PROJECT

" STRENGTH CHARACTERISTICS OF
GLASS BOTTLES. "

SUBMITTED TO THE FACULTY OF
AGRICULTURAL ENGINEERING,
MACDONALD COLLEGE,
MCGILL UNIVERSITY.

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ABSTRACT

The strength characteristics of bottles were studied using returnable, compact bottles, classified according to flaw intensity. Laboratory experiments consisting of drop, impact, thermal shock and internal pressure tests were performed to determine the arithmatic mean height (AMH) of break, thermal shock resistance, impact resistance and internal pressure resistance of each of the bottle samples. Result showed that the various strength characteristics of the new virgin bottles was significantly different from all the other samples tested. The impact resistance and internal pressure resistance decreased exponentially with increasing flaw intensity. An expression for impact energy and internal pressure at failure as a function of flaw intensity was derived. All the samples were able to withstand high temperatures in the thermal shock test.

ACKNOWLEDGEMENT

The author wish to express his many thanks to the Dominion Glass Company for the kind permission to use some of their testing facilities without which this study could not have been completed.

Appreciation is also due to the Company's Public Relation Manager,Mr.Bob.Callingon for his courteous coordination,Mr. Stephen R. Savereux of Quality Control Department and his crew for testing assistances and obtaining various informations.

Last but not least, Dr. Kok's continuous guidance and encouragement have made this project a complete and successful one and I must give him my heartiest gratitude.

CHAPTER	TABLE OF CONTENT	PAGE

CHAPTER I

INTRODUCTION

Large amount of glass containers are used in the food and beverage industries (Fig.1). It represents a total of 41% of all glass containers used. In which 70% are wide mouth containers or jars and the remaining 30% are bottles used for soft drinks and beverages (1).

Properties of glass and ceramics are generally well understood. But the information on strength characteristics of glass containers are very limited. Also there is no information available on properties and reactions between glass and its content that could affect its strength characteristics.

In this paper, the strength characteristics of glass bottles were studied and the objectives were:

a) To obtain the arithmatic mean height (Height at which 50% of bottles will break) of the normal bottle sample.
b) To check if the various samples can withstand the minimum thermal shock temperature differential as specified by ASTM Standard.
c) To determine the ultimate breaking strength of the bottles by impact tests (3,4).
d) To determine the internal pressure resistance of the bottles using internal pressure testing machine (2).

When these test results are obtained, then it is possible to evaluate the strength characteristics of the returnable containers at different flaw intensities.

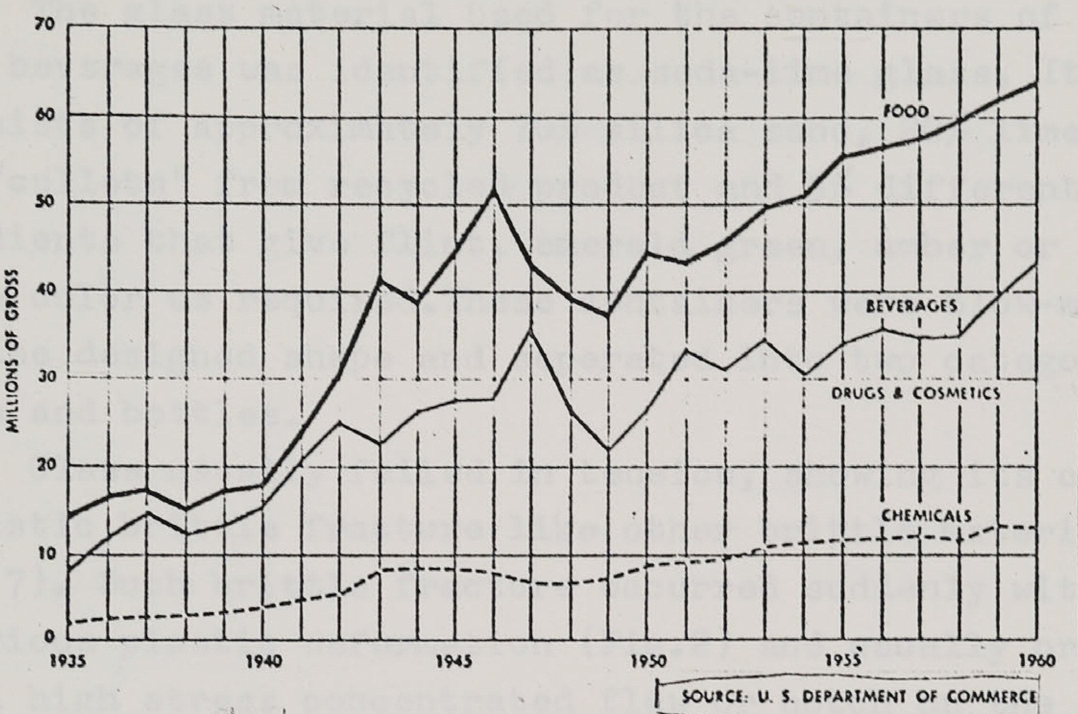


FIG. 1 GLASS CONTAINER SHIPMENTS FOR VARIOUS USES, BY YEAR

CHAPTER II

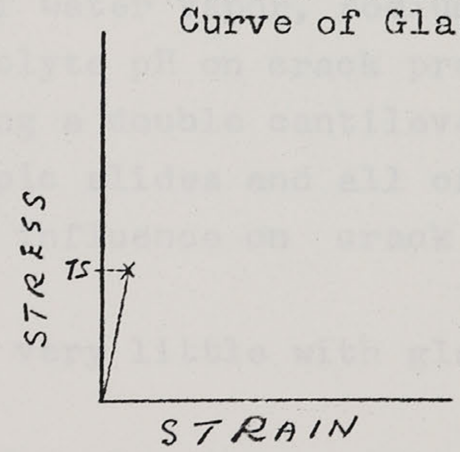
PROPERTIES OF GLASS MATERIAL AND CONTAINERS

The glass material used for the containers of food and beverages was identified as soda-lime glass. It consists of approximately 70% silica sand, 20% limestone, 5% "cullets" from recycled product and 5% different ingradients that give flint, emerald green, amber or royal blue color as required. These containers were blow-moulded to the designed shape and seperated into two categories, jars and bottles.

Glass usually failed in tension, showing its characteristic brittle fracture like other brittle materials (4, 5,6,7). Such brittle fracture occurred suddenly without previous plastic deformation (Fig.2) and usually originated at a high stress concentrated flaw or notch on the glass surface. It was also found that flaws were not a characteristic of glass per se but represented defects of accidential nature as a result of manufacturing processes and subsequent handling.

The condition required for brittle fracture is that the quantity of stored elastic energy caused by stress which was released during fracture must be greater than the energy absorbed by the crack during seperation. However, in ductile material, local yield around the flaw would receive high stress concentration so that the flaw would havelittle influence on breaking stress . But as reported, in glass, no such perceptible yield occurred so that relative stress concentration at fracture remained unchanged.

Fig.2: Stress-strain Curve of Glass.



Shand (4) further stated that flaw sizes were of an indefinate nature, and that the stress concentration factor depended mainly on its depth and length. Lawrence (8) gave a formula for stress concentration at the tip of flaw as:

$$\boxed{\sigma_c = 2\,\sigma_n (c/r)^{0.5}}$$

where;

σ_c = stress concentration

σ_n = normal tensile stress

c = depth of crack

and r = radius of curvature

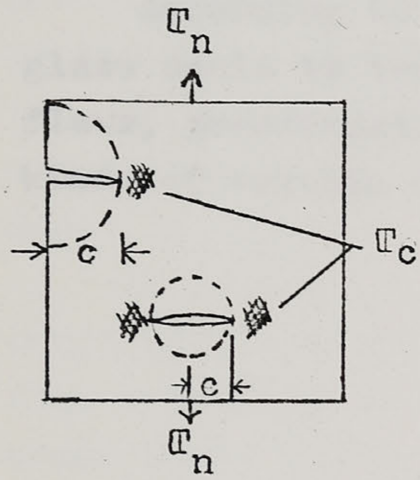


Fig.3

Stress Concentration on Glass surface.

Another important characteristics regarding brittle material fracture was the rapid propagation of fracture crack. Glass failed as a result of growth of existing crack and not usually generation of new ones. For existing crack or flaw to propagate, higher stress or load was essential. Recent researches (9,10,11) have gone further into the studies of the effects of water vapor, sodium-hydrogen ions exchange and electrolyte pH on crack propagations in soda-lime glass by using a double cantilever cleavage technique using microscopic slides and all of these were found to have definate influence on crack propagation.

The strength of glass varied very little with glass compositions (4,5).

In addition, static fatigue was also common in glass. Its breaking stress lowered with time-duration and repeated loading. Both static fatigue and strength could be improved if th moisture in glass could be removed.

"Variation in the strength of glass coupled with static fatigue, leads to long term practical tensile strength of glass as low as 2000 psi. Using a safety factor of two, the usually used design strength of glass is about 1000 psi. But careful consideration of problems and designs can raise this limit to 3000 psi for an annealed product and up to 20,000 psi for a tempered product" (5,7).

According to other sources (1,6), the strength of glass could be increased by removing large surface flaws, prestressing and surface coating with different kinds of organic compounds.

CHAPTER III

SAMPLING METHODS AND SELECTION CRITERIA

In this project, only the well designed compact bottles, from a recyclable standard stock having a capacity of 12 to 13 ozs., commonly known as "beer bottle" were used.

The bottle samples used were obtained from a grocery store. It had amber color, and was tempered in the lehr. Surface was coated for abrasion resistance and met the quality control requirements during the manufacturing processes. Dimensions of the bottle are shown in Appendix A.

