A PRACTICAL APPROACH TO THE ASSESSMENT OF HEAD RETENTION OF BOTTLED BEERS

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A method is described for the assessment of the head retention of bottled beers. The technique enables three aspects of head retention (head formation, adhesion and collapse rate of the foam) to be simultaneously determined. The procedure consists of the shock injection of a small volume of carbon dioxide under pressure into a known volume of beer, previously introduced without fobbing into a specially-calibrated glass vessel, followed by measurements at stated intervals on the foam so produced. The apparatus is simple and inexpensive and a determination can be completed in 7–8 min. Some results for bottled beers are discussed in respect of bottle-to-bottle differences; the effect on head retention of storage and of the use of wheat flour in the grist has also been examined. It is claimed that the method gives results which are more informative than those defined by a single factor such as half-life and are more in line with consumer judgement.

Introduction

The measurement of the head retention of beers in a comprehensive and reproducible manner has long been a difficult analytical problem. The simple method of pouring beer into a clean glass in the normal way is sufficient to give a good/bad type of answer and it is, of course, the method by which the consumer evaluates the product. Clearly, however, for both adequate process control

and product development, recourse must be made to more refined techniques.

Previous methods may be broadly divided into two groups. The first group, typified by the Helm[9] ("Carlsberg") method and, more recently, by those due to Hartong[8] and de Clerck,[6] produces the foam by a pouring procedure. The second group, exemplified by the Blom & Prip[3] ("Tuborg") method, relies on foaming the beer *in situ* by injection of gas and can therefore be also applied to worts and uncarbonated beers. The quantity of foam produced and its stability with respect to time may be determined from the volume or weight of foam itself, or indirectly from the volume of beer obtained when it is collapsed. The method of Ross & Clark,[12] in which foam is produced by either method, represents an attempt to obtain a single expression for foam stability, Σ, which is related to the half-life of the foam by the factor 1·44.

Many subsequent published methods are refinements of these fundamental approaches but with improvements in standardization of, and control over, the operating conditions. In this connection mention may be made of the techniques of Laufer & Ziliotto[11] in which the foam is weighed, and of Gray & Stone,[7] a modified Ross & Clark method in which Σ is determined together with an expression for foam density, 100 v/V (where V is foam volume and v is the volume of beer produced when the foam is collapsed).

Schuster & Mischke[14] produced foam by allowing sand particles to fall into a measured volume of beer from a predetermined height. On the other hand Brenner, McCully & Laufer[4] obtained foam by flashing the beer through a small orifice under an atmosphere of CO_2 to exclude air, while Brenner, Siebenberg & Zientara[5] recently advanced this method with closer control over temperature. Other well-known foaming methods are those of Rudin,[13] using CO_2 injection through a sintered disc and of Klopper[10] which includes the important measurement of foam adhesion as well as duration.

It is clear that the various methods for determining head retention involve a multiplicity of techniques, each one having certain advantages and disadvantages. Experience has shown that those methods which depend on foaming a beer artificially and determining the head retention in terms of the half-life of the foam (Σ value), do not always give results in line with consumer judgement. On the other hand pouring methods, based on the original technique of Helm, introduce errors because conditions of bubble formation are difficult to standardize and aeration effects will clearly be variable. Both de Clerck and Ross & Clark have drawn attention to the fact that bubble size must be controlled in any method for measuring foam stability in order to obtain consistent results. According to de Clerck & de Dijker,[6] foam stability depends more on the fineness of the bubbles than on the composition of the beer. Consequently, any method of producing foam by means of a porous candle or filter meets with the practical difficulty that the pores tend to get blocked with use and this, in turn, affects the bubble size.

From a practical angle it is difficult to see how the many facets of head retention can be adequately expressed by means of a single symbol, whether it be half-life in seconds, Σ value or any other unit. From the brewer's point of view, with carbonated beverages from bottle, keg or can, detailed information is required as to the amount of head produced on pouring and the adhesive quality and the rate of collapse of the foam. These three properties, if known, would fairly comprehensively define the behaviour of a beer in respect of head characteristics. It is important to know the amount of head formed since unsatisfactory head retention can sometimes be ascribed to poor carbonation. Helm[9] has already made the point that foam formation is approximately proportional to the level of carbonation in the beer. Although this value can be determined independently in numerous ways, it would be useful to have the information as part of the measurement of head retention. Klopper[10] has drawn attention to the importance of foam adhesion as a quality of beer foam while the brewer thinks of it as a "lacing" effect on the glass. In any complete definition of head retention, it is maintained that this character should be assessed. The third property, the collapse rate of the foam, is undoubtedly the most important characteristic of beer foam and all the published methods measure this—but in differing ways.

