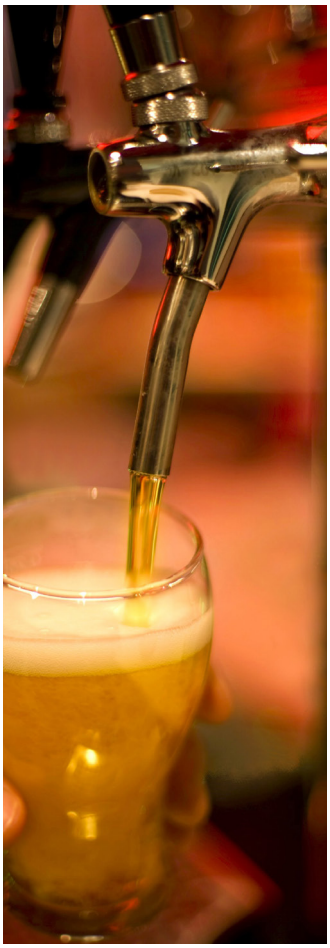
October
2013

Campden BRI
food and drink innovation

Instrument Assessment Report

Thermo Fisher Scientific - Gallery Plus Beermaster



Executive Summary

We have trialled the Thermo Scientific™ Gallery™ Plus Beermaster to establish whether it could meet the requirements for analysing a number of important beer and wort quality parameters.

In our work with the Beermaster we found that:

- The instrument was easy to use and there was a good level of technical support
- The software package was logical and user friendly.
- Maintenance and cleaning of the system was quick and straightforward
- Compared to traditional methods, the Beermaster was much quicker and less reliant on operator skills.
- The system has a low environmental impact due to minimal waste production and the very low reaction volumes (reagent and water) required

Our assessment of the ability of the Beermaster to analyse for pH, bitterness, free amino nitrogen and sulphur dioxide in beers and worts showed that based on the data obtained in this study, the test instrument gave comparable results to the reference methods. In the case of colour measurement, the Beermaster had similar precision to the reference method but consistently gave slightly lower results. By incorporating a factor of 1.05 in the methodology, the Beermaster results were shown to be comparable to the reference method. Overall, the Beermaster was more precise in the measurement of pH, FAN and sulphur dioxide when compared to the reference methods.

Instrument Assessment Report

Background

Thermo Fisher Scientific has developed an automated, discrete photometric based system that determines important quality parameters for beer and wort including colour, pH, free amino nitrogen (FAN), bitterness and sulphur dioxide (SO_2). The quick and accurate analysis requires no sample preparation except for prior degassing in the case of carbonated samples.

In this evaluation the Beermaster has been tested against traditional beer and wort analysis methods. The results were then compared for precision and repeatability.

Evaluation

Detailed instructions were provided for the instrument and the training at installation was sufficient for analysts experienced in use of spectrophotometers. The Beermaster is self-contained with no need for external water or drainage connectors. The instrument requires only a power supply and a supply of de-ionised water (to fill up the water container). Set-up is very straightforward. The instrument is controlled through a simple on-screen menu (which can be navigated by touch or via a mouse) and the included software has the capacity to store many methods. Results can be obtained with appropriate programming of methods. Once methods have been set the instrument can be started with minimal mouseclicks.

Initial calibration and subsequent calibrations were done with reference materials and the software will tell the user when an existing calibration is out of date. The Beermaster performs a series of dilutions on the calibration standard (removing the need for the user to perform these dilutions) and produces a calibration line for a specified range, quickly and accurately. QC samples were ran daily as calibration checks.