It is known that the flaws on the glass surface could reduce the strength of glass product. Therefore flaw intensity on the glass surfaces, irrespective of trade marks and dates of manufacturing was considered for grouping the samples as shown below :

#1 - Normal bottles: bottles having no flaws or insignificant flaws on its surface(usually new, used bottles).

#2 - Slightly flawed bottles: bottles having flaws less than 2.5 mm wide and without any deep flaws.

#3 - Heavily flawed bottles: bottles having flaws more than 2.5 mm wide and containing deep flaws.

In addition to these three, new-virgin bottles (bottles newly obtained from the manufacturer) were also used for testing and this group was classified as #4 - Virgin bottles.

Current proposed sampling mathod according to flaw intensity on the body is still in its early stage of development and has not been well established, although a somewhat crude "Model" using the "co-acting flaw" concept has been suggested for use (12). The standard method of sampling according to ASTM (2) was not used for this project.

Table 1 shows the distribution of samples in its category selected randomly from 10 cases containing 24 bottles in each irrespective of make (since chemical compositions had very little effect on glass strength). These showed an approximate ratio of 3:4:3 for classes #1, #2 and #3 respectively.

It is to reminded that there was no cracked or unreturnable bottles in the samples. It should also noted that Standard ASTM method of sampling was relevent, since it was meant only for in-plant sampling.

CASE	#1-NORMAL	#2-S.F.	#3-H.F.
1	4	5	15
2	6	9	9
3	9	7	8
4	19	3	2
5	4	11	9
6	5	17	2
7	6	13	5
8	7	10	7
9	5	12	7
10	10	10	4
Total:	75	97	68
Percent:	31.25%	40.42%	28.33%

Table 1: Percentage Distribution of Different Bottle Samples in Randomly Selected 10 Cases of Compact Bottles

CHAPTER IV

EXPERIMENTAL PROCEDURE

a) Drop Test :

The apparatus designed for drop test consisted of two components (Appendix B-1).

(1) The drop surface: This consists of a 12"x12"x.25" steel plate, embedded in an18"x18"x2"concrete base.

(2) The drop mechanism: This consists of a vacuum pump that supplies vacuum (greater than 1 atm.) for holding the bottle on a proper dropping position above the centre of the drop surface. The bottle sample for test was held against a 3" diameter rubber stopper(having a 5" hole) while the stopper was connected to a glass tube that provided the vacuum. The other end of the glass tube was connected by a vacuum tube which supplied the desired vacuum from the pump. The rubber stopper was supported against the side of a ring on the horizontal bar by means of a compressed helical spring. The stand scaled at 6" interval allowed vertical movement for the horizontal bar for different drop height needed for the tests. A 3-way stopcock was located in the vacuum line for the steady drop control.

The test sample of 75 Normal bottles were used for AMH determination using the statistical design called "up and down" method of sensitive testing (Appendix B-1). The resulting values are expected to produce a curve similar to Fig. 4. Next 100 bottles each in 3 other sample groups were dropped at the determined AMH for relative strength vs flaw intensity evaluation.

b) Thermal Shock Test :

An automatic Thermal Shock Testing machine was used for this test(Appendix B-2). Initially, among the two tanks available, the first one was filled with water for hot bath,at 145°F, while the other was filled with cold water at 70°F. Five bottles from each sample were placed upright on the basket and were slowly lowered into the hot bath and were completely filled and soaked in hot water for a predetermined time of 5 minutes. The basket was then transferred to the cold bath after 30 seconds (15 to 60 secs. range) of exposure to air during the transfer period. After immersing in the cold bath for 30 seconds, the basket was lifted up to examine for crack and failure. Percentage of failure expected should be zero at 75°F in order to meet the ASTM Standard. The above procedure was repeated by setting hot bath temperature at an increment of 5° steps, up to 185°F. Each time the breakage percentage was recorded.

c) Impact Test :

The common swing type hammer pendulum impact machine, scaled with velocity of strike and available energy, was used to test a total of 10 bottles in each group (Appendix B-3 for machine specification).

To perform the test, a bottle was placed in a fixed position such that the pendulum strikes the sample base at a velocity of 20 ins/sec.(equivalent to 1.07 in-lbs of available energy)

When the bottle didn't break, it was turned 60° to a new position of strike while the pendulum was readjusted to give an increment of 2.5 in/sec. for the velocity of strike. This was continued progressively till breakage occurred. Impact energy required for break vs the flaw intensity relationship was then examined using the datas collected.

d) Internal Pressure Test :

The ramp or internal pressure testing machine, equipped with a digital readout for the pressure was used (Appendix B-4). The bottle for test was partially filled with water and suspended from its "bead of finish" but not clamped. Hydraulic pressure was applied when the bottle was fully filled and sealed until the breakage point when the pressure was recorded. Higher limit for pressure was set at 350 psi. Atotal of 50 bottles per sample group were tested. With the data obtained, ultimate internal pressure at breakage vs the flaw intensity relationship was studied.

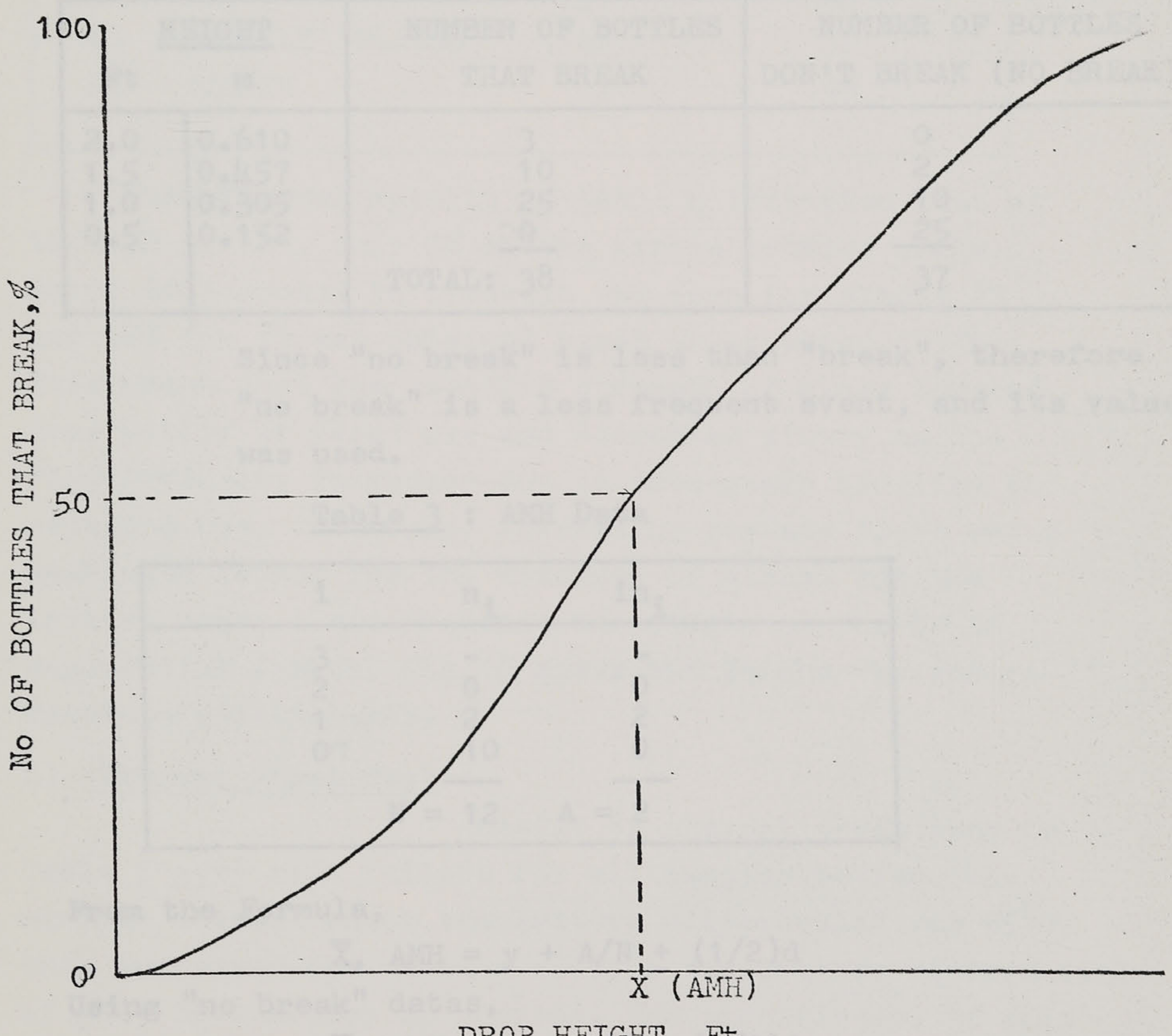


Fig.4 : SAMPLE CURVE

CHAPTER V

RESULTS AND DISCUSSION

a) Drop Test :

For the drop test, AMH was calculated using the tabulated data shown below:

Table 2 : Frequency of Break Datas

HEIGHT Ft	HEIGHT m	NUMBER OF BOTTLES THAT BREAK	NUMBER OF BOTTLES DON'T BREAK (NO BREAK)
2.0	0.610	3	0
1.5	0.457	10	2
1.0	0.305	25	10
0.5	0.152	0	25
		TOTAL: 38	37

Since "no break" is less than "break", therefore "no break" is a less frequent event, and its value was used.

