Hydrometry and slide rules in brewing and distilling

Tom Martin

‘Many other pretty things he showed us, and did give me a glass bubble to try the strength of liquors with.’

Samuel Pepys and his wife seeing Boyle's densimeter at Mr Spong's, December, 1668.

Introduction

The term hydrometer was often used interchangeably with aerometer by early developers of this instrument but aerometry is now associated with determining the density of gases and hydrometry, in addition to the determination of the density of liquids, has become associated with determination of water flow or even used as an alternative to hygrometry i.e. measurement of humidity.

The exact history of the hydrometer is unclear. There is conjecture that an instrument of this type was used by Archimedes and Hypatia of Alexandria is ascribed as inventor of the aerometer in AD 415. Whatever the truth, these early instruments appear to have lapsed into obscurity and the renaissance of the hydrometer is attributed to Robert Boyle who, in 1675, described his *New Essay Instrument*, a bubble furnished with a long and slender stem, to the Royal Society.[1]

The story of the simple hydrometer has interesting similarities to that of the slide rule. Developed by Boyle in 1675, about 50 years later than Oughtred's invention of the slide rule, it continued in widespread use until the 1970s when, as the slide rule gave way to the pocket calculator, much use of the hydrometer was replaced by electronic density meters and by rapid advances in instrumental methods of analysis. Like the slide rule, early impetus to development came from Customs and Excise who were anxious to find accurate ways of measuring alcoholic strength and protecting the revenue. Again, as with the slide rule, use of dedicated hydrometers spread into many traditional industries and in the early years hydrometer and slide rule manufacture was carried out side by side by the scientific instrument makers.

The hydrometer can do no more than measure the specific gravity or density of a liquid and there have been many recommendations that translation of such measurements to estimates of solution concentration or other properties related to density should be carried out separately, by calculation, or reference to tables.

Nevertheless a number of different density scales became established over the years and hydrometers indicating the concentration of specific compounds were developed for commerce and process control. Table 1 illustrates the range of instruments offered in old sales catalogues.

Given the historical, wide-spread use of hydrometers one might expect to find a strong association between these instruments and industry related slide rules. In fact it is difficult to find any examples outside Customs & Excise and the brewing and distilling industries. The wide range of slide rules used in the alcohol industry has been surveyed by Hopp[2] at the 1999 International Meeting in Cambridge and discussion here will be limited to those directly associated with hydrometer measurements.

Many works on the history of the fermentation industry give some account of the development of the hydrometer and its effect on both revenue legislation and product standardisation. Specific texts

Name	**Use**
Alcoholometer	Distilling
Saccharometer	Brewing
Samson	Cider
Brix	Sugar refining, Confectionery
Acetometer	Vinegar
Acidimeter	Acids, Batteries
Citrometer	Lime juice etc.
Salinometer	Steam raising boilers
Salometer	Brine pickling
Brinometer	Ice making
Lactometer	Milk
Ammoniameter	Refrigeration
Barktometer	Tanning
Oleometer	Linseed, rape, sperm oils etc.
Oil hydrometer	Oil and petrol
Marine Hydrometer	Sea water (Load Line Act)
Urinometer	Medical
Soil Meter	Particle size
Twaddell scale	General industry
Baume light scale	ditto
Baume heavy scale	ditto

Table 1: Examples of Industrial Hydrometers

include Scarisbrick,[3] an excise officer, on spirit assaying (1898) and Tate,[4] of the Laboratory of the Government Chemist, on alcoholometry (1930). A recent publication[5] is a history of the Customs and Excise, 1640-1845, by Ashworth (2003). Ashworth notes how the science of metrology (e.g. hydrometry) went hand in hand with increasing legal definition of the commodity and how the development of instruments for commercial purposes needed to be considered in relation to political debates, government policies, the actions of interest groups and social relations. The details of these issues are outside the scope of this short paper but they had a major influence on the selection of instrumentation by the Excise. The picture is further complicated by the former independence of the regional excise authorities within the United Kingdom. The Treaty of Union between England and Scotland in 1707 provided that the same duties in excisable liquors should be levied in Scotland as applied in England. However, the English and Scottish Boards of Excise continued to exist and spirit duties were not harmonised until 1855. Ireland also acted independently until the Act of Union in 1801. This independence fostered competing instrument developments and definitions of alcoholic strength with much vested skull-duggery. Differences in the basis of duty payment also resulted in separate developments of the distiller's spirit hydrometer and the brewer's saccharometer, the former being fiscal duty led and the latter a later and initially, commercial and process control innovation.

The spirit hydrometer

The principal problems relating to the measurement of the strength of alcohol solutions have been:

- Mixtures of alcohol and water are not additive but a net contraction of volume occurs on mixing. Within the trade this is referred to as the ‘bulk contraction.’
- With increasing temperature, alcohol expands much more rapidly than water thus altering the volumetric ratio of the two components.
- In hydrometry, expansion of the hydrometer bulb with temperature and pressure and also solution viscosity affect the instrument reading.
- It was relatively late in the 19th century before the specific gravity of pure anhydrous alcohol was established. The term 'proof' thus developed as a series of qualitative and then arbitrarily quantified standards, associated with developments in chemistry and instrumentation.

After Boyle, hydrometers began to be produced by a variety of makers, first as academic instruments, later attracting the attention of both Customs and Excise to assist in checking the strength of spirits. They were calibrated generally so that the middle of the stem became submerged in ‘proof,’ an equal mixture of water and the strongest spirit then known. The first models were made of glass or, naively, turned from box wood or ivory.

John Clarke, a ‘Turner and Engine Maker’ of Charing Cross, is recorded as

the person who took matters a stage further by devising a system to quantify concentrations above and below proof and also providing a system of notation. This was described in a paper to the Royal Society in 1730[6] (Fig. 1). After several trials with ivory he realised that this material absorbed alcohol and he made a metal hydrometer with a quarter-inch diameter brass wire going through and soldered to a copper ball. As shown in the figure, the hydrometer sank to mark 'M' in proof spirit. The marks 'A' and 'B' indicated whether the spirit was either one-tenth over or under proof meaning that one gallon of water 'added' to or 'removed' from ten gallons of the spirit would bring it to proof. By screwing on a wide range of weights at 'C' the entire range of spirit strength could be covered.

