the emptying is stopped at a set minimum weight or the tank is allowed to drain to an expected constant tare.

Another popular scale uses the principle of the unstable bent arm balance. When the scale tank fills to a critical weight, the beam tips. This action cuts off the input of juice and opens the outlet. When the weight reaches a critical minimum the beam tips back to the original position and the control valves revert to the filling condition.

The two types of scale just mentioned attempt to fill to a constant weight, empty to a constant weight and so discharge a constant weight each cycle. Their main limitation is that, at the moment when the inlet and discharge streams, respectively, are interrupted, some juice is in transit and, to the extent that this may vary, so may the actual weight discharged. Because of this limitation, wind and temperature effects and mechanical defects, constant weight scales do not discharge a weight that can be accepted as constant over long periods.

An independent tank scale is to be regarded as a necessary companion to constant weight scales. The tank scale should be so located that one or more batches from the process scales may be diverted into it for check weighing. Thus the actual discharge per tip is determined. This should be checked every shift.

Another batch weigher of later years is sounder in principle. It is an automatic steelyard type which fills the tank approximately to a selected weight and then sets the counter weight to balance the scale. This is the zero position. The tank is discharged down approximately to a selected weight and the counter weight then moves to the new position of balance. The integral of the movement of the counter weight is a true measure of the weight discharged.

This is a particularly good type of juice weigher, so good that, when it is operating properly it needs no check scale; but like all machines it can develop leaks and mechanical faults. The performance as to weighing and the integration of totals can be checked readily with the aid of built-in check weights. Leaky valves and froth overflows create incorrect results, but faults of this nature should be observed and corrected promptly in any case. The provision of a check scale in this instance may be classified as desirable but not essential.

The principle of weighing by pneumatic balancing of the hydrostatic pressure at the base of a tank of juice is accepted as sound and reliable enough. Successful application of the theory demands the following:

1. The juice tank must be of uniform cross sectional area, top to bottom. This is a matter of construction.

2. The cross section must remain uniform on a time basis. This is mostly a matter of cleanliness.
3. The juice must be of uniform density within each batch. Errors due to this cause are generally random and therefore negligible in the total of many batches.

Juice weighers, other than those which integrate totals, have to be provided with batch counters. Mechanical counters are strangely unreliable, and the provision of two does not help, for which of two different results is correct? Probably the best counter is a pressure differential recorder responding to the level of juice in the weigh tank because it produces documentary evidence of its functioning. A mechanical counter can serve as a stand-by.

The determination of the weight of mixed juice from its volume and density has been recognised in the past, with some misgivings. It is doubtful whether the practice survives, and if it does, it should be abandoned.

Weight of Clarified Juice:

If the mixed juice cannot be weighed the clarified juice may be weighed instead and the notes on weighing mixed juice will apply. Otherwise clarified juice is not normally weighed, its weight being determined from the weight and the proportion of pol that it contains.

Weight of Bagasse.

Bagasse has now been successfully weighed using several types of equipment. One of the most convenient devices is the continuous belt type of weigher, using beam balance or load cell detection of the weight. The bagasse is transported on a rubber belt. Because of the low loading per foot, the suspended section of the conveyor has to be relatively long, and the relatively high proportion of the weight of the belt in the total makes it necessary to keep the tare correction under close supervision.

A convenient device for calibration is a wheeled trolley of known weight placed on the belt over the suspended section, and tethered by a string parallel to the belt. In operation the weigher rapidly acquires a mantle of bagacillo, and the calibration at the end of the week will differ from that at the beginning when the unit was clean. It is necessary to judge by observation how long the bagacillo takes to build up to the angle of repose, and proportion the calibration factors accordingly.

A dumping type of batch weigher has been used successfully. Naturally it needs generous doors, but they should not be snap acting, because the sudden plunge of a great wad of bagasse into a bin creates a back rush of air that picks up clouds of bagacillo which can create a serious nuisance.

A radiation type of bagasse weigher has been used in Hawaii for some years. It operates by virtue of the fact that the absorption of gamma radiation by bagasse is reasonably constant per unit weight over the range of compositions encountered in practice. Hence the integral of the absorption by a stream of bagasse is proportional to the weight passing the source of radiation. Apparently the accuracy of the system is acceptable.

Weight of Imbibition Water.

The weight of imbibition water has traditionally been regarded as an item for precise determination, despite the rather obvious weakness of the mass balance method of deriving the weight of bagasse.

It is time to face up to the fact that such a proportion of the imbibition water will be lost by evaporation that it is not worth determining the initial quantity with great accuracy.

Scales, where they exist, will continue to provide a reliable weight, but it is not worth installing scales for the purpose. A good water meter will provide acceptable results, subject to the qualification that any water meter must be checked regularly.

Weight of Filter Cake.

When filter cake is removed promptly from a factory without any significant change in composition, it may be convenient to weigh it in loading hoppers or transport vehicles. When this is not practicable, or when the composition is promptly altered, e.g. by re-pulping with water, it is necessary to resort to sampling methods.

As filtration takes place usually on a well defined area of flat or gently curved surface the general principle is to weigh samples from a convenient fixed area and expand the average weight to the total effective area for the period of time involved. In the case of filter presses the unit for weighing may be the contents of one frame or a section isolated by a cutting frame. In the case of rotary filters, the cake from one frame may be transferred to a metal tray and weighed; the number of frames on the filter and the number of revolutions for the period together provide the amplification factor.

Unfortunately there are other situations not so easily dealt with. There are rotary filters not filtering on frames, and there are other types of pressure or vacuum filter in which the "area" of cake is variable. Where no convenient or reliable unit of area or plant is available, it is necessary to assess the total as well as possible by whatever means can be devised. Re-pulped muds may be weighed and analysed as such, for the real interest is more in the loss of pol than in the weight of filter cake. The demand on accuracy is not high, but it is still much better to measure the mud loss than to estimate it.

Weight of Final Molasses.

Subject to allowances for slow filling and emptying, liquid weighing scales in general are suitable for the weighing of final molasses; those which depend on a constant tare draining must be excepted.

In some cases the final molasses is shipped promptly in tank cars and, by weighing the quantity so shipped, a reliable record of production may be provided.

When the final molasses is stored in bulk tanks at the factory it is usually possible to arrange for it to be passed through a weigher, or, failing that, through measuring tanks of known capacity. A satisfactory measure of average density may be obtained by regularly weighing samples of known volume. For further details refer to Weights of materials in Process.-

Final molasses is commonly diluted to a standard density for various reasons. It matters little: whether the quantity is measured before or after dilution, but it goes without saying that, for chemical control purposes, the material measured and the material analysed must be the same.

Weight of Sugar.

In the past, the commercial sugar manufactured was almost invariably stored and transported in sacks. Where this practice continues, and shipment is prompt, the best measure of the weight of sugar is provided by weighing the loads of sugar leaving the factory.

If too much has to be held in store, the weight of sugar made in a period has to be calculated from the number of sacks filled and the average net weight per sack. In such a case the procedure is:

- (1) by automatic, or controlled manual filling, to keep the weight of sugar per sack as nearly uniform as possible, and
- (2) to check weigh a sufficient number of sacks on a platform scale reserved for the purpose. The number of sacks to be checked depends upon the sack-to-sack variation, and is a matter for local determination.

In all cases where sacks are used, the weight of the sacks must be deducted from the gross weight. Data for the correction are best provided by weighing a batch of 50 to 100 sacks from current stocks.

Most commercial sugar nowadays is stored and transported in bulk. Between the sugar conditioning equipment and the storage or loading facilities room can be made for a sugar weigher. Batch types and continuous types of scale are both in use and have both been found satisfactory.

Because of the high pol content of commercial sugar, its weight is of more significance in the pol balance than that of any of the other materials. However, the general tendency for storage to be minimized at factories and concentrated at communal warehouses, where first class weighing facilities are installed, means that an authentic check on factory weights is usually available at short delay. When no such check is forthcoming the weighing of commercial sugar at the factory must be treated with the importance that it merits.

The Weights of Materials in Process.

When a pol or Brix balance is to be taken out for a period during the currency of a season, it is necessary to take account of the quantities of pol or Brix in stocks at the beginning and the end of the period. Subsider juice, mud, syrup and a range of massecuites and molasses may be involved.

The materials are seldom, if ever, weighed, the weight of each being usually calculated from the volume and the nominal or actually measured density.

Massecuites and molasses of the lower grade are liable to carry occluded gases and a layer of foam, and proper estimations of volume and density are not made easily. The pneumericator, which measures the static pressure at the base of a tank, is not affected by bubbles in the liquid, but, except in special cases, the pneumericator can be used only in tanks of uniform horizontal sectional area.

When it is necessary to measure volume and density in a foamy material the following expedients may be adopted. To find the depth of liquid, take a tube large enough for the depth gauge to pass through it, and fit, at one end, a plug which may be dislodged from inside. Immerse the sealed end until it is below the foam layer and dislodge the plug. The liquid rises to the equivalent true liquid level and this may be measured with the depth gauge.

For the measurement of density there should be available a vessel of optional shape, normally conical, with a short cylindrical neck. A capacity of about 250 ml is suitable. By previous tests with water filling the vessel to a flat free surface at various temperatures, the temperature—volume relationships of the vessel should be determined. The vessel is then filled with the test liquid at the temperature of the bulk, the temperature being determined and recorded. The weight of the contents and the volume of the vessel at the recorded temperature yield the density at that temperature.

If the material is heavily aerated, its density will vary from top to bottom in a non-linear gradient. The density at middle depth is not average. The best policy is then *to* use a long tube to find the free level, deeply immersed so that it fills from near the bottom. Then take the density sample from the tube or from near the bottom of the tank.

The derivation of density from the Brix of a diluted solution of the product is not reliable and will be seriously in error when the product is aerated.

Miscellaneous Materials.

In factories of unusual layout, or for special purposes it may be necessary to know the weight of materials not normally involved in the chemical control. Only general rules can be laid down. The accuracy sought has to be related to the importance of the quantity measured, and, in general, weighing directly is more reliable than determining weight inferentially.

Condenser Water.

An attempt is made by some to account separately for sugar lost into the condenser water by entrainment from the last effect and the pans. Whilst the methods of analysis of condenser water for sugar are adequate for the detection of sugar and an indication of concentration, they are not to be depended upon for much accuracy. If the proportion of sugar in the water is determined with satisfaction, it becomes a question how much water is to be allowed for. The quantity can be calculated from evaporation and temperature data with great satisfaction to the mathematician and no accuracy to speak of, and it is better to ask the engineer how much injection water he is pumping. The loss of sugar by entrainment must be constantly watched and kept to a minimum, but it is not a figure for separate recording in the pol balance.

CHAPTER VI

Methods of Sampling

It is a truism worth repeating that no analytical result can be any more reliable than the sample from which it was derived. It should be the constant care of the laboratory staff to ensure that the samples presented for analysis were taken properly.

When a process is continuous the sampling of a material involved should ideally be continuous at a rate proportional to the rate of flow of the material. Practical considerations often enforce a departure from this principle because the rate of flow of the sample stream would necessarily be too low for reliability and regulation. Flow splitting is unreliable and limited in scope when the liquid to be sampled contains suspended solids. In such a case it is better in practice to establish a reliable continuous flow of the liquid as a sub-sample, and then to regulate the quantity taken for the actual sample by diverting the stream into the sample receiver at intervals in accordance with a regular time cycle.

When the material to be sampled does not lend itself to flow splitting at all, sampling must necessarily be by way of a series of "grab" or "snap" samples. Batch operations naturally call for batch samples.

In so far as sampling can be made automatic, it should be, but every automatic sampler requires regular inspection, maintenance and cleaning. Manual sampling is as reliable as the personnel who carry it out. It is used extensively in practice and is quite acceptable so long as the sampling personnel are reminded regularly that their work matters.

