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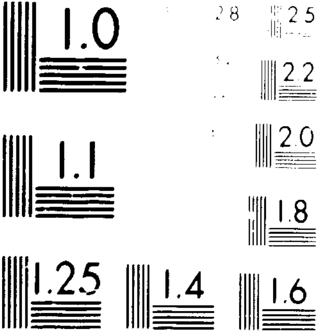
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DP/ID/SER.A/343
3 March 1982
English

ESTABLISHMENT OF A PACKAGING RESEARCH, TESTING, DEVELOPMENT AND JAMAICAN BUREAU OF STANDARDS

DP/JAM/77/008

JAMAICA.

Technical report: Glass containers*.

Prepared for the Government of Jamaica by
the United Nations Industrial Development Organization,
executing agency for the United Nations Development Programme

Based on the work of Kapil D. Sharma,
Glass container consultant

United Nations Industrial Development Organization
Vienna

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ABSTRACT

Project: JAM/77/008/A/01/37

Duration: 2 months (20 April to 19 June 1981)

A Packaging Centre has been established at the Jamaican Bureau of Standards under the above UNIDO project. The present Consultant, specializing in Glass Technology, was the ninth one who visited the Packaging Centre. His main duties were to advise the Centre on the application of laboratory test methods for the evaluation of glass containers and on problems associated with the production and use of these containers.

During his stay at the Packaging Centre the Consultant delivered 12 lectures covering the entire spectra of glass containers, including raw materials, methods of manufacture, physico-chemical properties of glass, laboratory test methods, fracture analysis, container design, surface coating, standard specifications and quality control. Detailed notes on the above subjects were prepared and discussed with the counterpart staff. Several visits were paid to plants of the manufacturer and the users of glass containers to identify and discuss their technical problems, and a 2-day training course was conducted for their senior officers.

Recommendations have been made regarding the selection of laboratory equipment, additional training for the counterpart staff and also relating to the production technology in use in the country. It has been suggested that work regarding rationalisation of sizes, shapes and colours of glass containers may be taken up at the Bureau.

JOB DESCRIPTION

DP/JAM/77/008/11-08/31.7.E

Post title	Glass Container Consultant
Duration	Two months
Date required	August 1980
Duty station	Kingston, with possibility of travel within the country
Purpose of project	The Government is endeavouring to upgrade the general level of packaging technology in the country. A packaging development laboratory is being created and the purpose of this project is to equip it in the best possible way and to teach local staff how to work out solutions for packaging problems in the various fields.

DUTIES

The expert will work with the staff of the newly created packaging department on problems associated with the use of the glass containers, and will be responsible to the Project Manager. The expert will specifically be expected to:

1. Carry out a survey on the existing situation in the country with respect to the quality and availability of glass containers.
2. Advise counterpart personnel on the application of laboratory test methods for the evaluation of glass container characteristics and advise on the types of equipment normally used for such tests. The interpretation of the results from these tests and how these relate to the performance of the containers under actual use conditions is the important part of this work.
3. Assist local companies in solving specific container problems.

4. Advise on the preparation of storage tests on glass containers filled with a variety of products for shelf life testing, the type of tests used to follow qualitative and quantitative changes during such storage trials and the relationship between these laboratory observations and container performance under actual use conditions.
5. Advise on the relationship between structural design of the containers and closures and their likely performance.
6. Present round-table training sessions for staff members of the manufacturing and user industries.

The expert will also be expected to prepare a final report, setting out the findings of his mission and his recommendations to the Government on further action which might be taken.

INTRODUCTION

The UNIDO project "Establishment of a Packaging Research, Testing Development & Information Department in the Jamaican Bureau of Standards" officially started on 12 March 1979 and terminated in April 1981. The main purpose of the project was to establish a packaging development laboratory with a view to upgrading the general level of packaging technology in the country.

Besides a Project Manager, ten consultants in various specialised fields were appointed by UNIDO. The Project Manager left on April 10, 1981 after completing his assignment and eight consultants visited the Bureau for various lengths of time. The author was the ninth consultant, specializing in Glass Technology, whose main duties were to advise the Packaging Centre of the Bureau on the application of laboratory test methods for the evaluation of glass containers and on the problems associated with the use of glass containers.

During his stay at the Packaging Centre, from 23 April to 14 June 1981, the consultant visited the only one existing glass container plant in Jamaica and the plants of several large consumers of glass containers with a view to identifying their problems & offering suggestions for improvement. The consultant delivered a series of 12 lectures to the staff of the Packaging Centre on the subjects of glass, glass containers, laboratory test methods and standard specifications. A training course, consisting of five lectures, was also conducted for the benefit of the glass and the bottling industries. A list of essential testing equipment, books and journals was compiled and submitted to the Bureau. The present report covers the work done by the consultant at the Packaging Centre, his observations and recommendations.

The author would like to place on record his appreciation of the co-operation and kind help, in official as well as personal matters, extended to him by Mrs. M. Domville, the dynamic head of the Packaging Centre, and her able staff.

RECOMMENDATIONS

Project: JAM/77/008/A/01/37

1. Adequate funds may be provided for the procurement of essential equipment for testing and evaluation of glass containers at the Packaging Centre. The first-priority equipment is estimated to cost U.S. $10,000.00 C.I.F.

   (For U.N.I.D.O.)

2. A Fellowship may be provided for 'practical training' in the methods of testing and evaluation of containers and in fracture analysis since such a training could not be imparted by the present Consultant due to non-availability of equipment at the Packaging Centre.

   (For U.N.I.D.O.)

3. The Packaging Centre, in consultation with the container manufacturer and users, should endeavour to rationalise the sizes, shapes and colours of glass containers as there are far too many varieties and distinctive designs in use at present. Rationalisation will help in reducing imports as well as cost of production of the indigenous containers.

   (For Packaging Centre)

4. The Bureau of Standards may take up the preparation of Jamaican Standards for glass containers. To start with, work may be taken up on glass bottles required for carbonated soft drinks and beers.