Table 3 : AMH Data

i	n_i	in_i
3	-	-
2	0	0
1	2	2
0	10	0
	N = 12	A = 2

From the Formula,

$$\overline{X}, \text{AMH} = y + A/N \pm (1/2)d$$

Using "no break" datas,

$$\overline{X}, \text{AMH} = y + A/N - (1/2)d$$
$$= 1 + 2/12 - (1/2)(1/2)$$
$$= 0.92' \quad (11'')$$

Energy at break at AMH

$$= 11'' \times 8.5/16 \text{ ibs}$$
$$= 5.84 \text{ in-lbs.}$$

Bottle samples dropped at the arithmatic mean height (AMH) gave the following result: (Appendix C-1)

Table 4

Percentage Failure of Different Sample

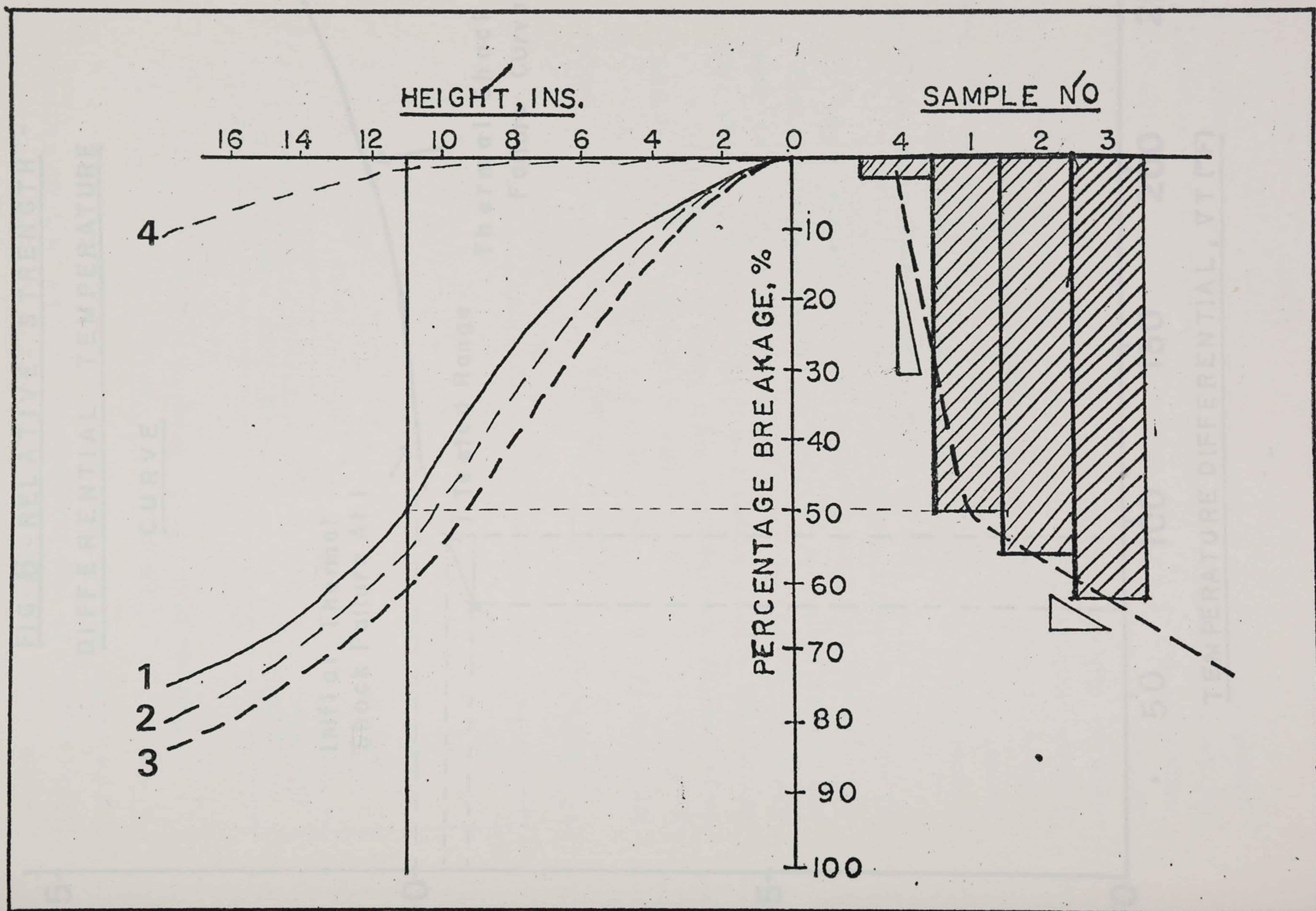
SAMPLE No	SAMPLE DESCRIPTION	DROPPED AT AMH (11")	
		BREAK(%)	NO-BREAK(%)
#1	NORMAL	50	50
#2	SLIGHTLY FLAWED	56	44
#3	HEAVILY FLAWED	62	38
#4	VIRGIN	2	98

Experimental results in Table 4 indicated that at the AMH of 11", only 2% of the virgin bottles broke. About 6% increase in breakage was seen for sample #2 and 12% for #3 was obtained based on expected 50:50. This meant that the relative strength of glass lowered drastically at first use and decreased slowly as the flaw intensity increased due to subsequent handling and repeated use. Obviously, increasing surface flaws was a weakening factor for the strength of glass, and the initial minor flaws weakened the virgin sample in an exponential fashon. Fig. 5 shows the Height-Percentage Breakage relationship.

b) Thermal Shock Test :

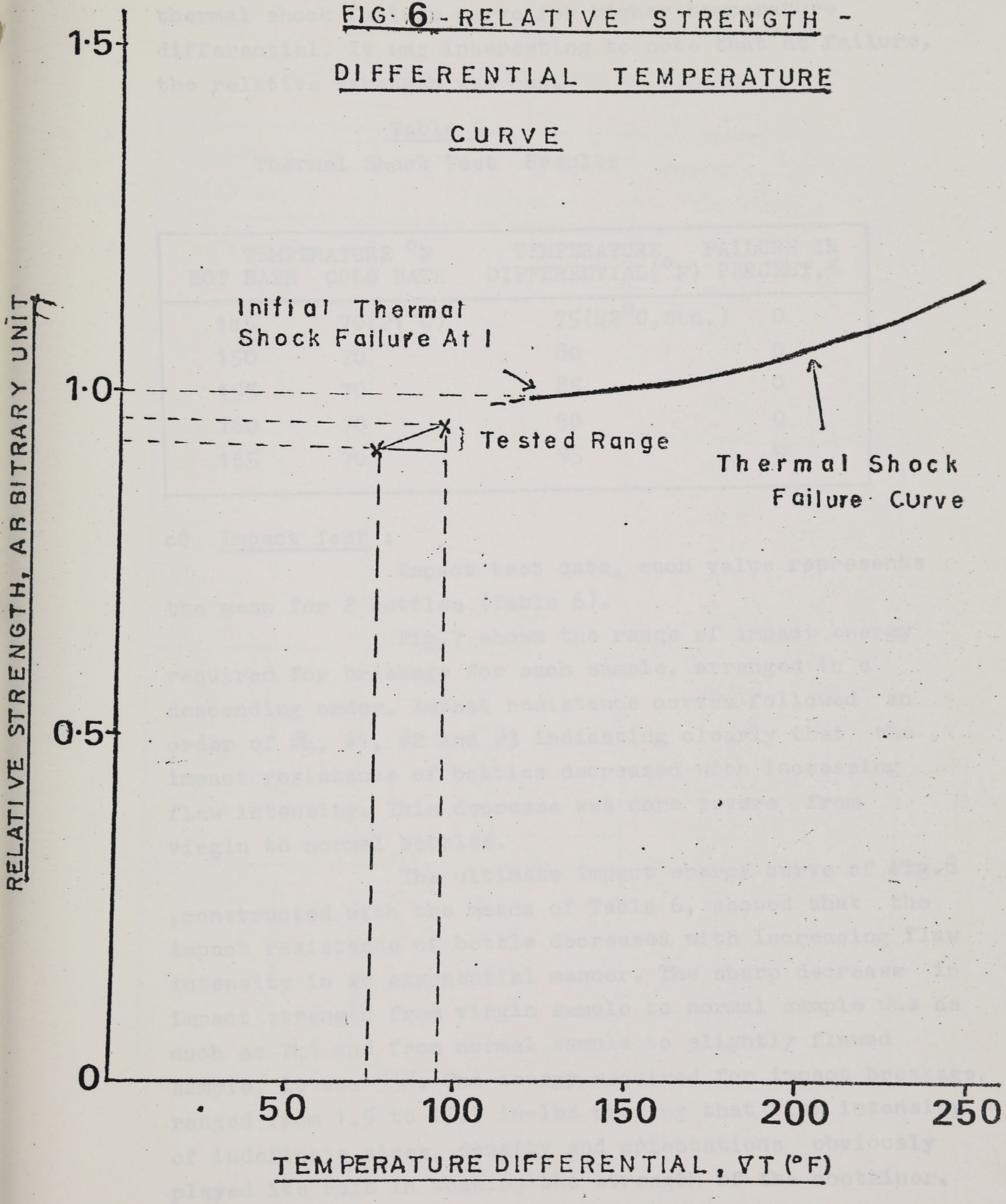
Result of thermal shock test in Table 5 gave zero failure for all samples tested. The maximum thermal shock temperature differential was 95°F, this surpassed the minimum of 75°F temperature differential of ASTM Standard by 20 degrees. The significance of this was that the thermal shock failure could not occur under various changes in temperature conditions during handling and processing.

