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Delete fourth line completely and substitute — "or second class land under natural conditions and it had been found necessary."

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# RECOVERY OF RUM VAT YEAST AT USINE STE. MADELEINE, TRINIDAD.

G. SWEYN SKINNER, Chief Chemist & Supt. Manufacture,
Gray's Inn Central Factory.

(Mr. G. T. Macdonald in the chair)

In presenting this paper I would like to emphasize that the recovery of Rum Vat Yeast at Ste. Madeleine factory, Trinidad, is still in the experimental stage and the apparatus used is necessarily of a make-shift nature. Efficient separation of the yeast and the use of drum driers are under consideration pending the results of feeding trials and of improvements in fermenting and distillery technique generally.

The value of the yeast from the fermenting vats at Ste. Madeleine as a material of high protein and vitamin content had been realised for some considerable time, but no serious attempt had been made to recover the yeast until 1944.

During that year sludge was collected and thickened in a 30" centrifugal using filter cloth as a liner in place of the usual copper mesh used for sugar. The yeast was washed fairly free from acid in the centrifugal and dried on wooden trays in the sun. This dried yeast was ground in the laboratory, using the soil sample mill, and stored in 100-lb. sugar bags using waxed paper liners.

The yeast so obtained was generally pale in colour and had quite a pleasant odour. After six months' storage it showed only small traces of mildew and had, apparently, lost none of its value as a foodstuff.

About this time the Trinidad Government became interested in this yeast as a material of high protein and vitamin content to be used in enrichening locally made poultry and pig foods. A series of tests with poultry were started, but unfortunately, they had to be abandoned. Investigations were however continued by the local Government and Imperial College staffs. As a result, a paper on Rum Vat Yeast in general was presented at the Annual Technological Conference in Barbados in 1944.

The Government Farm in Trinidad have undertaken a further series of extensive tests with poultry and are being supplied with 200—300 lbs. of yeast monthly by Ste. Madeleine.

The recovery procedure had been altered somewhat for the 1945 season. The drainage holes in the 30" centrifugal basket were sealed up and three flat rings welded at equal intervals inside.

These rings are cut from 1/8" M.S. plate and are 3" wide, they were put in to prevent the machine from oscillating when being fed with thin watery sludge.

The procedure adopted at the time of my leaving was as follows:—

Heavy sludge from the vat bottoms is placed in a 45-gallon drum diluted with from two to three times its volume of water and kept stirred. The drum is situated above the basket and provided with a ½" feed pipe. Approximately 30 gallons of heavy sludge are used for each charge and the drum is filled twice, using 15 gallons of sludge each time.

As soon as the machine is up to speed the feed valve is opened and the diluted yeast run in by gravity. The optimum rate of feeding was found by trial. The compartments 1, 2, 3, & 4 counting from below are filled in turn, the liquid finally overflowing from the top of the basket. This liquid is caught by the monitor casing in the ordinary way and runs to waste through the molasses outlet.

When heavy yeast starts to overflow the feed is stopped and the yeast allowed to compact against the wall of the basket. Before stopping, a further addition of the dilute sludge is made to ensure that the basket is properly full. If the feeding has been properly regulated this is of course unnecessary. The yeast is then extracted by hand using small wooden palettes. It is now in a stiff putty-like condition. It is broken up into small pieces and placed on wooden trays in the sun to dry.

## METHODS OF SPEEDING UP DISTILLERY OPERATIONS

M. B. FLORO. B.Sc.. Chief Chemist, West Indies Sugar Co., Ltd:, Frome:

(Mr. H. B. Springer in the Chair).

Broadly speaking the capacity of a Distillery in terms of Gallons Proof Rum output per 24 hours will depend on:—

1. Design of Distillery — that is relationship between Fermenting, Distilling and Rum Storage Capacities.
2. Types and Design of Equipment.
3. Types of Rum produced.

It is possible in building a new distillery to make a very close study of the above factors and incorporate all the desirable features which will ensure the attainment of maximum capacity and efficiency during operation.

In the cases of distilleries that are already in existence, and which the abnormal war conditions found ill prepared to cope with:

(a) unprecedented demand for Rum and Alcohol,
(b) inability to obtain new and replacement equipment, and
(c) constantly rising fuel and labour costs,

the main problem for the last five crops has been to find ways and means of increasing distillery productive capacity by minor additions and alterations in equipment, and slight modifications in operating technique. The improvements in distillery performance which can be accomplished along such lines will be surprising to many.

It is the aim of this paper to indicate the general direction on which particular care and attention can be focused to help speed up distillery operations. While the points which will be presented may already be familiar to the members of this Association, nevertheless, they are of enough importance to be again aired, even if only for the purpose of reminding us not to overlook the "little things" in quest for higher capacities and efficiencies in the present distilleries. It may also be true that conditions will vary in different distilleries, but it will be found that the possible sources of improvements listed below will be generally applicable to all existing distilleries.

A. **Maintenance of Equipment:**— It is rather surprising how much improvement can be done by the judicious expenditure of money for repairs and general maintenance of distillery equipment during the non-operating period. In some cases, possible sources of hold-ups may even be anticipated and remedied on the spot. It is in this particular direction that those who control the purse-strings of the Industry can be penny-wise and pound-foolish. To a very great extent, the economics of a distillery's operations are closely bound with what portion of its total output is produced during the sugar cropping period. This is understandable, since in practically all cases the distillery depends on the factory for steam and power. Breakdowns and hold-ups therefore, which could have been avoided by proper off-season maintenance, become very costly in prolonging off-season operations. To be able to keep production at minimum speed, equipment must be in tip-top shape.

B. **Maintenance of Quality of Raw Material:**— By raw material, I do not particularly refer to the molasses, but to the quality of the fermented liquor for distillation. One of the greatest helps in maintaining production, is to be able to process wash with practically constant alcohol content in the case of distilleries producing the heavier bodied rum type. The question naturally arises as to what the optimum content of the dead wash should be in terms of alcohol or rum. I make the distinction, alcohol or rum, as the latter should not only be considered as alcohol, but in combination with the volatile acids and other secondary constituents, which sets rum apart from dilute alcohol. There has been agitation lately, on the basis of Arroyo's claims and results obtained in Puerto Rico, to aim as high as 8%—10% by volume of alcohol in wash. In my experience this is only attainable by processing with pure



cultures. Here in Jamaica under present distillery conditions, an equivalent rum content of 6% alcohol by volume in the wash, will be a good target to aim at. The average generally attained is about 5% — 5.50%. To keep a reasonably constant alcohol or rum content in wash however, is not as easy as it appears. It involves very close control in the fermentation house in the following lines:—

(1) keeping a good alcohol or rum producing yeast strain;
(2) knowledge of the quality of the molasses or other materials for keeping constant concentration of sugar in the wash;
(3) knowledge of chemical reactions favourable for efficient fermentation;
(4) cleanliness around the fermenting house.

C. **Maintenance of Distillation Speed and Efficiency:**— Under this heading, phases of the distilling end which may be studied are:—

(1) Area and disposition of heating surfaces of the still in relation to volume capacity, and loading level. In the last report issued by the Sugar Technologist of the S.M.A., his survey shows that the sq. ft. of heating surface varies a good deal in stills of the same volume capacity. The average at Frome is 80 sq. ft. for a 1,500-Gallon Still with average working cycle of 4 hours. One point, however, which is adhered to is to install the heating surfaces with an eye to easier access for cleaning, by allowing enough room between the still bottom and sides, and the heating coils. It may be pointed out that a high H.S./ capacity ratio will only help in speeding the first step in the distilling cycle — that is bringing the wash to boil.

(2) **Raising the Temperature of the incoming Wash:** This has already been elaborated upon in previous papers presented to this body.

(3) **Pre-heating High Wine & Low Wine Charges in the Retorts:** Results obtained at Frome showed that a saving of about 8% in distilling time cycle may be affected at this point. Temperatures carried are 140°F in High Wine Retort and 160°F in Low Wine Retort.

(4) **Provision for Adequate Steam Supply:** The lack of sufficient steam supply to take care of the fluctuating demands during the distillation cycle, is probably responsible for a good deal of the variation observed in a comparison between performances of pot stills of identical designs.