There is a natural tendency to regard the process materials of the sugar factory as very variable *in* composition and the truth of this is easily demonstrated. It is therefore important to appreciate that the variations are mostly frequent, random and of limited amplitude, and that, on a broader scale, the process materials are characterised by a high degree of uniformity of composition.

The proof of this is to be found in the incredibly small sampling ratios which are found to yield acceptable average results for the factory. A mere 30 ten-pound samples have been found to give reasonable representation of 30,000 tons of cane. That is a sample ratio of 1 in 200,000. In Queensland, a minimum of six determinations of fibre in cane, each starting from 12 stalks of cane, can be taken to provide the average fibre in cane for a week's supply of 20,000 to 30,000 tons of cane. The sampling ratio is even less than 1 in 200,000. These instances are to be regarded only as illustrations of the inherent uniformity of cane on a large scale.

Cane.

Cane has been sampled for many years for the determination of field trash and fibre content. Field trash has been dealt with in Chapter V. For the determination of fibre in cane it is desirable that the cane be sampled in the prepared state, and if this cannot be done, "core" samples of the cane are the next preference. The last resort is to stalk samples.

An old established procedure of sampling cane, by stalks, for fibre determination is as follows. At least twice, preferably three times, a shift for three shifts select at random the parcel of cane to be sampled, and grasp at random a bundle of stalks aimed to have a selected weight in the range of 20 to 30 lb, 10 to 15 kg. Remove the bundle with the minimum loss of extraneous matter and place it in a bin in a cool sheltered place. Strip any loose trash and dirt into the bin. At the end of the 24-hour period lay out the accumulated stalks side by side in order of length, and by selection at regular numerical intervals choose 12 stalks to be the first sub-sample. Let them lie and discard the rest.

Mentally divide each stalk into six equal lengths; let the portions be numbered 1 to 6 from the top. With a cane knife cut out, from stalks 1 to 6 in order, portions 1, 3, 5, 2, 4, 6 respectively. From stalks 7 to 12, take portions 2, 4, 6, 1, 3, 5 respectively. This yields 12 pieces, equivalent to two whole stalks. If the original number of stalks in the sample was n , this sub-sample represents two n 'ths of the original.

From the sample bin take the trash and fibrous matter, chop it roughly, weigh it, and weigh out from it a representative portion weighing 2 n 'ths of the total. This is part of the final sub-sample.

Also, from the bin, take the dirt and any other granular matter and from it weigh out a representative 2 n 'ths. This is also part of the final sub-sample.

Combine the 12 billets, the trash aliquot and the dirt aliquot, comminute the lot and analyse for fibre. Repeat daily.

In many factories there is a point, between the last preparatory device and the first crushing unit, at which it is possible to sample cane in the prepared state. It is not to be presumed that the ability to grab a wad of prepared cane means that proper sampling can be achieved—but if it is established by testing that representative samples of prepared cane are procurable, then the way is open for the proper determination of not only fibre in cane, but also pol, Brix, and any other component of interest.

Conditions are very favourable when the final preparation is by a hammer mill shredder, set low, and discharging into an elevator feeding the first mill. When the shredder is above the mill hopper it is necessary to beware of classification of the particles in the hopper, and there may be a trickle of juice down the feed plate. The possibilities must be studied closely and critically.

If prepared cane can be sampled properly, the determination of fibre content may be made on a 24-hour composite of samples taken every one or two hours. Samples may be composited at the site because the deterioration during the 24 hours, though it makes its presence smelt, does not affect the fibre content significantly.

When prepared cane is sampled for full analysis, more elaborate precautions are necessary. A suggested programme is as follows. Take one sample, or composite two or more samples of prepared cane every hour. Sub-sample to 10-12 lb, 5-6 kg, and process the sub-sample in a Waddell hammer mill or like device. Mix and sub-sample to a standard quantity approximately 0.5 kg. Place the material in a plastic bag, add 1 ml of toluene, seal and store in a refrigerator at 0 — 5 C. Accumulate 8 samples, mix them and analyse the mixture. For the purposes of daily and weekly averages, weight the shift analyses in accordance with the shift tonnages of cane milled.

Mill Juices.

Where first expressed juice is used as a basis for cane payment, details of sampling are specified by law or agreement and are of no concern here. However, because of the accent on sampling beyond reproach, many ingenious and elaborate automatic samplers for first expressed juice are operating in factories, and most of them could be adopted for other juices if desired.

Mill juices other than the first expressed juice are of no interest except for milling studies and the routine sampling and analysis of these juices is a waste of time. During a test period they can be sampled intensively by the familiar "tin on a stick" sampler.

Mixed Juice.

As the weight of mixed juice is important, so is its composition, and so, therefore, is it necessary to ensure that the mixed juice is properly sampled. Actually, as far as Brix and pol are concerned, mixed juice is easy to sample, but proper representation of suspended matter is not so easily achieved.

The recommended procedure is, by repeated checking against a reliable manual sample, to locate a point in the main mixed juice line from which a representative sample may be drawn off. Here mount a branch pipe of a size which will not be blocked by solid particles, and join this pipe to a "time splitter" sampler, that is, any device which directs the stream into the sample can for part of the time, elsewhere for the rest of the time, according to a regular cycle.

To minimize evaporation, the sample can should be filled through a small hole in the lid. If the mixed juice is very warm, it is better to admit it through a small side tube connected to the sample can at the bottom, and to provide the sample can with a float, covering most of the free surface, as well as a lid.

Samples should be collected over a period of one hour. At the end of the hour, the sample has to be mixed well and sub-sampled promptly. The sample can should be emptied, washed, steamed and drained, another can being used for the next sample. The sample lines should be steamed out every shift, the first runnings thereafter being discarded. The steam-out line must be detachable or else two stop valves must be provided, with a drain cock between them.

Sample Containers for Juice.

Various materials are suitable for the construction of sample containers, the choice depending largely upon the service conditions. Vessels which pass to and fro between the factory and the laboratory have to stand rough treatment and are best made of metal. Stainless steel is outstandingly good, but it is expensive, and vessels of stainless steel having a domestic application are liable to vanish. Copper is excellent but it must be kept clean. Enamel ware is good but needs to be handled with care. Tin plate should not be used; it is cheap and readily available, but for some unknown reason it affects the Brix of juice. Plastic ware is becoming more and more popular and it has many excellent features. Most plastic cannot be sterilised by heat, and therefore it is desirable to choose vessels of such a shape that the inside surface can be scoured. Glass, of course, is the old favourite material for laboratory ware, but it has been partly displaced by plastic for the manufacture of many commonplace items of equipment such as beakers, funnels and wash bottles.

Sample containers should be seamless, but there is no objection to well-made joints and seams. Deep inaccessible crevices are to be avoided in any case. It is customary to specify tight fitting lids, but unless a lid is literally air tight it might as well be comfortably loose.

Preserving Juice Samples.

There is no substitute for a fresh sample, and before examining preservatives it is wise to question why preservation is necessary. If preservation is necessary, the question is — for what subsequent operations is the sample being preserved? It is easier and more accurate to composite analytical results than juice samples, but this calls for more analytical work, and the room for a compromise is acknowledged.

A sample of juice may be depended upon to last about four hours at room temperature without a significant change in Brix. If a sample for Brix alone has to be preservatized, the favourite preservative is mercuric chloride. A saturated solution of the salt in alcohol is used at the rate of 0.5 ml per litre. An alternative solution is made by dissolving 150 g of mercuric chloride in hot water, adding solid potassium iodide until the precipitate first formed re-dissolves, and diluting to one litre. This solution is added to samples at 0.2 ml per litre.

The sugars in a juice sample cannot be depended upon to remain unchanged for much longer than an hour. For the purposes of pol determination, the standard procedure is to clarify the sample with basic lead acetate, and let the liquid stand over the precipitate.

These preservative treatments are to be regarded as comparatively short term expedients. For preservation of samples in general there is no substitute for cold storage. Storage at domestic refrigerator temperatures of 35 up to 40°F, 1 to 4°C, is effective for days, but if the holding period is to be a week or more, frozen storage is to be preferred. The sample container must, of course, be sealed to prevent a change of water content, and at the end of the storage period the sample should be brought to room temperature and analysed without delay. If only the solids in a sample are of interest, it may be freeze dried. The dehydrated residue will last indefinitely.

Bagasse.

Bagasse is almost invariably sampled by hand. The principles are to sample from the full depth and the full width of the blanket—not necessarily in one operation.

The favourite sampler is a sheet metal trough which is inserted briefly into the stream of bagasse to catch the full depth of the blanket. The trough may be as long as the stream is wide, or it may be so short as to catch only a fraction of the width; in such a case successive samples have to be taken in conformity with a pattern of traverse across the blanket.

A regular time cycle of sampling at intervals of the order of 30 minutes, regardless of milling conditions, should be adhered to. If the size of the individual sample exceeds 2 lb, 1 kg, it should be reduced to about that weight by rapid mixing and random selection. Successive samples are to be stored in an airtight bin in which there should be a canister containing a pad saturated with toluene or a mixture of chloroform (1 part) and strong ammonia solution (6 parts) to act as a volatile preservative. Compositing periods of four and eight hours are common and quite safe.

The procedure outlined is essentially for the sampling of final bagasse for chemical control purposes. When intermediate and final bagasse are sampled for the study of milling performance, samples should not be taken until conditions are right, and then the sampling is usually intensive for a comparatively brief period.

Composite samples of bagasse are usually emptied onto a suitable tray or slab in the factory, mixed, and sub-sampled into a smaller container for transport to the laboratory. The mixing must be thorough but speedy because bagasse loses moisture rapidly on exposure to the air.

Clarified Juice.

It is customary to specify that clarified juice be sampled continuously or frequently but there does not appear to be any **valid** reason for this. In the chemical control, as distinct from process control, clarified juice is of minor importance. A 24-hour composite of hourly snap samples is convenient for analysis. The sample container is stored in the refrigerator. This disposes of the problem of evaporation and eliminates the need for preservatives.

Filter Cake.

Whenever possible the samples of filter cake should be taken from the bulk product of the filters. A cylindrical trier may be used to extract sample cores. Often this is not possible, and then the samples must be taken from the filters. This has the weakness that the samples will tend to be representative of a class of cake rather than all the cake. This is the result of a natural human tendency to identify the "normal" with the "average".

In many cases the samples of cake taken for the determination of weight of cake will serve also to provide a composite sample for analysis. Filter cake keeps fairly well, and four-hourly composite samples may be taken for the analysis. The use of chloroform-ammonia preservative is sometimes recommended, but it is doubtful whether it penetrates most of the cake.

Syrup.

Syrup is of minor importance in chemical control and needs no intensive sampling. The Brix will be under frequent or continuous checking for process control purposes, but a 24-hour composite of hourly samples is adequate for the general analysis. Preservatives are not needed if the syrup is of normal density and the sample is kept in a cool place or a refrigerator.

Massecurites.

Massecurite is normally sampled as it flows from the pan. The sample should be taken not from the first or the last runnings, but from the stream of uniform material emerging during the main course of the discharge. Preservatives are unnecessary.

Intermediate Molasses.

The procedure for sampling intermediate grades of molasses is dictated by the purpose of the exercise. If it is desired to associate a molasses with a massecurite the molasses will be sampled usually at the fuggals. To provide figures for the regulation of sugar boiling molasses is sampled from the stock tanks.

Final Molasses.

The molasses sampled has to be the same material as weighed or measured. In a factory equipped with molasses scales, it is usually

possible to arrange a sampler which takes a fixed quantity from each batch weighed. A point to be watched is that tubes and orifices will pass more fluid per unit time as the viscosity decreases.

When the final molasses is measured in tanks a system of compositing samples, one from each batch, may be practised.

In many factories it is desired to relate the analysis of final molasses to individual strikes of massecuite or individual crystallizer. Sampling is then done at or near the fugals, one sample for each strike or crystallizer. As the batch quantity is approximately constant, the simple average of the results is true of the whole production. This procedure has the weakness that samples are usually taken when the fugals have settled down to steady processing of the batch, and certain abnormal losses due to washings and irregular operation are liable to escape sampling.