No effort was made to determine the ultimate differential for breakage since above 95° of differential was seldom encountered in practice. Perhaps, interested



FIG·5 - PERCENTAGE BREAKAGE AT THE ARITHMATIC MEAN HEIGHT, AMH·

FIG 6 - RELATIVE STRENGTH - DIFFERENTIAL TEMPERATURE CURVE



reader could investigate the differentials for break of each sample to complete the picture. Fig.6 assumed the thermal shock failure curve for higher temperature differential. It was interesting to note that at failure, the relative strength was one.

Table 5

Thermal Shock Test Results

TEMPERATURE °F HOT BATH	COLD BATH	TEMPERATURE DIFFERENTIAL(°F)	FAILURE IN PERCENT,%
145	70(21°C)	75(42°C,Std.)	0
150	70	80	0
155	70	85	0
160	70	90	0
165	70	95	0

c) Impact Test :

Impact test data, each value represents the mean for 2 bottles (Table 6).

Fig.7 shows the range of impact energy required for breakage for each sample, arranged in a descending order. Impact resistance curves followed an order of #4, #1, #2 and #3 indicating clearly that the impact resistance of bottles decreased with increasing flaw intensity. This decrease was more severe from virgin to normal bottles.

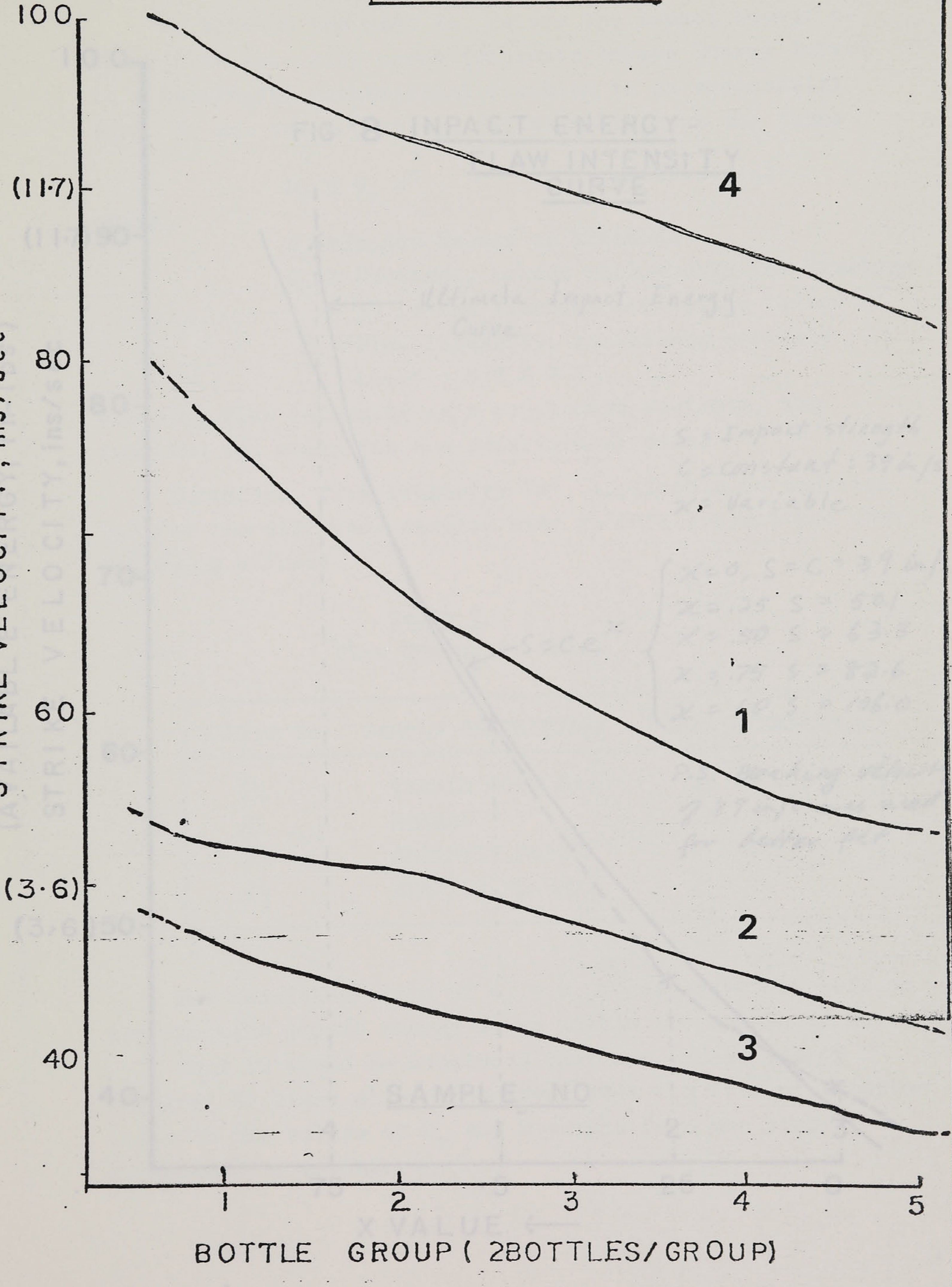
The ultimate impact energy curve of Fig.8 ,constructed with the means of Table 6, showed that the impact resistance of bottle decreased with increasing flaw intensity in an exponential manner. The sharp decrease in impact strength from virgin sample to normal sample was as much as 74% and from normal sample to slightly flawed sample, it was 53%. The energy required for impact breakage, ranged from 1.5 to 15.7 in-lbs proving that flaw intensity of indefinate sizes, density and orientations obviously played its role in weaking the strength of the container.

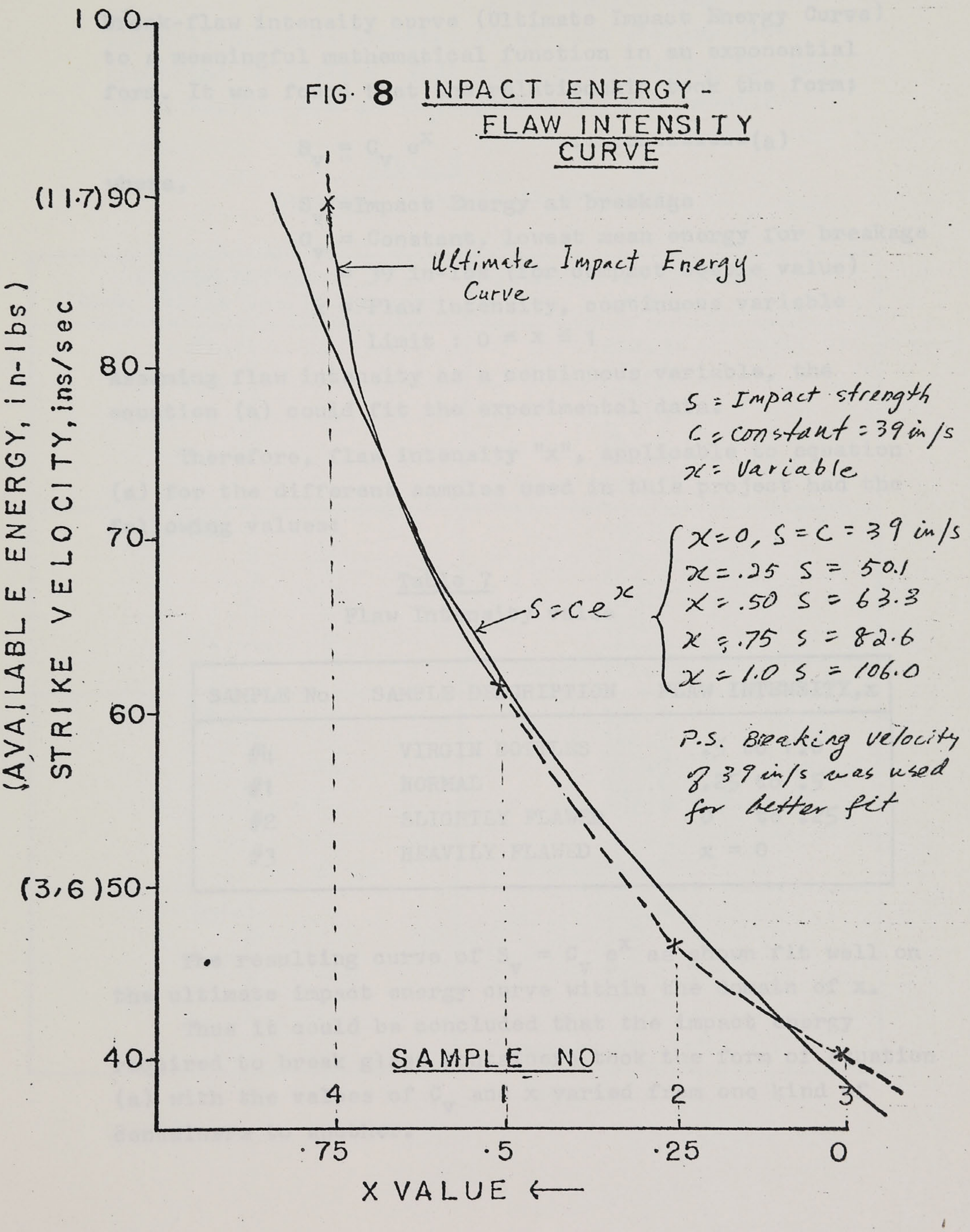
Table 6

Impact Energy of Breakage of Bottles

SAMPLE-BOTTLE (AVERAGE OF 2)	STRIKING VELOCITY (in/sec.)	AVAILABLE ENERGY in-lbs)
#1-- 1	75	8.2
2	62.5	5.6
3	55	4.4
4	65	6.1
5	52.5	4.0
	Mean= 61.96	Mean=5.66 S.D:1.66
#2-- 1	45	2.9
2	51.75	3.8
3	50	3.6
4	45	2.9
5	41.25	2.48
	Mean= 46.6	Mean=3.14 S.D:.55
#3-- 1	45	2.95
2	45	2.95
3	40	2.3
4	38.75	2.15
5	35	1.75
	Mean= 40.75	Mean=2.42 S.D:.52
#4-- 1	90	11.7
2	97.5	14.6
3	82.5	9.85
4	92.5	12.45
5	90.25	12.45
	Mean= 90.55	Mean=12.21 S.D:1.71

FIG. 7 AVAILABLE ENERGY - SAMPLE CURVE





FIG· 8 IMPACT ENERGY-FLAW INTENSITY CURVE

An attempt was made to relate the impact energy of break-flaw intensity curve (Ultimate Impact Energy Curve) to a meaningful mathematical function in an exponential form. It was found that the relationship took the form:

$$S_v = C_v e^x \qquad \text{-------------(a)}$$

where,

S_v = Impact Energy at breakage

C_v = Constant, lowest mean energy for breakage

= 39 in-lbs (for compact bottle value)

x = Flaw intensity, continuous variable

Limit : $0 \leq x \leq 1$

Assuming flaw intensity as a continuous variable, the equation (a) could fit the experimental data.