An analysis of the steam consumption during the different stages of distillation will show that the maximum demand occurs during the heating to boiling stage, and that the rate of consumption then is always twice, or more, the average rate for the cycle. Thus, adequate steam supply means not only adequate supply for the average requirement, but also a reserve for the peak requirement.

(5) **Cleaning of Heating Surfaces:** Scale, if allowed to accumulate on the heating coils can cut down the speed of distillation by as much as 50%. If heating coils are installed too close to the side or the bottom of the still, it will invariably result in scale accumulating, either on the underside, or on side next to still wall. This naturally cuts down effective heating surface by a high percentage. We have found boiling with alkali, followed by acid every 6 weeks in combination with weekly brushing, quite effective. In the case of column stills, boiling with caustic soda every 3 weeks will be found very beneficial.

(6) **Cleaning Inside the Goosenecks:** This is probably one of the most neglected phases of still maintenance work. It should be

noted that the deposit of sludge by splashing is practically unavoidable, and will vary according to the proportion of suspended solids in the wash, and the regulation of steam pressures during distillation. The presence of sludge deposits inside the goosenecks and vapour pipe leading to the low wine retort, has a throttling effect on the vapour line with resulting increase in vapour velocity. The Sugar Technologist has asked me to refer to the effects of still design on time cycle, with particular emphasis on still top, taper piece and goosenecks. My personal opinion is that very little if any improvement can be made on the design as supplied by the makers, and if it is found necessary to build a part locally, the original dimensions and shapes should be adhered to. The only alteration which can be suggested is to have the goosenecks and still top in flanged sections to make those parts more accessible for cleaning and repairs. More than likely the absence of correlation between still design and time cycles noted by the Technologist, is due to the varying stages of internal cleanliness of the goosenecks. It should be of interest to find how many distilleries include dismantling of still tops and goosenecks as part of routine crop and out of crop maintenance.

(7) **Provision for Sufficient Vapour Outlet Space in Retort Injection Pipes.** Either too small or too big a space should be avoided. The ideal condition is to provide a space equivalent to the theoretical volume of vapour coming through. This however, will be influenced by the size of the charge and the design of the retorts themselves. We have found it very helpful, once the right size of space has been determined, to keep a constant volume of charge for every distillation.

(8) **Insulation of Still Bodies and Retorts:** Aside from the saving in steam consumption per proof gallon rum produced, insulation of the exposed areas of still bodies and retorts may account for a saving in the time cycle of as much as 10% depending on still locations and prevailing outside temperature.

D. **Maintenance of Proper Process Control:—**

Since the organization of the J.A.S.T., strong recommendations have been made to the distillery owners with regard to the establishment of proper chemical control in every Island distillery. There is no necessity, therefore to enlarge further on this subject. It should be very gratifying to every member of this body to observe the results of their efforts and to know that those responsible for distillery management now fully realize that Chemical control in rum processing is just as useful and just as inseparably bound to efficient work as in the sugar branch of the Industry.

E. **Maintenance of Efficient Supervision:—**

The importance of having an adequate number of efficient and well remunerated distillery staff cannot be over emphasized. It is said of the good old days. that when distillery book-keepers came to work on Monday, they were more or less prepared for a 6-days stay. That kind of working condition has now no place except in the memories of old-timers like myself. Present day distillers must be treated and remunerated on the same basis as in any other branch of the Sugar Industry. It is only thus that an interested and efficient organization can be built up.

Before closing it may not be out of place here to sound a note of warning that, as in the post World War 1 period, there will again be difficult times ahead, and the very existence of many of the present distilleries will depend on how economically a gallon of proof rum can be produced, or in other words, up to what state of efficiency and productivity they can be developed. It is my earnest hope that this paper will at least serve the purpose of starting the ball rolling in the direction of higher distillery performance.



## DISCUSSION.

**The Chairman** declared the subject open for discussion.

**Mr. J. G. Davies** asked if there would be any benefit in altering the ratio of heating surface of the top and bottom still coils. He enquired of the strength of the solutions used for cleaning. He quoted figures showing that there was no correlation between size of still top and gooseneck and the time cycle.

**Mr. Floro** thought that little would be gained by altering the h.s. ratio. The cleaning solution was caustic soda and trisodium phosphate in the proportion of 2:1 and at about 15° Be'. 1% hydrochloric acid could be used instead.

**Mr. Henzell** asked whether softened water used for mixing wash would help in scale prevention.

**Mr. Floro** replied that if the water was originally hard, softeners would help.

**Mr. J. G. Davies** confirmed this from his observations in Puerto Rico.

**Mr. Floro** described for **Mr. Robertson** their cleaning procedure.

**Mr. Nurse** agreed with the author that the cleaning of goose-necks was very important. At one factory the goose-necks had been flanged to facilitate this process.

**Mr. Graham** felt that there must be an ideal shape for the top of stills, gooseneck and vapour pipe, and wondered whether the makers had any method in designing shapes or if their product were a result of trial and error. He also wanted to know if there were any big differences between old and new stills.

**Mr. Floro** said that two new stills which had recently come to the island had not shown such favourable time cycles as older ones.

**Mr. Cuthill** asked if the limiting factor in speed of boiling was not prevention of entrainment and Mr. Floro replied that it was, as far as the still was concerned. Mr. Cuthill asked if the time cycle of large stills would vary from that of smaller stills apart from time of preliminary heating and discharging.

**Mr. Floro** replied that it would depend on whether heating surfaces in a big still were properly distributed. He felt that for a larger still there should be correspondingly larger heating surfaces, and theoretically, the time cycle should not be longer. However, in practice, it would be found that the time cycle was longer for a bigger still.

**Mr. Nurse** said that at Barnett the original still was 1500 gallons in capacity and a belt was added to make this up to 2200 gallons. Last crop, they loaded to only 1800 gallons. The number of loadings was therefore increased but the total output of rum per 24 hours was also increased.

**Mr. Floro** thought that the reason for the Barnett experience was the distribution of the heating surface and its effect on entrainment.

**Mr. Robinson** said that at United Estates, they had two stills — an old type and one which had been erected after the last crop. Both were of the same capacity, 1200 gallons each. The newer still took three-quarters of an hour less per cycle than the other one. Both had the same heating surface. For the new still, the goose-neck had been copied exactly from the old still. The only slight difference was in the shape of the bottoms of the stills. The bottom of the newer still was a little more shallow and smaller than that of the old one, so the sides had been raised a little. To compensate for that, the dome was made a little flatter. The gooseneck was flanged to facilitate

cleaning. He inquired as to what effect holes in the vapour pipes to the retorts would have upon the operation of these stills.

**Mr. Floro** said that holes in the vapour pipes would lead to the by-passing of vapours and it would be difficult to obtain the required strength of rum.

**Mr. J. Scott** asked Mr. Floro whether at Frome, wash was screened before it went into the still and if so, had this any influence on the ether content of the distillate.

**Mr. Floro** replied that they did not use fine screens but centrifugal separation. This was done in order to prevent any "rice grain" entering the stills.

**Mr. Springer** thought that it might be possible to speed up operation by cutting off the rum at a higher proof, the limiting factors being the type of rum and the distillation efficiency desired. It was interesting to mention that the time cycle guaranteed by makers of new stills was not covered by any conditions of operation.

**The Chairman** then thanked Mr. Floro for his very interesting paper.

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## OBSERVATIONS ON THE EVAPORATION OF ALCOHOL DISTILLERY SLOP

M. B. FLORO, B.Sc.

Chief Chemist. West Indies Sugar Co. Ltd., Frome.

(Mr. G. S. Skinner in the Chair)

### INTRODUCTION:

In view of the importance of the problem of distillery slop disposal to the Sugar Industry in Jamaica, it is felt that observations on actual industrial application and results obtained by a method of treatment seen in the U.S.A. would be of interest to members of the Association.

The observations made in this paper are based on observations made from seeing actual operation of the new slop concentration plant recently erected by the U.S. Industrial Chemical Inc. in their New Orleans Plant. It may be mentioned that the Company's aim in the evaporation of slop, is not to solve the problem of disposal. but to obtain a substitute for beet molasses as a binder for stock feed. All surplus slops are discharged into the Mississippi River. While it must be confessed that the results obtained were far below the writer's preconceived notion of what such a plant could do, the operating data and results given below will nevertheless be found extremely useful as a guide to any one contemplating evaporation as a method of slop disposal.