Since the rate of collapse of beer foam depends on so many diverse factors, *e.g.*, the size of bubble, the nature of the gas in the bubble, the composition of the beer especially

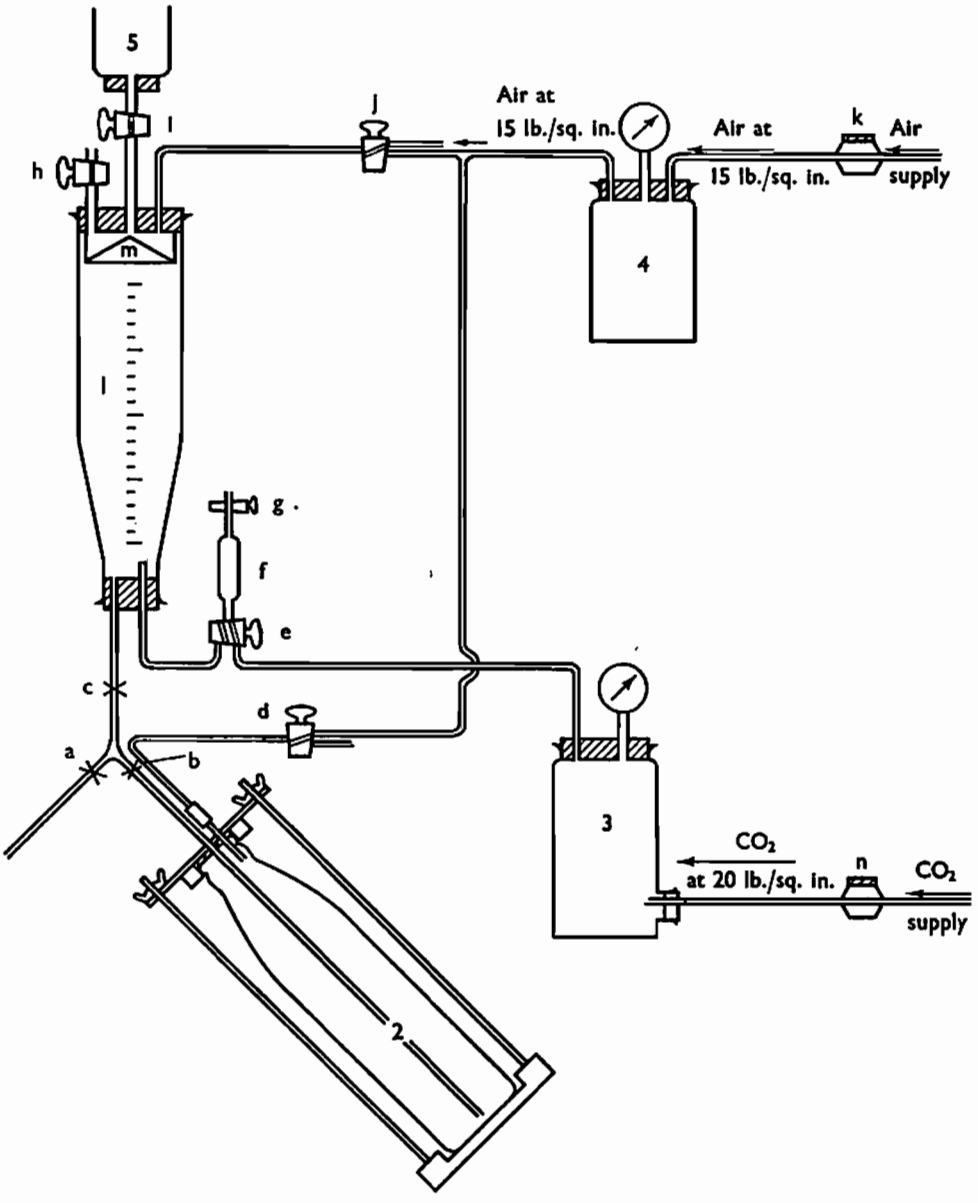

Fig. 1.—Head retention apparatus. For details, see text.