   (For the Bureau of Standards)

5. The West Indies Glass Company may thoroughly reorganise their quality control department so that it becomes an effective tool in maintaining control over glass-making operations and the quality of products.

   (For West Indies Glass Company)

6. To conserve energy and obtain a better temperatute control, West Indies Glass Company, may consider installation of the modern all-electric forehearths during rebuild of the melting furnace. These forehearths give a saving of 75 percent in energy consumption.

(For West Indies Glass Company)

7. Manufacture of surface-treated glass containers for intraveous fluids, as per USP Type II, may be taken up as the process is very simple and enough demand exists for these containers in Jamaica and the neighbouring countries.

(For West Indies Glass Company)

8. The West Indies Glass Company is at present importing all moulds. It will be economical and advantageous if the machining of moulds can be taken up locally. To start with, mould copying machine may be installed for the production of most commonly used moulds.

(For West Indies Glass Company)

II PRODUCTION AND AVAILABILITY OF GLASS CONTAINERS IN JAMAICA

Role of glass in packaging

Glass has been an important packaging material for over 300 years. Despite competition from other alternative materials, like plastics, paper and metal, the glass container industry in industrially developed countries has been steadily growing at the rate of 3 to 5 percent per annum. This is due to certain unrivalled characteristics of glass, viz. its compatibility with almost all liquid and solid products, high degree of sterility, odour resistance and container appeal.

Glass containers constitute an important packaging material in Jamaica which produces large quantities of rum and other liquors for export, beers, soft drinks, preserved fruits and other food products.

Production of glass containers in Jamaica

At present there is only one glass plant in Jamaica, viz. West Indies Glass Company, which uses modern I.S. 6-section, double gob machines for the production of soda-lime glass containers. Up until 1973, the plant produ- both colourless and amber coloured containers but thereafter the production of amber glass was discontinued due to financial and labour problems. In recent years the plant had been in serious financial crisis which adversely affected the maintenance of machines, replacement of moulds and procurement of spare parts. The productivity of the plant in respect of colourless glass containers had been extremely low, the percentage of packed ware being only 30 to 35 percent (in April and early May 1981) as against the attainable figure of 80 to 85 percent. Almost all consumers, visited by the consultant, had serious complaints about the availability and quality of containers. At present, all coloured glass containers for beer, liquors and soft drinks, and colourless glass bottles for export of rum and for pharmaceutical preparations are imported, resulting in a substantial drain on the foreign exchange reserves of the country.

The West Indies Glass Company has recently received sizeable financial assistance and is now under complete reorganisation with the technical collaboration of Rockware Ltd. of U.K. New I.S. 6-section machines have been installed with new moulds and the 110 tonne daily draw colourless glass melting furnace, which is over 7 years old, is going to be rebuilt with an improved design so as to give a better glass to oil ratio and a more uniform temperature in the forehearths and feeders. The production capacity of the plant for colourless glass is around 38,000 tonnes per annum.

Quality

The main complaints about the quality of containers, as voiced by the users, are: (i) uneven wall thickness resulting in high breakage on filling lines (ii) too much variation in dimensions (iii) low thermal shock resistance and (iv) greenish blue tint of glass. The uneven wall thickness can be reduced by improving the temperature uniformity of gob through better control of forehearth and feeder temperature, better glass level control, proper preparation of delivery chutes and more precise allignment and design of blank moulds. Variation in dimensions is probably due to worn out moulds and would be corrected by replacing the old moulds. Low thermal shock resistance may be due to inhomogeneous glass and uneven thickness and baffle marks at the bottom.

The bluish green colour is due to high iron content of silica sand and use of too high a proportion of cullet (broken glass). Iron oxide content of the sand is stated to be around 0.1 percent which is very high for the manufacture of colourless glass. It is learnt that samples of sand have been sent to Rockware as well as the Jamaican Bureau of Standards for suggesting methods of upgrading the material.

Quality control

The quality control laboratory of West Indies Glass Company needs a thorough reorganisation. In a glass plant, quality control has two distinct functions. One is to control the quality of the products so as to maintain it at the given level. This is done by regularly testing the glassware for dimensions, capacity, verticality, thermal shock resistance, internal pressure resistance, etc. The second purpose is to maintain control over glass-making operations for efficient manufacture of glassware. The techniques that have been found most useful for this purpose are (i) to control glass composition through density measurement, calculating the daily average ($\bar{X}$) and the density range (R) and plotting the values on a control chart (ii) chemical analysis for SiO_2, RO, RO_2 and R_2O_3 (iii) control of working characteristics of glass through measurement of softening point and annealing point (iv) homogeneity of glass by the ring section method (v) seed count (vi) furnace bridgewall temperature (vii) daily glass pull and (viii) percentage pack. The control charts should be displayed on the wall so that they are available to the production personnel for correlating the changes in the forming operations to the changes in glass composition and quality.

Instrumentation

To improve quality of glass and increase speed and efficiency, instrumentation has assumed a very important role.

The variations in gob weight are mostly due to change in the glass level and temperature in the forehearth and feeder. The glass level control should be within ± 0.25 mm and the temperature at the orifice should be maintained at ± 1°C which requires an instrument accuracy of better than 0.1 percent. A 1°C change in temperature gives a 10 percent change in viscosity which results in variation of the gob weight. For maintaining the above type of close control on temperature, a system known as Deviation Control or Set-Point Control should be used.

For the melting furnace a new instrument to continuously monitor oxygen in the flue gases has been developed by Corning Glass Works, U.S.A. The instrument helps to maintain a control on the excess air used for combustion and thereby gives a saving in fuel consumption.

Recommendations for West Indies Glass Company

(i) To conserve energy, for which there is no known indigenuous source at present, the management may seriously consider installation of recently developed all-electric forehearths during rebuild of the melting furnace. These forehearths give a saving of 70 to 80 percent in energy consumption and will also not require imported liquid petroleum gas used at present by the company.