The probes used in the Beermaster are able to detect when they have reached the surface of a sample or reagent and use 'dip and sip' reagent consumption. Each reagent tube is barcoded and from this the Beermaster will know the reagent vessel size, where it has detected the surface and therefore how much volume of reagent it has for use. The user is then displayed the volume of reagent left and the number of tests that can be performed using that volume of reagent. If the volume of reagent is getting low or the volume left is not enough to perform the required number of tests the user is alerted to the fact and can insert another full reagent tube into the machine. The original tube does not have to be removed, the analyser knows to move onto the new one once that one is finished with. This 'dip and sip' facility contributes to the minimal waste that is produced, which along with the small sample and very low reagent and water volumes required, provides analysis with a very low environmental impact. The analyser will also know from the reagent barcode the reagent's expiry date and will inform the user when the reagent is out of date and has to be changed. Plus removing and inserting new samples, reagents or cuvettes did not interrupt any analyses that were currently underway.

One clear benefit of the Beermaster is the ability to simultaneously determine a number of different analytes on one sample. In this study all but bitterness could be run on the same sample. As the bitterness test takes slightly longer to run than the other tests investigated in this study (one test takes ten minutes to run) and this test also uses slightly more sample volume, it is advised that this test is run separately. During the test, the beer bittering substances are extracted in a coated capillary column from interfering compounds present in the sample matrix prior to the photometric analysis at 275nm. The methodology used still employs the use of a solvent but the volumes required are significantly less than that required in more traditional bitterness methods (including the one used in this study), thus reducing health and safety concerns and environmental impact.

Any sample results that exceed the test range of the method are automatically diluted by the analyser back into range. This is ideal for handling those samples where you are unsure if pre-dilution is required and saves on pre-treatment time. It is also possible to pre-dilute one sample, even just for one test, with all the other tests performed on a neat sample.

Result reports can be printed to paper or saved electronically as pdfs or as an excel file. The analyser also has the ability to network to LIMS system, thus allowing for smooth and timely production of reports.

The manual provided included details for troubleshooting. During the evaluation only one incident was encountered when a cuvette became jammed in the carousel. With the help of the on-screen instructions and Thermo Fisher Scientific's friendly telephone support team this was sorted promptly enabling analysis to continue without too much hindrance.

The only maintenance actions required were the daily automated start up and stand by procedures which only took a few minutes to perform. No build-up of sample components was apparent during the evaluation.

Sample analysis

To establish robustness over a range of alcohol and colour values, ten small pack beer samples and ten worts were analysed in duplicate using the Beermaster and the reference methods for:

- pH
- Colour
- Bitterness
- Free Amino Nitrogen (FAN)
- Bitterness
- Sulphur Dioxide (SO_2) – beers only

The worts (Table 1) were stored frozen prior to analysis to ensure product stability. They were gently defrosted overnight at room temperature and then centrifuged at for minutes to remove any cold trub that had formed upon freezing. Ten small pack beers with alcohol contents ranging from 0.5 to 9% (Table 2), and covering a range of colour values were analysed in duplicate. All the beers were degassed by leaving them overnight on the bench in a conical flask. In the case of SO_2 analysis a fresh can of sample was opened just prior to analysis.

Table 1 Worts used in study

Code	Type
WA	1038 Ale
WB	1040 Ale
WC	1040 Ale
WD	Adjunct
WE	1050 Best Bitter
WF	16 Plato Lager
WG	11 Plato Lager
WH	11 Plato Lager
WI	1050 Best Bitter
WJ	16 Plato Lager

Table 2 Beers used in study

Code	Type	Declared ABV (%)
BA	Lager	0.00
BB	Lager	2.30
BC	Stout	2.80
BD	Ale	3.50
BE	Lager	3.80
BF	Stout	4.20
BG	Lager	4.80
BH	Ale	5.20
BI	Ale	6.60
BJ	Lager	9.00

Tables 3-13 summarise the mean and precision data for the duplicate analyses of the wort and beer samples using the Beermaster and reference methods, together with any assigned values for the samples used in the tests.

pH Analysis

Samples were analysed for pH using the Beermaster and the reference UKAS accredited method (Campden BRI Method AM/029 based on Analytica EBC, 9.35, 2004 and 8.17, 1999)