in respect of surface active protein compounds, the drainage rate of the beer from the foam, to mention but a few, it is surprising to find many methods apparently disregarding the importance of controlling experimental conditions. Pouring methods, for example, result in a variable amount of air being entrapped in the foam while foaming methods using porous candles give a variable bubble size and with long periods of foaming, tend to alter the physical-chemical relationship at the gas-liquid interface to the detriment of the foam stability. Since temperature affects the rate of drainage of beer from the foam, this is another factor which must be strictly controlled.

In the method to be described, an attempt has been made to resolve these difficulties and to give precision to a method for evaluating beer foam in line with consumer judgement. This concept has been notably neglected in hitherto published methods. In order to simulate the conditions obtaining in practice when beer is poured into a glass, the cylindrical, calibrated glass vessel used for head-retention measurements is made nearly the same diameter as a beer glass. The sample (100 ml.) is carefully introduced into this vessel under counter-pressure without foaming and the beer head is produced instantaneously by the sudden injection of a fixed volume of CO_2 under pressure. The jet through which the CO_2 is injected has a single orifice which is accurately standardized so that bubble size in the foam is precisely controlled. The volume of the head so produced is read off directly in the calibrated cylinder and the value can be shown to be linearly related with the level of carbonation. The difference between the level of the foam ring at the start and after 4 min. gives a measure of adhesion while the volume of foam left after 4 min. compared with the volume at the start gives a measure of collapse rate. In this way, in a single determination, foam formation, foam adhesion and foam collapse are measured. Foam formation is returned as a percentage of the original beer volume (100 ml.) while the adhesion and collapse values are returned as percentages of the total head. All determinations are carried out at 70° F., the temperature being strictly adhered to both in respect of apparatus and of sample. Special precautions are taken to ensure that the interior of the glass vessel is free from any traces of grease and that conditions are the same at the commencement of each determination. The purity of the CO_2 is checked before use and any supply contaminated with air is rejected.

Experimental

Description of apparatus.—The apparatus (Fig. 1) consists of a cylindrical glass measurement vessel (1) which is open at both ends and tapers toward the lower end. It is calibrated in ml. with the zero mark (0) at the 100 ml. level. In order to withstand pressures up to 15 lb. p.s.i., heavy duty glass is used for this vessel and for the reservoirs for carbon dioxide (3) and air (4). All fittings for the apparatus are wired or attached with metal bands and all taps are spring-loaded.

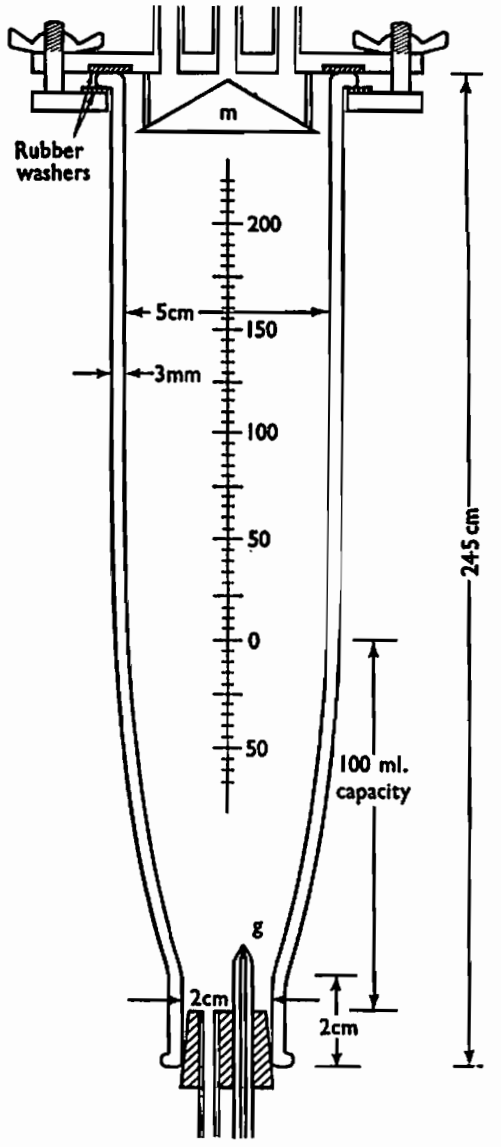

Fig. 2.—Calibration vessel (1 in Fig. 1).