Commercial Sugar.

Commercial sugar is a difficult material to sample properly because its relatively high variability, as it flows from the plant, makes frequent spot sampling necessary—yet it is hard to protect the sample from change during the compositing period.

Early sampling is important in the interests of process control, because if the sugar departs from the specifications, it is desirable that not too much be processed before matters are put right. Subsequent handling soon reduces the range of variation within the sugar and, from the point of view of chemical control, it is better to sample sugar later in the line of flow.

A bulk receiving station, besides being the arbiter of weight, usually takes a reliable official sample and this provides the best source of the composition of the commercial sugar.

If sugar has to be sampled at the factory, there is a multitude of gadgets which will scoop, scrape or flick a few grains regularly into a sample receiver. The standard precautions are to keep the sampling device free of encrustation, to use a sample container with a small orifice, and to composite over moderate periods, not exceeding eight hours.

Manual sampling is by no means excluded. In association with bulk handling it may be convenient to take a standard measure of sugar from each box, bin or car of sugar despatched. When sugar is packed in sacks a trier may be used to sample sacks at regular numerical intervals.

Waters.

The previous editions devoted some attention to the sampling of condenser water, boiler water and waste water.

The routine sampling of condenser leg waters is practised in many mills as a precautionary measure. The sampling is normally casual until an alarming result is recorded; the offending unit is then placed under close supervision.

Condensates returned for boiler feed water may become charged with sugar products, but this happens almost invariably through a mechanical failure, and a routine programme of sampling and analysis is unlikely to detect the failure before it is obvious in the factory. Conductivity detectors fitted with alarms have a chance of rendering some useful service.

Compositing Samples.

In the general operation of a system of sampling and analysis, there has to be a compromise between short term compositing, with frequent analyses, and long term compositing with few analyses. At one end of the scale, the samples are in the best condition but the demand on laboratory service is high; at the other end of the scale the sample may be deteriorating, and the demand on the accuracy of the individual analysis may be excessive.

There has to be a compromise dependent upon circumstances and facilities. However, in general, it may be accepted that, if the sample material may be composited safely for eight hours, the frequency of analysis, yielding 15 to 20 results for the week, is entirely satisfactory for chemical control purposes.

There is room, in compositing samples, for each successive aliquot to be scaled in size to the quantity of material which it represents. In most cases this is an unnecessary elaboration, and by far the commonest practice is to assume uniformity of throughput and take a fixed aliquot from each successive sub-sample. Major departures from continuity of operations can be allowed for by arbitrary adjustment of the relevant aliquots.

Methods of Analysis

The selection and specification of methods of analysis of sugar products are the acknowledged functions of ICUMSA, and where an ICUMSA standard method exists, it is to be regarded as the proper one. However ICUMSA methods do not cover the whole field, and even within their scope there is room for consideration of alternatives according to the purpose of the analysis.

The discussion of methods of analysis necessarily involves two considerations — the material to be analysed and the component to be measured. It would be convenient if either one of these would serve as the basis of an order of presentation, but, in some cases, the material is the dominant item; in other cases, the component.

This chapter will therefore deal firstly with the more common constituents to be measured, then discuss the analysis of particular materials, and conclude with some miscellaneous items.

Brix.

The term Brix, unqualified, is used to refer to Brix determined by a densimetric method, that is, by spindle, Westphal balance or pycnometer. The order of precision and accuracy of these devices rises from first to last, but the spindle is by far the most commonly used and its precision is of acceptable order.

Brix spindles are usually certified accurate to $\pm 0.1^\circ$ and will measure the sucrose content of a pure solution with that accuracy. The basis of calibration is the concentration of sucrose *in vacuo*, a standard temperature is specified, and the surface tension of pure sucrose solution is allowed for.

In practice most solutions tested are impure and Brix then is not a true measure of total dissolved solids except by coincidence. Furthermore the Brix spindle may no longer yield a correct measure of Brix, for two reasons:

1. Most industrial sugar solutions contain suspended matter which is not Brix but affects the spindle as if it were Brix.
2. The surface tension of juices in general is below that of pure sucrose solution. The reading is thereby inflated.

Despite these acknowledged limitations the Brix spindle is used as the routine instruments in most sugar countries.

For many years there have been two standard temperatures for the calibration of Brix spindles, 20°C and 27.5°C . The former is an international standard temperature for many purposes; the

latter is a practical recognition of the fact that the cane sugar industry belongs to the tropics and the mean temperature there is nearer to 27.5 than to 20°C.

Saccharimeters are invariably calibrated at 20°C, and this has influenced many in favour of the same reference temperatures for the Brix spindle. The introduction of air conditioning into many sugar laboratories has made it possible to work at or near 20°C and this temperature will probably supersede 27.5°C in the long run.

The alternative principle for the determination of Brix is the measure of refractive index by refractometer. This basis of determination is steadily gaining favour. The technical advantages of the refractometer over the Brix spindle are:

- (1) In general the change in refractive index caused by the substitution of soluble impurities for sucrose is less, in terms of Brix, than the corresponding change in density, also in terms of Brix. More simply, refractometer Brix in general gives a better measure of total dissolved solids than densimetric Brix.
- (2) Though not insensitive to solids in suspension, the refractometer is much less affected thereby than the Brix spindle.
- (3) The refractometer is not affected by surface tension.

The chief disadvantage of the familiar Abbe type of refractometer is that its limit of precision is about 0.0002 in refractive index, equivalent to 0.15 in Brix. However this is no longer of any real importance. The precision refractometer designed by Bausch and Lomb specially for the Hawaiian sugar industry more than satisfies the requirements as to range and accuracy. It is outstanding in its class, but expensive. If there has to be a compromise financially, there are now several adequate refractometers in a more modest price category.

The Brix of a juice, whether densimetric or refractometric, is determined directly, but syrup and pan products are customarily diluted for the purpose. The influence of suspended matter is not usually of any consequence but, for the sake of the refractometer, samples should be at least finely screened. Filtration or centrifuging is better.

Previous editions of this book devoted some space to the question of degree of dilution. It is well known that the Brix of pan products, determined by spindle on diluted material and calculated back to the undiluted basis, increases with increasing dilution. The Brix of final molasses, based on 1 + 5 dilution may be 3° higher than the Brix based on 1 + 1 dilution. These dilutions are about the limits in practice.

Noel Deerr concluded that, for the purposes of mutually consistent purity figures, Brix should be determined at about that concentration of impurities typical of undiluted juice. No matter how technically correct the conclusion may be, it runs to absurdity in practice, for the dilution required for final molasses would be of the order of 1 + 40. It has to be recalled that the error of the final result is the product of the error of the actual determination and the dilution factor. Hence, if the Brix actually measured is accurate to 0.1°, the final result at 1 + 1 dilution is accurate to 0.2°, but at 1 + 5 the error may be 0.6°. High ratios of dilution are excluded for this reason, and there is a strong tendency to adopt the lowest practical dilution consistent with a convenient factor—that is, 1 + 1.

Higher dilution ratios have their advocates and it is not hard to raise an argument on the subject. However it is not worth argument these days, for the simple solution is to abandon the Brix spindle in favour of the refractometer. Brix (undiluted) determined by refractometer at successive dilutions is not quite constant, it varies unpredictably, but it has no consistently increasing bias, and at no rational dilution is the error prohibitive. Of course the refractometric Brix still does not equal the dry substance, but the disparity is about half that associated with densimetric Brix.

At the other end of the Brix scale are the low figures characteristic of cane extracts, bagasse extracts and imbibition fluids. Formerly it was necessary to have recourse to the pycnometer and as the measurement of Brix by this device is tedious and exacting, these determinations were avoided if possible. Modern refractometers yield reliable results so easily that the measurement of low Brixes is no longer a problem, but suspended solids must be removed from the sample.

Dry Substance.

Dry substance and moisture are complementary quantities and are invariably determined concurrently by a quantitative drying.

Many of the normal constituents of sugar factory materials are subject to decomposition at elevated temperatures. When this phenomenon is of low significance, drying is carried out at 100°C or higher; if decomposition has to be kept to a minimum, the product is dried at about 60°C under vacuum.

Some products, being viscous fluids, release moisture very reluctantly. In such cases, to assist evaporation, the area of exposed surface is artificially increased by the addition of quartz sand or by absorbing the product into filter paper.

Dry Substance in Cane.—Knowledge of the dry substance and moisture contents of cane is desirable for the direct determination of pol and Brix in cane and the indirect determination of fibre in cane.

The cane must first be comminuted by a fibrator, hammer mill, cutter grinder or like machine. Evaporation and loss of juice must be avoided, so totally enclosed machines are to be preferred.

A sample of not less than 1 kg is dried in a Spencer type oven at about 105°C. The operation is simple and results are highly reproducible.

Dry Substance in Bagasse.—A convenient and desirable standard weight of bagasse for drying is 500 g and the drying canisters and the Spencer oven should be proportioned accordingly.

Final bagasse, having a low content of dissolved solids may be dried safely at up to 130°C, but for bagasses richer in sugar it is desirable to be more conservative, and 110°C is a good temperature for drying bagasses in general.

Dry Substance in Filter Cake.—Weigh not less than 5 g of the cake into a tared dish or tray and dry at 100-105°C. Rotary filter cake, being rich in fibre, dries readily. If the fibre content of the product is low, evaporate most of the water below 100°C and then raise the temperature to normal.

Dry Substance in Sugars.—The drying of sugars is normally carried out in aluminium or glass dishes, about 2 inches in diameter, 1 inch high, with lids. A catch weight of sugar about 5 g is transferred to the tared dish, sealed without delay, and weighed.

There are many standard conditions for drying. ICUMSA specifies a temperature of 60°C, a pressure not exceeding 50 mm of mercury, an air bleed, and a final loss in weight not exceeding 1 mg per hour.

Other standards are 3 hours at 103-105°C, 5 hours at 98-99°C and 20 minutes in a Spencer oven at 110°C. This list is not exhaustive; it merely indicates that there is a tendency to prefer, for routine use, a rapid method that yields acceptable results. Most sugars leaving the factory are subject to analysis by a trade laboratory, and one obvious expedient is to adopt the same procedure as the trade laboratory.

Dry Substance in Juice, Syrup, Massecuite and Molasses.—Juice is taken undiluted, but for the drying of massecuite and molasses it is convenient to take the diluted product prepared for other purposes, or to make up a 1 — 1 dilution. Syrup may be handled either way.

The classical methods—the sand method and Josse's filter paper method—are set out in many books of reference. If syrup, molasses or massecuite is weighed undiluted it may be diluted cautiously later to promote its distribution over the absorbent.

Drying is best performed at low temperature under vacuum as for sugars, but this takes some 16 hours. The common practice is

to achieve results by drying at 103-105°C for a set period which is of the order of four hours.

Tate and Lyle have designed a special vacuum oven and specified a standard procedure for this application. The extender is aluminium powder. The Tate and Lyle method is probably the best available, but it is most likely to be used only as a standard of reference for establishing the constants of a rapid method. For general purposes the filter paper method is the most attractive.

Pol.

Pol is the equivalent sucrose content of a material, as measured by a saccharimeter.

A saccharimeter is calibrated at a standard temperature, 20°C, for a specific weight of sucrose, the normal weight. The normal weight of sucrose dissolved in water, made up to 100 ml at 20°C and tested in a 200 mm tube at 20°C yields a saccharimeter reading of 100°.

There is no need to recount the problems of earlier years, confusion over the c.c. and the ml, the Herzfeld Schonrock scale, the Ventzke scale—suffice it to say that there are still several standard scales in use, but for each of them there is an accepted normal weight. The normal weight for the International Sugar Scale is 26.000 g and this value has been adopted in this book when a normal weight is expressed in figures. Those who work on a different standard will substitute accordingly.