Table 3 Summary of pH analysis results for ten different wort samples

		Measured[1]	Thermo Scientific Method					Campden BRI					
Analysis	Sample				Mean	Std Dev	SE Mean			Mean	Std Dev	SE Mean	*P-Value*
pH	WA		5.13	5.08	**5.11**	0.035	0.025	4.86	4.86	**4.86**	0.000	0.000	***0.065***
	WB	5.22	5.22	5.21	**5.22**	0.007	0.005	5.12	5.12	**5.12**	0.000	0.000	***0.033***
	WC	5.15	5.21	5.21	**5.21**	0.000	0.000	5.14	5.12	**5.13**	0.014	0.010	***0.079***
	WD	5.07	5.08	5.06	**5.07**	0.014	0.010	4.96	4.96	**4.96**	0.000	0.000	***0.058***
	WE	4.87	5.11	5.12	**5.12**	0.007	0.005	4.95	4.95	**4.95**	0.000	0.000	***0.019***
	WF	5.26	5.25	5.25	**5.25**	0.000	0.000	5.22	5.23	**5.23**	0.007	0.005	***0.126***
	WG	5.30	5.28	5.28	**5.28**	0.000	0.000	5.23	5.24	**5.24**	0.007	0.005	***0.070***
	WH	5.31	5.26	5.25	**5.26**	0.007	0.005	5.22	5.22	**5.22**	0.000	0.000	***0.090***
	WI		5.09	5.09	**5.09**	0.000	0.000	4.90	4.88	**4.89**	0.014	0.010	***0.032***
	WJ	5.22	5.23	5.23	**5.23**	0.000	0.000	5.21	5.18	**5.20**	0.021	0.015	***0.258***

[1]These are the Campden BRI mean readings on the fresh pre-frozen worts.

Table 4 Summary of pH analysis results for the ten different beer samples

		Measured[2]	Thermo Scientific Method					Campden BRI					
Analysis	Sample				Mean	Std Dev	SE Mean			Mean	Std Dev	SE Mean	*P-Value*
	CB44	4.08	4.16	4.16	**4.16**	0.000	0.000	4.16	4.03	**4.10**	0.092	0.065	***0.500***
pH	BA		4.12	4.12	**4.12**	0.000	0.000	3.98	3.92	**3.95**	0.042	0.030	***0.111***
	BB		4.37	4.34	**4.36**	0.021	0.015	4.28	4.21	**4.25**	0.049	0.035	***0.212***
	BC		5.03	5.02	**5.03**	0.007	0.005	3.93	3.96	**3.95**	0.021	0.015	***0.009***
	BD		4.21	4.32	**4.27**	0.078	0.055	4.00	4.12	**4.06**	0.085	0.060	***0.241***
	BE		4.39	4.30	**4.35**	0.064	0.045	4.26	4.29	**4.28**	0.021	0.015	***0.379***
	BF		4.62	4.63	**4.63**	0.007	0.005	3.98	4.03	**4.01**	0.035	0.025	***0.026***
	BG		4.12	4.11	**4.12**	0.007	0.005	4.00	4.05	**4.03**	0.035	0.025	***0.176***
	BH		4.20	4.20	**4.20**	0.000	0.000	3.81	3.80	**3.81**	0.007	0.005	***0.008***
	BI		4.27	4.33	**4.30**	0.042	0.030	4.25	4.28	**4.27**	0.021	0.015	***0.486***
	BJ		4.10	4.09	**4.10**	0.007	0.005	4.06	4.09	**4.08**	0.021	0.002	***0.426***

[2]This is the QC sample (a commercially available lager), the value is the mean of readings taken at Campden BRI between February 2013 and July 2013

The standard deviations of the duplicate samples showed that the precision of the Beermaster to the reference pH method was similar for both beers and worts, and overall the precision of the Beermaster in measuring pH proved better than that of the reference method and was well within acceptable tolerances for such an instrument. Statistical analysis using the two-sample *t*-test and the one-way ANOVA test suggested that in the majority of cases and based on current data there is no statistically significant evidence (p-value >0.05) for a difference in pH measurements for beer and wort when using the Beermaster versus the reference pH method.