(ii) At present moulds are entirely imported. For a factory of the size of W.I. Glass Company, it will be advantageous and economical to create facilities for making their own moulds. If necessary only castings may be imported.

(iii) The control laboratory should be reorganised so that it becomes an effective tool in maintaining control over glass-making operations and in maintaining the quality of products at the desired level.

(iv) Glass technology and preventive maintenance sections should be strengthened.

(v) Manufacture of surface treated soda-lime containers for intravenous fluids, as per USP Type II, can be taken up as the process is quite simple and does not require any investment except for moulds.

III. PHYSICAL TEST METHODS FOR EVALUATING GLASS CONTAINERS IN A LABORATORY

Two of the important functions of the Packaging Centre of the Jamaican Bureau of Standards are (i) to form an independent linkage between the manufacturers and the consumers and (ii) to formulate standard specifications for the products in consultation with the manufacturers and the consumers. For this purpose it is necessary to organise an independent laboratory for testing and evaluation of the products

Several laboratory tests have been evolved to evaluate glass containers for their likely performance in use. The tests adopted by the American Society for Testing & Materials (ASTM). the Indian Standards Institution (ISI) and the British Standards Institution (BSI) are:

(i) polariscopic examination
(ii) thermal shock resistance
(iii) internal pressure resistance
(iv) dimensions & capacity and
(v) verticality

Polariscopic examination

The polariscopic examination is carried out to evaluate the containers for the quality of annealing. The containers, when examined by a polariscope under polarizing light and compared to Standard Strain Discs, should show a Real Temper Number not greater than 4. In calculating the Real Temper Number. correction for thickness should be made by multiplying the apparent temper number by 4, which is the thickness in mm of standard disc, and dividing the product by the average thickness of glass in mm. Temper No 4 is equivalent to birefringence or retardation of 92 millimicron since one standard disc produces a retardation of 23 millimicron. If glass containers are not well-annealed, they are liable to crack during washing, filling, handling or storage.

The test is described in detail in ASTM:C 148-71 and ISI: C 148-77.

Thermal shock resistance

Thermal shock resistance is essential because most containers have to undergo some thermal shock, either during washing or sterilization, filling with hot products, pasteurization or cooling during storage or use. Thermal stability of a container depends on the magnitude of the stress produced by the sudden chilling of one surface which in turn depends upon the thermal expansion of glass, its modulus of elasticity, tensile strength and thickness. For a soda-lime glass container whose coefficient of thermal expansion is around 90×10^{-7} per °C and the effective tensile strength of the outside surface is around 30 MN per m^2, the relationship between maximum temperature differential and thickness is as follows:

$$T_{max} = \frac{30}{0.342 \sqrt{t}}$$

where T_{max} is the maximum temperature differential in °C and t is the thickness of the container in mm.

The soda-lime glass containers should be able to withstand a hot to cold thermal shock, as carried out in accordance with ASTM:C 149-71 or ISI:6506-72. The temperature differential, as specified in various standards for soft drink and beer containers, is around 40°C. If the containers fail to pass the prescribed test, the failure may be due to any one or more of the following causes.

i) Concentration of stresses at the base at spots like the baffle mark.

ii) A bruise at the junction of the bottom and side wall.

iii) Too thick or uneven bottom.

iv) Bad annealing.

Internal pressure resistance

Adequate pressure resistance is essential for bottles required to withstand internal hydrostatic pressure, such as bottles for beers and aerated waters, The bottles should pass the test as carried out in accordance with ASTM:C 147-69, Method A, or ISI:1107-1957. For the pass test, the pressure prescribed in various standard specifications varies between 1.2 and 1.6 MN per m^2 (12 to 16 kg per cm^2) for 1 minute.

For returnable bottles used for carbonated products, a testing pressure of 1.4 MN per m^2 appears to be adequate, provided the test is carried out on bottles "as delivered to the bottlers" and not on new, untouched bottles. For untouched bottles, the magnitude of pressure should be increased by 50 percent.

In a typical bottle, such as for ginger ale or beer, the peak stress caused by the internal pressure occurs on the side wall of the bottles and the fracture originates on the outer surface of the wall as a short vertical split which travels completely round the bottle and may extend in the form of fissures. The origin is usually a thin spot or a bruise.

Dimensions and capacity

Although the cast iron moulds, in which containers are blown to shape, can be made to an accuracy of 0.05 mm when new, during use their inner surface gets oxidised which causes the cavity to become slowly larger in volume. The moulds may also warp slightly in use. These changes in mould affect the dimensional accuracy of the containers blown in them. Further, due to small changes in the gob temperature and the rate of cooling of the moulds the glass may set too quickly or it may not be sufficiently rigid when it leaves the mould which may also affect the shape and dimensional accuracy of the container.

Height of the container is a critical dimension and, if not controlled within certain limits, may cause serious problems at the filling line. It has been found by experience that the most useful way of stating glass container tolerances is to use what are known as "2-sigma limits", indicating that theoretically not over 2.3% of the containers may be above the upper limit and not over 2.3% below the lower limit.

The tolerances on height, diameter and capacity of a container are usually fixed by the manufacturer in consultation with the customer. However, the following standard specifications are available which may be consulted for details.

i) British Standards Institution
   BS 4590 - Part I; 1970: Non-Returnable Soft Drinks Bottles

ii) Indian Standards Institution
   2091-1973 : Glass Beer Bottles
   1107-1957 : Aerated Water Glass Bottles

iii) National Bureau of Standards, U.S.A.
   Standard TS 214C : Carbonated Soft Drink Bottles

Based on the 2-sigma limits, the Glass Manufacturers' Federation of U.K., has worked out the following equation for tolerances on container height and diameter.

i) Tolerance on overall height (H) = $\pm$ (0.6 + 0.004H)
ii) Tolerance on body diameter (D) = $\pm$ (0.5 + 0.012D)

In a laboratory, height and body dimensions are measured by using appropriate gauges to an accuracy of one-tenth of a millimeter.