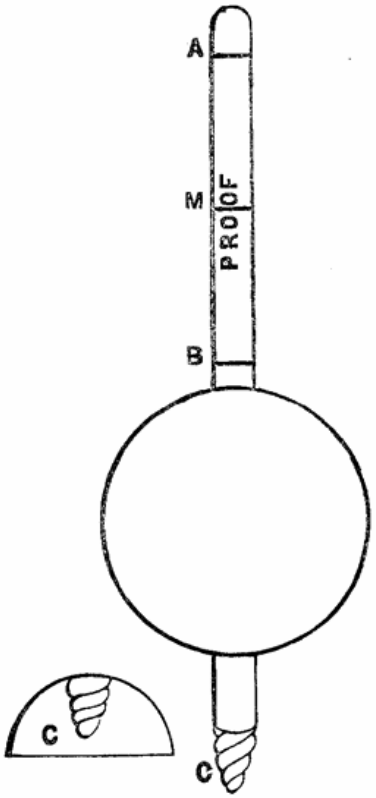

Figure 1. Clarke's hydrometer, 1730, (Scarisbrick(3))

The Government was now showing increasing interest in a good hydrometer for fiscal purposes and instrument makers began to take notice, hoping to produce a hydrometer approved by the revenue. In 1759 Martin produced a hydrometer with 9 weights that claimed to indicate specific gravity. This was supported by a small book to bring his work to the attention of the public. To convert his hydrometer readings to spirit strength Martin supplied a slide rule or 'Scale of Lines' with each instrument. He also advanced on Clarke by correcting for temperature, using a special series of numbers on his Scale of Lines. Clarke came back by adding a series of five 'air' or 'weather' weights. These were used for correcting for *air* temperature and were termed 'very cold' (32-41ºF), 'cold' (41-50ºF), 'temperature' (50ºF), 'warm' (50-65ºF), 'very warm' (65-80ºF). Although Clarke's instrument appears to have been in use for a number of years, the first official mention of a hydrometer by the Excise was in 1761 when Clarke's was adopted as standard. Clarke's weather weights were now increased to

eleven and to make his hydrometer more useful Clarke added a series of 'per cent' weights for import staff and another set for testing weak spirits in distilleries. Clarke's hydrometer now used:

23 gravity weights
11 weather weights
9 per cent weights
11 weak spirits weights

54 in all. Other modifications included a fixed lower bulb on which the weights were suspended rather than screwed. An example held in the Customs & Excise National Museum is shown in Fig. 2.

Clarke's hydrometer continued to be cause for complaint, the defects incurable and his adopted notation cumbersome. In spite of these shortcomings, use of Clarke's hydrometer was recognised by statute in 1787 and made permanent in 1801. Tate[4] shows an example of about 1815 with 140 weights and it is reported that a final version even used 300 weights.

In passing it is interesting to note that on Clarke's death his business passed to his son Richard who married the sister of John Dring. Dring later took over the business in partnership with William Fage. They adopted Clarke's 'half moon and dagger mark' and formed the company Dring & Fage, so well known for its slide rules and other instruments for the next 150 years.

Figure 2. Clarke's hydrometer with 42 weights. Reproduced with permission of the National Museums Liverpool (Customs & Excise National Museum)

At the same time as recognising Clarke, the 1787 Act declared it expedient that experiments should be made to find a suitable instrument for estimating spirit values for revenue purposes, a task assigned to the Royal Society. Over the next 15 years a series of reports were produced on the accurate determination of the specific gravity of alcohol and water mixtures but the Society's quest for a new instrument was not advanced. Acrimony over duty charges based on Clarke increased and at this time the Excise authorities in England, Scotland and Ireland were following separate routes. The hydrometer of William Speer, surveyor and assayer of spirits in the Port of Dublin was adopted in Ireland in 1802 and the USA had adopted the hydrometer of Dicas of Liverpool as the standard in 1790. The Act of Union of 1801 gave impetus to seeking a common base for duty payment for Britain and Ireland and in 1802 an act was passed 'To authorise the Lord High Treasurer or Commissioners of the Treasury in Great Britain and the Lord High Treasurer or Commissioners of the Treasury in Ireland to Order the Use of the Hydrometers now employed in the Management of the Revenue to be discontinued and other instruments to be used instead thereof'

A Committee of Enquiry was appointed and this placed advertisements in the public press. It is reported that 19 instruments were submitted with some makers providing more than one type. The Committee then instructed 'That every person who has sent in more than one hydrometer be desired to withdraw every instrument but that on which he is meant to rely'. The principal competitors seem to have been -

- Dicas - the USA standard, submitted by Miss M Dicas, daughter of George Dicas who had died. It had 36weights
- William Speer - hydrometer adopted in Ireland
- James & George Quin - this had received official acceptance for use and had 7weights
- Atkins & Co - instrument makers
- Clarke's Centigrade - This was a much simplified version developed by Dring & Fage using only 4 weights. Centigrade did not refer to temperature but that the instrument covered the full range of alcohol concentration in 100 units.
- Dring - own design
- Miller & Adie - instrument makers who submitted an instrument combining the principles of the hydrometer and the hydrostatic balance.
- Mrs Andoe
- Saunders
- Bartholomew Sikes - a hydrometer of gilded brass with 9 weights

The final assessment was reduced to nine instruments and it has been suggested that these had marked similarities, varying mainly in their methods of temperature compensation. Quin's attempts to establish the ground rules are recorded in a later memoir by him (reported in Scarisbrick[3]):

'Construction of the Hydrometer and Sliding Rule:- In the first place it was nec-

essary to know at what the Government had determined to fix hydrometer proof. For this purpose I waited on Mr Vanisttart (now Chancellor of the Exchequer) at the Treasury who then honoured me with an interview and informed me that the Lords of the Treasury had agreed to fix hydrometer proof at 0.920 specific gravity, 60º of heat, considering pure water to be 1.000 specific gravity, at the same temperature, consequently all the different strengths should agree with these two points.'

This was scientifically sound for the time but as we shall see this is nothing like the final outcome. A description of Quin's 7-weight hydrometer is given in Boyle's *The Publican and Spirit Dealer's Companion*, 1800,[7] as shown in Fig. 3.

A description of Clarke's Centigrade, Dring & Co., 4-weight hydrometer and slide rule is given also by Boyle as shown in Fig. 4.

The point of most interest to this paper is that all competitors, with the exception of Sikes, had provided hydrometers with accompanying slide rules. Sikes, instead, presented the examiners with a hydrometer and a table of six pages. Sikes was a man of 73 who had entered the Excise in 1754 and had followed the development of the hydrometer closely. As sometime Secretary to the Board of Excise he was well aware of the controversy surrounding Clarke's instrument and is credited with solving most of its faults before it was abandoned. In developing his system, Sikes used his detailed knowledge of studies on the density of alcohol/water mixtures. With a hydrometer (Fig. 5) scaled in 10 units, graduated at 0.2 unit intervals and 9 additional weights he covered the then known range of alcohol concentration in 500 steps. His hydrometer scales have no defined unit of measurement but provide a reading, termed an 'indication.' The tables converted this indication, at the temperature of measurement, to percentage proof alcohol at 50º Fahrenheit and so allowed a true revenue charge to be levied.

In an evaluation of the various instruments submitted, over a limited range of concentration and temperature, Sikes' hydrometer was neither the fastest nor most accurate. It was, however, considered the easiest to handle in inexperienced hands, suitable for travelling excise men and the tables gave directly the units on which duty was payable. As Scarisbrick noted of Sikes' competitors:

'They bent their energies towards making a perfect instrument, while neglecting the equally urgent and important matter, viz., that of furnishing a perfect method of translating its indications into expression of strength.'

Sikes hydrometer and new system for expressing 'proof' gave a value for proof alcohol close to that of Clarke and the Excise Commissioners asked him to modify his system to minimise any change in the duty base. After further tests and calculations a compromise was agreed to accord with the tables and proof spirit became defined as 'that at which at the Temperature of 51 Degrees

DIRECTIONS

FOR USING

QUIN'S

NEW CONSTRUCTED

HYDROMETER;

ACCURATELY ADJUSTED.

As required by Act of Parliament.

By the use of Quin's Hydrometer, (which is usually sold for a guinea, and may be had of most mathematical-instrument-makers) may be clearly discovered, without any sort of difficulty, how much spirits of any strength are above or below proof, with so much exactness, as to shew the effect of a single pint of water in 100 gallons.