### EQUIPMENT.

1. Quadruple effect evaporator of old design previously used in Paper Mill — all copper including Vapour Pipes — with total heating surface of approximately 11,000 sq. ft.
   Brass tubes in the 2nd, 3rd, and 4th vessels, stainless steel in the 1st.
2. Jet condenser.
3. Steam driven condensate pumps with float valve controls.
4. All Copper piping.
5. Meter for steam supply and meter for dilute slop supply.

### OPERATION DATA.

(a) Steam supply at 10 lbs. per sq. inch pressure.

(b) The slop is pumped direct from ethanol stills processing molasses wort to the evaporator supply tank. Difficulty is experienced due to settling of yeast bodies at bottom of this tank. The average density of the slop is 5.50° Brix.

(c) The concentrated slop is pumped out at a density of 28°-30° Beaume or approximately 46% solids by drying and is loaded in tank cars from the storage tanks.

(d) Cleaning is done once a week. No. 1 vessel has to be examined and its plugged tubes drilled with electrically operated drills and scrapers. Chemical cleaning consists of boiling with a mixture of soda ash and caustic soda solution at atmospheric pressure for 4 hours and followed by boiling with 2% hydrochloric acid, also at atmospheric pressure. It used to take 36 hours for cleaning but this time was gradually cut down.



### OPERATING RESULTS.

| | | |
|---|---|---|
| Average Rate of Production | — | 440 U.S. Gallons concentrated slop per hour. |
| Equivalent to | — | 4,000 U.S. Gallons of dilute slop evaporated per hour. |
| Evaporation Rate | — | 3.50 lbs. water per sq. ft, H.S. |
| Steam Consumption | — | 0.263 lbs. per 1 lb. of water evaporated. |
| Dilute Slop Evaporated | — | 0.364 U.S. Gallons per sq. ft. H.S. per hour. |

### POSSIBLE SOURCES OF BETTER PERFORMANCE.

1. More modern design of Evaporator.
2. Pre-heating slop supply to 230° — 240°F.
3. Separation of all suspended bodies in slop before evaporation.

It should be noted that in Jamaican rum distilleries, the density of the dunder is much higher, 10° — 12° Brix, and therefore more quantity per sq. ft. of H.S. would be capable of being handled by a plant of this type.

### DISCUSSION.

The Chairman declared the subject open for discussion.

**Mr. Dron** asked what size of evaporator tubes were used, and **Mr. Floro** replied that they were 1-5/8" outside diameter, 1¼" inside diameter and 3' long.

**Mr. Henzell** asked whether the concentrated slop pumped into the storage tank was stored for any appreciable time, and **Mr. Floro** replied that the total storage capacity was 14,000 gallons, consisting of two tanks of 7,000 gallons each. The maximum time of storage was 36 to 48 hours.

**Mr. J. G. Davies** said that two things struck him — that evaporation was not being used as a means of disposal but to produce something saleable, and the point made about operation data — "that the vessels had to be examined and plugged tubes drilled with electrically operated drills and scrapers", there must be an appreciable decrease in heating transmission towards the end of the operation period and he wondered whether suitable operating conditions could still be maintained towards the end of the run.

**Mr. Floro** replied that they paid close attention to that phase of the operation — analysis of slop being made every hour. Once the rate of evaporation dropped below a predetermined figure the evaporators were cleaned.

In reply to a question by **Mr. Cuthill** as to where the steam came from, **Mr. Floro** said that the plant was a big one with a central power plant supplying steam to alcohol stills etc. The plant used fuel oil, but was also equipped for burning natural gases.

**Mr. J. G. Davies** enquired for details of construction of the evaporators. **Mr. Floro** stated that the equipment was not modern and the down-take was not big enough: also, the edge of the down-take was 2" above the calandria which was not baffled — the incondensible gas lines were also inadequate.

**Mr. Cuthill** asked what was the nature of the product and to what commercial use could it be put.

**Mr. Floro** replied that the concentrated slop was sent to the Mid West as a binder for stock feed as a substitute for beet molasses which was unobtainable during war time, being required for alcohol production. The product was in liquid form of a density of 28° to 30° Beaume.

**Mr. J. G. Davies** doubted the efficacy of such a plant for dunder disposal in Jamaica, and wondered whether if such a plant were used, the concentrate could be disposed of in Jamaica.

**Mr. Floro** thought that the only possible adaption would be in conjunction with the burning of the concentrate or that the concentrate might be put through an Oliver filter which together with mud could be applied to the fields for fertilising purposes.

**Mr. Whitaker** said some years previously, he had had specifications of a plant for dunder disposal similar to the method described by Mr. Floro. It was a question of injection of slop on to hot rollers which produced a powder which could be used for fertiliser but the process would prove much too expensive under local conditions

**The Chairman** thanked Mr. Floro for his paper.

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## SOME ASPECTS OF THE CHEMISTRY OF RUM PRODUCTION.

J. R. McFARLANE, B.Sc., A.R.I.C., Chief Chemist, Caymanas Estates Ltd.

(Mr. V. Williams in the Chair)

Since rum production in Jamaica dates far back into the dim and distant past, it is not surprising that the methods employed have come to be regarded as axiomatic or that rule of thumb and empirical formulae have been the rule rather than the exception, and the Sugar Industry Commission (1) has summarised the position admirably when it states: "The production of rum in Jamaica is, in general, still regarded more as an art than as a science." However, in view of the advances made in recent years in the sugar industry, it must seem a little strange that little or no attention has been paid to the scientific aspect of rum production in the Island. At the beginning of the century, a foundation was laid by the excellent work of Cousins (2) Ashby (3), Allen (4), and Greg (5) but since that time any attempt to build on their structure has been very limited. Arroyo, in Puerto Rico, has carried out extensive researches, some of the results of which may be found in his many papers, and he has added considerably to our knowledge, but his suggestions do not seem to have met with wide approval here. In the last year or so, a determined effort has been made to establish chemical control in our distilleries, but this has been made more with a view to obtaining some idea of the efficiency of alcohol production than to investigating the conditions governing the production of Jamaica rum, but even so it does not yet appear to have the whole hearted support of the manufacturers. So far as can be ascertained, no serious attempt has been made to correlate the proportions of the various constituents present in the wash with the quality of the rum produced or to determine the conditions under which the desired proportions of those constituents can be produced at will. In an attempt to show that rum production is indeed a scientific industry and deserves to be treated as such, it has been thought that a brief outline of the chemistry of fermentation as far as it is concerned with the manufacture of rum and of the reactions



which are involved in the production of those substances which go to make up what is known as Jamaica Rum, will serve to demonstrate these facts, and to induce a new and different outlook on the problems which arise in the industry. It is to be regretted that, with the limited time available, it has not been possible to do more than to touch on the more important aspects of the subject, but it is hoped that this paper, incomplete though it may be, will arouse fresh interest in the chemical aspects of the industry.

It is not proposed to consider the various types of Jamaica rum in any detail other than to recognise the main ones which may be taken as Common Clean, Plummer, Wedderburn and Flavoured, since the reactions involved in their production and the nature of their constituents are essentially the same though the practical methods of production may vary considerably and the proportions of constituents may differ with each type.

Jamaica rum can be considered as an aqueous mixture of ethyl alcohol, aliphatic acids, esters, higher aliphatic alcohols, aldehydes, furfurals, and traces of certain unidentified substances which appear to be responsible for the character of the product as distinct from other spirits. Rum is produced by the alcoholic fermentation of aqueous solutions of molasses (or cane juice) and dunder by means of yeasts in the presence of bacteria and other micro-organisms which promote subsidiary reactions leading to the production of substances other than alcohol. It has long been claimed that environment plays an essential part in the production of specific marks of rum and, for this reason, great care has been taken not to destroy the character of the fermentation, manufacturers having gone to such extremes in this direction in the past, that some of the distilleries were definitely insanitary. While under the conditions of adventitious fermentation as practised in Jamaica, there is little doubt that each distillery produces a distinct rum, Floro, at Frome, has demonstrated the possibility of manufacturing several marks, which were previously made on individual estates, at one central distillery. It has also been regarded as essential to employ pot stills but, while this type of still will normally produce rum with a greater proportion of higher boiling constituents than the continuous type, good rum has recently been made in a continuous experimental still at Frome and there is no reason why, with careful setting of the plates, all but the heaviest types of Jamaica Rum cannot be distilled in this manner. Arroyo (6) has succeeded in producing a rum in Puerto Rico, under very different conditions to those obtaining in Jamaica, which, he claims, is "indistinguishable from Jamaica rum in taste, bouquet and chemical analysis,"can be manufactured "in a fraction of the time required for the confection of rums of similar quality under Jamaican methods and conditions" and ages so rapidly that a three month old rum offers the chemical analysis of a two year old Jamaica rum, while a six month old product is comparable with five year old Jamaica Rum. (23). This would seem to indicate that the control of conditions of fermentation is the most important factor in the production of rum.