Therefore, flaw intensity "x", applicable to equation (a) for the different samples used in this project had the following values:

Table 7

Flaw Intensity value

SAMPLE No	SAMPLE DESCRIPTION	FLAW INTENSITY,x
#4	VIRGIN BOTTLES	.5 to 1.0
#1	NORMAL	.25 to .5
#2	SLIGHTLY FLAWED	0 to .25
#3	HEAVILY FLAWED	x = 0

The resulting curve of $S_v = C_v e^x$ as shown fit well on the ultimate impact energy curve within the domain of x.

Thus it could be concluded that the impact energy required to break glass containers took the form of equation (a) with the values of C_v and x varied from one kind of containers to another.

d) Internal Pressure Test :

Experimental results for internal pressure breakage of all the samples were tabulated in Table 8. Each value representing the mean of 10 bottles are shown (Appendix C-3 for details).

Table 8

Internal Pressure At Breakage

SAMPLE-BOTTLE (Each Bottle Rep.10 values)	PRESSURE AT BREAKAGE (psi)
#1--1	212.3
2	227.3
3	218.2
4	218.3
5	241.6
	mean =223.54
#2--1	185.7
2	176.3
3	183.6
4	184.5
5	190.1
	mean =184.04
#3--1	142.7
2	141.5
3	147.8
4	146.6
5	152.9
	mean =146.3
#4--1	325.0 *
2	350
3	350
4	350
5	350
	mean 350

*set limit

Fig.9 shows the range of ultimate internal pressure required for failure for each sample, arranged in descending order. Internal pressure resistance curves followed the descending order of #4, #1, #2 and #3 and proved that the internal pressure resistance of bottles decreased with increasing flaw intensity. The decrease was also very severe from virgin to normal bottle.

Within the set pressure limit for the experiment, virgin sample exceeded the normal sample in mean resistance by at least 35%. Variation from sample #1 to #3 was fairly uniform and is equal to 20% decrease in each case. This again indicated that the decrease in the internal pressure resistance was of an exponential nature, as could be seen in Fig.10 (Ultimate Internal Pressure Curve). A similiar exponential function as before was obtained:

$$S_p = C_p \, e^x \qquad \text{-------------(b)}$$

where,

S_p = Internal Pressure at breakage

C_p = Constant, lowest mean internal pressure at breakage

= 145 psi (for compact bottle)

x = Flaw intensity, continuous variable

Limit : $0 \leq x \leq 1$

assuming that the flaw intensity as a continuous variable, the equation (b) could fit the experimental data.

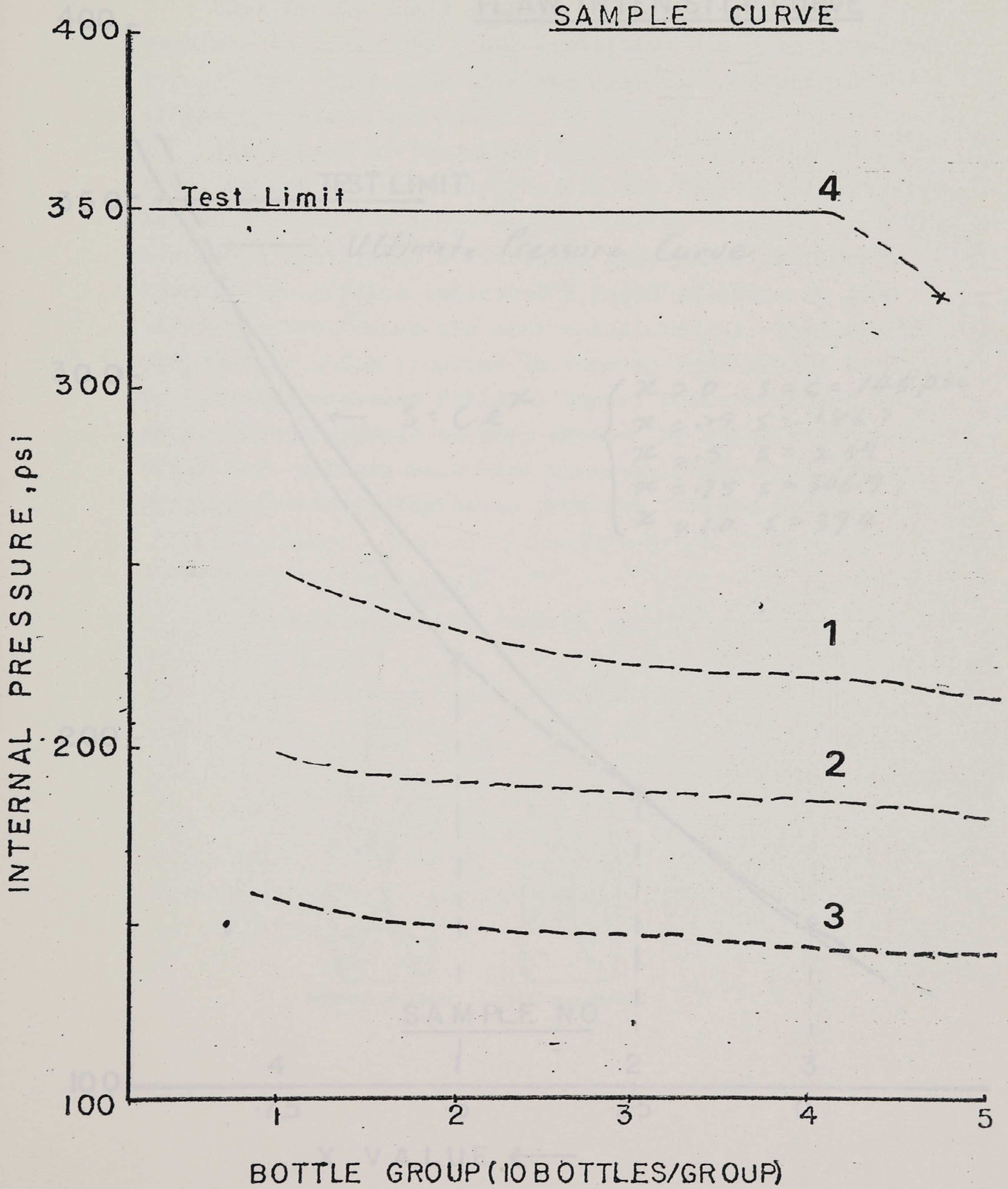
Therefore, flaw intensity x had the following values corresponding to the different sample used in the experiment:

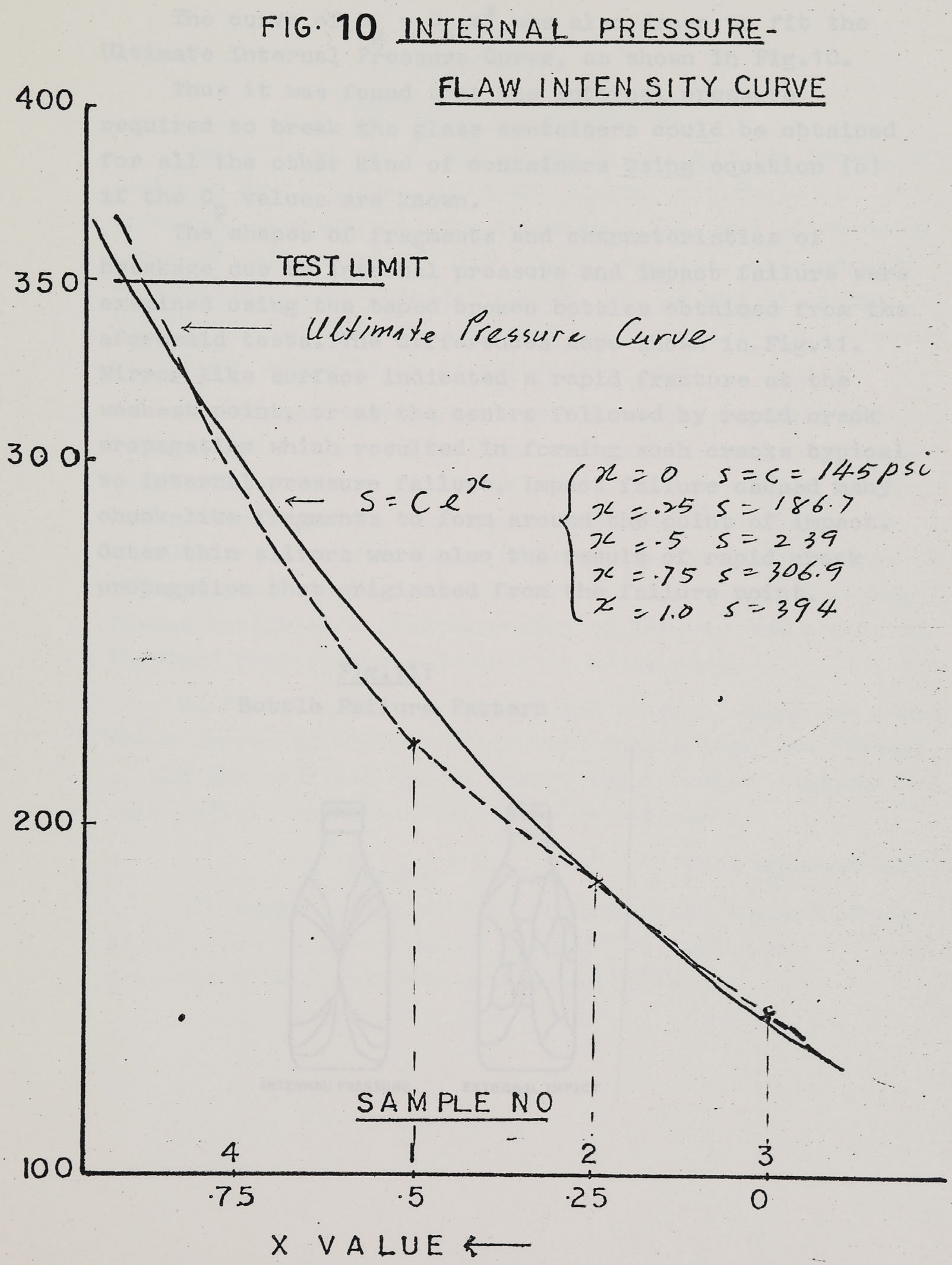
Table 9

Flaw intensity value

SAMPLE No	SAMPLE DESCRIPTION	FLAW INTENSITY,x
#4	VIRGIN BOTTLES	.5 to 1.0
#1	NORMAL	.25 to 0.5
#2	SLIGHTLY FLAWED	0 to 0.25
#3	HEAVILY FLAWED	x = 0

FIG. 9 INTERNAL PRESSURE-SAMPLE CURVE




FIG· 10 INTERNAL PRESSURE-FLAW INTENSITY CURVE
400
350
300
200
100
TEST LIMIT
Ultimate Pressure Curve
S = Ce^x
x = 0 s = c = 145 psi
x = .25 s = 186.7
x = .5 s = 239
x = .75 s = 306.9
x = 1.0 s = 394
SAMPLE NO
4
1
2
3
·75
·5
·25
0
X VALUE

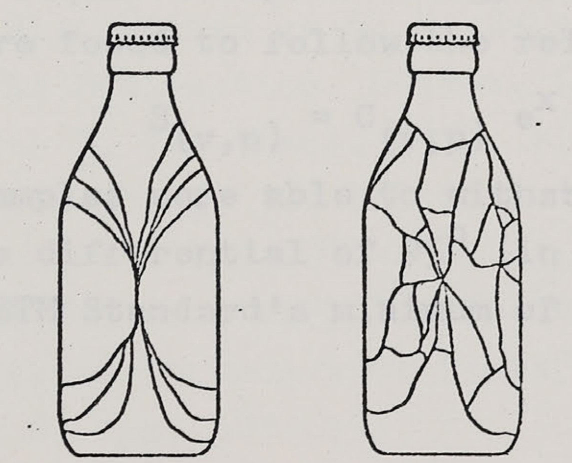
The curve of $S_p = C_p\ e^x$ was also drawn to fit the Ultimate Internal Pressure Curve, as shown in Fig.10.

Thus it was found that the internal pressure required to break the glass containers could be obtained for all the other kind of containers using equation (b) if the C_p values are known.

The shapes of fragments and characteristics of breakage due to internal pressure and impact failure were examined using the taped broken bottles obtained from the aforesaid tests. The differences were shown in Fig.11. Mirror like surface indicated a rapid fracture at the weakest point, or at the centre followed by rapid crack propagation which resulted in forming such cracks typical to internal pressure failure. Impact failure caused many chunk-like fragments to form around the point of impact. Outer thin slivers were also the result of rapid crack propagation that originated from the failure point.

Fig.11:

Bottle Failure Pattern



CHAPTER VI

SUMMARY AND CONCLUSIONS

The AMH, at which 50% of the Normal bottles broke, was found to be 11 inches, with the energy of 5.84 in-lb for breakage. Dropping at the determined AMH, the descending order of failure of 2%, 50% (Normal sample), 56% and 62% respectively were obtained for #4, #1, #2 and #3 groups. This indicated that the relative strength of bottle lowered with flaw intensity in an exponential form.

The impact energy required for breakage ranged from 1.5 to 15.7 in-lbs, while the internal pressure requirement ranged from 146 psi to 350 psi and more. According to the Brewery Association, impact resistance of 1.8 in-lbs (30 in/sec) or more and minimum internal pressure resistance of 175 psi were considered satisfactory. This meant that highly flawed bottle with flaw intensity of x=0 was below the ASTM Standard requirement and couldn't be reused.

Both the impact resistance and internal pressure resistance decreased exponentially with increasing flaw intensity, x, and the required impact energy and internal pressure at failure were found to follow the relationship:

$$S_{(v,p)} = C_{(v,p)}\ e^{x} \qquad \text{(from equation(a)+(b))}$$

All samples were able to withstand the thermal shock temperature differential of 95° (in °F), which was 20° higher than the ASTM Standard's minimum of 75°F.

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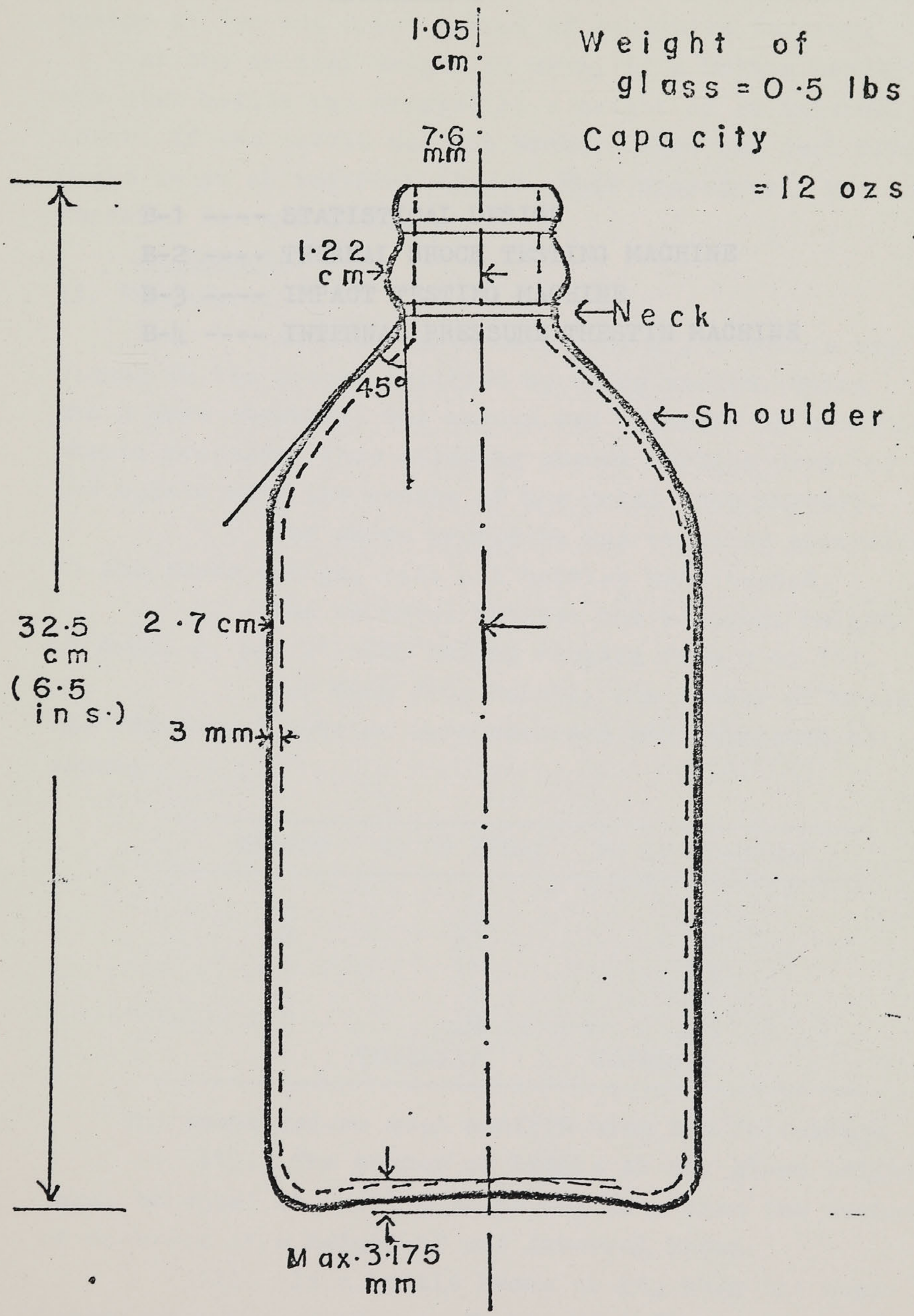
APPENDIX A

THE BOTTLE DIMENSIONS

THE BOTTLE DIMENSIONS



APPENDIX B

B-1 : STATISTICAL DESIGN

The determination of AMH employed the statistical design of "up and down" method of sensitive testing.