The upper end of vessel (1) is closed with a metal adaptor which seats on the lip of the glass cylinder (as shown in Fig. 2). It consists of an upper circular metal plate having an inset rubber washer and a lower flat metal ring which makes contact with a rubber washer round the lip of the cylinder.

An air-tight seal is made by screwing the top plate down on to the metal ring by means of two wing nuts. There are three circular holes in the upper metal plate, one admitting compressed air at 15 p.s.i. via tap (j), a second washing liquid from reservoir (5) while a third carries a pressure release tap (h). Secured to the underside of the top plate is a metal cone (m), the apex of which is directly in line with the tube leading from reservoir (5). On turning tap (i), a stream of washing liquid is deflected by this cone on the walls of the cylinder and this facilitates easy washing of the glass vessel at the conclusion of a determination.

The tapered end of vessel (1) is fitted with a bung which carries two glass tubes, one of which is used both for filling and emptying the vessel. The other tube consists of capillary tubing (O.D. 6 mm., I.D. 1·5 mm.) which has been drawn out to form a micro-jet. It projects 1 cm. above the bung and is 12·5 cm. in length from tap (e) to the tip of the jet (Fig. 1). The jet is made by sealing a piece of the capillary tubing and grinding one end down with emery cloth to form a fine orifice with diameter approximately 5/1000 in. The precise size of this jet is such that when attached to a vessel of capacity 400 ml. containing carbon dioxide at 20 p.s.i., it will release gas to the atmosphere at such a rate that the pressure falls from 20 lb. to 10 lb. in 160 sec. The capillary tube and jet are connected by means of a two-way tap (e) to a small CO_2 reservoir (f), the top end of which is closed by means of tap (g). The volume of this reservoir together with that of the capillary tube is 2·5 ml. The other arm of tap (e) is connected to the large CO_2 reservoir (3) which is filled with CO_2 at 20 lb. pressure via reducing valve (n). Both CO_2 reservoirs act as dust-traps, an important requirement since even small dust particles will affect the orifice of the jet.

Reservoir (4) is filled with air at 15 lb. p.s.i. via reducing valve (k) and is used to pressurize vessel (1) by means of the two-way tap (j) and also the bottled sample by means of the two-way tap (d). The sample bottle is held in place by a clamping device (2) consisting of a solid base into which two rods have been permanently fixed. Their free ends are threaded and bear wing nuts which screw down on to an upper metal plate carrying two central tubes, the lower ends of which pass into the sample bottle. This upper plate fits over the mouth of the opened bottle and a rubber washer forms an airtight seal when the two wing nuts are tightened. The two ends of the plate are slotted to accommodate the upright metal rods and nuts.

The shorter of the two central tubes leading into the bottled sample is connected by a short piece of rubber tubing to the two-way tap (d) and thence to the air reservoir (4). The longer tube, which consists preferably of polythene tubing and which reaches to the bottom of the sample bottle, is connected by tubing to the Y-tube leading into the bottom of vessel (1). Screw clips are sited in positions (a), (b) and (c), and these control respectively the removal to waste and the entry and exit of beer into vessel (1).

The gas reservoirs (3) and (4), capacity approximately 500 ml., consist of stout glass jars closed with tightly fitting bungs each carrying a pressure gauge and inlet and outlet glass tubes (O.D. 6·7 mm. and I.D. 4·5 mm.). Vessel (5) is essentially a reservoir for filtered beer used for rinsing vessel (1) prior to a determination. Flow into vessel (1) is controlled by tap (i).

Experimental procedure.—The principle of the method is based on the careful introduction of 100 ml. of beer into vessel (1) without fobbing and the subsequent injection of a small amount of CO_2 (2·5 ml.) into the beer with such force that the beer immediately foams. All determinations are made at 70° F. but it is advisable to carry out one or two "dummy" runs with bottled beers before a series is actually started. Some waste beer should be previously filtered for use as washing liquid in reservoir (5).