Production of ethyl alcohol is the major process in rum manufacture since alcohol comprises over 80 percent by volume of rum distilled. Alcoholic fermentation is brought about by yeasts, but the yeasts employed in rum distilleries are, in general, incapable of fermenting any carbohydrate more complex than the hexoses. Since some 30 per cent of the total sugars in molasses are present as sucrose, it is necessary, therefore, to convert this disaccharide into dextrose and laevulose before complete fermentation of sugars can be effected. The yeasts employed contain in their cells a mixture of complex substances, the exact chemical natures of which are still unknown. These substances, the enzymes, may be likened to catalysts, in that they can promote reactions without apparent detriment to themselves, but it must be pointed out that they are extremely specific and many of them will promote one particular reaction and that reaction alone. One of these enzymes, invertase, or more correctly sucrase, brings about the inversion of sucrose to dextrose and laevulose.

$$\underset{\text{Sucrose}}{C_{12}H_{22}O_{11}} + H_2O = \underset{\text{Dextrose and Laevulose}}{2\,C_6H_{12}O_6}$$

so that there is no need to effect the hydrolysis of the sucrose by any other means.

The production of ethyl alcohol and carbon dioxide from hexoses by fermentation is the result of a series of involved reactions, mainly effected by the action of different enzymes but the overall result may be represented as

$$C_6H_{12}O_6 = 2\ CH_3.CH_2.OH + 2\ CO_2.$$

Hexose — Ethyl alcohol — Carbon dioxide

where 100 parts of hexose will, theoretically, yield 51.11 parts of alcohol and 48.89 parts of carbon dioxide. In practice, using pure yeast cultures in sterile substrates, it is possible to obtain a conversion in excess of 90 per cent of the theoretical but, for reasons which will be appreciated later, the efficiency in rum production is considerably lower.

A great deal of research has been carried out on the mechanism of alcoholic fermentation and the various theories put forward have been discussed by Meyerhof (7). One of the more widely accepted theories which, while it may now be considered incorrect, serves to show the complexity of the reactions involved, is as follows:—

1. Hexose and phosphate, in the presence of the enzyme phosphatase, combine to yield hexose diphosphate

$$C_6H_{12}O_6 + 2\ RH_2PO_4 = C_6H_{10}O_4\ (RHPO_4)_2 + 2\ H_2O$$

Hexose — Hexose diphosphate

2. The Hexose diphosphate, by the action of zymo-hexase, yields two molecules of triose phosphate. probably glyceraldehyde phosphate

$$C_6H_{10}O_4\ (RHPO_4)_2 = 2\ C_3H_5O_2\ (RHPO_4)$$

Hexose diphosphate — Glyceraldehyde phosphate

3. By internal oxidation-reduction (comparable to the Cannizzaro reaction) in the presence of water, one molecule of glyceraldehyde phosphate, acting as hydrogen acceptor, is reduced to glyceryl phosphate and a second molecule oxidised to glyceric acid phosphate. This reaction is promoted by mutase

$$H_2 + CHO.CHOH.CH_2(RHPO_4) = CH_2OH.CHOH.CH_2(RHPO_4)$$

Glyceraldehyde phosphate — Glyceryl phosphate

$$O + CHO.CHOH.CH_2(RHPO_4) = COOH.CHOH.CH_2(RHPO_4)$$

Glyceric acid phosphate

4. These phosphates are dephosphorylised in the presence of apozymase, glyceryl phosphate yielding glycerol and phosphate, and glyceric acid phosphate, pyruvic acid and phosphate

$$CH_2OH.CHOH.CH_2(RHPO_4) + H_2O = CH_2OH.CHOH.CH_2OH + RH_2PO_4$$

Glyceryl phosphate — Glycerol

$$COOH.CHOH.CH_2(RHPO_4) + H_2O = COOH.C(OH)_2.CH_3 + RH_2PO_4$$

Glyceric acid phosphate — Hypothetical substance

$$COOH.C(OH)_2.CH_3 = COOH.CO.CH_3 + H_2O$$

Pyruvic acid

5. In the presence of carboxylase and co-carboxylase, pyruvic acid decomposes to yield acetaldehyde and carbon dioxide, the latter being liberated

$$COOH.CO.CH_3 = CHO.CH_3 + CO_2$$

Pyruvic acid — Acetaldehyde

6. Acetaldehyde now replaces glyceraldehyde phosphate as acceptor in reaction 3. yielding ethyl alcohol and glyceric acid phosphate, little or no glyceryl phosphate being formed once the production of acetaldehyde has commenced

$$H_2 + CHO.CH_3 = CH_3.CH_2OH$$

Acetaldehyde — Ethyl alcohol

$$O + CHO.CHOH.CH_2(RHPO_4) = COOH.CHOH.CH_2(RHPO_4)$$

Glyceraldehyde phosphate — Glyceric acid phosphate



The glyceric acid phosphate formed is decomposed to yield pyruvic acid as in reaction 4 and the subsequent reactions proceed until fermentation is complete. Hence the main products of fermentation are ethyl alcohol and carbon dioxide with small quantities of glycerol and acetaldehyde. Certain other substances are formed during fermentation but they have been shown to be the waste products of yeast metabolism or to be produced by reactions involving bacteria or other organisms and either sugars or products of fermentation. They cannot, therefore, be regarded as direct products of alcoholic fermentation.

The efficiency of conversion of hexoses to alcohol and carbon dioxide is governed by a diversity of factors of which the most important are:

**a. Type of yeast employed.**

The type of yeast used for fermentation will have considerable bearing both on the yield of alcohol and on the quality of rum produced since every type has peculiar characteristics and each strain of any particular type may produce different results.

In general, top-fermenting yeasts are employed in rum distilleries in spite of the fact that most other distilleries employ bottom fermenting yeasts. Although alcohol fermentation would appear to be a purely anaerobic process, yeasts are in reality facultative anaerobes, and work best with a limited oxygen supply. With excess oxygen, the sugars are completely oxidised to carbon dioxide and water

$$C_6H_{12}O_6 + 12\ O = 6\ CO_2 + 6\ H_2O$$

However, the carbon dioxide liberated during fermentation dilutes the oxygen present while reactions involving bacteria have a large and preferential oxygen demand, so that, under normal conditions complete oxidation is not pronounced. Even with a very large excess of oxygen and in the absence of bacteria, it is not likely that more than 20 per cent of the total sugars will be oxidised completely and this would be a decidedly abnormal condition.

The yeasts most usually found in distilleries are of the budding type (Saccharomycetes sp.) and the production of alcohol will be found to vary widely with different strains. In alcohol distilleries it is customary to develop a particular strain of yeast which gives the most desirable results, but this, of course, only applies to pure culture work. In rum production pure cultures are not used, the fermentation being spontaneous and it is obvious that undesirable strains will be present. This will affect the efficiency and it is probable that a fermentation efficiency of 85 per cent is exceptional. This fermentation efficiency must not be confused with the overall efficiency reported by a number of our distilleries, but is the percentage of the theoretical yield of alcohol which would be produced in the absence of all reactions other than alcoholic fermentation. Although the adoption of a pure culture system seems remote there is no apparent reason why cultures which would ensure a preponderance of desirable strains should not be employed in an attempt to raise the efficiency.