At the initial Height of drop, if a bottle broke, the next bottle was dropped at a height of an interval lower. If the bottle was not broken, then the next drop would be at an interval higher. This procedure was repeated for all bottles.

An Example:

a). Procedure:

At a suitable height of 4', a bottle was placed in its proper position by using vacuum. Using the 3 ways stopcock, the vacuum was released to atmospheric pressure, thus allowing steady upright drop of the bottle onto the centre of the metal drop surface.

The above procedure was repeated according to the above design, till all bottles were tested.

The interval between the adjacent height at drop, d, was 2' with height ranging from 0 to 15'.

For each drop height, the number of "break" and "no-break" bottles were recorded and tabulated as shown:

HEIGHT	NO OF BREAK	NO OF NO-BREAK
10	2	0
8	22	2
6	11	23
4	2	11
2	0	2
	TOTAL:37	TOTAL:38

The above values must conform with the following:

(1). The number of breaks at any given height must bo equal to, more than or one less than the number of No-break at a height of one interval lower.

(2). If a bottle broke at 2', then the next bottle will be recorded as No-break at 0' and is considered proper to set aside as if it had been dropped.

If the total of breaks is less than the total of No-break, then the "Break" is referred to as "Less Frequent Event". On the contrary, then the "No-break" is the "Less Frequent Event".

The data of the "Less Frequent Event" were then tabulated as follows for AMH determination.

i	n_i	in_i
3	2	6
2	22	44
1	11	11
0	2	0
	N=37	A=61

Where,

i = 0, 1, 2, 3 etc

i = 0 is for the lowest height at which break start to occur

n_i = frequency of break (number of bottles) at each level of i

A = sum of in_i

N = total bottles in less frequent event

b). Calculation of the Arithmatic Mean Height (AMH) :

$$\bar{X} = y + A/N \pm (1/2)d$$

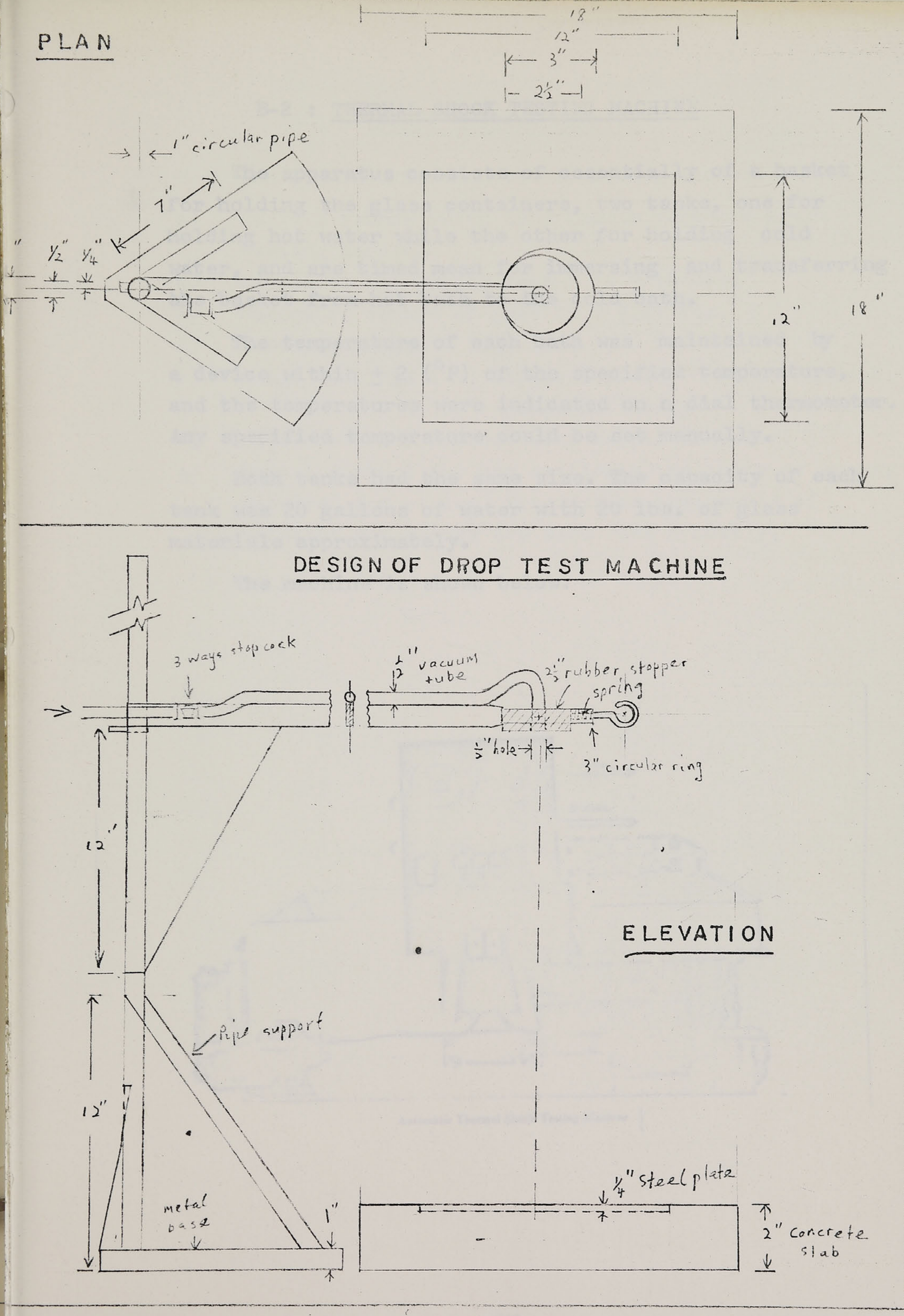
Where,

y = lowest height at which Less Frequent Event occurs, ft.

$\bar{X}$ = AMH, ft.

Therefore,

$$\bar{X} = 2 + 61/37 + (1/2)(2)$$
$$= 4.65 \text{ ft.}$$



DESIGN OF DROP TEST MACHINE

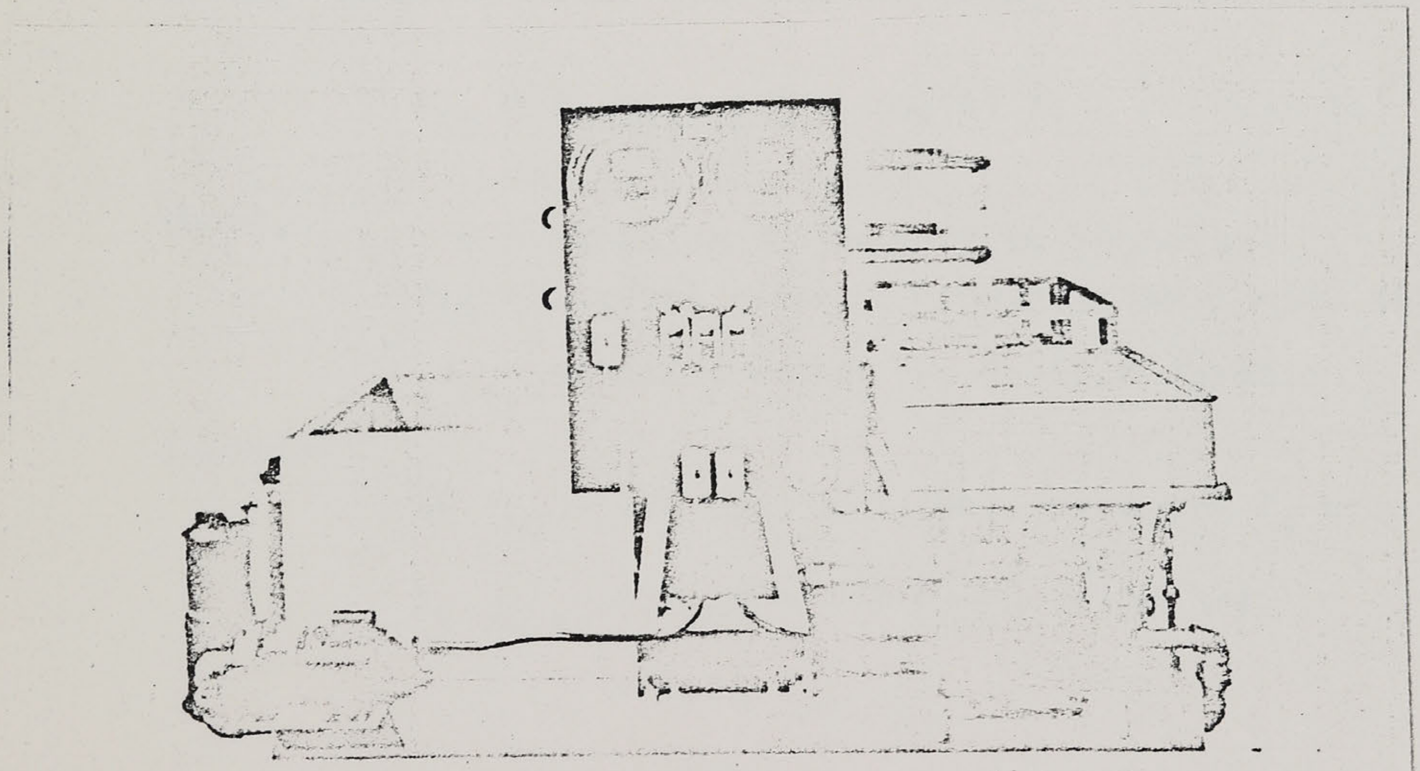
B-2 : THERMAL SHOCK TESTING MACHINE

The apparatus consists of essentially of a basket for holding the glass containers, two tanks, one for holding hot water while the other for holding cold water, and are timed mean for immersing and transferring the basket from hot bath to the cold bath.