OVER PROOF.			UNDER PROOF.		
No. of the Weights.	Gallons in 20 over-proof		No. of the Weights.		Gallons in 19 under-proof.
1	16	The weight No. 7, must be on the Instrument in all under-proof spirits.	4	7	1
4	15		2 4		2
1 4	14		3 4		3
5	13		5		4
1 5	12		2 5		5
4 5	11		3 5		6
1 4 5	10		4 5		7
6	9		2 4 5		8
1 6	8		3 4 5		9
4 6	7		6		10
1 4 6	6		2 6		11
5 6	5		3 6		12
1 5 6	4		4 6		13
4 5 6	3		2 4 6		14
1 4 5 6	2		3 4 6		15
7	1		5 6		16
1 7	proof		2 5 6		17
			3 5 6		18
			4 5 6		19

The Hydrometer has 7 weights to shew all the strengths under and over-proof of 7ld. 12 ounces the gallon; that being the weight allowed, and to which the instrument is adjusted.

The weights are numbered 1, 2, 3, 4, 5, 6, 7, and are used on the top of the instrument in the following order.

Note, After filling a tin or glass vessel, with about a pint of spirits, (the heat being first tried by the Thermometer) gently immerge the instrument therein.

The use of the preceeding Table is so very simple and obvious, that I apprehend a few examples will be quite sufficient to illustrate it.

Let the weight No. 1, be put on the instrument, immersed in the spirits; if it sinks to the bead on the stem, it shews every 20 gallons of such spirits are 16 gallons over-proof. If the weight No. 4, is put on the instrument, and it sinks to the bead, as before, it shews 20 gallons is 15 gallons over-proof; but if the weights 1, and 4, are put on the hydrometer, and it sinks to the bead, it shews 20 gallons is 14 gallons over-proof. And so of the rest of the over-proofs.

The weights No. 1, and 7, are put on for proof, but if the weights 4 and 7, are put on the instrument, immersed in the spirits, and it sinks to the stem, it shews 22 gallons of such spirits to be 1 gallon under-proof; if the three weights 2, 4, 7, are put on the instrument, and it sinks as usual, it shews 20 gallons to be 2 gallons under-proof, and is worth no more than 18 gallons of proof-spirits. And so of the under-proofs, as low as 19 gallons of water to 1 of spirits, as may be seen by the Table.

This Hydrometer is adjusted to temperate, or 50 degrees of Farenheit's scale, in itself, which is the best heat for trying spirits; but when the spirits are not at that heat, for every four degrees warmer, allow 20 gallons to be one quart weaker; and for every four degrees colder, allow 20 gallons to be one quart stronger.

Note, That one degree on the stem is 1 pint on 100 gallons; and that any quantity of spirits, (not less than half a pint) may be tried with this instrument.

Figure 3. Directions for use of Quin's 7-weight hydrometer as described by Boyle.[7]

DESCRIPTION OF,

AND

DIRECTIONS FOR USING

A NEW CONSTUCTED

HYDROMETER,

Being the latest and best Improvement of that most useful Instrument, for ascertaining the exact strength of Spirits, from Alcohol to Water: and likewise points out the strength as it appears by CLARKE's HYDROMETER, *in the most plain and simple Manner, by the use of four weights only.*

DESCRIPTION OF THE HYDROMETER.

THIS Hydrometer has one fixt Balance Weight at Bottom, the upper Stem is ſquare, on which is engraved 20 diviſions, numbered from 1 to 20. Each principal Diviſion divided in half for greater accuracy. There are four weights which are dropt over the Stem, as the Strength of the Spirits may require, on theſe Weights are engraved A.B.C.D. On the Weight A. is engraved (20). On the weight B. [40]. On the weight C. (60). On the weight D. (80). By the uſe of theſe four weights, the length of the ſtem is repeated five Times, and the Numbers continued from 1 to 100, which will ſhew all the Strength of Spirits, from the ſtrongeſt that can be procured down to water.

DESCRIPTION OF THE SLIDING RULE.

On the firſt ſide of the rule on the right hand is the Thermometer ſcale, from 30 degrees to 80, over which on the ſlide is a line with a ſtar, which is moved and ſet to any degree of heat the Thermometer deſcribes. Then the ſlide is divided progreſſively on both ſides from 1 to 100. Each diviſion ſub-divided in halfs, theſe numbers correſpond with the upper ſtem of the Hydrometer, as will be ſeen by the following Examples.

The diviſion on the Rule cloſe to the ſide is the Spirit line, or the ſtrength of the Spirits, divided into gallons, over and under-proof, from 80 Gallons to the 100 over-proof, down to Water; the figures on the next line, is the ſtrengths, as they appear by Clark's Hydrometer, over and under-proof, with the firſt Weights.

The Thermometer being ſo well known needs no deſcription.

EXAMPLE I.

Nearly fill the Cylinder with the Spirits to be tried, then immerſe the Thermometer therein: Obſerve where the Mercury fixes, ſuppoſe at 63, then ſet the Star of the ſlide Rule before deſcribed at 63 of Thermometer Scale, then lay the rule before you, and immerſe the Hydrometer into the Cylinder of Spirits to the bottom thereof. If the Hydrometer, floats therein, with part of the upper ſtem immerſt in the Liquor, without any weight over the ſtem, then look what figure of the ſtem is even with the ſurface of the liquor. Suppoſe it 16, then look at 16 on the ſlide of the Rule, and you will find 62 on the ſpirit line beneath it, which ſhews thoſe ſpirits are 62 Gallons to the 100 over-proof, and will admit of 62 Gallons of water to every 100 Gallons thereof, to reduce them to Proof.

EXAMPLE II.

Suppoſe when you have immerſt the Thermometer in the ſpirits as before, and the heat thereof ſhould be 70, then ſet the ſtar of the ſliding rule before deſcribed at 70 of the Thermometer ſcale, then immerſe the Hydrometer as before. Suppoſe it ſhould be up to the Ball and require the weight engraved A. numbered 20 to float it in the ſpirits, with part of the upper ſtem immerſt therein. Look what figure is even with the ſurface of the Liquor, ſuppoſe it be 13½ then you reckon 20 on the weight and 13½ on the ſtem, make 33½ look on the ſlide of the rule for 33½, and you will find it even with 37½ on the Spirit Line above it, then thoſe Spirits are 37 gallons and a half to the 100 over-proof, and will admit of 37 gallons and a half of watar to reduce it to proof. By Clarke's Hydrometer this ſtrength is between one to two, and one to three over-proof, as may be ſeen on the outer Line of the Rule.

Figure 4. Directions for use of Clarke's centigrade hydrometer and slide rule as described by Boyle.[7]

by Fahrenheit's Thermometer weighs exactly twelve thirteenths of an equal measure of Distilled Water.' When we look at Sikes hydrometer we see the nine circular weights which slot onto the lower stem. In addition we have a square cap which fits on top of the stem. With the '60' weight applied, the hydrometer will read 'proof' at 60.8 at 51ºF. If the cap, which weighs one twelfth of the combined weight of the hydrometer and '60' weight, is added the hydrometer will now sink to the same point in distilled water at the same temperature to prove the accuracy of the instrument.