Capacity, which is defined as the internal volume at 20°C, is determined by weighing the empty container, filling it with water to the appropriate level, weighing the full container and then establishing the weight of water by subtracting the weight of the empty container from the weight of the full one. The result is corrected to 20°C by multiplying it by a conversion factor which takes care of the change in density of water due to temperature and error due to buoyancy during weighing. The conversion factors for water temperature of 15°, 20° and 25° are 1.00208, 1.00284 and 1.00387 respectively (cf BS 1797:1968).

Verticality

Verticality is defined as the horizontal distance by which the centre of the bottle finish deviates from its intended position in relation to the bottle base when the bottle is rotated through 360°. This is important for locating bottles accurately under filling and capping heads. Non-verticality is due to slight bending of the neck or warpage of the base which may occur during lifting up of the bottle from the blow mould on to the conveyor or during annealing.

The recommended 2-sigma tolerances on verticality have a constant value for bottle heights up to 120 mm. Thereafter they increase linearly according to the following equation:

Tolerance on verticality for overall height (H)

$$= 0.3 + \frac{H}{100} \text{ in mm}$$

Impact test

Although impact test has so far not been recognised as a standard test, it is commonly used in the industry since impact is undoubtedly the most frequent cause of breakage of bottles in use. The test consists of a rigid pendulum with a hardened steel ball, the vertical height through which the striker falls being the measure of the impact energy.

When a bottle breaks due to impact, the origin of the crack is usually a bruise or a thin spot. A blow from a round hard object may drive a cone of percussion through glass at the point of impact. The fracture moves out from that point in a series of waves giving rise to bending or "hinge" stresses on the outside surface which may give rise to complex hinge fracture, at some distance from the point of impact.

Causes & types of fractures

The mechanical and thermal tests described above, viz. internal pressure test, impact test and thermal test, if carried out and analysed intelligently, can provide a lot of information about the causes responsible for the container failure since the cracks are a definite response to the forces producing them. The four basic principles in determining the origin and propagation of cracks are:

i) A crack has only one immediate cause, viz. mechanical stress. This stress is always a tensile stress and is at right angles to the crack.

ii) Generally speaking there is a single minute starting point for all fractures and the various fissures are propagated through the bottle from this point.

iii) The fractures nearly always originate at a surface, outer or inner, and not in the interior of the glass mass.

iv) The fractures may be propagated with differ [illegible]cities, from zero up to the speed of sound in glass.

IV CHEMICAL RESISTANCE OF GLASS AND TEST METHODS FOR SHELF LIFE

Chemical durability of glass

Most commercial glasses are fairly inert and do not react readily with materials with which they are liable to come into contact during use. Glass is chemically very durable against acids (except hydrofluoric acid and hot phosphoric acid) and acidic products have very little effect on it. In this respect the manufacturers of soda-lime containers are in a very favourable position because over 90 percent of the products packed are acidic in nature, e.g. carbonated beverages, milk, preserved fruits, most liquors, and about 90 percent of all medicinal solutions. In the reaction involving an acidic solution, sodium ions diffuse out of glass and hydrogen ions diffuse into glass, forming a hydrated porous layer at the surface. This layer then acts as a barrier, slowing down any further attack.

In the reaction involving an alkaline solution, the silicate network itself is demolished and this degradation mechanism is responsible for a major part of the chemical attack. Soda-lime glass is therefore not so stable against an alkaline attack and its solubility increases with the alkalinity of the solution, particularly at elevated temperatures.

Soda-lime glasses also react slowly with water vapour or materials containing water. Initially the reaction proceeds as a simple ion exchange reaction in which sodium ions diffuse out of the glass into water and hydrogen ions diffuse into the glass. However, the extracted alkali changes the attacking solution into an alkaline solution and with increase in basicity it causes the attack to change over to the net work degradation type, attacking all constituents of glass, including silica.

Tests on glass containers for shelf life

The chemical action of various products with glass at room temperature or under conditions of actual use is so slow that it would take years of study which would be an almost unsurmountable task. Several accelerated tests have therefore been designed to give a fairly reliable indication about the performance of glass containers in commercial use at room temperature. The results obtained by these tests are interpreted in terms of the alkalinity of glass, i.e. the amount of alkali extracted from glass or glassware under the prescribed conditions.

These tests are generally based on attack on glass surface by water at elevated temperatures as the rate of attack increases rapidly with rise in temperature, the increase being of the order of 2½ times for each increase of 1°C.

Methods of test

1) International Standards Organisation (ISO) Recommendation No. R719: According to this method, 2g of the freshly prepared powdered sample of 300 micron to 500 micron grain size is digested with high purity water at 98°C for 60 minutes. The extract is titrated against 0.01N HCl. The value in ml per g of the sample and its equivalent in alkali extracted as microgrammes of Na_2O per 1g of glass are reported.

1 ml of 0.01N HCl $\cong$ 310 microgramme of Na_2O

The Indian and the German Standards are based on the above method with slight modifications.

2) ASTM Standard : C225-73 (1978)

There are three test methods prescribed in the above standard, viz. (i) Method B-A, for determining the resistance of whole container to dilute acid (ii) Method B-W, for determining the resistance of treated containers to attack by water and (iii) Method P-W, for determining the resistance of powdered glass to attack by water. In these methods, the whole container or the glass powder of 300 micron to 425 micron size, as applicable, is digested with the prescribed attacking medium at a temperature of 121°C for 60 minutes and the extract is titrated against a standard alkali or acid solution as the case may be.. The results are reported as millilitres of 0.02 N H_2SO_4 consumed in the test.

Grading of glass containers in respect of chemical durability

The United States Pharmacoepia (USP) has classified the glass containers into the following four types based on the quantity of 0.02 N H_2SO_4 consumed in the test, carried out as per ASTM methods of test described above.