Like Brix, pol may be regarded as a weight of notional matter, and as such, it is not affected by temperature. However, as in the case of Brix, the result of a determination is influenced by temperature. In the case of Brix, the thermal relationships of sucrose solutions are known, and the behaviour of impurities is so nearly the same as to make it reasonable to adopt sucrose temperature corrections for solutions in general. Relative to the saccharimeter, impurities in general behave nothing like sucrose, and therefore pol cannot be corrected for temperature unless either the proportion of impurities is small, or the impurities are known and can be compensated for individually.

Probably because the normal solution is made up at 20°C and the quartz wedge saccharimeter is calibrated for that temperature, it is customary to regard 20°C as the temperature at which pol should be determined. This is certainly desirable for testing sugars, and air conditioning has made it possible in many laboratories to test all samples at close to 20°C. If operations cannot be conducted at 20°C the next precaution is to see that the solution for testing is made up or tested for Brix, as the case may be, at the same temperature as the polarization is determined

There is a strange inconsistency between the bases of Brix and pol. Brix is a concentration, weight to weight, in vacuo, as mentioned

earlier. By the specification of the normal weight, pol is a concentration, weight to weight, in air with brass weights.

Consider a solution of pure sucrose in water, having a Brix of 20. A normal weight (26 g) of this solution will have a true weight of 26.026 g (with moderate accuracy) and will therefore contain 5.2052 g of sucrose, in vacuo. The weight of sucrose which, dissolved in 100 ml of solution, gives a reading of 20 is 5.2034 g in vacuo or 5.2000 g in air with brass weights. Hence the normal solution under consideration, containing 5.2052 resp. 5.2018 g of sucrose would give a reading of 20.007, and this, by definition is its pol. This also is the concentration of a 20 Brix solution of sucrose in water, measured in air with brass weights.

When samples have densities of the same order as that of sucrose the buoyancy effects cancel out and the pol coincides with the concentration based on true weights. Steps have been taken recently to express the normal weight as a true weight of sucrose. The whole matter is distinctly academic and the defects of old established practice are negligible.

There is a further point in relation to pol that deserves mention. The standard formula relating polariscope reading to pol is—

$$\text{Pol} = \frac{\text{Reading} \times \text{Normal Weight}}{\text{Wt. of 100 ml in air with brass weights}}$$

For practical use this is often rendered into the form:

$$\text{Pol} = \frac{\text{Reading} \times \text{Normal Weight}}{99.718 \times \text{s.g. } 20/20^{\circ}\text{C of solution.}}$$

The 99.718 is the weight in grams of 100 ml of water, weighed in air with brass weights at 20°C. For the purposes of a formula which is general as to temperature, the s.g. should be s.g. $t/20^{\circ}\text{C}$, where t is the temperature of the solution as tested. Since specific gravity figures are available for only a few particular temperatures, it is expedient to make use of the observed Brix to derive the specific gravity. If temperature effects on the Brix spindle itself are ignored (the error being tolerable) every Brix reading represents a definite density at any temperature; moreover, the reading of a 20°C spindle in a solution at $t^{\circ}\text{C}$, when applied in a table relating Brix to s.g. 20/20°C, will yield the s.g. $t/20^{\circ}\text{C}$ of the solution.

Hence, the second formula is general as to temperature if the term "s.g. 20/20°C" is interpreted as "the result obtained by applying the observed Brix of the solution in a table relating Brix to s.g. 20/20°C".

It is opportune to mention that, if the Brix is determined by refractometer, the observed refractometer Brix serves just as well as the observed spindle Brix for the purpose of determination of pol. However it must be remembered that a spindle assumes the temperature of the test solution but the test solution assumes the

temperature of a refractometer. It may be necessary to adjust a refractometer Brix reading to the temperature of the solution as tested in the polariscope.

Clarification for Pol Determination.- - By far the most commonly used reagent for the clarification of sugar products in general is basic lead acetate also called sub-acetate of lead. The dry reagent is familiarly known as Home's dry lead after the specific formulation prepared by Dr. Home. However, the several contemporary specifications of basic lead acetate do not agree with Dr. Home's formula, and it seems that the name for general use should be merely "dry lead".

The A.C.S. specification of dry lead is as follows:

Water	; not more than 1.5 per cent.
Total lead (as PbO)	; not less than 76 per cent.
Basic lead (as PbO)	; not less than 33 per cent.
Fineness	; all to pass 35 mesh Tyler not less than 70 per cent to pass 115 mesh Tyler.

For clarification without dilution dry lead stands almost alone. The only competitor is dry neutral lead acetate which has the advantage of not interfering appreciably with the rotation of fructose; however it is so inferior as a clarifying agent that it is not used unless the effect of dry lead on fructose must be avoided.

Dry lead made into a standard solution in water becomes the clarifying agent called wet lead. In many cases, when there is no ban on dilution, wet lead is used in preference to dry lead, as it is easier to control the quantity added and the clarifying effect is generally better.

For cane juices and products of like composition which may be polarized undiluted, dry lead is the preferred clarifying agent. The pol subsequently determined is essentially the pol of the liquid component. When pol is determined by diluting one or more normal weights of sample to 100 ml wet lead is preferred. The pol is essentially the pol of the sample material including any insoluble matter which it may contain, and is subject to an error caused by the fact that any insoluble matter and precipitate occupy part of the 100 ml final volume so the volume of solution is less than 100 ml. A special case is the Schmitz method wherein 100 ml of a juice are taken, clarified with wet lead, and diluted to 110 ml. A factor of 1.1 is applied to the polariscope reading, the result being taken as the reading of an undiluted juice. The pol determined is that of the liquid phase, subject to the error caused by insoluble matter and precipitate.

Cane juice which has suffered deterioration may not respond satisfactorily to the clarifying effect of dry lead. The addition of up to four drops of strong ammonia solution may make the necessary difference. If not, Herles' reagent should be tried. Herles' reagent is a mixture of two solutions:

A. Dissolve 100 g sodium hydroxide in 2 litres of water.

B. Dissolve 1 kg of lead nitrate in 2 litres of water.

Check that on mixing equal volumes of the two, the reaction of the mixture is acidic. If alkaline, dilute the caustic soda solution as required to yield an acidic mixture.

Take either two normal weights or a measured 50 ml of the juice in a 100 ml flask, add 5 ml of solution B, 5 ml of solution A, dilute to near 100 ml, shake and make up to the mark. If 5 ml of each solution are insufficient, more of each may be used up to a practical limit of 15 ml. If two normal weights were taken, the pol is half the polariscope reading; if 50 ml were taken, double the reading and calculate the pol as for an undiluted juice.

Herles' reagent appears to be the best clarifying agent available. If it fails there is little hope of achieving dependable results.

Pol Determination.

Cane.—See later under the Analysis of Cane.

Bagasse.—See later under the Analysis of Bagasse.

Juices.—Cool, if necessary, to room temperature or 20°C, clarify with dry lead, filter and polarize. Determine the observed Brix, and using this and the polariscope reading, derive the pol from Schmitz's Table. The standard addition of dry lead is 1 g per 100 ml for raw juice; less is required for diluted or clarified juices.

Filter Cake.—In view of the error created by the insoluble portion of filter cake it is customary to achieve a rough compensation by taking 25 g as the normal weight. Take 50 g of the cake, add water and mix to a paste with a stirring rod. Wash the mixture into a 200 ml flask and add wet lead as required for clarification (about 10 ml). Make up to 200 ml, mix, filter and polarize in a 400 mm tube. The pol is half the polariscope reading.

Pan Products.—Syrup and all grades of massecuite and molasses are tested for pol by normal weight methods. The strength of solution made up ranges from normal, in the case of syrup, to as low as one-fifth normal for some specimens of final molasses. A solution of one normal weight in 300 ml is popular for intermediate products.

If dry lead is used for clarification, the quantity required ranges from 1 g per normal weight for syrup up to 8 g per normal weight for final molasses. Wet lead is easier to use and is generally more effective. The quantity ranges from 2 ml to about 15 ml.

After clarification the solution is made up to volume, mixed, filtered and polarized. The polariscope reading

must be corrected for the normality of the solution. Insoluble matter and the lead precipitate cause errors which are ignored. There is also some error due to the effect of dry lead on the rotation of fructose, an error which naturally becomes more serious as the proportion of fructose rises.

An attempt is usually made to eliminate this error, in the case of final molasses. After the filtration, 50 ml of the filtrate are taken in a 50-55 ml flask, 2 ml of acetic acid (1 vol. 96 per cent acid + 4 vol. water) are added, and the volume made up to 55 ml with water. This solution is mixed and polarized. The polariscope reading must be corrected for the dilution as well as the normality. The acidification restores the rotation of the fructose.

It has to be acknowledged that the pol of final molasses is of very little significance except for internal comparisons, and there seems to be very doubtful virtue in going to some pains to restore the rotation of fructose. There would be more merit in suppressing the rotation of the glucose, if this were feasible.

Professor J. A. Lopez Hernandez has published claims that the rotations of the reducing sugars are suppressed by the addition of a solution of sodium borate. It is true that the rotations of the reducing sugars are greatly lessened, but the quantity of borate required to render the reducing sugars ineffective causes a significant reduction in the rotation of the sucrose.

It seems that no standard addition of sodium borate can be depended upon to yield a pol consistently of the same order as sucrose, but the principle of proportioning the borate solution approximately to the concentration of reducing sugars has not yet been properly studied and may yield gratifying results.

The accepted formula for the correction of a sugar pol for temperature is—

$$p_{20} = p_t - 0.0003 S(t - 20) - 0.004 R (t - 20)$$

Where

p_{20} = pol corrected to 20°C

P_t = pol at $t^\circ\text{C}$

S — per cent sucrose in sample

R = per cent reducing sugars in sample (assumed to be invert sugar)

t = temperature of solution.

For general purposes S is taken to be 100 and R is usually neglected, so the more familiar formula is—

$$P_{20} = P_t + 0.03 (t - 20)$$

The two temperature correction formulae stated above are specifically for *quartz wedge compensated saccharimeters*, and embody corrections for both the sugar and the instrument. A polarimeter-saccharimeter has no temperature co-efficient of its own, and when such an instrument is used, the value of the S term should be halved, that is, 0.0003 becomes 0.00015. For corrections from below 20°C, use 0.0002.

In previous editions of this book it was argued that, in the absence of air conditioning in the laboratory, pol , in general, would be determined at the prevailing temperature and must be recorded as determined; therefore the same should apply to sugars. This is quite appropriate for magma and remelt sugars, but shipment sugars normally are checked by a trade laboratory where the pol is determined at or corrected to 20 C, and this is the procedure obviously to be followed.

Sugar.—Mainly for commercial reasons, the determination of the pol of raw sugar has become highly specialised, and the equipment and method are specified in minute detail. The full statement occupies about eight pages of print, and only a bare outline will be given here.

Mix the sample with a minimum of exposure to the air and rapidly weigh out the normal weight within 0.002 g. Wash with about 60 ml of water into a 100 ml flask graduated correctly within 0.02 ml. Dissolve the sugar and add 1 ml of wet lead. Mix, add water to just below the neck and swirl the flask to promote mixing. Stand aside for 10 minutes to stabilise temperature. Add water to bring the volume exactly to the graduation mark. Mix and filter, taking precautions against evaporation. Polarize in a 200 mm tube accurate to 0.03 mm. Take five readings of the polariscope, to 0.05, and average the reading to 0.01. Open the polariscope tube and take the temperature of the contents.

Whether the temperature be 20°C or otherwise it is customary to arrange as well as possible that the making up of the solution and the testing in the polarimeter are conducted at one temperature, and the temperature correction formulae quoted are based on this premise. If the temperature of making the solution, t_m , differs from the temperature of reading the rotation, t_r , compensation may be achieved by adding to the result the correction $0.03 (t_r - t_m)$.