Although Sikes' hydrometer and tables were recommended for fiscal use in 1803 they did not finally replace Clarke's until 1816. partly due to the need to make an adequate number of instruments. The Act of 1816 was provisional one authorising use of the hydrometer and tables until 1818. This Act also authorised the use of 'three accurate scales or sliding rules' for use with the hydrometer - a very rare

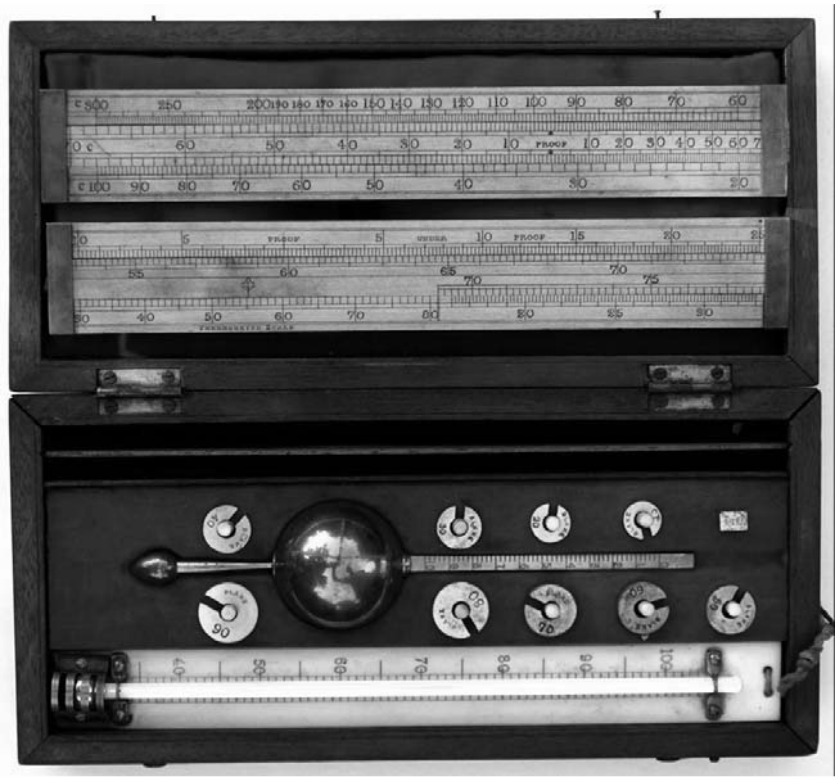

Figure 5. Sikes' hydrometer with thermometer and proof and comparative slide rules

case of slide rules being enshrined in an Act? The first rule was to allow calculation of the volume of spirit at one strength to the equivalent volume at any other strength. The second rule was for stock control in distilleries where distillers were allowed 19 gallons at 8% over proof for every 100 gallons of wash. The third rule was for use at rectifiers where a standard of 28% under proof was in use.

The hydrometer and tables were legalised, finally, in the Hydrometer Act of 1818, when ‘From and after the passing of this Act, all spirits shall be deemed and taken to be of the degree of strength at which the said hydrometer, called Sikes Hydrometer, used under the direction of the Commissioners of Excise, shall, upon trial by any Officer or Officers of the Customs or Excise denote such spirits to be ...’ For some reason use of the slide rules was not renewed in this Act.

A number of mysteries surround Sikes' work:

- It is suggested that his design was taken from a continental model or a modified form of Clarke's Centigrade hydrometer.
- He did not make his own instruments but appeared to use several others including his competitor, Atkins.
- He provided no details of the basis of his calculations to the Committee of Enquiry or the Commissioners.

In 1803 Sikes petitioned the Commissioners to be the supplier of his hydrometer but died suddenly that year before a contract was made.

We now come to another significant family connection. Sikes' daughter Anna Maria married the nephew of Sikes' wife, one Robert Brettell Bate who became the well known instrument maker ‘Bate of the Poultry.’ A recent monograph by Anita McConnell[8] surveys Bate's life and work, including his association with the hydrometer makers of the time. On Sikes' death his wife made a series of petitions for both a lump sum in recognition of Sikes' work and also, in competition with Atkins, Speer and Dicas, the right to supply. She pointed out that she held all Sikes notebooks and tables and that her son-in-law and nephew, Bate, could manufacture them. After much prevarication, in 1810, she received £2,000 and the supply agreement which lasted until her daughter's death in 1851. As McConnell says, this was a licence to print money and underpinned Bate's business for the rest of his life.

Sykes hydrometers and books of tables very rarely have dates and it is impossible to tie a book to an instrument. Eventually they became made by a wide range of suppliers; Buss, who claimed to be successor to Bate, Dring & Fage, Long, Blake, Lumley, etc. but it is likely that hydrometers not bearing Bate's name are post 1851. There was also a large business in repairing and adjusting hydrometers and hydrometer boxes became over-stamped with the adjuster's name.

Although Sikes produced only a set of tables it is evident that, in addition to those authorised in the 1816 Act, slide

rules for use with the hydrometer soon became available. Throughout the history of the instrument, manufacturers offered hydrometer boxes (Fig. 5) containing none, one or two rules, approximately 9 inches long in boxwood or ivory. The two rules became known as ‘The Proof Rule’ and ‘The Comparative Rule.’ Bate describes versions of both of these in the 3rd edition of Sikes' tables (undated) where he also describes himself as ‘Only representative of the inventor, HYDROMETER MAKER for the USE of THE REVENUE OF THE UNITED KINGDOM.’

Bate's proof rule allowed calculation of % proof at 51ºF from the hydrometer indication and temperature between 30º and 80º. He also provided a pair of log lines - ‘The finely divided lines on the fourth edge of the slide and side are logarithmic numbers, usually called multiplying lines, but so arranged as to admit of a single radius performing the office commonly assigned to two, which affords double the usual length to each several division.’ This log line does not seem to have been adopted generally and later rules as shown in Fig. 6 only provide ‘proof’ from hydrometer indication and temperature. The slide rule is unable to compensate for the full range of the tables and use is limited to between 35% under proof to 55% over proof. Weak and strong spirits still can only be measured by reference to the tables.

The comparative rule has two functions. As expressed by Bate:
Costing - ‘The Slide contains the Strength

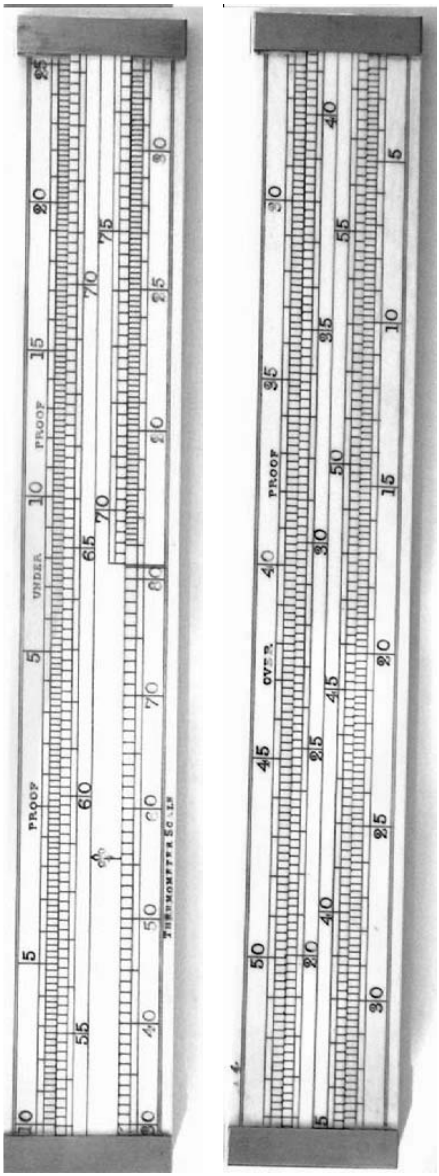

Figure 6. Bate's proof rule (ivory) (actual size 225 x 35mm)

of the Spirits from 70 per cent Over Proof to 70 per cent Under Proof and the lines A, B, shew the Comparative VALUES of those strengths in Shillings and Pence.' Reducing - 'The lines C, D, shew the Comparative QUANTITIES of Spirits with reference to their Strengths upon the Slide.'