It is of interest and possible importance to note that, whereas budding yeasts now appear to predominate in Jamaican distilleries, the presence of a fission yeast (Schizosaccharomyces mellacei) was reported by Greg (loc. cit.) some 50 years ago and was alleged to be partially responsible for the characteristic flavour of Jamaica rums (Allen, loc. cit.). There is little evidence of this type of yeast being present in most distilleries in any appreciable quantities at the present time. Arroyo (8) has suggested that a top-fermenting fission yeast will produce a more desirable quality of rum than the usual budding type, and has investigated the problem employing Pombe yeast (Sch. pombe) which was discovered by Lindner in 1887 (9) Re-introduction of a fission yeast into our distilleries in sufficiently pure culture to ensure its being the predominant organism, might lead to improvement of both efficiency and quality since it is reported that Sch. mellacei yields 6.6 — 7.6 per cent alcohol.

**b. Temperature.**

The metabolic activity of yeast depends very largely on the temperature at which it is maintained and, while there appears to be no definite optimum

temperature at which a yeast thrives best, there is a fairly narrow range over which reasonably good results can be obtained. For the production of rum it is not usual to allow the maximum temperature of the wash to exceed 35°C, and temperatures above 37.5°C should most certainly be avoided if reasonable yields are to be expected. Actually, the lower the temperature the slower will be the fermentation, but the better will be the quality of the rum produced and it is generally accepted that distilleries at higher elevations produce better rum for this reason. Arroyo (10) claims that, for good quality rum, the temperature should be maintained at about 27°C, but, without elaborate cooling devices, this would be extremely difficult to achieve in most Jamaican distilleries.

While the rate of metabolism increases gradually with increase in temperature, at temperatures above 37.5°C, the metabolism is disturbed and, due to the fact that it is highly improbable that the various enzymatic processes taking place during fermentation will have the same optimum temperature, some processes will be speeded up more than others by an increase in temperature. The production of involution forms to be found in yeast cultures propagated at high temperatures is regarded as evidence of this latter fact.

**c. pH of Substrate.**

The degree of acidity of the substrate in which the fermentation takes place has an important bearing on the rate of fermentation and on the nature of the reactions taking place and therefore of the final products. In general, low pH values favour reactions involving yeasts and higher values those involving bacteria, although it is possible to acclimatise micro-organisms to conditions very different to those under which they normally thrive best, though the products of metabolism may, and most probably will, be different in these cases. In the production of alcohol, as distinct from rum, the optimum pH value is in the vicinity of 5.0 but, for rum production, a pH of 5.8 is claimed by Arroyo (8) to yield the best results. This degree of acidity would seem to allow of sufficient bacterial activity to ensure the production of those amounts of secondary constituents required to maintain the quality of the rum at the desired level, whereas, at a pH of 5.0 the bacterial activity is almost completely suppressed. The maintainance of a constant pH during fermentation is advocated by Arroyo (11), who states that, by this means, "rums of great cleanliness of aroma which aged rapidly were produced, while the mature rum had mellowness, smoothness and delicacy of flavour." No progress in this direction appears to have been made in Jamaica though the buffering effect of dunder must have a limited influence on the pH of the wash.

**d. Yeast Nutrients.**

The quantity and proportions of different food materials can greatly alter the metabolism of yeast cells both qualitatively and quantitatively and yeasts grown on different media and under different conditions can show extreme variability in composition. Thus, the fat, protein and carbohydrate content of a yeast may vary through wide limits depending on the conditions of growth and this must mean that there will be variations in the metabolism of the yeast during growth. These are reflected in the differences in the fermenting power and products of fermentation of the resulting yeasts.

With regard to the actual nutrients required, with the exception of carbon, hydrogen and oxygen, which are supplied by the sugars, the main requirements appear to be nitrogen, phosphorus and an alkali metal though there is little doubt that trace elements, may play an important part in yeast metabolism.

It has been shown that, when a small quantity of yeast is used for inoculation, cell growth is very slow, whereas, with larger seedings, normal rapid growth takes place. This fact was first observed by Pasteur and later confirmed by Wildiers, who suggested that the failure to grow rapidly from a small inoculation was due to the absence of a specific indispensible substance which he called 'bios' and which would be introduced in appreciable quantity only when using larger quantities of yeast for seeding. For many years nothing more was heard of this 'bios' until, about 1920, it was suggested that it was identical with a vitamin of the B group now termed biotin or Vitamin H, one component of which (d biotin) has been synthesised (26).



In rum manufacture, nitrogen is supplied in the molasses and in dunder, where the precursors of amino-acids are produced as the result of breaking down of yeast proteins. Nitrogen in the form of ammonia appears to be most easily assimilated, hence the use of ammonium sulphate as a nutrient in the production of alcohol and of light rums in other countries, and it is not surprising that, in the absence of ammonium salts, de-amination of amino acids occurs resulting in the formation of ammonia and aliphatic alcohols.

$$CH_3CH_2CH(CH_3).\ CHNH_2\ COOH + H_2O = CH_3\ CH_2\ CH(CH_3)\ CH_2OH + CO_2 + NH_3$$

Isoleucine — d—Amyl alcohol

Owen (27) states that 0.5—2.0% of autolysed yeast added to the wash increases the efficiency of fermentation. This may be due to the supplying of a more readily available source of nitrogen or to an increase in the amount of "bios" present.

It is of interest to note that none of the normal products of yeast metabolism contain nitrogen and this would indicate that nitrogen is used purely for synthesis in the yeast cell.

With regard to phosphorus, this is always present in molasses in the form of phosphates and it is also to be found in yeast nucleic acids which, combined with proteins, are present in the yeast cells as nucleoproteins. Yeast nucleic acid has been postulated tentatively as

Phosphoric acid — Pentose — Guanine
Phosphoric acid — Pentose — Cytosine
Phosphoric acid — Pentose — Cytosine
Phosphoric acid — Pentose — Adenine

in which the pentose has been identified as d-ribose. Guanine and adenine are purine bases and cytosine a pyramidine.

It has been claimed that potassium plays an important part in the metabolism of yeasts (12). This element is one of the main elemental constituents of molasses ash. It is probable that sodium, which is also present in fair quantity in molasses, can replace potassium in the metabolism.

In passing, it should be pointed out that, while a certain amount of sugar is undoubtedly employed as a source of yeast food, this amount is small compared with the total amount used up in fermentation and it would seem that the yeasts derive energy rather than food from sugars. This was first indicated by Pasteur, in 1861, when he showed that the production of one part of yeast required 176 parts of sugar under anaerobic conditions but only 8 parts under normal aerobic conditions. Considering the energy relations of the overall fermentation reaction and that involving complete oxidation

$$C_6H_{12}O_6 = 2\ CH_3\ CH_2OH + 2\ CO_2 + 87\ B.Th.U.$$

$$C_6H_{12}O_6 + 12\ O = 6\ CO_2 + 6\ H_2O + 2674\ B.Th.\ U.$$

where the figures represent the total theoretical energy liberated when one gram mole of hexose is decomposed, the ratio of energy liberated under aerobic and anaerobic conditions is approximately 30: 1, while the quantities of hexose involved in the production of unit quantity of yeast under the same conditions are in the ratio of 1: 22.

Remembering that a certain amount of sugar will be used up as yeast food, the reasonably close agreement would indicate that, as suggested, the yeast cells derive energy rather than food from the decomposition of sugars.

The process under anaerobic conditions may be regarded as respiration without any marked growth whereas, under aerobic conditions, propagation occurs with very considerable cell growth and multiplication.

**e. Effect of Metabolic Products.**

The products of metabolism of yeasts have the effect of retarding the metabolism, and may also cause the formation of involution forms which are usually associated with old cultures where there are accumulations of waste products.

Since the composition of the substrate will change rapidly due to utilisation of food materials and accumulation of waste products, it is obvious that

it will be impossible to maintain yeast cells on what might be termed a constant diet under normal conditions of fermentation and, after some time, the growth of yeast will slow down and finally cease. This is, probably, due more to the accumulation of waste products than to a lack of sufficient nutrients, but the effect of different waste materials is by no means the same. The accelerated rate of growth caused by aeration of the substrate is probably due to the removal or dilution of waste products in the immediate vicinity of the cells rather than to facilitation of absorption of food materials. These factors have been taken into account in the continuous fermentation process proposed by Bilford et al (13) wherein the concentrations of nutrients and of waste products are kept constant and agitation is effected by means of carbon dioxide.