Type	General description of glassware	USP Test Name	ASTM Test code	Limit of 0.02N H_2SO_4 in ml
I	Highly resistant borosilicate	Powdered glass	P-W	1.0
II	Treated soda-lime	Water attack	B-W	0.71 to 0.20 depending upon capacity
III	Soda-lime	Powdered glass	P-W	8.5
NP*	General purpose soda-lime	Powdered glass	P-W	15.0

*NP means non-parenteral

Most of the general purpose colourless soda-lime glass containers fall under Type III while all containers must pass the Type NP test. These containers are suitable for packing all varieties of products, except injectable liquids and intravenous fluids, and the packed products will not be affected by glass so far as the shelf life is concerned. For injectables, Type I or Type II glass should be used.

V. EQUIPMENT FOR TESTING AND EVALUATION OF GLASS CONTAINERS

Essential items of equipment

The following equipment is recommended for the Packaging Centre of the Jamaican Bureau of Standards for testing and evaluation of glass containers. The equipment is listed according to priority.

First Priority	Price in U.S.$
1. Polariscope, Model 110 (Polarizing Instrument Co. Inc. 616 Washington St, Peeksill, N.Y. 10566)	1,175.00
2. Standard Strain Discs (British Glass Industry Research Assn, Sheffield 10, U.K.	2,100.00
3. Bottle Pressure Tester (American Glass Research Inc. P.O. Box 149, Butler, Pa, U.S.A)	3,310.00
4. Wall Thickness Gage (American Glass Research Inc. Butler, Pa)	670.00
5. Gauges for measuring height, diameter and verticality of glass bottles (Research Tool Mfg., 11100 Greenstone Ave., Santa Fe Springs, Calif. 90670).	Not Known

Second Priority		
1. Impact Tester (American Glass Research Inc. Butler, Pa.)		1,715.00
2. Autoclave 3. Mortar & pestle 4. Misc. apparatus, like flasks, burette, water bath etc.	As per ASTM: C225-73 (1978)	Not Known
5. Thermal Shock Testing Machine (American Glass Research Inc.) A simplier version of the machine can be fabricated at the Bureau.		12,310.00

Provision of funds for purchase of equipment

On scrunity of the project document it was found that most of the items of equipment listed above had been included therein. These were, however, not ordered as their essentiality could not be established without consulting an expert in the field of glass technology. The present consultant considers the above items of equipment essential for work at the Packaging Centre and strongly recommends that adequate funds should be available for their procurement.

Fellowship

It is also considered essential to provide one Fellowship for practical training in the testing and evaluation of glass containers as such training could not be imparted adequately by the present consultant due to non-availability of the equipment at the time of his visit. Suitable training facilities may be available at the American Glass Research Inc., Butler, Pa, U.S.A., who are designers and manufacturers of the important items of equipment listed above.

This establishment has been a pioneer in the field of container testing, fracture analysis and interpretation of results.

VI DESIGNING OF CONTAINERS & CLOSURES

A. Designing of Glass Containers

A majority of the glass containers are designed keeping in view the performance required of them during filling, handling and transport, although distinctive and attractive packages account for much of the variety, for example as used for packing expensive products like perfumes, cosmetics and liquors. Since over two thirds of the container production are for foods, milk, beers, wines, soft drinks, and pharmaceuticals, their design must be adapted to a variety of mechanical handling devices, like washing and sterilizing machines, brush spindles, fillers, cappers, pasteurizers, labelers, conveyors and cartoners, which differ very widely. The cost of the container being an important factor for the above types of products, the container weight must be the minimum in order to reduce initial cost as well as freight etc. To achieve the minimum weight with adequate container strength and high speeds of production on the modern glass forming machines, the design of container has to be given a very careful consideration. Of the various practical shapes for containers, a short cylinder is the most economical of material since the surface area required to enclose a given volume is the minimum. Theoretically, the cylinder most economical of material is one whose height approximately equals its diameter. However, since a bottle has a shoulder and finish its height has to be somewhat greater than its diameter but the ratio should be kept as low as possible to ensure sufficient glass thickness at the lowest cost. The container shapes which are the most economical of material are also the strongest since they give the maximum wall thickness for a given weight of glass.

Influence of design on thermal shock resistance: Investigations have shown that in all glass containers, whether cylindrical or of any other shape, there is a concentration of localized bending stresses in the region of the base of the bottle where it is connected to the sidewall. If the base of the container is joined to the sidewall by a smooth curve ('insweep') the bending stresses are much reduced. A smooth inswept junction also makes this part of the container less prone to damage by impacts received during handling and filling. This is very important as a bruised heel will markedly reduce the thermal shock resistance of a container. A tapered junction also gives a good distribution of glass during the forming process. In regard to the designing of shoulder and neck of the container, the basic principle is that glass should flow smoothly during the forming process giving a uniform wall thickness in this region.

Influence of design on internal pressure resistance: Theoretical calculations are not able to predict exact values for bursting pressure of bottles but the following relationship illustrates the effect of the main design features when a thin-walled hollow cylinder of internal diameter d and wall thickness t, is subjected to an internal pressure p. The tensile strength, s, at every point in the outer surface will be:

$$S = \frac{pd}{2t}$$

If the limiting value of stress at which failure occurs is taken as 350 bars, the maximum bursting pressure of the cylinder, P_{max}, is given by the equation:

$$P_{max} = 350 \times \frac{2t}{d} \text{ bars}$$

The bursting pressure is proportional to wall thickness and inversely proportional to the bottle diameters.

The greatest tension due to internal pressure is on the wall of the barrel and the failure normally occurs either at the thinnest spot or at a bruise. A good distribution of glass is therefore an essential requirement for a reasonably strong bottle. As a cylindrical shape, with rounded cross-sections at all heights, gives the best distribution of glass it will be the strongest. Bruises or surface damage during filling and handling can be reduced if sharp corners or bulges, where the containers rub against each other on the conveyor belt, are avoided. A cylindrical body with waist is also satisfactory provided there are two different heights on the body at which the a diameter is equal. The junction of the sidewall with base should be/smooth curve and the shoulder should be streamlined.