This rule changed little from its original design. As shown in Fig. 7. On the costing side the slide runs from 70% under proof to 70% over proof. The lower stock runs from one shilling and sixpence to 8 shillings per gallon and the upper stock from 6 to 30 shillings. In later versions of the rule, as duty increased, the stocks run from 6 to 30 and from 20 to 100 shillings. On the reducing side, the slide again runs from 70% under to 70% over proof. The lower stock runs from 20 to 100 gallons and the upper from 60 to 300 gallons. This side does not appear to have changed throughout the life of the instrument and surprisingly, contains a cardinal error. It treats dilution or concentration of spirits as a direct mathematical ratio and makes no allowance for the bulk contraction factor. This correction appeared only on later specialist trade slide rules such as those of Farmar in the early 20th century.

Sikes hydrometer and definition of proof provided the basis of duty payment for wines and spirits for the next 160 years with various modifications.

It was recognised that only Sikes' table had any legislative authority and in 1833 Bate proposed a table of specific gravity

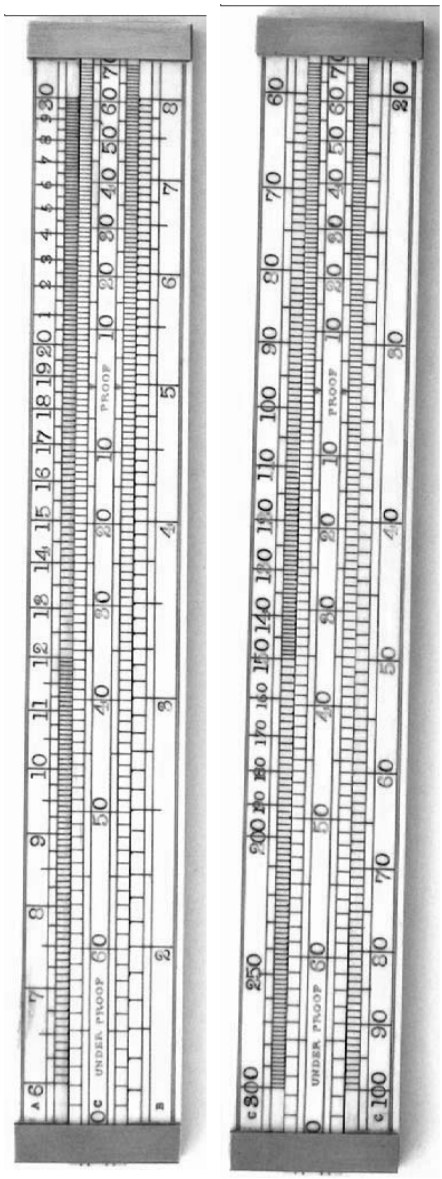

Figure 7. Bate's comparative rule (ivory) (actual size 225 x 35mm)

expressed as pounds per gallon at 62ºF which was legalised in 1855. This Table is picked up on Farmar's Spirit Rule (but not his other rules) as a line correlating proof spirit with pounds per gallon at 62ºF. The Finance Act of 1901 allowed the Customs and the Excise to regulate other means of determining alcoholic strength and in 1907 official tables were published relating spirit strength to specific gravity. As technology developed, higher concentrations of alcohol than those recognised by Sikes became available and the range of working temperatures widened. A supplementary Sikes 'A' hydrometer was legalised in 1915 and a further 'B' hydrometer which, with a poise, could act as an 'A' hydrometer was adopted in 1930.

Sikes and proof finally succumbed to the European Union in 1980, being replaced by the OIML system of measuring alcohol by volume and mass.

This section of the paper has given a very simplified account of the development of the legally defined measurement of alcohol in the UK. There were of course many other issues such as ‘obscuration’ which could include addition of substances such as sugar to alter the specific gravity and defeat the revenue or be an entirely legitimate factor as with sugar residues in rum. With improving definition of the relation of proof to specific gravity, sets of glass hydrometers reading Sikes' indication became available. These required special versions of Sikes' table to allow for the different expansion of glass and, as such were adopted as the official method by the Indian Government. Many manufacturers produced glass hydrometers giving a direct reading of proof spirit but no one argued with the excise man and his little brass instrument!

The brewer’s saccharometer

Brewer's interest in the hydrometer developed much later than in the distilling industry and from a different standpoint.

John Richardson[9] is generally credited with the introduction of the hydrometer to brewers in 1784 coining the term ‘saccharometer’ through its use to measure the ‘saccharin’ or fermentable extract in brewers' worts.

There were, however, earlier developments. The first recorded interest is that of Reddington who proposed a simple instrument for estimating the commercial value of beer:
‘As many shillings as you value your Beer at, so many Divisions you should make between the Height to which the Instrument rises in the Water, and the height to which it rises in the Beer. By this method you may estimate what proportion the value of any Beer bears to the price of the Strongest ... ’[10]

In 1762 Benjamin Martin made a hydrometer calibrated in specific gravity which he advertised as ‘useful in discovering the strength of beer, ale, wine and worts.’ In his experiments, however, he became so

confused with his mass of data that he considered the instrument of no use. The entrepreneurial brewer James Baverstock[11] purchased one of Martin's hydrometers in 1768. Baverstock had obtained, already, a thermometer in 1762 which ‘he was forced to conceal and to use by stealth, his father objecting vehemently to such 'experimental innovations.’

Using a much more systematic approach Baverstock demonstrated the value of the hydrometer in determining the strength of brewers' worts, work which the disillusioned Martin was unwilling to accept as of any value. Baverstock then obtained an introduction to Samuel Whitbread who also dismissed the matter saying "go home, young man, attend to your business and do not engage in such visionary pursuits".

Baverstock subsequently met the much more enlightened brewer Henry Thrale and conducted experiments for him, often in the presence of Thrale's friend, Dr Samuel Johnson. Thrale gave his opinion that ‘the hydrometer is an instrument of great use to the brewer in various parts of his business’ and Johnson added his approbation ‘tending to render that a scientific and practical pursuit which had hitherto been considered a practical operation, requiring neither superior skill nor judgement.’