The inhibitory effect of alcohol is well known and has a direct bearing on rum and alcohol production though it is by no means certain that the concentration of alcohol in the wash is the limiting factor in the inhibition of yeast growth. The degree of inhibition of the higher alcohols is more marked than that of ethyl alcohol and appears to depend on the position of the alcohol in the homologous series. Segal (14) gives the following percentages of alcohols as completely inhibiting alcoholic fermentation (and also yeast growth).

| | |
|---|---|
| Ethyl alcohol | 12.0 per cent |
| Propyl alcohol | 3.4 " " |
| Butyl alcohol | 1.5 " " |
| Iso-amyl alcohol | 0.6 " " |
| Fusel oils | 0.8 " " |

The degree of inhibition of other metabolic products does not seem to have been investigated at any length, but there can be little doubt that this phenomenon does occur.

Yeasts, however, can be acclimatised to greater concentrations of various substances as is instanced by the fermentation of washes set at high Brix which, with the ordinary strains of yeasts, would only be partially fermented (15). Actually, the process of acclimatisation consists of the selection of the very small proportion of cells which have the desired properties and their propagation at the expense of the remainder.

Next to alcohol, the organic acids constitute the most important components of rum and they are found in the final product not only in the free state but also combined with alcohols as esters. Of the free acids, some 97-98 per cent is acetic acid, the remainder being about 1 per cent butyric acid together with traces of formic, caproic, pelargonic, capric and other aliphatic acids.

There are three methods in which the acids may be produced; first, by the direct fermentation of sugars by means of bacteria; second by the bacterial oxidation of the products of alcoholic fermentation and third, by the de-amination of amino acids, probably brought about by enzymatic action.

In the case of acetic acid, it is probable that the greater part is formed by the oxidation of alcohol by acetic acid bacteria although organisms are known which can produce acetic acid directly from sugars as is evidenced by the souring of cane juice under anaerobic conditions. Acetic acid bacteria of which there are many known varieties, (e.g. B. aceti, etc.) work under aerobic conditions and, in this reaction

$$CH_3 CH_2 OH + 2\,O = CH_3 COOH + H_2O + 456 \text{ B.Th.U.}$$

Alcohol — Acetic acid

100 parts of alcohol yield 130 parts of acid. In practice, the yield is probably much lower due to a certain amount of complete oxidation to carbon dioxide and water, but it is obvious that, for every 100 parts of acetic acid produced, the yield of alcohol will be reduced by a minimum of 77 parts. This will be independent of the method by which the acid is produced, that is, either internally in the wash or externally and added at some later stage of production, and will help to explain why it is impossible to obtain a high efficiency in rum production, when that efficiency is calculated on potential alcohol production. The greater the increase in acidity between live and dead wash, the greater the amount of acid which has been produced, and the lower the yield of alcohol and therefore of rum.



In adventitious fermentations such as are general in Jamaica sufficient acetic acid bacteria are usually present in the wash for the production of the acid required in the production of the lighter rums, but it appears customary to prepare acid externally in the case of the heavier rums, though there would seem to be no fixed practice for this.

It seems likely that butyric acid is formed by the direct anaerobic fermentation of sugars by bacteria, the Clostridia, of which these bacteria form an important group, being part of the normal floro of molasses, entering the factory on the soil about the cane roots. Arroyo (16, 17) has investigated the formation of butyric acid and has isolated an organism which can yield some 45 per cent of butyric acid on sugar converted together with hydrogen and carbon dioxide. Such active bacteria are not normally present in wash but Arroyo quotes Buchner and Meisenheimer's figures for B. butyricus Fritz which produced the following amounts of various products per 100 parts of sugar.

| | |
|---|---|
| Butyric acid | 26.0 |
| Acetic acid | 7.5 |
| Formic acid | 3.4 |
| Lactic acid | 10.0 |
| Ethyl alcohol | 2.8 |
| Butyl alcohol | 0.7 |
| Hydrogen | 1.6 |

The optimum pH for the formation of butyric acid appears to be between 7.0 and 7.2 which is well outside the range of normal wash acidities so that the percentage of butyric acid present in the wash will, most probably, be very low. The direct formation of butyric acid from hexose is represented by

$$C_6H_{12}O_6 = CH_3\,CH_2\,CH_2\,COOH + 2\,H_2 + 2\,CO_2$$

the hydrogen being assimilated, but it is highly improbable that the reaction takes place along such simple lines, particularly in view of the figures quoted above. Butyric acid is a yeast poison but, in the small quantities present, it is not likely to have more than a slight retarding action on fermentation. Moreover, Arroyo (6) reports that certain butyric acid bacteria (Clostridium saccharo butyricum Arroyo in particular) can live symbiotically with yeasts, especially those of the fission type. The effect of the bacteria is to accelerate the rate of fermentation and to improve the quality and aging properties of the rum produced. Since the beneficial effect can be exerted through quartz, it is considered probable that the bacteria produce radiant energy capable of stimulating the yeast cells to a very rapid rate of multiplication. (17a) In the production of butyric acid from molasses small amounts of caproic and capric acids are invariably produced and the traces of esters of these acids present in rum are probably derived from this source. These acids are most probably formed as the result of degradation of proteins present in the bacteria.

This process of degradation is also responsible for the production of the other higher acids found in rum, proteins being decomposed to yield amino-acids which are reduced with the liberation of ammonia, this being assimilated by both yeasts and bacteria

$$R.CHNH_2\,COOH + 2\,H = R.CH_2\,COOH + NH_3$$

or oxidised, as in the case of glutamic acid, which particular substance yields succinic acid, an inevitable product of alcoholic fermentation.

$$\begin{array}{l} CH_2.\,COOH \\ | \\ CH_2\,CHNH_2.COOH \\ \text{Glutamic acid} \end{array} + 2\,O = \begin{array}{l} CH_2COOH \\ | \\ CH_2COOH \\ + CO_2 \\ + NH_3 \end{array}$$

The acids generally found in rum, either in the free state or as esters are

| Acid | Formula | B.P |
|---|---|---|
| Formic | H.COOH | 101° |
| Acetic | $CH_3$ COOH | 118° |
| Butyric | $CH_3.CH_2.CH_2.COOH$ | 162° |
| Valeric | $CH_3.(CH_2)_3COOH$ | 185° |
| Caproic | $(CH_3)_2CH.CH_2.CH_2.COOH$ | 200° |
| Heptylic | $CH_3.(CH_2)_5.COOH$ | 223° |
| Caprylic | $CH_3(CH_2)_6.COOH$ | 236° |
| Pelargonic | $CH_3.(CH_2)_7.COOH$ | 186° @ 100 mm. |
| Capric | $CH_3.(CH_2)_8.COOH$ | 268° |

The majority of these acids are to be found in traces in rum, and, in view of their high boiling points as compared with alcohol (78°C.), are probably distilled in steam towards the end of the distillation, They should, therefore, be more concentrated in the retort lees, a fact which is borne out by the use of these lees for the preparation of 'lime salts' used in the preparation of 'high ether' rums.

The presence of esters, or 'ethers' as they are usually termed in Jamaica, in rum has already been indicated when discussing the acids, from which they are formed by combination with alcohols with the elimination of water

$$CH_3.CH_2OH + CH_3.COOH = CH_3.CH_2.OOC.CH_3 + H_2O$$

Ethyl alcohol Acetic acid Ethyl acetate

The ester content has come to be regarded as the criterion of quality in a rum and, although it is not the essential factor in determining its characteristics, there is a definite trend showing increase in other constituents with increase in esters, so that there is a real basis for a system of classification of rum types according to their ester content. With regard to the four main types, the ester content is usually given as

| | | | |
|---|---|---|---|
| Common Clean | 80 — | 150 | parts per 100,000 alcohol |
| Plummer | 150 | 200 | do. |
| Wedderburn | 200 | 300 | do. |
| Flavoured | 700 | 1600 | do. |

The reaction involving the formation of esters from alcohols and acids is reversible and should be written

$$\text{Alcohol} + \text{Acid} \rightleftharpoons \text{Ester} + \text{Water}$$

equilibrium being established when the two opposing reactions, esterification of the alcohol and saponification of the ester, attain the same velocity.

Applying the Law of Mass Action, at equilibrium

$$\frac{\text{Concentration of Ester} \times \text{Concentration of Water}}{\text{Concentration of Alcohol} \times \text{Concentration of acid}} = K$$

where K is the Equilibrium Constant and concentrations are expressed as gram moles.