Sucrose.

Regrettably, the determination of sucrose is still a lengthy and exacting operation. By common consent the pol of bagasse

and filter cake is accepted as a sufficiently accurate measure of sucrose. Syrup, massecuites and molasses are analysed primarily for factory control purposes, and whether this control is based on pol or sucrose is a matter for local decision.

The real advantage of sucrose over pol is the more accurate accounting for sucrose as a material in process, and the key materials are mixed juice, shipment sugar and final molasses.

Sucrose is traditionally determined by a process of double polarization. There is no point in reiterating the history of the development of methods from the original one of Clerget through the modifications by Herzfeld and later by Jackson and Gillis.

It is accepted nowadays that the best measure of sucrose is provided by a double polarization method using invertase to effect the inversion, but the standard method for routine use is the Jackson and Gillis Method No. IV. This method is set out in numerous manuals and text books and need not to re-stated here.

The method of inversion specified is that according to Walker. The sugar solution is heated to 65°C, acidified and allowed to stand in the ambient air for about 30 minutes. Under cool conditions the inversion of some solutions may not then be complete. For this reason many operators prefer the U.S. Customs method of inversion. The acid is added to the cold solution which is then heated to 60°C, agitated at that temperature for three minutes and cooled rapidly to room temperature.

The detailed theory of the measurement of sucrose by double polarization is fully set out in other publications. Suffice it to say that a normal solution of pure sucrose, if inverted at 20°C, without contamination, would undergo a change of polarization representing 131.7 degrees of saccharimeter scale. In practice this characteristic is influenced by two factors—the additive associated with the inversion, and the concentration of dissolved solids in the solution. There is also a temperature co-efficient of change of polarization.

Hence the "Clerget divisor" has to take account of the method of inversion, the concentration of dissolved solids, and the temperature. The divisor is always expressed in terms of a normal solution polarized at half-normal strength.

Currently accepted values of the Clerget divisor are as follow:

Inversion with invertase—

Divisor = $132.1 - 0.0833 (13 - m) - 0.53 (t - 20)$

Inversion with acid, Walker method—

Divisor = $132.63 - 0.0794 (13 - m) - 0.53 (t - 20)$

Inversion with acid, U.S. Customs method—

Divisor = $132.56 - 0.0794 (13 - m) - 0.53 (t - 20)$

where m = grams of dissolved solids per 100 ml of invert solution as polarized

t = temperature of readings in °C.

None of the figures is indisputably correct, chiefly because the "constants" in reality vary in response to many secondary influences.

The temperature co-efficient 0.53 is due for review. It is based on temperature co-efficients of 0.50 for invert sugar and 0.03 for sucrose. Although these co-efficients are of opposite senses, that of sucrose being laevo-going, and that of invert sugar dextro-going, they are additive because above 20°C they both reduce the change of rotation on inversion.

The change of rotation of 0.03 for sucrose is acceptable, so long as it is recalled that this includes the temperature effect on a quartz wedge saccharimeter.

The change of rotation of 0.50 for invert sugar is probably based on a very old temperature co-efficient of change of rotation of fructose, that is, 0.006757. On inversion, a normal weight of sucrose will yield 13.685 g of fructose which will contribute a rotation of — 74.3 polariscope degrees, and, on the above temperature co-efficient, this rotation will change by 0.50 per °C.

More recent values of the temperature co-efficient of change of rotation of fructose indicate that it varies with temperature and concentration, but is consistently less than 0.006757. For the standard conditions, the co-efficient appears to be about 0.0063, in which case the change in reading due to the effect of temperature on the fructose is 0.47 per °C. The rotation of the glucose present is not affected by temperature, and the resultant overall correction is $0.47 + 0.03 - 0.50$ for °C. It would appear that the original Clerget correction of 0.5 (t — 20) is more nearly correct than the present 0.53 (t — 20). The difference is of little consequence.

Mixed juice is usually tested for sucrose according to the undiluted juice procedure, as follows. Take 150-200 ml of the juice, clarify with dry lead and filter. Take 50 ml for direct polarization and another 50 ml for inversion and polarization as specified in Jackson and Gillis method No. IV. Calculate the change in rotation due to inversion and multiply by 2 to represent undiluted juice. By table or calculation, use the Brix of the juice to derive a Clerget divisor, correct the divisor for temperature and divide it into the change in rotation, multiplying by 100 at the same time. Apply the result as a polariscope reading in Schmitz's table in conjunction with the observed Brix and interpret the resultant pol as sucrose.

When the commercial sugar manufactured is of high pol, 98 degrees or higher, the pol is commonly accepted as a sufficiently accurate measure of sucrose. If the sucrose content of raw sugar is to be determined, the standard method may be followed precisely.

When it comes to final molasses, the scope of the double polarization method is tested to the limit. Interfering impurities are

present at maximum concentration, sucrose is at low concentration, and the solutions must be polarized at low normality. The multiplying factor on the change in polariscope reading is frequently eight, and any error is magnified accordingly.

For these reasons it is common practice to determine the sucrose content of molasses by measuring the concentration of reducing sugars before and after inversion.

The Lane and Eynon method of determination of reducing sugars requires a test solution containing about 0.1 to 0.3 g reducing sugars per 100 ml. Most samples of final molasses can be tested at a strength of 1 g per 100 ml, the solution being titrated directly as made up. For the invert test, portion of the original solution has to be diluted to bring the concentration of total sugars into the working range. The inversion itself normally involves a dilution of 1 volume to 2 volumes but further dilution either before or after inversion will probably be necessary, as the overall dilution required is likely to be 1 volume to 3 or 4 volumes.

Inversion may be carried out the same as for double polarization, but after the inversion the solution must be neutralized before the final volume is established.

The change in reducing sugars per cent original material is a measure of the reducing sugars created by the inversion of sucrose. The result must be multiplied by 0.95 to provide a measure of sucrose as such.

The determination of sucrose by double measure of reducing sugars is limited to materials in which the original concentration of reducing sugars is high relative to sucrose. As the ratio of sucrose to reducing sugars rises, the dilution factor associated with the inversion becomes excessive and the final result is too susceptible to error.

Reducing Sugars.

Of the numerous methods of determination of reducing sugars, the method of Lane and Eynon is easily the most popular for general purposes.

For the proper determination of reducing sugars the sample material should be clarified with neutral lead acetate, not basic lead acetate, and excess lead and calcium should be removed by adding dry potassium oxalate or a solution containing potassium oxalate and sodium phosphate.

These precautions are well founded, but in regular practice they are ignored more often than not. For the purposes of factory records the reducing sugars contents of general interest are in final molasses, raw sugar and mixed juice.

The reducing sugars content of final molasses is determined directly on a solution of molasses containing 1 to 2 g per 100 ml.

Dry sodium or potassium oxalate should be added to precipitate calcium, but the precaution is generally ignored.

Raw sugars are usually made up into a solution containing 25 g per 100 ml. Sugars polarizing over 98 degrees will generally yield a solution containing less than 0.1 g reducing sugars per 100 ml, and it is then necessary to add standard invert solution in quantity sufficient to raise the content of reducing sugars by, say, 0.1 g per 100 ml. The standard invert solution contains 1 g of reducing sugars per 100 ml, and therefore 10 ml of this, added to the sugar solution to be made up to 100 ml, will provide the specified addition of reducing sugars. The addition must, of course, be allowed for in the calculation of results.

Mixed juices vary widely in their contents of reducing sugars and may need to be tested at strengths in the range from zero dilution to 20 g in 100 ml. Clarification is commonly dispensed with, the solution being titrated as prepared.

The Lane and Eynon method is set out fully in many works of reference. Various slight modifications, and devices to assist in the detection of the end-point of the titration have been proposed — but the original method and the methylene blue indicator still find favour with the majority.

When a more elaborate method is sought, the LufT-Schoorl method is often selected. It is one of the many variants of a general method in which reducing sugars react with portion of the copper as cupric oxide in a standard solution. The excess cupric oxide liberates iodine from an excess of potassium iodide. The free iodine is titrated with a standard solution of sodium thiosulphate. The method responds equally to glucose and fructose, and it has a wide range — zero to 0.24 g of reducing sugar in 100 ml.

For very low concentrations of reducing sugars, de Whalley's method is probably the most attractive.

Ash.

It is possible to indulge in almost unlimited speculation as to the real significance of the term ash. This is inconclusive and ash has to be defined in terms of its derivation.

When any commercial sugar product is incinerated, there remains a residual which, in the vernacular, is ash. Ash, as determined quantitatively in this way, is known as carbonated ash. The procedure is unsatisfactory in that the test is sensitive to the conditions of incineration, there is an uncertain measure of chemical reduction, and there is a loss of metal ions in volatile salts.

For these reasons it is customary to perform the incineration in the presence of an excess of sulphuric acid at the start. The ash thus determined is known as sulphated ash. (An attempt to have it called gravimetric ash seems to have found no support.) The

replacement of halogen and organic acid radicles by the sulphate radicle is acknowledged; sulphated ash is not a measure of something alleged to exist in the original sample — but at least the silica and the iron and the calcium and the phosphorus and the alkali metals are retained, and measured in a uniform state of combination. It is common practice, after the carbon is burned off, to add a little sulphuric acid and repeat the incineration. This not only disposes of any possible reduction of sulphates to sulphides in the first incineration, but also yields a residue much safer to handle, as the first ash is susceptible to disturbance by the slightest draught.

One of the standard procedures is to take the weighed sample in a platinum dish, evaporate to a thick syrup if liquid, add 0.5 ml of concentrated sulphuric acid, and cook to a cinder over a flame or hot plate. Incinerate at 550°C (barely visible red heat) in a gentle stream of air until the carbon is oxidised, cool, moisten the residue with drops of sulphuric acid, and incinerate at 800°C for about 15 minutes.

For many years it was customary to deduct an arbitrary 10 per cent from sulphated ash as determined and to report the reduced figure. This has no justification in technology and doubtless represented a compromise for trade purposes, specifically in relation to raw sugars. The deduction has now been abandoned, except in connection with the commercial evaluation of raw sugars in some countries.

It has long been recognized that the elements and radicles which constitute ash in a product will impart conductivity to the solution of that product. As there are ash components which have virtually no conductivity, and conductors which have no ash, the relationship between conductivity and ash is neither rigid nor constant.

There have been proposals to endow conductivity with an absolute significance, but sulphated ash stands as such a familiar and tangible property of a substance that conductivity is invariably related to sulphated ash. As stated above, the relationship is by no means inflexible, but the correlation is high enough and the trends smooth enough to enable tests of conductivity to yield acceptable values of sulphated ash, subject to regular determination of the current interrelationship.

The determination of the conductivity of a sample — usually at an arbitrary low concentration — is easier and quicker than an incineration, and when conductivity is used, as it usually is, to provide an approximate measure of sulphated ash, the result should be reported as sulphated ash.

The Analysis of Cane.

Brix and Pol.—Normally cane is analysed for one or more of the components pol, Brix, fibre and water. In reference to the last

three, it is usual to assume that, as percentages, they total 100. This involves the assumption that the Brix is a true measure of the total dissolved solids, which is not so. However the assumption is tolerable, particularly when the Brix is determined by refractometer.

Water can be determined as an independent exercise, and with relatively high accuracy. Fibre can also be determined independently, but the accuracy is relatively low because of the extreme difficulty of leaching out all "soluble" solids without loss of "insoluble" matter. The words soluble and insoluble are highlighted because cane contains some material which defies classification into one category and not the other.

Brix cannot be determined independently; it is necessary to have an adequate measure of either water or fibre as a corollary. For the highest precision the measure of water content is to be preferred, but for most purposes the fibre content will serve if it happens to be available.