In spite of the value of his work Bavenstock failed to attract wider interest and only published his *Hydrostatical Observations and Experiments in the Brewery*[12] in 1785, as a response to

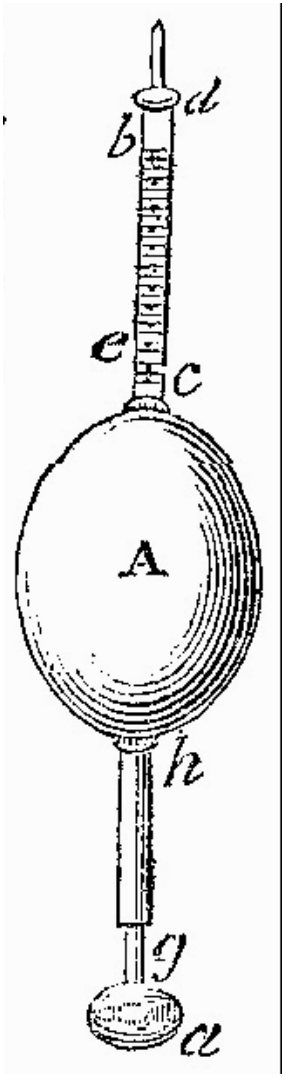

Figure 8. Richardson's saccharometer (after Booth[13]).
Scale b-c, range -1lb/brl, divisions - 0.1lb/brl.
Water ‘regulator’ g.
Weights equivalent to 1,2,3,4,5,10,20, or 30 lb/brl applied at d.

Richardson's claims to originality in 1784 when he published his *Statistical Estimates*.

Although Baverstock's tardy publication did bring him much interest it was Richardson's instrument that attracted the interest of the larger brewers possibly partly due to the name and also the unit of measurement that he adopted and the saccharometer is frequently referred to as ‘the brewers' compass’ in the older brewing texts.

The driving force behind Richardson's work was quantifying the quality and yield of extractable matter from malt. As a unit he adopted the term ‘brewers' pounds’ which he defined as the number of pounds by which a barrel of wort exceeded the 360 lb of an equivalent barrel of water (lb/brl). At this time Richardson assumed that the weight of water and extract were additive, i.e. he did not allow for the partial displacement of water by extract. Thus although he obtained relative values for the yield of extract from malts they were not absolute. Nevertheless the term became widely adopted and generally used in the industry for almost 200 years.

Richardson's saccharometer is illustrated in Figs. 8 & 9. The first instruments had a stem scale of 1lb and the range was increased by adding weights at the top of the stem. Richardson also recognised that brewing water had a density greater than that of distilled water and he introduced a ‘regulator’. The lower hollow stem could be lengthened or shortened by a sliding tube which altered the volume without changing the mass to give a zero value for

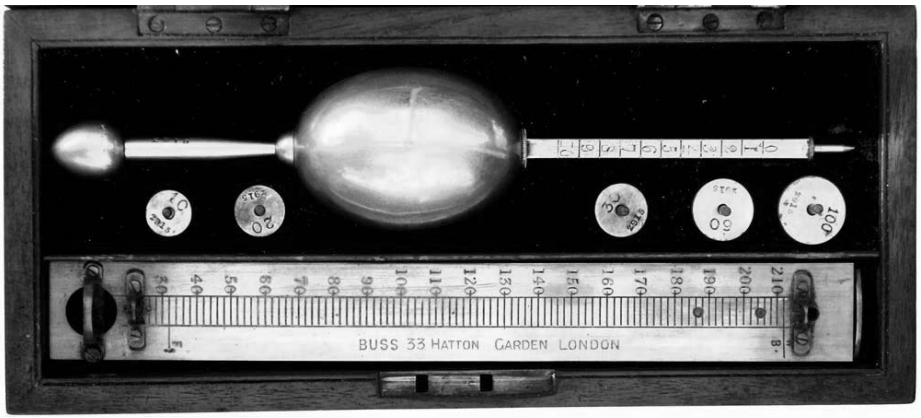

Figure 9. Richardson's saccharometer by Buss. Later model calibrated in specific gravity.

Year	Beer	Malt	Hops	Sugar
1643	Introduced			
1660	Charged on 'strong' and 'small' beer			
1697		Introduced		
1711			Introduced	
1830	Beer duty repealed			
1847				Use allowed and dutied
1863			Repealed	
1880	Re-introduced based on standard 'original gravity' of 1057	Repealed		Duty repealed
1889	Standard changed to 1055			
1993	Changed to 'end product' duty based on % alcohol at point of sale			

Table 2. Summary of excise duty in the English brewing industry.

any particular water. This feature was notoriously difficult to make watertight for long term use and was eventually abandoned.

Richardson's work led to the larger brewers making major changes in malting and brewing practice and standardisation of product strength. Richardson is said, also, to have suffered financially from traditionalists suspicious of his activities and the saccharometer was not adopted by smaller country brewers for many years.

The ability to measure wort strength resulted in discussions on the payment of excise duty on beer according to specific gravity, but nothing came of it. A simplified history of excise duty on beer is shown in (Table 2). The Excise continued to charge duty on beer according to its classification of 'strong,' 'small' or 'table.' Beer duty itself was withdrawn in 1830 and it was not until 1880 that Gladstone re-introduced a duty on beer, this time based on the specific gravity, termed 'original gravity,' of the wort.

In the absence of any Excise imperative a range of competing saccharometers appeared on the market. Accum[14] in 1820 noted that the principal instruments were those of Dicas which was calibrated to indicate the true weight of extract in 36

gallons, Quin, Richardson, and Dring and Fage who all adopted Richardson's lb/brl notation. In Scotland, Allan's saccharometer was in use. This was calibrated in ounces per cubic foot, assuming, slightly inaccurately that a cubic foot of water contained 1000 ounces, thus giving a reading similar specific gravity.

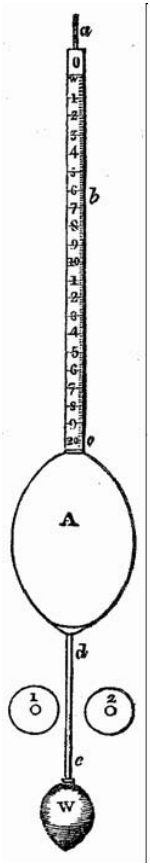

Figure 10. Dring & Fage saccharometer (After Accum[14]). Scale b *range - 20lb/brl, divisions - 0.2 lb/brl. Weights* 1 *or* 2 *added at 20 or 40 lb/brl.*

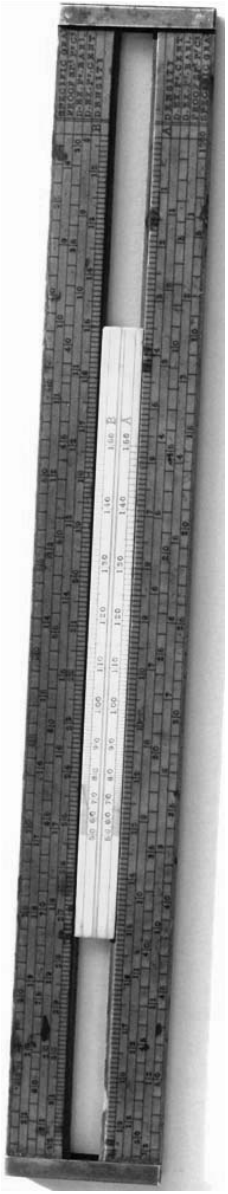

Figure 11. Dring & Fage slide rule for use with saccharometer (Actual size 335 x 45 mm)

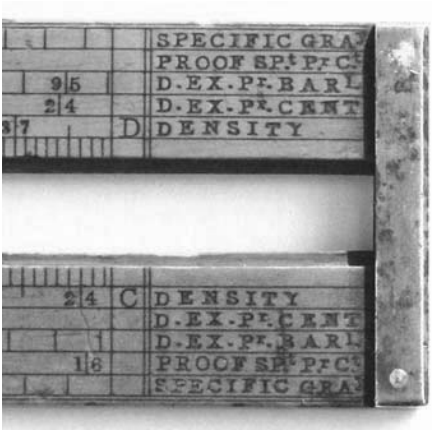

Figure 12. Scales detail to Figure 11.