At the beginning of each determination, screw clips (a), (b) and (c) and taps (d), (e) (h), (i) and (j) are closed. Taps (e) and (g) are opened and any air is swept out of reservoir (f) by passing CO_2 at 20 lb. p.s.i. to atmosphere for 15 sec. Tap (g) is then closed. Tap (j) is turned to allow air from reservoir (4) to pressurize vessel (1) and is then closed. Meanwhile tap (e) is turned so that carbon dioxide from reservoir (f) is forced into vessel (1). Tap (e) is then reversed to re-fill the reservoir. This procedure ensures that the portion of the tube between tap (e) and the top of the jet is primed with carbon dioxide.

After attemperating to 70° F., the sample bottle is carefully opened without disturbing the beer and fitted into the sample holder (2). The wing nuts are screwed tight and tap (d) is turned so that the bottle is pressurized with air at 15 lb. p.s.i. Screw-clips (b) and (a) are opened in that order so that beer ex sample bottle flows to waste. When 10–15 ml. have run to waste, screw-clip (a) is closed. Screw-clip (c) is opened at the same time as tap (j) is closed in the neutral position. By partially opening tap (h), the beer sample is slowly allowed to enter vessel (1), care being taken that the beer does not fob. Fobbing can be prevented only if the pressure in vessel (1) is released slowly via tap (h). Beer is allowed to enter until it reaches the zero mark (0) and screw-clip (c) is then closed. When equilibrium pressure in vessel (1) has been reached, tap (h) is fully opened to atmosphere. Tap (e) is then sharply turned through 180° so that carbon dioxide is suddenly released from reservoir (f) through the fine jet into the beer. A stop-watch is started at the same time. The following readings are taken:—

(i) *After* 5 *sec.*, the top of the beer foam. Measurement (A)

(ii) *After* 30 *sec.*, the level of the residual beer below the zero mark. Measurement (B)

(iii) *After* 240 *sec.*, the top of the beer foam. Measurement (C)

(iv) the level of the centre of the foam, Measurement (D)

(v) and the level of residual beer. Measurement (E)

The initial and final states, at which these five measurements are made, are diagrammatically represented in Fig. 3.

From the five measurements, A–E, it is possible to derive mathematical expressions for maximum head formation, percentage adhesion and percentage collapse of the head, *viz.*—

$$\text{Maximum head formation} = A + B$$

$$\% \text{ Adhesion} = \frac{(A + B) - (A - C)}{(A + B)} \times 100$$

$$\text{or } \frac{(B + C)}{(A + B)} \times 100$$

$$\% \text{ Collapse} = \frac{(A + B) - (D + E)}{(A + B)} \times 100$$

After each determination the vessel is cleaned in the following manner. Tap (d) is opened to atmosphere to release the pressure on the sample bottle. Screw-clip (b) is closed and the wing nuts on the sample holder slackened in order to remove the bottle. Screw-clips (a) and (c) are then

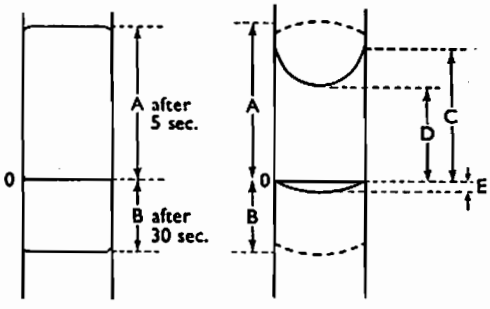

Fig. 3.—Diagrammatic representation of the initial and final states in the measurement of head retention.
Initial head: A + B
Final head formation: D + E
Fall of foam boundary: A − C.
The diagram on the left shows the initial state; that on the right shows the final (4-min.) state.

opened to drain off the sample and filtered beer from reservoir (5) is allowed to flow down the sides of vessel (1) for a few moments. The apparatus is then ready for the next determination. When the apparatus is not in use, vessel (1) should be kept full of a cleaning agent such as trisodium phosphate.

Results and Discussion

The method described has been in routine use in our laboratories for several years and in the hands of a trained assistant, a single determination can be completed in 7–8 min. The method has an additional advantage in that it is possible to carry out a second determination on the same sample if this should be required.