The following table by F.W. Preston gives ratios of pressure resistance for bottles of different shapes.

Shape	Ratio of pressure resistance
Cylinder	10
Ellipse (major axis twice the minor)	5
Square with well rounded corners	2.5
Square with sharp corners	1

For the above reasons, all bottles required to withstand internal hydrostatic pressures are cylindrical in shape, with well rounded base and shoulder and a small height to diameter ratio.

Influence of design on vertical load strength

A well-designed bottle is able to withstand high compressive stresses without any problem provided all parts of the bottle are evenly compressed and no significant tension is produced. On a filling line the capping machine may exert a weight of nearly 150 kg on the top of a bottle and the greatest stress occurs in the region of the bottle shoulder. The shoulder should therefore be well-designed with a large radius of vertical curvature. It has been found that the larger the radius of curvature the larger is the load bearing strength of the bottle. The shoulder of a champagne bottle is a good example in this respect.

Influence of design on impact resistance: The principles employed to obtain greatest impact resistance are exactly the same as for internal pressure resistance and vertical load resistance, viz. the maximum wall thickness for a given weight of glass, uniform distribution of glass, rounded cross-sections at all heights, and large radius of vertical curvature. A cylindrical body, without any sharp curvatures or corners, is the strongest against impact.

Rationalization of designs

For a country of the size of Jamaica there are far too many shapes, sizes and colours of glass containers prevalent in the market, even for products like carbonated beverages, wines, syrups and sauces. This is mostly due to using distinctive shapes and colours, in [illegible] cases due to the insistence of the foreign collaborator. Since production of so many varieties of glass containers is very uneconomical because of high cost of moulds and down-time for job changes, many bottlers are importing the empty containers causing a drain on the foreign exchange resources of the country. The Government, as a matter of policy, should endeavour to reduce the varieties required in the country to the minimum so that import of empty bottles could be reduced. In this task of rationalising the sizes, shapes and colours of glass containers, the Bureau of Standards, in collaboration with the manufacturer and the users, could play a significant role.

The results achieved are expected to benefit other Caribbean countries also.

B. CLOSURES FOR CONTAINERS

A closure is defined as anything intended to seal the neck of a container. For obtaining a good seal it is essential that the closure and the container finish should properly match each other. For general purpose containers there are three types of seals viz. i) Normal seals ii) Vacuum seals and iii) Pressure seals

The vacuum seal is mostly used in the packing of food products and the pressure seal for beers and carbonated beverages.

In the commonest type of bottle seal, a flat resilient disc or ring is pressed downwards on to the top of the sealing surface of the bottle. The sealing disc may be made in two parts: i) a sufficiently thick pad of resilient material, called the 'wad' and ii) a thin layer of facing material which is compatible with the product. Alternatively a flowed-in liner is formed inside the closure. In this method the sealing medium is dispersed in a suitable liquid, injected into the closure, and solidified with heat.

Resilient sealing materials

The commonly used 'wad' materials are cork, pulpboard, rubber and plastics. Pulpboard is now the most commonly used sealing liner. The plastic sealing materials consist of fairly hard polyethylenes, softer ethyl vinyl acetates (EVA) and various grades of polyvinyl chloride (PVC). The flowed-in compounds or plastisols are dispersions of PVC resins in plasticicisers. None of the materials in the closure that may come in contact with the packed product must in any way react with it physically or chemically.

Facing materials

For the majority of uses, the wad materials have to be lined with a facing material that is compatible with the product packed. Almost all facing materials are based on paper, such as bleached sulphite or bleached kraft, coated with white-pigmented synthetic resins such as vinyl copolymer PVA/PVC. Metal foils (aluminium and tin) are used where maximum resistance to solvents and impermeability to gases is required.

Closure Materials

The basic metals for closure manufacture are tinplated steel, pure aluminium, and aluminium alloys. Crown closures are always made in tinplate because of its high strength and rigidity. Other closure materials are thermosetting plastics, like urea formaldehyde or phenol formaldehyde, and thermoplastic materials like polyethylene or polystyrene.

Closure tolerances

In most cases closure manufacturers aim for a clearance of about 0.1 mm between the maximum finish and the minimum closure dimensions. For crown finish and continuous-thread-screw finishes the British Standards, BS 1918:Part 2 and BS 1918:Part 1, may be consulted.

VII DEALKALIZATION AND COATING OF CONTAINER SURFACE

Dealkalization of glass surface

The purpose behind dealkalizing the inner surface of a soda-lime glass container is to improve its chemical resistance by removing a part of the alkali and thereby leaving a surface layer which differs in composition from the main glass. The USP Type II containers for parenteral products are based on this process.

De-alkalization is carried out by treating the glass surface, at a temperature between its annealing and softening points, with an acidic gas - sulphur dioxide or hydrogen chloride. The sodium ions in the glass diffuse towards the surface where they react with the acidic gas to produce a crystalline sodium salt which can be removed by washing the surface. An efficient method of de-alkalizing the inner surface of a container is to drop a pellet of ammonium sulphate into the hot container before it enters the annealing lehr. Ammonium sulphate decomposes to ammonia and ammonium acid sulphate which, in the vapour state, reacts with sodium ions that diffuse to the glass surface to form sodium sulphate. The sodium sulphate layer being soluble is removed during washing of the container with water.

Coating of containers

As already explained, glass is an extremely strong material but when blown into a container its strength falls very rapidly due to the formation of "Griffith flaws" which are caused by mechanical damage to the glass surface during the blowing operation. After the annealing process, when the containers are passed through high speed inspection equipment or through high speed filling machines they rub against each other causing further damage to the outer surface which results in considerable reduction in the container strength. The damage due to the rubbing action can be very much reduced if lubricity is provided to the outer surface of the container so that when one such treated surface is rubbed against similarly treated surface, the two surfaces slide over each other without producing a scratch, whereas untreated glass surfaces rubbed together undoubtedly scratch each other.