Accum considers that Dring and Fage was the preferred instrument of the town brewers at this time and describes both it and its accompanying slide rule (Figs. 10-12).

The saccharometer has a square stem and is weighted from the top. The first side of the stem is calibrated 0-20lb for use without a weight. Side 2 runs from 20-40lb with weight 1 on top and side 3 runs from 40-60lb with weight 2 on top. The open frame slide rule is made of boxwood with a short ivory slide with a temperature scale. The four face of the stock marked ABCD provide continuous, but overlapping scales for five parameters. The innermost scale (Density) gives Richardson's lb/brl. The second scale (D. Ex. Pr. Cent) gives the lb dry extract contained in 100 lb of wort. The third scale (D. Ex. Pr. Barl) gives the lb dry extract in a barrel of wort. The fourth scale (Proof Spt. Pr. Ct) gives the number of wine gallons of proof spirit that can be obtained from 100 wine gallons of wort at the appropriate density (lb/brl). The fifth, out-

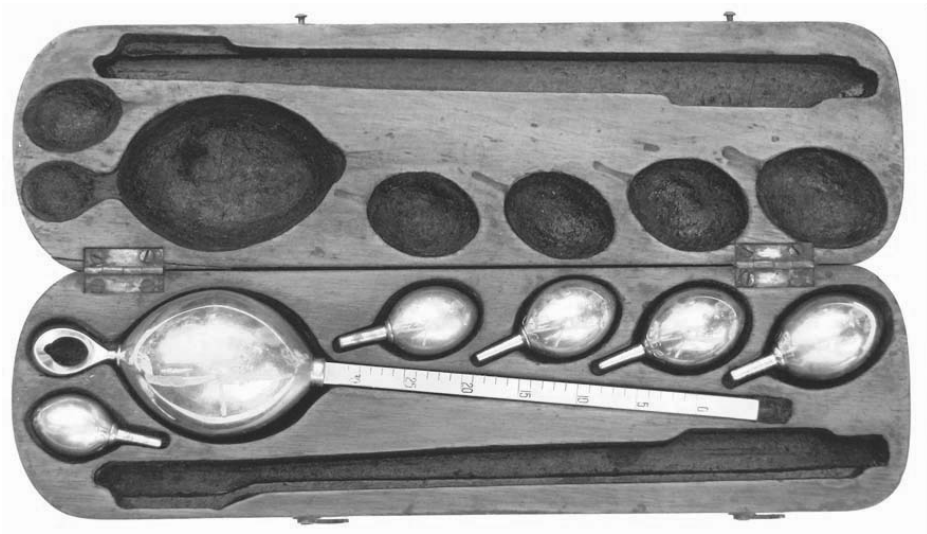

Figure 13. Bate's 5-poise saccharometer in 'spectacles case' (thermometer missing).

ermost line (Specific Grav.) gives the equivalent specific gravity.

Excise ambivalence to the duty on beer did not extend to the distilleries of Scotland where duty was being paid on the malt, the wort (or wash) and the spirit and an Act of 1816 specified Allan's saccharometer as the instrument to be used to assess wort strength.

Here we must return to Bate. As Anita McConnell describes,[8] in 1821 the English Board of Excise ordered 80 Allan saccharometers through their official supplier Bate, who was anxious to obtain the same monopoly for saccharometers as he had for hydrometers. Bate dispatched one of his journeymen to Edinburgh who took all of Allan's men to an alehouse and kept them intoxicated for nearly a fortnight and then had them carried to London by boat. Deprived of his workforce Allan's order was much delayed and although completed, Bate had used the opportunity to persuade the Excise into adopting his own instrument. Bates' saccharometer replaced Allan's in Ireland in 1823, in Scotland in 1825 and was legalised in England in 1826.

Bates saccharometer (Figs. 13 & 14) was usually made of gilt brass. The upper graduated stem covers 30 degrees of specific gravity and the lower stem ends in a loop which holds a range of weights (or poises) each increasing the range by 30deg. The instrument takes two forms: a brewer's saccharometer covering the range 1.000 to 1.150 and a distiller's saccharometer covering the range 0.970 to 1.150.

Tizard[15] writing in 1850 considered that Bate's improvement on his predecessors ‘consisted chiefly of having 5 poises instead of Allan's 13 … and the abolition of the sliding rule, for which he substitutes tables for practical men.’

Tizard goes on to commend the work of Joseph Long in producing a simple and elegant saccharometer scaled in lb/brl and using only one poise. He also meets Tizard's approval by ‘his mode of applying his thermometer and saccharometer side by side, by which correct results are at once given without calling in the aid of the sliding rule in the common routine of business.’

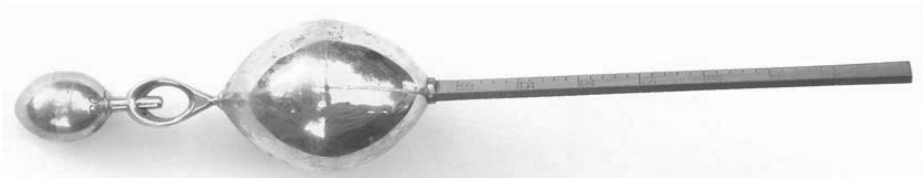

Figure 14. Bate’s saccharometer with poise.

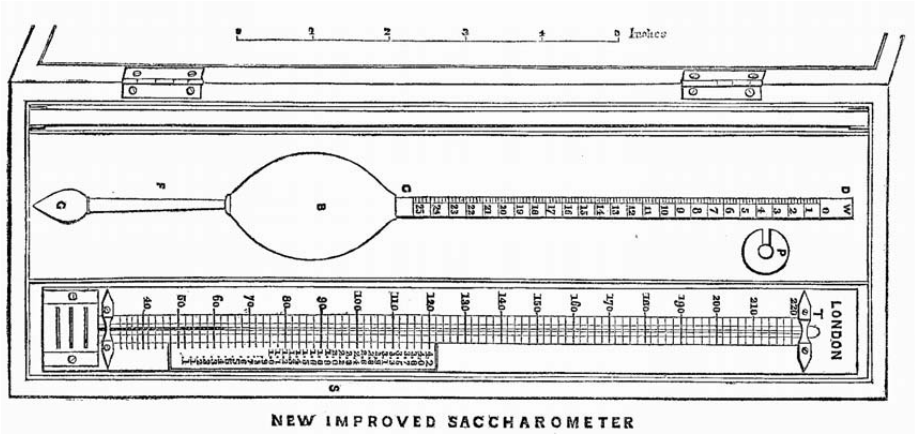

Figure 15. Loftus catalogue 1866. New improved saccharometer with single poise. Supplied with slide rule, thermometer with saccharometer temperature corrector and instructions.