Reproducibility of results.—Experience has shown that, providing experimental conditions are strictly observed, the technique gives extremely reproducible results. This was demonstrated by carrying out ten successive determinations on the same bulk sample of carbonated beer. Results are shown in Table I.

The very small range over which the results vary and the low standard deviation indicate

TABLE I

HEAD RETENTION OF SAMPLES DRAWN SUCCESSIVELY FROM THE SAME BULK BEER

Determination	Maximum head formation	% Adhesion	% Collapse
No. 1	175	78	75
No. 2	177	75	77
No. 3	177	78	76
No. 4	178	79	78
No. 5	177	77	78
No. 6	177	78	77
No. 7	178	79	78
No. 8	178	76	78
No. 9	177	78	77
No. 10	178	79	78
Range	175–178	75–79	75–78
Standard deviation	0·919	1·337	1·033

that the reproducibility of the method is very good.

The relationship between head formation and carbon dioxide content of the beer.—According to Helm,[8] head formation is related to the carbonation level of the beer and can therefore be readily assessed by a simple determination of the carbon dioxide content. Attention was drawn earlier in this paper to the convenience of being able to record a figure for head formation simultaneously with other head retention values. It is now demonstrated that the head-formation value recorded in the present method bears an approximately straight-line relationship to the level of carbonation of the beer. In Table II and Fig. 4 are shown head formation values for different levels of carbonation of the same beer.

It can be seen that in the carbonation range 0·300–0·650 g. CO_2/100 ml., the head-formation values are directly related to the CO_2 content of the beer. Below a CO_2 content of 0·300 g./100 ml., head formation is poor and erratic. On the present system of recording head formation, therefore, values below 100% represent poor and unsatisfactory carbonation.

TABLE II

RELATIONSHIP BETWEEN HEAD FORMATION AND CARBONATION LEVEL OF THE BEER

CO_2 content of the beer (g./100 ml.)	Maximum head formation (%)
0·308	66
0·354	89
0·410	111
0·447	131
0·555	201
0·643	244

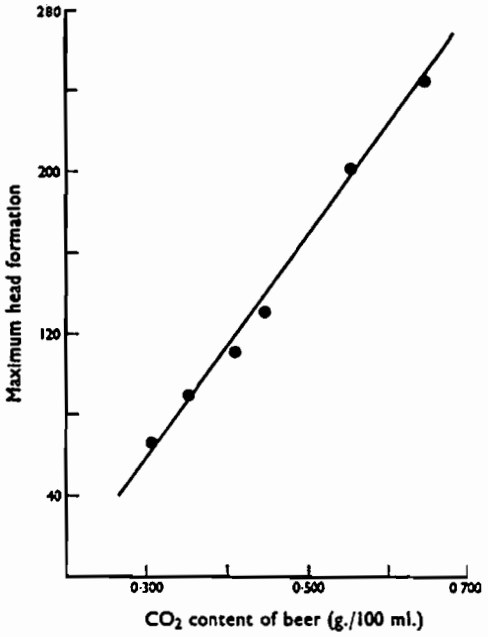

Fig. 4.—Relationship between head formation and CO_2 content of the beer.

Variation in head retention of bottled beers during bottling.—The present method has been used to show that during bottling slight bottle-to-bottle differences in head retention do exist. This was demonstrated by carrying out on several occasions, head retention determinations on every bottle in a crate from one bottling. Results are shown in Table III.

It can be seen, from an inspection of the tabulated results and from a comparison of the standard deviations with those shown in Table I, that the variation among individual bottles from a single bottling is very much greater than that due to the method alone. This suggests that the bottle-to-bottle differences are real and are not due to experimental error. Statistical treatment of further results obtained on a wider scale with a greater number of operators confirmed the