Colour Analysis

Samples were analysed for colour using the Beermaster and the reference UKAS accredited spectrophotometric method (Campden BRI Method AM/028 based on Analytica EBC, 9.6 2000)

Table 5 Summary of colour analysis results for ten different wort samples

		Measured[1]	Thermo Scientific Method					Campden BRI					
Analysis	**Sample**				**Mean**	**Std Dev**	**SE Mean**			**Mean**	**Std Dev**	**SE Mean**	***P-Value***
Colour	WA		25.78	26.05	**25.91**	0.190	0.140	27.48	27.50	**27.49**	0.014	0.010	***0.055***
(EBC)	WB	38.00	31.09	31.12	**31.10**	0.021	0.015	33.50	33.55	**33.53**	0.035	0.025	***0.008***
	WC	35.00	31.15	30.95	**31.05**	0.141	0.100	33.63	33.65	**33.64**	0.014	0.010	***0.025***
	WD	12.00	11.90	11.88	**11.89**	0.014	0.010	12.85	12.88	**12.87**	0.021	0.015	***0.012***
	WE	37.00	36.77	36.74	**36.76**	0.021	0.015	38.65	38.70	**38.68**	0.035	0.025	***0.010***
	WF	20.00	19.40	19.44	**19.42**	0.028	0.020	20.15	20.18	**20.17**	0.021	0.015	***0.021***
	WG	11.00	11.48	11.48	**11.48**	0.000	0.000	11.55	11.60	**11.58**	0.035	0.025	***0.164***
	WH	13.00	13.10	13.12	**13.11**	0.014	0.010	13.33	13.33	**13.33**	0.000	0.000	***0.029***
	WI		39.59	39.55	**39.57**	0.028	0.020	40.98	41.05	**41.02**	0.049	0.035	***0.018***
	WJ	21.00	19.28	19.32	**19.30**	0.028	0.020	20.48	20.50	**20.49**	0.014	0.010	***0.012***

[1]These are the Campden BRI mean readings on the fresh pre-frozen worts.

Table 6 Summary of colour analysis results for the ten different beer samples

		Measured[2]	Thermo Scientific Method					Campden BRI					
Analysis	**Sample**				**Mean**	**Std Dev**	**SE Mean**			**Mean**	**Std Dev**	**SE Mean**	***P-Value***
	CB44	8.88	8.50	8.52	**8.51**	0.014	0.010	8.93	8.93	**8.93**	0.000	0.000	***0.015***
Colour	BA		7.76	7.77	**7.77**	0.001	0.005	8.13	8.10	**8.12**	0.021	0.015	***0.029***
(EBC)	BB		5.08	5.09	**5.09**	0.007	0.005	5.38	5.38	**5.38**	0.000	0.000	***0.011***
	BC		165.77	165.66	**165.71**	0.080	0.055	181.30	184.50	**182.90**	2.263	1.600	***0.059***
	BD		14.46	14.46	**14.46**	0.001	0.001	15.15	15.20	**15.18**	0.035	0.025	***0.022***
	BE		8.12	8.11	**8.12**	0.007	0.005	8.68	8.70	**8.69**	0.014	0.010	***0.012***
	BF		91.77	91.99	**91.88**	0.156	0.110	102.30	103.00	**102.65**	0.495	0.350	***0.022***
	BG		7.36	7.32	**7.34**	0.028	0.020	7.58	7.58	**7.58**	0.000	0.000	***0.053***
	BH		52.69	52.94	**52.82**	0.177	0.130	58.80	59.30	**59.05**	0.354	0.250	***0.029***
	BI		13.39	13.40	**13.39**	0.007	0.005	14.08	14.15	**14.12**	0.049	0.035	***0.031***
	BJ		13.12	13.11	**13.11**	0.007	0.005	13.68	13.73	**13.71**	0.035	0.025	***0.027***