From this formula it is possible to calculate the amount of ester which will be formed at equilibrium if the initial concentrations of alcohol and acid are known

If a = gm. molecular concentration of alcohol at start
b = " " " " acid at start
x = " " " " ester at equilibrium

then $$x^2/(a-x)(b-x) = K$$



Ethyl acetate comprises more than 98 per cent of the total esters present in rum, ethyl butyrate about 1 per cent and a mixture of higher esters the remainder. It is probable that the greater part of the esters in lighter rums is formed by direct esterification of the alcohol produced by fermentation but micro-organisms are known which are capable of the production of esters directly from sugars. One of these organisms was isolated by Peck and Deerr (18) and produced over 7000 parts of esters per 100,000 parts of alcohol while an even more active organism was isolated by Ashby (loc. cit.) in Jamaica. These organisms are apparently non-sporing Torulae and play an important part in the production of high ester rums.

Since most of the esters are produced by direct esterification it is obvious that the acid content of the dead wash will be a controlling factor in the production of esters in the rum and, in general, the higher the acidity of the wash, the greater the amount of esters formed. Hence the yield of alcohol will be decreased as the esters increase since sugars will be used up in the formation of those acids necessary for their production and the higher concentration of acids in the wash will also tend to inhibit the process of fermentation to some degree. Therefore, from an economic standpoint, an increase in esters will mean an increase in cost because (i.) more molasses will be required to produce each gallon of rum, and (ii) the production will be slower in that each still will yield less rum. A reduction of 2 per cent in overall efficiency due to increased acid production would mean an increase of approximately 4 per cent in the amount of molasses required per gallon of rum under normal Jamaican conditions of efficiency, while a drop from 100 gallons per still to 95 gallons would increase the cost of production by 5 per cent.

Although it is improbable that equilibrium, as expressed by the equation quoted, is ever attained, due to the hydrolysis of the esters by enzymes (esterases) and to the relative short time for which the wash is kept before distillation, it is of value to calculate the theoretical amounts of esters which would be formed under varying conditions of concentration of alcohol and acid. The tendency of the ester content to increase with increasing acid and constant alcohol concentrations is illustrated by the following figures which relate to a wash containing 5 per cent alcohol and 82 per cent water, the acid content varying from 0.5 to 1.5 per cent expressed as acetic acid.

| Concentration of acid | Concentration of acid gm. mol. | Concentration of ester gm. mol. |
|---|---|---|
| 0.5 | 0.0083 | 0.000875 |
| 0.75 | 0.0125 | 0.001125 |
| 1.00 | 0.0167 | 0.001600 |
| 1.25 | 0.0208 | 0.002087 |
| 1.50 | 0.0250 | 0.002375 |

These figures would represent a range of some 1500 to 4000 parts of ester per 100,000 parts of alcohol in wash, figures very much higher than those for the rums which would be produced from such washes. Since the boiling points of ethyl acetate and alcohol are almost identical, practically the whole of the ester will distill with the rum and, moreover, conditions in the retorts are such that they favour the formation of additional esters so that a certain amount of the esters in rum must be the result of esterification in the retorts. Hence it is probable that the amount of esters formed in the wash is very much smaller than the calculated figure and it would be of interest to determine the actual ester content of dead wash although this might be a difficult analytical procedure. It must be pointed out that the total acidity of the wash does not represent the acid available for esterification, both because acid has been added to the wash in the form of dunder and because all the acid produced during fermentation is not acetic or butyric acid (ignoring the small percentage of essential higher acids formed), but includes lactic acid, etc.

The production of high esters by the 'lime salt' process is an example of how the equilibrium can be shifted by the removal of one product of reaction. In this process, calcium salts of the acids from retort lees are treated with

sulphuric acid in the presence of alcohol (high wines) and the mixture of acids, after precipitation of calcium sulphate, used in the high wine retort. The concentrations of alcohol and acid as compared with that of water will be enhanced by the removal of this latter constituent by the excess sulphuric acid and the degree of esterification will be greatly increased.

When strong rum is broken down with water, the equilibrium is disturbed and the reaction from right to left, that is, saponification of the ester is accelerated. Hence the ester content of freshly diluted rum is invariably lower than that of the original strong rum and Arroyo (19) states that a period of from six to twelve months may elapse before equilibrium is re-established. He also suggested the use of pre-treated aqueous alcohol for breaking down rum.

It has long been recognised that certain rums, on aging will decrease in ester content while others exhibit the opposite phenomenon. Analyses of these rums will show that these changes are due, for the most part, to the gradual establishment of equilibrium, the rise or fall of ester content depending on whether there is an excess or deficit of ester compared with the amount demanded by the equilibrium equation.

In addition to ethyl alcohol, rum contains varying amounts of higher aliphatic alcohols including n-propyl, n-butyl, iso–butyl, active and inactive amyl and traces of higher members of the series. These are generally considered to add body to the rum and the amounts present increase with the degree of heaviness of the rum. The toxicity of these alcohols is such that it has been stated that the after effects of over indulgence in rum are due to them, their rate of decomposition or expulsion from the system being very much slower than in the case of ethyl alcohol, but it has been suggested that the esters are equally responsible for such effects.

It has already been indicated that the de-amination of amino-acids is a possible mode of formation of these higher alcohols and there seems little reason to doubt that the amyl alcohols, which comprise the greater part of these substances, are produced in this manner.

$$\underset{\text{Leucine}}{(CH_3)_2CH.CHNH_2.COOH} + H_2O = \underset{\text{iso-Butyl carbinol}}{(CH_3)_2CH:CH_2CH_2:OH} + NH_3 + CO_2$$

These amyl alcohols. which are known as fusel oils, may, therefore, be regarded as degradation products of yeast proteins. The principal source of such substances must be the dunder which will contain products of decomposition of yeasts in addition to dead yeast cells and it would be interesting to compare the higher alcohol content of rums prepared with ordinary dunder and with dunder from which all yeast cells had been separated.

The main reason for the production of these compounds is the nitrogen demand of the yeast cells, the ammonia produced being easily and readily assimilated. The use of ammonium sulphate, as practised in other countries, results in the production of rums in which the higher alcohol content is much lower than in Jamaica rums, this being due to the preferential assimilation of ammonia in simple form and the suppression of the process of de-amination.

The traces of propyl and butyl alcohols present are most probably produced by the direct fermentation of sugars by bacteria and Allen (loc. cit.) has attributed the formation of butyl alcohol to the presence of B. mesentericus which he isolated from the wash. According to Owen (20) the Mesentericus group of bacteria are invariably present in final molasses. Arroyo (16, 21) has isolated such bacteria as B. tetryl and B. aceto-butylicum which produce butyl alcohol, butyric acid and acetone by anaerobic fermentation of sugars, but since no traces of acetone have been reported in rum, this substance must be oxidised to carbon dioxide and acetic acid if these organisms play any part in rum production.

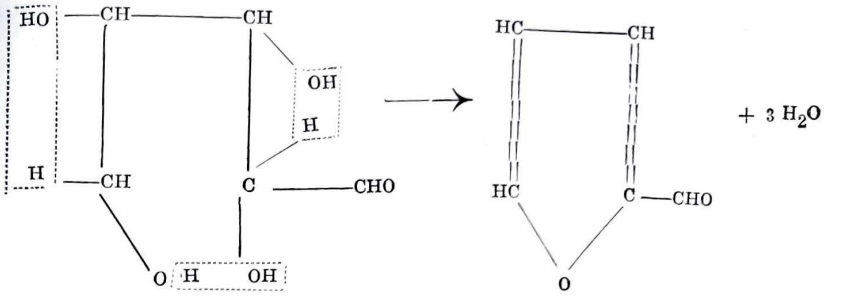
The production of acetaldehyde as an intermediate in alcoholic fermentation has been mentioned already and this is probably the source of this substance in rum although it might be produced by the oxidation of alcohol

$$\underset{\text{alcohol}}{CH_3.CH_2OH} + O = \underset{\text{acetaldehyde}}{CH_3.CHO} + H_2O$$



Traces of formaldehyde and of formic acid are probably formed by oxidation of hexoses on which the 5 and 6 positions are unsubstituted (cf. oxidation with periodates (28) ).