The modern method of analysis of cane involves intensive disintegration of a known weight of cane in a proportioned weight of water. Various devices for the purpose are described in sugar literature. They all involve one or more high speed impellers fitted with sharp blades that whirl in the mixture of cane and water contained in a suitable vessel. The design data are fairly critical, and it is not to be assumed that any sort of impeller in any old can will serve; it is a matter of copying or proving a design. The homogenizing of the liquid phase is usually completed in 15 to 40 minutes. At the longer times heating is serious and the vessel must be water cooled.

The higher the ratio of water to fibre, the easier it is to achieve extraction and the lower is the rise in temperature—but the more dilute is the extract. If the ratio of water to fibre is too low, heating is serious, and the extract is very difficult to filter out of the slurry. In South Africa a ratio of two parts of water per part of cane has been adopted, representing about 13 parts of water per part of fibre. This is to be regarded as the upper limit of concentration of fibre. In Queensland the standard for bagasses is one part of fibre to about 20 parts of water, which would mean one part of cane in three parts of water; however cane is commonly analysed at one part in four parts of water. After the disintegration a portion of the liquid extract is filtered off and tested for Brix, by refractometer or pycnometer, and also tested for pol, if desired.

The purely theoretical development of the formulae for the derivation of Brix and pol per cent cane is as follows:—

Let weight of cane $\rightarrow C$
 (added) weight of water $= W$
 Brix per unit cane $= b_c$
 Brix per unit extract $= b_e$
 fibre per unit cane $= f_c$
 (contained) water per unit cane $\rightarrow w_c$

Hygroscopic water is taken to be 0.25*f*.

After the disintegration, the amount of Brix in the extract is $C \times b_c$.

The amount of water in the extract is $W + C \times w_c - C \times 0.25 f_c$.

Hence

$$b_e = \frac{C \times b_c}{W + C(w_c - 0.25f_c) + C \times b_c}$$

$$\text{but } f_c = 1 - w_c - b_c$$

$$\text{hence } b_e = \frac{C \times b_c}{W + C(1.25w_c - 1.25b_c - 0.25)}$$

solving for b_c

$$b_c = b_e \frac{W + C(1.25w_c - 0.25)}{C(1 - 1.25b_e)}$$

This is the purely general form. Normally W is a simple multiple of C ; assume the factor is 3. Then

$$b_c = b_e \frac{2.75 + 1.25w_c}{1 - 1.25b_e}$$

Do not forget that all quantities are expressed on a unit basis.

Simplification can be achieved by the use of an approximation.

The amount of hygroscopic water in one part of cane is 0.25*f*.

Hence, in a 3 to 1 mixture, the proportion by which the weight of

extract is reduced by hygroscopic water is $\frac{4 - 1.25f_c}{4 - f_c}$. At 12 per

cent fibre in cane this factor has the value 0.992; at 16 per cent fibre

it falls to 0.990, that is 0.05 per cent change per unit of fibre. A constant

correction factor, say 0.99, may be adopted. Then—

$$b_e = \frac{C \times b_c}{W + C(w_c + b_c)} \times \frac{1}{0.99}$$

whence

$$b_c = 0.99b_e \frac{W + Cw_c}{C(1 - b_e)}$$

and, in the case where $W = 3C$

$$b_c = 0.99b_e \frac{3 + w_c}{1 - b_e}$$

Pol in cane is determined by applying the purity of the extract to the Brix in cane.

With fibre in cane as the ancillary datum, the calculations are simpler. The weight of Brix is still $C \times b^{\wedge}$. The weight of extract is $W + C(1 - 1.25f_c)$.

Hence

$$b_e = \frac{C \times b_c}{W + C(1 - 1.25f_c)}$$

whence

$$b_c = b_e \left[\frac{W}{C} + 1 - 1.25f_c \right]$$

and when

$$b_c = \frac{3C}{b_e} (4 - 1.25f_c)$$

In this case it may also be established that, if p represents pol, then—

$$p_c = p_e (4 - 1.25f_c)$$

Thus, if fibre in cane is known, pol in cane may be determined without reference to Brix. Values of the term $4 - 1.25f_c$, or the term appropriate to any other proportions adopted, may be worked out for a range of fibre contents and tabulated. The calculation of pol or Brix in cane is then very simple. Intervals of 0.5 per cent fibre are adequate, this difference representing 0.03 as pol per cent cane, (mixture 3:1, 1.6 per cent pol in cane).

Given cane to analyse, the operator has the choice of determining water or fibre. The former is easier, quicker and more accurate and will generally be preferred. In order to avoid the cumbersome calculations the Sugar Milling Research Institute of South Africa suggests the following procedure. Select a fibre at a venture, and use it and Brix of extract to find Brix in cane. From Brix and moisture in cane derive fibre in cane, if the two fibres do not agree select another fibre, and repeat until the two fibres agree within 0.5 per cent.

The wet disintegrator for the analysis of cane has already proved to be a most valuable tool. One word of warning is necessary. Careless operation and neglect of the machine almost invariably lead to low results which can be most acceptable and indicative of flattering performances. Technique and maintenance must not be allowed to flag.

Fibre.—When fibre in cane is to be determined directly a suitable sample must be comminuted finely with the aid of one of the many devices designed for the purpose. Sealed machines are to be preferred because the physical loss of juice and the loss of water by evaporation are more than might be expected. The machine should always be wetted by processing a trial batch of cane.

The finely divided cane is mixed thoroughly but rapidly and spread on a tray. Portions are pinched out at random and put into a tared bag made of linen, calico or other suitable fabric. The fabric must be close woven but not waterproof; a typical weight is 8 oz per square yard, 270 g per square metre.

The bag is firmly tied at the mouth and weighed. A typical bag, 9 in by 7 in inside seams, holds 150 to 200 g of cane comfortably. According to the Hawaiian method the bag and contents are washed free of soluble matter by an alternation of kneading in cold water followed by heavy pressing. The Queensland method steeps the bags in cold water for one hour, with four squeezings, followed by one hour in boiling water, with two squeezings. In both cases the washed fibre is dried and weighed.

The technical objection to the Queensland method—that boiling partly dissolves pentosans and pectins—is of no consequence in practice. Even in cold water cane fibre continues to lose weight. The real weakness of washing methods in general is that some components of cane, properly classed as fibre, are too fine to be retained by any practical bag. Soil, from which cane is rarely free, may be retained in high proportion or hardly at all according to its type.

Careful quantitative studies have revealed that the accuracy of determination of fibre in cane by washing is better than is generally believed, and is certainly good enough for factory control. However, low results must be expected when the cane is contaminated by soil.

The Analysis of Bagasse for Brix and Pol.

It has long been the practice to analyse bagasse by extracting the dissolved solids into a body of water. This was invariably achieved by stewing or boiling the mixture, but since the wet disintegrator was developed, it serves as well for bagasse as for cane.

Bagasses in general having much higher fibre contents than cane, more water per unit bagasse must be allowed for; the favoured proportions are 10 water to 1 bagasse. The formulae provided for cane serve equally well for bagasse, subject to adjustment for the proportions of the mixture.

Almost invariably the ancillary datum is moisture, and generally the quantity to be determined is pol. Brix may be of passing interest, or none at all.

It was mentioned in connection with the analysis of cane that hygroscopic water reduces the weight of extract by a factor about 0.99. The same factor serves for bagasses at 10 water to 1 bagasse. Hence, substituting pol for Brix, where applicable, and amending the ratio,

$$p_a = 0.99 p_e \frac{10 + w_a}{1 - b_e}$$

If the Brix of the extract is not known, it may be derived from the pol by adopting an assumed value for the purity of the extract. Since $bQ = p$ (unity basis) the formula may be re-stated as:

$$p_a = 0.99 p_e \frac{10 + w_a}{1 - \frac{p_e}{Q}}$$

Furthermore, it is convenient to proceed directly from the polarimeter reading, R , to the result. It is assumed that the normal weight is 26 g and the observation tube 400 mm Then —

$$p_a = \frac{0.129 R (10 + w_a)}{100 - \frac{0.13R}{Q}}$$

In more familiar form, with p , w and Q expressed per centum—

$$p_a = \frac{25.7 R (1,000 + w_a)}{20,000 - 26 R \times \frac{100}{Q}}$$

In the compilation of tables for routine use, the correction for hygroscopic water is usually ignored and Q is given a value about 70.

Suspended Matter (Fibre) in Mixed Juice.

It has been mentioned earlier that mixed juice contains an undissolved component which is technically fibre and belongs with fibre in the accounting for materials.

It is natural to think of filtration as the means of separating the suspended solids, and a tested procedure is as follows. Prepare a Buchner filter with a filter paper of which the dry tare is known. Prepare a weighed quantity, about 6 g, of keiselnugl or filter aid, weighed dry. Stir the mixed juice well, catch a volume of about 300 ml in a tared beaker and determine the weight of juice. Heat to about 60°C, stir in the filter aid and filter the mixture. Wash the cake free of solubles using hot water, dry the cake on the paper at 105°C and weigh. Deduct the weights of the filter aid and the paper.

It is easier to determine the weight of suspended solids by quantitative centrifuging of a known weight of the juice in tared cups. After the first spinning, for 30 minutes, pour off the supernatant juice, and redisperse the solids in a volume of water about equal to the original volume of juice. Spin for 30 minutes again, decant, dry the residue and weigh it. This method yields low results, but the error is gratifyingly stable at 0.06 per cent on juice. This difference should be applied as a plus correction to the results obtained by the centrifuge method.

CHAPTER VIII

Definitions and Interpretations

This Chapter recapitulates the terms invoked in the narrative text. In some cases the explanations may be regarded as definitions, but in others the purpose has been to draw attention to the significance of terms in the peculiar parlance of the industry, or the implications which accompany their use.

1. *Cane*. Dutch—*Riet*. French—*Canne*. Spanish—*Cana*.

The raw material delivered to the factory, including clean cane, field trash, water, etc.

If the cane is subjected to a cleaning process before milling, the cane received will be distinguished as "gross cane" which, when processed becomes "net cane". Both materials will comprise "clean cane" and other components commonly referred to as "extraneous matter" or "field trash".

2. *Field Trash*. D—*Met riet ingevoerd vuil*. F—*Paille*. Sp—*Paja*.

Leaves, tops, dead stalks, roots, soil, etc. delivered as part of the cane.

3. *Fibre*. D—*Vezelstof*. F—*Ligneux*. Sp—*Fibra*.

The dry water-insoluble matter in the cane.

Terms such as "dry" and "water-insoluble" have, of course, to be given practical interpretations. Note that the definition embraces not only fibrous matter but also any other insolubles such as soil and stones.

4. *Absolute Juice*. D—*Gemiddeld Sap*. F—*Jus Absolu*. Sp—*Jugo* or *Guarapo*, *absolute*.

All the dissolved solids in the cane plus all the water, that is, cane minus fibre.

Absolute juice is a concept. It comprises all the real juice of the cane plus any hygroscopic water. To the extent that hygroscopic water may be neglected, absolute juice may be regarded as the average juice of the cane.

5. *Undiluted Juice*. D—*Onverdund sap*. F—*Jus non-dilue*. Sp—*Jus sin diluir*.

All the juice existing as such in the cane.

In practical milling some of the undiluted juice is expressed in that condition and some is expressed or remains in the bagasse in diluted form. The juice is not uniform but conventionally the undiluted juice that has suffered dilution is regarded as having had the

same original Brix as expressed undiluted juice, that, is primary juice or first expressed juice. The "real juice" referred to in Def. 4 is formally Undiluted Juice.

6. *Undetermined Water.* D—*Restwater.* F—*Eau non determinee.* Sp—*Agua no determinada.*

Cane minus fibre minus undiluted juice.

Theoretically the undetermined water is the hygroscopic water but the practice of attributing to all the undiluted juice the Brix of an expressed portion thereof causes the quantity to be underestimated. Hence the undetermined water as measured exceeds the hygroscopic water by an uncertain amount.