Scratch resistant coatings for glassware generally consist of two different coatings - the hot end coating to give a scratch resistant surface and the cold end coating to provide surface lubricity. Hot end coating is applied by spraying a finely atomized solution of stannic chloride pentahydrate onto hot containers when they pass from the forming machine to the annealing lehr. The coating is only a few milli-micron in thickness and is invisible. Similar effect may be obtained by vapour deposition of tetra-isopropyl titanate on hot glass surface. The cold end coating, which provides lubricity to the surface and is applied while the glass is at a temperature of 100 to 120°C, generally consists of derivatives of polyethylene, such as polyethylene glycol or polyethylene stearate and polymers of vinyl alcohol. All single-trip carbonated beverage bottles are generally required to have both hot-end and cold-end coatings.

Coated glass is as much as three times as strong as uncoated glass, under impact breaking stress, after it has been through a typical filling line. Line breakage is reduced to a tenth or less of that found before surface treatment.

VIII. SPECIFICATIONS FOR GLASS CONTAINERS USED IN MAJOR PACKAGING INDUSTRIES

A. Essential requirements

The main purpose of formulating standard specifications for a product is to ensure that the product has been manufactured so as to be suitable and safe when used for the intended purpose, and to provide the manufacturers, consumers and other interested parties with a basis for common understanding of the characteristics of that product.

In the field of glass containers a number of voluntary product standards are available specifying the essential requirements of containers for various products. Some of the requirements, viz. accuracy of dimensions and capacity, verticality, annealing, freedom from such visual defects that may interfere in the filling, capping and sealing operations or may result in premature failure of the container in service are common for all containers. The special requirements will depend upon the severity of conditions during washing, sterilization, filling and pasteurization, internal pressure created by the product, sensivity of the product to chemical reaction with glass, etc. Examples of the special requirements of containers used for some major products are given below.

1. Bottles for carbonated beverages, like beers and soft drinks.
   - i) Thermal shock resistance of 40°C from hot to cold.
   - ii) Internal pressure resistance equivalent to a hydrostatic pressure of 14 kg per sq. cm for 1 min.
   - iii) Colour i.e. transmission of light at certain wave length (for amber bottles the transmission should be between 30 and 50% at 550 nm for 2 mm thickness).

2. Jars for jams and jelleys.
   - i) Thermal shock resistance of 40°C from hot to cold.

3. Containers for transfusion fluids and injectables.
   - i) Chemical resistance, as per USP Type I or II for borosilicate glass or treated soda-lime glass respectively.
   - ii) Thermal shock from 260°C to ambient temperature for borosilicate glass containers.

4. Containers for vitamin preparations, pharmaceuticals and products affected by light.
    - i) Chemical resistance, as per USP Type III.
    - ii) Colour, i.e. transmission of light at certain wave lengths.
    - iii) Thermal shock resistance of 40° from hot to cold.

B. Standard specifications for carbonated soft drink bottles

Since the largest proportion of glass containers consists of bottles for soft drinks and beers, the following standard specifications have been analysed to illustrate their essential requirements.

i) National Bureau of Standards, U.S.A.
Standard TS 214C: Carbonated Soft Drink Bottles.

ii) British Standards Institution
BS 4590: Part I:1970: Non Returnable Soft Drink Bottles. Bottles with crown finish.

iii) Indian Standards Institution
IS:2091-1973:Glass beer bottles
IS:1107-1957:Aerated water glass bottles, crown type.

The essential requirements of the above glass bottles, as specified in the above standards, are as follows.

Dimension & Capacity: The most critical of the dimensions on a glass container are those relating to height, body diameter and finish. These are important to the packer, especially on high speed filling machines. Suitable tolerances are specified in the standards listed above. The British Glass Manufacturers' Federation has recommended the use of 2-sigma limits for tolerances on dimensions and capacity.

Verticality: Verticality is the horizontal deviation of a convenient point on the outside of the finish relative to the outer surface of the bottle near the base. The tolerance for verticality, as specified in the above standards, varies between 2.1 and 3.1 mm.

Annealing: The bottles should not show greater than Real Temper No. 4 when examined under polarized light and compared to Standard Strain Discs in accordance with ASTM C 148-71. In calculating the Real Number, correction for thickness should be made.

Thermal Shock Resistance:

The bottles should withstand a hot to cold thermal shock, as carried out in accordance with ASTM:C 149-71. The temperature differential, as specified in the above standards, varies between 33° and 42°.

According to ASTM, if a cold bath temperature other than 70°F (21°C) is used, the specified differential may be decreased (increased) by 1°F (0.5°C) for each increase (decrease) of 10°F (5.6°C) above (below) the cold bath temperature.

Bursting Pressure Test

The bottles should pass the test as carried out in accordance with ASTM:C 147-69, Method A. For the pass test the pressure prescribed varies between 175 psi and 225 psi for 1 min duration for returnable bottles.

The pressure test should be carried out on new bottles "as delivered to user". Brand new and untouched bottles should have a higher bursting pressure by about 50 percent,

Impact Test

This test is not included in any standard but National Bureau of Standards has prescribed a simulated impact by application of at least 50-pound force per vertical inch (39 N per vertical cm) of bottle sidewall loaded in a squeeze-roll tester.

Glass Colour

The light transmission for amber glass used for beer bottles should be in the range of 40 ± 10 percent when measured in air through glass 2 mm thick at a wavelength of light of 550 nm.

IX QUALITY CONTROL IN CONTAINER GLASS MANUFACTURING OPERATIONS

One of the functions of the quality control department in a glass plant is to maintain control over glass-making operations for efficient manufacture of glassware. For this purpose it is necessary to select only those measurements and techniques that have been found to be most useful and fairly quick for maintaining an effective control.