TABLE III

BOTTLE-TO-BOTTLE DIFFERENCES IN A SINGLE BOTTLING

Bottling No. 1				Bottling No. 2				Bootling No. 3			
Bottle Number	Max. head formation	% Adhesion	% Collapse	Bottle Number	Max. head formation	% Adhesion	% Collapse	Bottle Number	Max. head formation	% Adhesion	% Collapse
1	166	74	87	1	163	67	82	1	140	73	69
2	180	78	81	2	165	70	83	2	155	74	69
3	164	67	85	3	162	69	79	3	154	68	73
4	180	71	82	4	157	74	80	4	154	71	72
5	173	65	82	5	156	68	81	5	156	69	73
6	169	66	81	6	160	76	78	6	168	73	73
7	131	53	95	7	159	73	79	7	162	65	73
8	160	53	89	8	158	71	82	8	166	67	70
9	183	74	78	9	161	72	82	9	156	69	71
10	181	71	74	10	164	75	83	10	160	69	71
11	169	70	73	11	165	70	79	11	160	67	73
12	162	75	73	12	160	67	80	12	154	71	71
13	165	61	85	13	157	73	77	13	156	67	71
14	166	61	77	14	161	76	76	14	156	69	73
15	169	63	75	15	163	71	81	15	155	73	69
16	172	63	73	16	162	72	81	16	164	70	71
17	164	62	78	17	164	68	80	17	152	66	72
18	167	61	80	18	158	74	82	18	156	70	72
19	170	58	81	19	156	69	79	19	167	69	72
20	161	61	76	20	159	75	77	20	—	—	—
Average	169	67	81		160	72	80		157	69	72
Range ..	131–183	53–78	73–95		156–165	67–76	76–83		140–168	65–76	69–73
Standard deviation	11·35	6·683	5·515		2·947	2·946	2·038		6·432	2·547	1·428

results shown in Table III. Hence, some factor other than the operator or the experimental error of the method is responsible for this difference and it seems reasonable to ascribe it to bottle-to-bottle variation.

Effect of storage on the head retention of bottled beers.—In order to determine the effect of storage on the foam stability of bottled beers, two sets of eight pale ale brews were maintained at 60° F. and head retention determinations were carried out on each at fortnightly intervals up to 6 weeks. One set of brewings was treated at the bright beer stage with 10 p.p.m. of a proprietary chill-proofing enzyme; the other was untreated. Little variation in head retention values was noted among the individual brews in each set and only the average results for each set of eight brews are therefore recorded in Table IV.

Over a 6 weeks' storage period at 60° F., there were only marginal changes in both beers. Thus, the enzyme-treated beers showed some slight improvement in foam stability while the untreated beers deteriorated slightly in adhesion properties. It is interesting to note that at the start the enzyme-treated beers had somewhat poorer head retention properties than the untreated beers and that the residual proteolytic activity left after pasteurization apparently had no deleterious effect on foam stability. Both sets of brews had a shelf-life in excess of 6 months.

TABLE IV

EFFECT OF STORAGE ON THE HEAD RETENTION OF BOTTLED BEERS

Storage period (weeks)	Enzyme treated ales		Untreated ales	
	% Adhesion	% Collapse	% Adhesion	% Collapse
0	67·0	79·6	70·2	74·6
2	68·6	78·6	68·8	73·2
4	67·8	77·8	63·8	73·0
6	66·8	75·6	64·6	72·6

The effect on head retention of the use of unmalted wheat flour in the grist.—In 1962, Birtwistle, Hudson & MacWilliam[2] drew attention to the advantages attaching to the use of a proportion of commercial wheat flour in the grist. Apart from a superior shelf-life, it was claimed that the beers showed a marked improvement in head retention compared with controls brewed from all-malt grists. Later, Anderson[1] showed that a glycoprotein present in wheat flour had pronounced foam-stabilizing activity and suggested that this might be a contributory factor in the improved head retention of beers brewed with wheat flour as an adjunct. We have been able (Table V) to confirm the enhanced foam stability of such beers by considering the average yearly head retention results for a bottled pale ale before and after the use of wheat flour at approximately 7½% replacement in the grist.

It will be observed that, since the use of wheat-flour, there has been a notable improvement both in adhesion and collapse rate of the foam. The percentage adhesion value has increased from 71 to 94% while the collapse rate has fallen from 75 to 55%. The improvement in the adhesive quality of the beer foam was most noticeable since it resulted in practice in a heavy "lacing" on the sides of the glass.

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TABLE V

EFFECT OF WHEAT FLOUR ON HEAD RETENTION

Year	% Wheat flour in grist	Average yearly head retention results		
		Maximum head formation	% Adhesion	% Collapse
1962–63	Nil	175	71	75
1964	0–6	182	84	68
1965	7½	199	93	54
1966	7½	166	94	55

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