7. *First Expressed Juice.* D—*Eerst uitgeperst sap.* F—*Jus de premiere pression.* Sp—*Primer jugo extraido.*

The juice expressed by the first two rollers of a mill tandem.

8. *Primary Juice.* D—*Voorperssap.* F—*Jus primaire.* Sp—*Jugo primario.*

All the juice expressed undiluted.

9. *Secondary Juice.* D—*Naperssap.* F—*Jus secondaire.* Sp—*Jugo secundaria.*

The diluted juice which joins the primary juice to form mixed juice.

10. *Mixed Juice.* D—*Bruto rim sap.* F—*Jus melange.* Sp—*Jugo mezclado.*

The mixture of primary and secondary juices which enters the boiling house.

11. *Last Mill Juice.* D—*Latste molensap.* F—*Jus du dernier moulin.* Sp—*Jugo del ultimo molino.*

The juice expressed by the last mill of a tandem.

12. *Last Expressed Juice.* D—*Laatste uitgeperst molensap.* F—*Dernier jus exprime.* Sp—*Jugo final.*

The juice expressed by the last two rollers of a tandem.

13. *Residual Juice.* D—*Sap in ampas.* F—*Jus residuel.* Sp—*Jugo residual.*

The juice left in the bagasse; bagasse minus fibre.

Note that this definition categorizes residual juice as absolute residual juice. Bagasse comprises fibre, hygroscopic water and a juice which technically is entitled to be described as "dilute undiluted juice". To avoid this oxymoron it could be expedient, when the distinction matters, to use the terms absolute residual juice and true residual juice.

14. *Bagasse*. D—*Ampas*. F—*Bagasse*. Sp—*Bagazo*.

The residue of cane after crushing in one mill or a train of mills. Bagasses are named successively as first mill bagasse, second mill bagasse and so on to last mill bagasse or final bagasse or simply bagasse.

15. *Imbition*. D—*Imbititie*. F—*Imbibition*. Sp—*Imbibition*.

The process in which water or juice is applied to a bagasse to enhance the extraction of juice at the next mill. The term is also applied to the fluid used for the purpose.

16. *Maceration*. D—*Maceratie*. F—*Maceration*. Sp—*Maceration*.

A form of imbibition in which the bagasse is steeped in an excess of fluid. The term is also applied to the fluid used, and loosely as an alternative to the term imbibition.

17. *Dilution*. D—*Imbititiewater in ruwsap*. F—*Eau de dilution*. Sp—*Agua de dilution*.

The portion of imbibition water which enters the mixed juice.

18. *Extraction*. D—*Winningsquolient*. F—*Extraction*. Sp—*Extraction*.

That proportion (usually percentage) of a component of cane which is removed by milling. Familiar components in this connection are juice, Brix, pol and sucrose, and the word extraction is qualified accordingly. Extraction alone normally signifies pol extraction. The term juice extraction needs an accompanying specification of the reference juice and the basis, e.g. absolute juice, Brix basis.

19. *Clarified Juice*. D—*Dunsap*. F—*Jus clair*. Sp—*Jugo clarificado*.

The finished product of the clarification process. As it normally goes to the evaporators it is often referred to as effTet supply juice, E.S.J.

20. *Subsider Juice*. D—*Schoonsap*. (1 ste or 2 de) F—*Jus defeque*. (1 er or 2 nd) Sp—*Jugo decantado* and *Jugo de las cachaceras*.

When single clarification is practised the subsider juice is clarified juice. When compound clarification or double settling is practised there are primary and secondary subsiders yielding treated juices. These may be designated primary and secondary subsider juices.

21. *Filtrates*. D—*Filtersap*. F—*Jus desfiltres*. Sp—*Jugo de losfiltros*.

The liquid that has passed through the screens of the filters. May be characterized as first or second, cloudy or clear, or combined.

22. *Filter Cake*. D—*Filtervuil* F—*Tortaux desfiltres*. Sp—*Cachaza* or *Tortas de losfiltros*.

The material retained on the screens of the filters.

23. *Syrup*. D—*Verdampingsdiksap*. F—*Clairce* or *Sirop*. Sp—*Meladura*.
Concentrated juice, the product of the evaporators.
24. *Massecuite*. D—*Kooksel*. F—*Massecuite*. Sp—*Masa cocida*.
The mixture of crystals and mother liquor discharged from a vacuum pan. Massecuites are classified according to descending purity as first, second, etc., or A, B, etc.
25. *Molasses*.
The mother liquor separated from a massecuite by mechanical means. It takes its designation from the massecuite, e.g. A massecuite yields A molasses.
Intermediate molasses: D—*Afloop*. F—*Egout*. Sp—*Miel*.
Final molasses: D—*Melasse*. F—*Melasse*. Sp—*Miel final* or *Melaza*.
26. *Magma*. D—*Aangepapte suiker*. F—*Magma*. Sp—*Magma*.
A suspension of crystals in saturated liquor made by mixing sugar with water, juice, syrup, molasses, etc.
27. *Wash*. D—*Klaarsel*, *dekstroop* or *klare*. F—*Egout riche*. Sp—*Lavados de las centrifugas*.
Diluted molasses thrown out by the centrifugals during washing and collected separately.
28. *Jelly*. D—*Draadkooksel*. F—*Cuite au filet*. Sp—*Filete*.
A boiling concentrated without graining to such a degree that it will crystallize spontaneously on cooling. The time honoured test is the string proof, hence the continental terms.
29. *Sugar*. D—*Suiker*. F—*Sucree*. Sp—*Azucar*.
Sugar crystals as produced in the factory by separation from a massecuite and any subsequent treatment. Many grades are recognized and designations are local.
30. *Seed* (1) D—*Intrekmasa*. F—*Pied de cuite*. Sp—*Pie*.
Magma or fine grained massecuite used as a footing for boiling a massecuite.
(2) D—*Entgrein*. F—*Amorce de crystallization*. Sp—*Semilla*.
Powdered sugar, dry or in suspension in an inert liquid, used to provide or create a crop of crystals to initiate a massecuite.
31. *Normal Weight*. D—*Normaal gewicht*. F—*Poids normal*. Sp—*Peso normal*.
The weight of sucrose which, when dissolved in water to a volume of 100 ml at 20°C and tested at 20°C in a sugar polarimeter under the conditions specified for the instrument, gives a reading of 100 degrees of scale.

The normal weight has customarily been expressed as a weight in air with brass weights but there is a growing tendency to express the normal weight as weight *in vacuo*.

The term saccharimeter now appears to be reserved for quartz wedge compensated instruments and "sugar polarimeter" is more general.

The former specification of an observation tube 200 mm in length, though it is essential in the interpretation of specific rotation, was never a necessary part of the definition of normal weight. The "conditions specified" for the instrument must comprise a standard tube or cell and a form of illumination.

32. *Pol.* D—F—Sp—/W.

The apparent concentration w/w per cent of sucrose in a material, derived by determining the optical rotation of a sample under standard conditions and attributing that rotation to sucrose. *Pol* is used in calculations as if it were a real substance.

33. *Sucrose.* D—*Saccharose.* F—*Saccharose.* Sp—*Sacarosa.*

The chemical compound so named, also known as saccharose or cane sugar. In a quantitative connection the term "sucrose" should mean sucrose specifically, as distinct from *pol*. The term "cane sugar" is used to some extent, signifying *pol*, not sucrose.

34. *Brix.* D — F—Sp—*Brix.*

The apparent concentration w/w per cent of dissolved solids in a solution, derived by determining the density of the solution and attributing that density to sucrose in aqueous solution at the same temperature.

The term *Brix* alone implies a densimetric basis of determination. It is possible to derive *Brix* alternatively by reference to the refractive index of the solution, in which case the result is to be designated Refractometer *Brix*, D—*Refractometrische Brix.* F—*Brix refractometrique.* Sp—*Brix refractometrico.*

Brix is used in calculations as if it were a real substance, and that substance may be referred to also as Gravity Solids.

35. *Dry Substance.* D—*Ware droge stof.* F—*Matieres seches reeles.*
Sp—*Materia seca.*

The material remaining after drying the product examined.

The concept of dry substance is clear even though there may be limitations in our ability to remove from a substance only water, originally present as such, leaving other components unchanged in quantity by the operation.

In practice the drying is achieved almost invariably by evaporation of the moisture at elevated temperature under standardized conditions. The result is frequently a compromise between incom-

plete drying with negligible decomposition and complete drying with significant decomposition.

36. *Purity*. Three terms are used:

Apparent Purity. D—*Schijnbare reinheid*. F—*Purete apparente*.
Sp—*Pureza aparente*.

The percentage proportion of pol in the Brix.

Gravity Purity. D—*Saccharose reinheid*. F—*Purete Clerget*.
Sp—*Pureza sacarosa/Brix*.

The percentage proportion of sucrose in the Brix.

True Purity. D—*Ware reinheid*. F—*Purete reelle*. Sp—*Pureza real*.

The percentage proportion of sucrose in the dry substance.

The term purity alone normally signifies apparent purity.

37. *Reducing Sugars (R.S.)*. D—*Reducerende suiker*. F—*Reducteurs*.
Sp—*Azucares reductores*.

Reducing substances in cane and its products interpreted as invert sugar.

Invert sugar is the equal parts mixture of glucose or dextrose and fructose or levulose resulting from the hydrolysis of sucrose.

The term glucose should be reserved for the specific sugar of that name, and not used in reference to reducing sugars generally.

38. *Ash*. D—*As*. F—*Cendres*. Sp—*Cenizas*.

The residue remaining after incinerating the product under specified conditions.

The concept of dry substance is tolerable because one can allow that there might be a means of eliminating the specific component, water, from a substance. In the case of ash, the components to be eliminated are nebulous, and the residue may not care to exist without a substitute such as oxygen. Hence ash has to be defined in terms of the method of its determination.

Many of the components of sugar products that contribute ash also act as electrolytes in solution. Ash may be determined by reference to the conductivity of a solution of the product, the two variables being related by a factor.

If that factor is based on the current typical relationship between conductivity and sulphated ash, the result should be reported merely as ash. However if an invariable factor based on some standard electrolyte is used, the result should be reported as Conductometric Ash.

APPENDIX I

Introduction.

The accepted standard system of metrology for international purposes is the metric or c.g.s. system. Its use is obligatory in many countries and optional or partially compulsory in most others. Of the alternative systems the American and the British, which in most respects are identical, have the greatest significance for the sugar industry. Numerous other systems of weights and measures are in use throughout the world but they operate mainly for local usage and are restricted to fundamental units or simple derivatives thereof. Perhaps the most commonly encountered in the parlance of the sugar industry are the units of Spanish origin.

It is fortunate that the sugar technologist, in converting units from one system to another, is rarely interested in preserving the highest degree of accuracy. If this is attempted it is necessary to recognise that there are slight differences of opinion as to some of the fundamental figures, and many of the relationships normally regarded as constant actually vary slightly over different ranges of temperature or other influential factors.

In the Tables and notes which follow, the significant figures rarely exceed four, which is more than sufficient to accord with the general standard of technical calculations in the sugar industry. It behoves any person seeking a high degree of accuracy to resort to more specialised publications where the conditions applying to some of the relationships are precisely stated.

The Tables have been restricted to American, British and Metric units. Conversion figures have been applied for some other units known to be in regular use. In regard to the latter it should be noted that a unit may differ in magnitude from country to country though the name remain unchanged.

Note on the Units of Volume

The units of volume might reasonably be expected to be based on the units of length, and in the metric system such units are exemplified in the cubic metre, cubic centimetre and others of analogous form. However for the major part of the current century, units of volume based on mass have not only been recognized but accepted as standards. In the metric system the familiar ones are the litre and the millilitre.

The originators of the metric system of weights and measures attempted to make the mass units numerically compatible with volume units by electing to make the kilogramme equal to the mass of one cubic decimetre of water at the temperature of its maximum density (4°C). With the best accuracy then available, this mass was determined and reproduced in a mass of metal which was designated the standard kilogramme.