The temperature of each bath was maintained by a device within $\pm$ 2 (^{o}F) of the specified temperature, and the temperatures were indicated on a dial thermometer. Any specified temperature could be set manually.

Both tanks had the same size. The capacity of each tank was 20 gallons of water with 20 lbs. of glass materials approximately.

The machine is shown below.



Automatic Thermal Shock Testing Machine

B-3 : IMPACT TESTING MACHINE

The machine used has the following features:

a) It is a common swing type hammer pendulum impact testing machine.

b) Radius to the strike face = 11 9/16 ins.

c) Radius to centre of gravity = 9.41 ins.

d) Pendulum weight = 1.35 lbs.

e) Scale Readings : i) Strike Velocity 0 - 500 ins/sec.
ii) Available Energy 0 - 46.15 in-lbs.

f) Adjustment for various size bottle samples.

g) Manual control for any setting of velocity or energy required for strike. Progressive increments of velocity and energy are also done manually.

B-4 : INTERNAL PRESSURE TESTING MACHINE

The machine employed water as the working fluid. The pressure pump supplied a uniform pressure during testing.

The apparatus consisted of a fork-like holder on which the "bead of finish" of the bottle was suspended, a manually operated resilient sealing member which acted with the sealing surface of the container to retain the pressurized medium during the period of test and within the centre of the sealing member was a glass tube. Initially, this glass tube supplied water to fill the container, then fluid pressure was applied internally in a progressive manner till the container failed.

As the internal pressure increased, the digital counter gave a continuous pressure readout till the set pressure of 350 psi (in this project) was reached. If the container didn't break at this limit, higher limit could be set.

The pressure readout at breakage was equivalent to the test pressure for a one minute duration. Pressure required at any duration could be obtained using the relationship:

$$P_{60} = \left(\frac{7.97 + 1.53}{10.69}\ \log t\right) P_i \qquad \text{-----(c)}$$

Where,

t = duration of test (3 to 60 secs.)

P_{60} = digital readout pressure, at 1 min. duration

P_i = actual pressure at desired duration

Example:

At P_{60} = 100 psi, a 3 secs. pressure P_i would be

$$P_{3\ \text{secs.}} = P_{60} \left\{ \left(\frac{7.97 + 1.53}{10.69} \right) (\log 3) \right\}$$

$$= 1.23\ P_{60}$$

$$= 123 \text{ psi.}$$

APPENDIX C

C-1a---- DATA FOR AMH DETERMINATION
C-1b---- DETAIL DATA OF SAMPLE DROP AT AMH
C-2 ---- EXPERIMENTAL DATA OF IMPACT TESTING
C-3 ---- EXPERIMENTAL DATA FOR INTERNAL PRESSURE TEST

C-1a: DATA FOR AMH DETERMINATION
(NORMAL SAMPLE)

BOTTLE No	HEIGHT	BREAK(Y/N)	BOTTLE No	HEIGHT	BREAK(Y/N)
1	2 (ft)	yes	36	.5	n
2	1.5	y	37	1	y
3	1	no	38	.5	n
4	1.5	y	39	1	n
5	1	y	40	.5	y
6	.5	n	41	1	y
7	1	y	42	.5	n
8	.5	n	43	1	y
9	1	y	44	.5	n
10	.5	n	45	1	y
11	1	y	46	.5	n
12	.5	n	47	1	y
13	1	y	48	.5	n
14	.5	n	49	1	y
15	1	y	50	.5	n
16	.5	n	51	1	y
17	1	n	52	.5	n
18	1.5	y	53	1	y
19	1	n	54	.5	n
20	1.5	y	55	1	y
21	1	y	56	.5	n
22	.5	n	57	1	y
23	1	y	58	.5	n
24	.5	n	59	1	n
25	1	y	60	1.5	y
26	.5	n	61	1	n
27	1	n	62	1.5	y
28	1.5	y	63	1	y
29	1	y	64	.5	n
30	.5	n	65	1	y
31	1	y	66	.5	n
32	.5	n	67	1	y
33	1	n	68	.5	n
34	1.5	y	69	1	n
35	1	y	70	1.5	n
			71	2	y
			72	1.5	n
			73	2	y
			74	1.5	y
			75	1	n

C-1b : <u>DATA OF SAMPLES DROP AT AMH OF 11"</u>

(y = break at AMH of 11"
n = no-break at AMH)

BOTTLE No	SAMPLES No			BOTTLE No	SAMPLE No		
↓	#2	#3	#4	↓	#2	#3	#4
1	n	y	n	51	n	y	n
2	y	y	n	52	y	n	n
3	y	y	n	53	n	n	n
4	n	n	n	54	n	n	n
5	n	y	n	55	y	y	n
6	y	n	n	56	y	n	n
7	n	y	n	57	y	y	n
8	y	n	n	58	n	y	n
9	n	y	n	59	y	y	n
10	n	y	n	60	n	n	n
11	y	y	n	61	n	n	n
12	y	n	y	62	n	y	n
13	y	y	n	63	n	y	n
14	n	y	n	64	y	n	n
15	y	n	n	65	y	y	n
16	n	y	n	66	n	y	n
17	y	y	n	67	y	n	n
18	y	y	n	68	y	y	n
19	y	n	n	69	y	y	n
20	y	y	n	70	y	y	n
21	y	y	n	71	n	y	n
22	y	n	n	72	y	y	n
23	n	y	n	73	n	y	n
24	y	n	n	74	y	n	n
25	n	n	n	75	n	y	n
26	y	n	n	76	n	n	n
27	n	y	n	77	n	y	n
28	y	y	n	78	y	n	n
29	y	n	n	79	n	n	n
30	y	n	n	80	y	y	n
31	y	y	y	81	y	n	n
32	y	y	n	82	y	y	n
33	n	n	n	83	n	y	n
34	y	n	n	84	y	y	n
35	y	y	n	85	n	y	n
36	n	n	n	86	n	y	n
37	y	n	n	87	n	y	n
38	y	n	n	88	n	y	n
39	n	y	n	89	y	y	n
40	n	n	n	90	y	y	n
41	n	y	n	91	n	n	n
42	n	y	n	92	y	n	n
43	n	y	n	93	n	y	n
44	n	y	n	94	y	y	n
45	y	n	n	95	y	n	n
46	y	y	n	96	y	n	n
47	y	y	n	97	n	n	n
48	y	y	n	98	y	y	n
49	y	y	n	99	n	n	n
50	y	y	n	100	n	y	n

C-2 : EXPERIMENTAL DATA OF IMPACT TESTING

SAMPLE#-Bottle No ↓	STRIKING VELOCITY (in/sec.)	AVAILABLE ENERGY (in-lbs.)
#1-1	65	6
2	85	10.4
3	60	5.2
4	65	6
5	55	4.4
6	55	4.4
7	70	7.
8	60	5.2
9	50	3.6
10	55	4.4
#2-1	45	2.9
2	45	2.9
3	52.5	4
4	50	3.6
5	50	3.6
6	50	3.6
7	45	2.9
8	45	2.9
9	47.5	3.2
10	35	1.75
#3-1	40	2.3
2	50	3.6
3	50	3.6
4	40	2.3
5	40	2.3
6	40	2.3
7	37.5	2
8	40	2.3
9	32.5	1,5
10	37.5	2
#4-1	85	10.5
2	95	12.9
3	95	12.9
4	100	14.3
5	80	9.2
6	85	10.5
7	105	15.7
8	80	9.2
9	80	9.2
10	105	15.7

C-3 : DETAIL EXPERIMENTAL DATA FOR INTERNAL PRESSURE TESTS (Values in psi)

Bottle No	#4	#1	#2	#3
1	350	233	163	146
2	350	214	196	121
3	350	172	176	141
4	325	213	195	128
5	350	222	167	147
6	350	192	164	135
7	350	174	187	183
8	350	244	221	128
9	350	186	184	145
10	350	273	204	153
11	350	184	189	126
12	350	235	161	130
13	325	273	133	169
14	350	270	157	137
15	-	210	148	148
16	-	227	161	123
17	-	214	199	161
18	-	212	159	151
19	-	230	201	143
20	-	218	203	127
21	-	176	184	125
22	-	243	174	188
23	-	232	191	134
24	-	187	168	163
25	-	226	165	136
26	-	204	152	125
27	-	227	210	147
28	-	225	164	144
29	-	264	167	132
30	350	198	233	184
31	-	189	148	174
32	-	249	198	171
33	-	211	221	139
34	-	163	195	149
35	-	301	156	122
36	-	211	159	129
37	-	199	204	152
38	-	243	247	171
39	-	193	181	128
40	-	224	206	131
41	-	239	162	177
42	-	240	173	126
43	-	255	174	147
44	-	261	152	138
45	-	190	205	140
46	-	264	210	132
47	-	278	191	149
48	-	202	255	172
49	-	200	188	158
50	350	287	210	136

APPENDIX D

ASTM DESIGNATION LIST USED

1). Standard Drop Test For Glass Aerosol Bottles
-- ASTM D-3071 --

2). Thermal Shock Test On Glass Containers
-- ASTM C-149 --

3). Standard Method Of Internal Pressure Test In Glass Containers
-- ASTM C-147 --

4). Standard Method Of Sampling Glass Containers
-- ASTM C-244 --