1. Control of Glass Composition

Density: The glass property which is sensitive to small changes in the composition and is suitable for statistical treatment is density. By using a density comparator, employing the sink-float method, it is possible to determine density of five annealed samples, taken at regular interval in a 24-hour period from the same machine, simultaneously and calculate the Density Range (R) and a Daily Average ($\bar{X}$) in one hour. The values of $\bar{X}$ and R are plotted daily on control charts. After 2 weeks the average of the daily averages ($\bar{\bar{X}}$) and the average range ($\bar{R}$) are computed and these values form the central control lines for the first one month.

After one month new averages are computed and extended to 2 months and likewise after 2 months, extended to 4 months.

The control limits, i.e. the upper control limit (UCL) and the lower control limit (LCL) are best established from practical considerations. Arbitrary limits for $\bar{X}$ have been established at ± 0.002 g per c.c. and for $\bar{R}$ at ± 0.0005 g per c.c. Out-of-control values for average daily density $\bar{X}$ or daily range R are indicative of an abnormal condition that can be identified upon investigation. Abrupt changes are indicative of major batch upsets and require immediate attention. A steadily changing average density, without abnormal values for daily range, gives evidence of a gradual shift in the glass composition, which may be due to a continuous change in a raw material or a trend towards greater volatilization loss or refractory pick up.

Standard Test Method for Density of Glass by the Sink-Float Comparator is given in the ASTM Specification C729-75.

Chemical Analysis: Chemical analysis of glass carried out at regular intervals, say once in two weeks, should be an essential activity of the control laboratory because density measurements do not yield positive information about other properties or chemical composition of glass, particularly of the minor constituents, such as sulphate or fluoride, which have a marked influence on the melting and working characteristics of glass. Another use for chemical analysis is to positively identify the source or cause for out-of-control density points. For the purpose of control charts it has been found that plotting of silica, alumina, lime and total alkali effectively represents the chemical composition in a majority of cases. A practical set of limits for chemical control of these constituents is given below:

Constituent	Percent
Silica (SiO_2)	± 0.35
Total lime ($CaO + MgO$)	± 0.20
Total alkali ($Na_2O + k_2O$)	± 0.20
Alumina + iron oxide (R_2O_3)	± 0.10

Standard Methods of Chemical Analysis of Soda-Lime and Borosilicate Glasses are given in ASTM Specification C 169-75.

2. Control of Working Characteristics of Glass

Behaviour of glass during the forming process depends upon the rate of change of viscosity. This can be determined in the form of Working Range Index for which A.K. Lyle worked out the following empirical equation.

$$WRI = S - A$$

where S is the Softening Point of glass at which log viscosity = 7.65 and A is the Annealing Point of glass at which log viscosity = 13.0. Standard Methods of determining the softening point and the annealing point are described in ASTM Specifications C 338-73 and C 336-71 respectively.

The working range index can be determined once in two weeks and plotted on the control chart.

The density, the chemical analysis and viscosity measurements provide a means of cross checking each determination.

3. Homogeneity of Glass

Homogeneity of glass is a good index of the success of the entire control programme. An effective method for measuring the homogeneity of glass containers is the ring section method in which a ring section cut from the container is examined under a polarizing microscope using a graduated quartz wedge or a Bereck compensator to measure retardation in nm produced by the cords present in the glass. The glass is then graded on a relative scale between A (complete absence of cords) and E (presence of extremely high tensional cords on the outer surface) and the grade is plotted on a control chart. An isolated change of one-half ring section grade, say from B to B^+ or B to B^-, can occur without detectable cause but one-half grade change in monthly average level is very significant.

4. Seed and bubble count

Controls of the quality of glass include seed and bubble count. This is done by using a seedscope and expressing the result in terms of number of seeds per 10g of glass. In container ware, a seed count of 20 to 25 per 10g of glass is not objectionable to appearance.

Seed count is done daily and the value is plotted on the control unit.

5. Furnace Temperature (Bridgewall temperature measured by optical pyrometer)

The values are plotted daily (once in each shift) on the control chart.

6. Glass Pull: Values of glass drawn in tonnes per day are plotted daily on the control chart.

7. Percent Pack: The values are plotted daily.

The control charts should be displayed on the wall of the laboratory and also in the production department so that changes in the forming operations and percent pack can be correlated to changes in the glass. This knowledge is also helpful in the evaluation of the containers and in assigning reasons for their premature failure during testing or use.

APPENDICES

APPENDIX 1

LECTURES DELIVERED TO STAFF OF THE PACKAGING CENTRE

1. Introduction to Glass - A Review
2. Container glass compositions; batch materials and batch calculations.
3. Glass melting and forming of containers (with slides).
4. Glass annealing and polariscopic examination.
5. Properties of glass - physical, thermal and chemical.
6. Laboratory test methods for evaluation of glass containers. Part I: Thermal shock resistance, pressure resistance and impact resistance. Types of fractures and interpretation of results.
7. Laboratory test methods for evaluation of glass containers. Part II: Dimensions, capacity and verticality.
8. Laboratory test methods for evaluation of glass containers. Part III : Chemical durability and grading of containers for shelf life.
9. Defects in glass containers.
10. Designing of containers and closures.
    Surface coatings, decoration and dealkalization.
11. Specifications for glass containers used in major packaging industries.
12. Quality control in manufacture of glass containers.

APPENDIX 2

PLANT VISITS

1. West Indies Glass Co. Ltd., Kingston
2. Desnoes & Geddes Ltd., Kingston
3. Wray & Nephew Ltd., Kingston
4. Federated Pharmaceuticals, Kingston.
5. DaCosta Brothers, Kingston.
6. Estate Industries Ltd., Kingston.

APPENDIX 3

PROGRAMME FOR THE TRAINING
COURSE FOR INDUSTRY

Dates: 3 & 4 June 1981

1. An introduction to glass and the manufacture of glass and glass containers.
2. Properties of glass.
3. Terminology relating to container glass industry and container defects.
4. Laboratory test methods.
5. Standard specifications and their applications in packaging.
6. Quality control of glass manufacture.