Subsequent experience with masses, volumes and densities revealed small discrepancies, indicating that the original correlation was slightly in error. The volume of 1 kg of water at 4°C was demonstrated to measure 1.000027 dm³. In order to preserve numerical equality, this volume was designated one litre, and a new series of volume units was created. The litre was officially defined and adopted as standard for volumetric work in 1901.

The decision was slow to register for, at least 20 years later, volumetric glassware was still being calibrated in cm³. However the cm³ was eventually superseded by the ml, and for the past generation volume, and derived quantities such as density, have been expressed in terms of the litre. In 1950 the factor for conversion of litres to dm³ was amended to 1.000028.

In 1964 the 12th General Conference of Weights and Measures resolved to revert to the purely linear basis of expression of volumes, so the cubic units once again became standards. Regrettably the litre was redefined to equal the cubic decimetre. This means that the term "litre" may now represent either of two volumes, and for precision it is necessary to invoke the officially unrecognized terms "old" litre and "new" litre. It would be better to reserve the term litre for the volume which it originally represented and to use the cubic terms for the truly linear based volumes.

Once again, the response to the change is very slow. Volumetric glassware is still being calibrated in (old) millilitres, and many chemists are not aware that there has been any alteration in the standards.

For the most part the difference between the old ml and the cm^3 , a difference of 0.0028 per cent, is of no significance. Theoretically it alters the specification of the normal solution (International scale) from 26,000 g in 100 ml to 25,999 g in 100 cm^3 —but who can or need take account of this fine distinction when associated tolerances are substantially higher. The only section of sugar technology affected by the change is that which involves densities. A density of 1.00000 g per ml will become 0.99972 g per cm^3 . Density tables based on the linear units are not readily available yet, but when they do appear they will doubtless add confusion to an already complex subject.

Linear Measure Equivalents.

km	cm	in	ft	Yard	Mile
1	10 ⁵	39,370	3,280.83	1,093.61	0.62137
10 ⁻⁵	1	0.3937	0.032808	0.010936	0.62 × 10 ⁻⁵
2.54 × 10 ⁻⁵	2.54	1	0.0833	0.02778	0.158 × 10 ⁻⁴
3.048 × 10 ⁻⁴	30.48	12	1	0.3333	0.1894 × 10 ⁻³
9.144 × 10 ⁻⁴	91.44	36	3	1	0.5682 × 10 ⁻³
1.6093	—	—	5280	1760	1

1 Cuban vara = 0.848 metres = 33.385 inches

1 Spanish vara = 0.836 m. = 32.91 inches

1 Spanish pulgada = 2.322 cm. = 0.9141 inches

Surface and Area Equivalents.

m ²	in ²	ft ²	yd ²	Acre	Hectare
1	1,550	10.76	1.196	0.0002471	0.0001
0.0006452	1	0.006944	0.0007716	—	—
0.0929	144	1	0.1111	—	—
0.8361	1,296	9	1	0.0002066	—
4,047	—	—	4,840	1	0.4047
10,000	—	—	11,960	2.471	1

The are is an area of 100 sq. m. The multiple, Hectare = 100 ares is in more common use. Some other measures of area are—

Cuba—			
1 caballeria	∴ 1.42 ha	∴ 33.162 acre	
1 cuarteta	∴ 0.8388 ha	∴ 2.072 acre	
1 roza	∴ 0.7191 ha	∴ 1.177 acre	
Puerto Rico—			
1 cuerda	∴ 0.3930 ha	∴ 0.971 acre	
Argentine—			
1 cuadra	∴ about 1.6 ha	∴ about 4 acre	
Brazil—			
1 alquirc	∴ 2.42 ha	∴ 5.98 acre	
Egypt—			
1 feddan	∴ 0.42 ha	∴ 1.038 acre	
Java—			
1 bouw	∴ 0.716 ha	∴ 1.77 acre	
Mauritius—			
1 arpent	∴ 0.422 ha	∴ 1.04 acre	
South Africa—			
1 morgen	∴ 0.86 ha	∴ 2.12 acre	

Mass Equivalents.

kg	Ounce avoir.	lb avoir.	Tons		
			Long	Short	Metric
1	35.27	2.205	0.0009842	0.001102	0.001
0.02835	1	0.0625	0.0000279	0.00003125	0.00002835
0.4536	16	1	0.0004464	0.0005	0.0004536
1,016	35,840	2,240	1	1.12	1.016
907.2	32,000	2,000	0.8929	1	0.9072
1,000	35,274	2,205	0.9842	1.102	1

The arroba is frequently quoted as a measure of weight, though the actual weight of the arroba varies from country to country. The Cuban arroba has been standardized accurately and may be taken as equal to 25.353 lb avoirdupois = 11.5 kg. Except in Brazil and Colombia these quoted weights may be accepted for the arroba with only slight error. The arrobas of Colombia and Brazil are heavier, weighing 27.5 lb (12.5 kg) and 32.4 lb (14.7 kg) respectively. A quintal is a weight of 100 pounds (local system) or 4 arrobas. The term quintal may also be applied to 100 lb avoirdupois, and no great error will be incurred by rating the quintal generally at 100 lb avoirdupois, or one-twentieth of a short ton. A weight of 100 lb may also be termed a "short hundredweight". The normal hundredweight is of 112 lb avoirdupois. The metric quintal is of 100 kg (220.5 lb avoirdupois).

Whereas the long ton is generally used as the "ton" in British countries, American usage of the term "ton" generally signifies the short ton. The metric ton lies intermediate between the two but may be considered equal to the long ton for approximate calculations. The short Spanish tonelada is of 2000 Spanish pounds = 2028 lb avoirdupois. The long Spanish tonelada = 2240 lb Spanish = 2272 lb avoirdupois.

Some other weight units are—

Egypt—			
1 cantar	=	99 lb	= 45 kg
Formosa—			
1 picul	=	133.3 lb	= 60.5 kg
India—			
1 Maund	=	82.3 lb	= 37.3 kg
Java—			
1 picul	=	136 lb	= 61.8 kg
Philippines—			
1 picul	=	139.4 lb	= 63.2 kg

Volume and Capacity Equivalents.

in ³	ft ³	Imp. gal	U.S. gal	Litre	m ³
1	0.0005787	0.00360	0.00433	0.01639	1.639×10^{-3}
1,728	1	6.225	7.481	28.32	0.02832
277.42	0.1605	1	1.2	4.546	4.546×10^{-3}
231	0.1337	0.833	1	3.785	3.785×10^{-3}
61.03	0.03531	0.22	0.2642	1	1×10^{-3}

One must be constantly on guard against confusion between the two "gallon" units of the English-speaking peoples. Fortunately the ratio relating the two is simple—10 : 12 so that they are readily interconvertible. The problem is solved when volumes are specified in cubic ft. In the metric system, for larger volumes, the Hectolitre = 100 litres is commonly used.

Density Equivalents.

g/ml	lb/ft ³	lb/Imp. gal
1	62.43	10.02
0.01602	1	0.1604

Pressure Equivalents.

lb/in ²	Columns of mercury at 0° C.		Columns of water at 10° C.		kg/cm ²	Atmosphere
	mm	in	in	ft		
1	51.715	2.036	27.70	2.309	0.07031	0.06804
19.34	1,000	39.37	535.7	44.64	1.3596	1.3158
0.4912	25.4	1	13.61	1.134	0.03453	0.03342
0.0361	1.867	0.0735	1	0.0833	0.00254	0.00245
0.4332	22.4	0.8819	12	1	0.03045	0.02947
14.22	735.56	28.96	394.96	32.84	1	0.9678
14.696	760.00	29.92	407.23	33.94	1.0332	1

Heat, Energy and Work Equivalents.

Joules	ft lb	kWh	Hp-h	cal	Btu
1	0.7376	0.2773×10^{-6}	0.3725×10^{-6}	0.2390	0.0009478
1.356	1	0.3766×10^{-6}	0.505×10^{-6}	0.3241	0.001285
3.6×10^6	2.655×10^6	1	1.341	860,565	3,412.8
2.6845×10^6	2.7375×10^6	0.7455	1	641,615	2,545
4.184	3.086	0.1162×10^{-3}	0.1558×10^{-3}	1	0.00397
1,055	778.2	0.000293	0.000393	252	1

Heat Flow Equivalents.

cal/s cm ²	cal/h cm ²	Btu/h ft ²
1	3,600	13,263
.0002778	1	3.684
.0000754	0.2714	1

$$1 \text{ cal/cm}^2 = 10 \text{ kcal/m}^2$$

Conversions of Some Common Unit English—Metric Systems

Length—

		Factors
inch	$\times 2.54 \rightarrow$	$\leftarrow 0.3937 \times \text{cm}^*$
foot	$\times 0.3048$	$3.281 \times \text{m}$
yard	$\times 0.9144$	$1.0936 \times \text{m}$
mile	$\times 1.6093$	$0.6214 \times \text{km}$

- * To convert a dimension in inches to centimetres multiply by 2.54.
To convert a dimension in centimetres to inches multiply by 0.3937.

Approximate Equivalents for Mill Sizes

in	mm	in	mm
10	254	48	1220
28	710	54	1370
30	760	60	1520
32	810	66	1675
34	860	72	1830
36	915	78	1980
38	965	84	2130

Area—

in ²	$\times 6.452 \rightarrow$	$\leftarrow 0.155 \times \text{cm}^2$
ft ²	$\times 0.0929$	$10.76 \times \text{m}^2$
yd ²	$\times 0.8361$	$1.196 \times \text{m}^2$
acre	$\times 0.4047$	$2.471 \times \text{ha}$
mile ²	$\times 2.59$	$0.386 \times \text{km}^2$
10 ft ² per short ton = approx. 1 m ² per metric ton.		

Volume—

in ³	x	16.39	→	<-0.061	x	cm ³
ft ³	x	28.32		0.0353	x	litre
Imp. gal	x	4.546		0.22	x	litre
U.S. gal	x	3.785		0.264	x	litre
10 ft ³ per short ton	---	approx. 3.1 hl				per metric ton
1 Imp. gal/ft ²	=	49		1/m ²		
1 U.S. gal/ft ²	=	41		1/m ²		

Weight—

oz (avoir.)	x	28.35	→	<-0.0353	x	g
lb (avoir.)	x	0.4536		2.205	x	kg
short ton	x	0.9072		1.102	x	metric ton
long ton	x	1.016		0.9842	x	metric ton

Pressure—

lb/in ²	x	0.0703		14.22	x	kg/cm ²
1 kg/cm ²	—	approx. 1 atmosphere				
1000 lb/in ²	—	approx. 70 kg/cm ²		= 68 atmosphere		
10 short tons per ft	—	approx. 3 metric tons per dm				

Heat—

Btu	x	0.252	→	<—	3.97	x	kcal
Btu/ft ²	x	2.71		0.369	x	kcal/m ²	
Btu/ft ² =F _x		4.88		0.205	x	kcal/m ² /°C	
Btu/lb	x	0.555		1.8	x	kcal/kg	

Power—

1 h.p. (abs.)	=	550 ft lb/s	=	approx. 746 watts		
1 CV	=	75	kgm/s	= 735.5 watts		
h.p.	X	1.014	→	<—0.986	x	CV

Condensed Temperature Conversion Table
Equivalents

°C	°F	°C	°F
0	32	110	230
10	50	120	248
20	68	130	266
30	86	140	284
40	104	150	302
50	122	200	392
60	140	250	482
70	158	300	572
80	176	350	662
90	194	400	752
100	212		

Interpolations

°C ..	1	2	3	4	5	6	7	8	9	10
°F ..	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	18

°F ..	1	2	3	4	5	6	7	8	9
°C ..	0.6	1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0
°F ..	10	11	12	13	14	15	16	17	18
°C ..	5.6	6.1	6.7	7.2	7.8	8.3	8.9	9.4	10