The firm of W.R. Loftus seems to have been in the business of making and supplying copies of all the main types of measuring equipment at this time. Loftus' catalogue diagram of a Long type saccharometer and thermometer is shown in Fig. 15. A later model with conventional thermometer is shown in Fig. 16. Long is credited also with the re-introduction of an open frame slide rule. A Loftus copy is shown in Fig. 17. On one side an extended scale on both stocks allows for temperature correction and also conversion from lb/brl to true lb dry extract/brl. On he reverse side the upper stock correlates wort strength in lb/brl with barrels

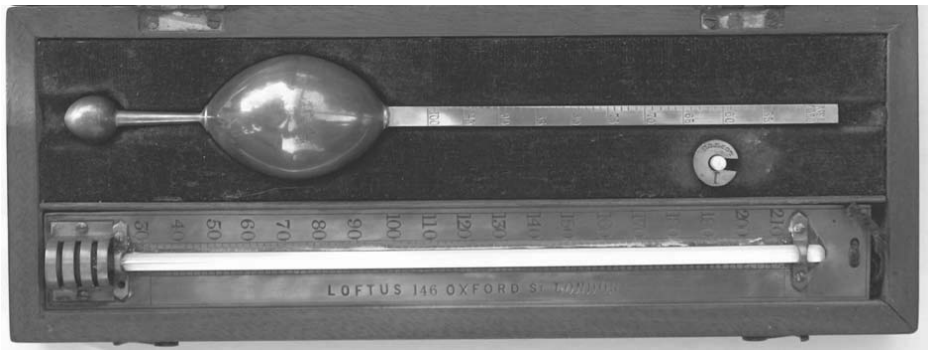

Figure 16. Loftus single-poise saccharometer (specific gravity version).

brewed, the lower stock has a shillings per quarter scale for estimating the commercial value of malt against the strength of the brew.

Loftus' catalogue of 1866 (Fig. 18) suggests that the newer saccharometers continued to compete with a range of the older instruments for many years. ‘Blind’ thermometers and saccharometers were available also for process work so that the brewer could engrave his own scale for his workmen, preventing them from revealing his recipes.

As shown already, in Table 2, beer duty was re-introduced in 1880. This was based on the specific gravity of the wort, termed the original gravity, converted to a notional volume at a standard 57 and later 55 degrees. Over the next 40 years official tables and methods of analysis were developed by which the reduction of specific gravity, or quantity of alcohol formed, during fermentation, were converted into ‘degrees lost’ to calculate the original specific gravity of the wort. As with spirits, these calculations were always performed with the use of tables and the slide rule never developed as a specific tool associated with beer duty payment. Bates saccharometer, often termed ‘the revenue saccharometer,’ continued as the Excise reference instrument for specific gravity determination and by now it was being made by a range of instrument makers. Such instruments were available commercially but always subservient to the Excise man's own instrument which he guarded with some care. As the Commissioners

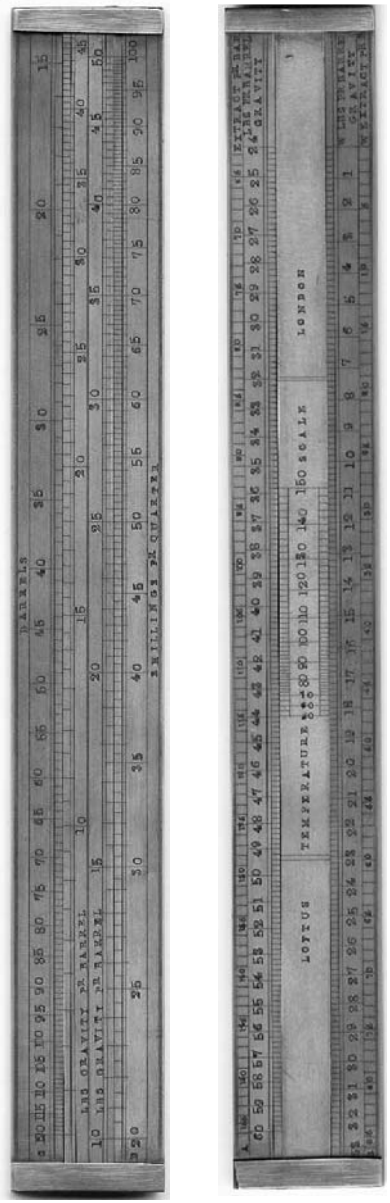

Figure 17. Loftus Brewers’ slide rule for use with saccharometer.

W. R. Loftus, 6, Beaufoy Terrace, Edgware Road, London. W.

SACCHAROMETERS,

For the use of Brewers, Distillers, British and Foreign Wine Makers, West India Sugar Planters, and Sugar Refiners, &c.

MANUFACTURED BY WILLIAM R. LOFTUS.

PRICES.	£	s.	d.
FIG. 1. New Improved Brewing Saccharometer, extra and best gilt, with Thermometer, Rule, and Instructions, complete; using but one weight, and in accordance with "Loftus's Universal Treatise on Brewing." (1st Class)	5	5	0
Ditto ditto.....(2nd Class)	4	4	0
Ditto ditto.....(3rd Class)	3	3	0
Ditto ditto .....(4th Class)	2	10	0
Brewing Saccharometer, using two weights, extra and best gilt, with Thermometer, Rule, and Instructions, complete. Lbs. as Dring & Fage. (1st Class)	4	4	0
Ditto ditto .....(2nd Class)	3	3	0
Richardson's Saccharometer .....(1st Class)	4	4	0
Ditto ditto .....(2nd Class)	3	3	0
Bates's Patent Saccharometer, with five poises or weights, adapted to Distillers and Export Brewers, as shewing the specific gravity in degrees, with Thermometer, Book of Tables and Instructions.....(1st Class)	5	5	0
Dicas's Saccharometer, ditto ditto	5	0	0
Allan's ditto ditto ditto	4	4	0
Glass Saccharometers, with Ivory Scale, warranted correct	0	10	6

Figure 18. Loftus' list of saccharometers for sale 1866.

ordered, 'The hydrometers and saccharometers are to be kept locked up when not in use, and upon no pretext whatever must any of them be suffered to pass, even momentarily, into the hands of a trader or his servants Any neglect of this injunction will be visited with the extreme displeasure of the Board.' In practical terms Bates instrument was supplemented with a range of simple metal and glass hydrometers especially where the range of specific gravities to be measured was limited and predictable.

Within many breweries tradition was hard to break. Joseph Long's catalogue continued to offer a version of Richardson saccharometer as late as 1932, possibly with reason, since it must have been easier to change dry weights at the top of the stem

rather than the Sikes/Bates instruments which required removal from the liquid for each change. The use of the brewers' pound continued for process measurements and both specific gravity and brewers pounds were recorded alongside of each other into the 1950's. Overall, brewing textbooks and journals show little interest in the use of the slide rule. In the case of hydrometry this may be associated with high duty rates and the need to agree exact figures with Customs and Excise.

In 1905 the Birmingham brewers met to hear a paper on *The Development of the Slide Rule with some Examples of its use in the Brewery.*[16] In a two-edged discussion following the paper William Waters Butler of Mitchell's and Butler's considered that they would not all rush out to buy a slide rule although the paper was a revelation to the possibilities of the slide rule in the brewing room. Brewers had too much clerical work 'they did not want to be casting out nines when they should be casting the coppers.' Another contributor did not think that they need bother calculating the wages per hour - 'the workmen did it generally for them and nearly always got it correct' and 'however the standard work on the subject appeared to be *The Slide Rule* by Charles Hoare, C.E.'

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