The small amounts of furfural always found in rum are produced from pentoses which either enter with the molasses or are produced by degradation of the yeast nucleic acids, of which d-ribose is a component part. Distillation of pentose in acid solution results in the removal of three molecules of water and cyclisation of the remainder of the molecule to furfural.




Pentose Furfural

In addition to the identified constituents there are always present certain unidentified substances which, although they are to be found in minute traces, serve to characterise the rum. Greg (loc. cit.) isolated a substance from dunder by extraction with petroleum ether which appears to be responsible in part at least for the characteristic odour of rum. This substance was also investigated by Micko (22) who suggested that it might be related to the terpenes. It is probably identical with the rum oil of Arroyo (23). This latter author considers that 'rum oil' is the essence of all aroma in rum and, though its constitution is unknown, it would appear that the amount present depends on the type of yeast employed for the fermentation, fission yeasts being particularly effective in this respect. Since the rum oil has a high boiling point, the higher temperatures attained in a pot still towards the end of the distillation are more favourable to its distilling over than the steady lower temperatures existing in a continuous still and, unless a very effective yeast is employed it is possible that the prospects of making Jamaica rum in a continuous still may be remote.

With regard to the aroma, there can be little doubt that the esters, more particularly ethyl butyrate and the higher esters, play an important part. It has been suggested that the more volatile ethyl acetate serves as a vehicle to convey them to the nose, but Cousins (loc. cit.) claims that the accentuation of aroma on dilution is due to a reduction of the volatility of the acetate, making the effect of the higher esters more pronounced. The development of those substances responsible for the aroma and flavour of rum has been attributed to numerous causes. Greg (loc. cit.) was of the opinion that the type of yeast used was the main factor whereas Allen (loc. cit.) considered that a combination of fission yeasts and butyric acid bacteria played a very important part. This latter view is supported by Arroyo and in his opinion 75 per cent of the aroma is controlled during fermentation by the type of yeast and bacteria used, together with correct temperature and pH control. The remaining 25 per cent may be attributed to proper distillation and aging. He stresses the desirability of centrifuging the wash prior to distillation, the removal of pectins, albuminoids, etc. preventing the formation of an unpleasant aroma. The type of fermentation appears to be of importance, Ashby (loc. cit.) observing that a slow fermentation with a top-fermenting fission yeast accentuated the production of high esters and good flavour. Kayser (24) states that with spontaneous uncontrolled fermentation the esters and volatile acids are higher but the higher alcohols lower than when using steril-

ised material and pure cultures of fission yeasts. In the case of flavoured rums the Torulae probably play an important part by the direct production of esters from sugars.

It will be seen from the foregoing survey that it is not possible to produce rum without the utilisation of a proportion of the sugars for the production of constituents other than alcohol. Hence any increase in these constituents will mean a decreased yield of rum. Some idea of the losses inherent to the production of Jamaica rum is given by Floro (25) who considers that an efficiency of 70 per cent of the theoretical yield of alcohol would be very good in a Jamaican distillery. He points out that the losses will be least for the lightest rums and will increase with increasing heaviness.

In view of the much better yields which are possible with pure culture fermentation. it might be thought that some progress in this direction would have been made but it must be remembered that various marks are standardised with regard to quality and the manufacturer is very chary of doing anything which, while it would increase his yield, might cause deterioration in quality. There is little doubt that it would be possible to employ modern methods of fermentation with pure yeast and bacteria cultures and temperature and pH control, for the production of Jamaica rum and to manufacture all but the heaviest types of rum in a continuous still, but a considerable amount of research and experimental work on a semi-industrial scale would be necessary before such methods could be applied in Jamaica on a commercial scale. Under the present haphazard system of spontaneous fermentation as practiced here the type of rum must depend very largely on the conditions obtaining in the distillery and this has given rise to the belief that any particular mark of rum can be produced in one particular distillery only. As already mentioned, this has been shown to be a fallacy, several distinct marks having been made in one distillery, but, so long as conditions in the distilleries remain unchanged, environment will be an essential factor in the production of Jamaica rum. The pronouncements of the Sugar Industry Commission (loc. cit.) are particularly illuminating in this respect and there can be no doubt that, if progress is to be made in the Industry, some attempt must be made to set it on a scientific basis. A start has been made in the right direction with the institution of chemical control in the distilleries and this will bring home the extremely low efficiency of production, but it will be necessary to go much further and to set up a research scheme, preferably under the aegis of the Sugar Manufacturers' Association whereby all knowledge may be pooled, before any real progress can be made towards the realisation of a really efficient rum industry in Jamaica. In particular, isolation in pure culture of all useful micro-organisms in distilleries and examination of their properties and productive potentialities, investigation of the relation between the relative proportions of constituents in wash and the composition and quality of the rum produced from that wash, and of the means of production of the requisite quantities of those constituents in the wash by the use of pure cultures, all require attention. The possibility of employing a process of continuous fermentation and of distillation in continuous stills should also be investigated while there are numerous other problems which will have to be solved and the results applied in practice before rum manufacture in Jamaica can be termed a 'scientific industry'. In view of all this, the logical step would be the acquisition of a first class bio-chemist with experience in fermentation processes so that any scheme which might be evolved would be certain to start along the right lines for, under present conditions, the chemists in the Island have neither the time nor (as they will be the first to acknowledge) the necessary experience to carry any such scheme to a successful conclusion and this proposition should, therefore, receive the earnest consideration of all who are interested in the further progress of the rum industry in Jamaica.



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**FOOTNOTE:** It is regretted that because of limitations of type available it has not been possible in all cases to reproduce chemical formulae faithfully from the script. Everything possible has been done however to publish formulae as accurately as possible within the above mentioned limitations.

—**Editor.**

## DISCUSSION.

**Mr. Williams,** Chairman, complimented Mr. McFarlane on the able and detailed treatment of his subject. The paper was then declared open for discussion.

**Mr. Springer** said he had seen top fermenting yeast only once, in Jamaica. He did not agree that alcohol fermentation was an anaerobic process. In Martinique, E. A. Pairault had claimed a 30% increase in recovery by using pure yeast culture in a pilot plant, and stated that the rum produced was of good quality. The temperature of 27°C. mentioned by Arroyo might slow down fermentation and involve increasing vat capacities. In Guadeloupe, yeasts were stored successfully in a substrate of pH 2.5 to 3 for periods of 6 months.

**Mr. McFarlane** replied that in Jamaica he had seen mixture of top and bottom yeasts. In regard to temperatures, Arroyo had said that at 27°. C. he had obtained a better rum.

**Mr. Floro** complimented the author on his paper. He said there was still a lot to be done in Jamaica on the multiplication of yeast, and particularly in relation to carbohydrate requirements.

**Mr. Schonbeck** asked what was the advantage of using pure yeast culture in rum production and also asked whether the culture could be kept pure under such conditions as at present existed in commercial distilleries in the Island.

**Mr. McFarlane** doubted whether the culture could be kept pure under present Jamaica conditions. The present aim should be to obtain predominance of the most desirable strains.

Referring to organisms yielding exceptionally high esters **Mr. Smedmore** pointed out that one such organism had been identified in a distillery making high ether rum.

**Mr. J. G. Davies** asked whether in view of the effect of temperature, Worthy Park rum was considered to be of better quality than other common clean rums. He inquired whether there were any figures available of the fusel oil content of rum made from dunder from which all yeast had been separated. **Mr. McFarlane** doubted that the relatively slight difference in temperature at Worthy Park would have any significant effect. He was not aware of any data of the type mentioned.

**Mr. Floro** asked whether the Chairman would contribute to the discussion in view of his experience of Food Yeast Production and the investigations he had recently been undertaking at the Gray's Inn distillery.

**Mr. Williams** said he had isolated 6-7 yeasts from Gray's Inn wash. In the laboratory, one or two had yielded a 92-93% conversion of sugars. Particular yeasts had specific types of fermentation and their products were specific.

**Mr. Whitaker** congratulated the author on his paper. He informed the meeting that the S.M.A., had under active consideration the appointment of a fermentation chemist to conduct investigations into the production of Jamaica rum.

**Mr. MacDonald** proposed a vote of thanks which **Mr. J. G. Davies** seconded,