[2]This is the QC sample (a commercially available lager), the value is the mean of readings taken at Campden BRI between February 2013 and July 2013

The standard deviations of the duplicate samples showed that the precision of the Beermaster to the reference colour method was similar for both beers and worts. Interestingly in all cases the colour readings from the Beermaster were slightly lower than that of the reference method and as a result, statistical analysis using the two-sample *t*-test and the one-way ANOVA test suggested that based on the current data there was statistically significant evidence (p-value >0.05) of a difference in colour measurements for beer and wort when using the Beermaster versus the reference colour method.

To assess whether inclusion of a factor would compensate for these differences, the statistical tests were re-run using the original Beermaster values multiplied by a factor of 1.05. The results for both the beer and wort analyses are shown in Tables 7 and 8.

Table 7 Summary of colour analysis results for ten different wort samples (the Beermaster data includes a factor of 1.05)

		Measured[1]	Thermo Scientific Method					Campden BRI					
Analysis	**Sample**				**Mean**	**Std Dev**	**SE Mean**			**Mean**	**Std Dev**	**SE Mean**	***P-Value***
Colour	WA		27.07	27.35	**27.21**	0.199	0.140	27.48	27.50	**27.49**	0.014	0.010	***0.296***
(EBC)	WB	38.00	32.64	32.67	**32.66**	0.019	0.015	33.50	33.55	**33.53**	0.035	0.025	***0.021***
	WC	35.00	32.70	32.50	**32.60**	0.142	0.100	33.63	33.65	**33.64**	0.014	0.010	***0.061***
	WD	12.00	12.50	12.48	**12.49**	0.016	0.010	12.85	12.88	**12.87**	0.021	0.015	***0.031***
	WE	37.00	38.61	38.58	**38.59**	0.018	0.015	38.65	38.70	**38.68**	0.035	0.025	***0.222***
	WF	20.00	20.37	20.41	**20.39**	0.032	0.020	20.15	20.18	**20.17**	0.021	0.015	***0.070***
	WG	11.00	12.06	12.06	**12.06**	0.002	0.000	11.55	11.60	**11.58**	0.035	0.025	***0.033***
	WH	13.00	13.76	13.78	**13.77**	0.017	0.010	13.33	13.33	**13.33**	0.000	0.000	***0.014***
	WI		41.57	41.53	**41.55**	0.027	0.020	40.98	41.05	**41.02**	0.049	0.035	***0.048***
	WJ	21.00	20.24	20.29	**20.26**	0.033	0.020	20.48	20.50	**20.49**	0.014	0.010	***0.076***

[1]These are the Campden BRI mean readings on the fresh pre-frozen worts

Table 8 Summary of colour analysis results for ten different beer samples (the Beermaster data includes a factor of 1.05)

		Measured[2]	Thermo Scientific Method					Campden BRI					
Analysis	**Sample**				**Mean**	**Std Dev**	**SE Mean**			**Mean**	**Std Dev**	**SE Mean**	***P-Value***
	CB44	8.88	8.93	8.95	**8.94**	0.015	0.010	8.93	8.93	**8.93**	0.000	0.000	***0.500***
Colour	BA		8.15	8.15	**8.15**	0.001	0.005	8.13	8.10	**8.12**	0.021	0.015	***0.258***
(EBC)	BB		5.34	5.34	**5.34**	0.004	0.005	5.38	5.38	**5.38**	0.000	0.000	***0.070***
	BC		174.06	173.94	**174.00**	0.084	0.055	181.30	184.50	**182.90**	2.263	1.600	***0.113***
	BD		15.18	15.18	**15.18**	0.001	0.001	15.15	15.20	**15.18**	0.035	0.025	***0.874***
	BE		8.53	8.52	**8.52**	0.008	0.005	8.68	8.70	**8.69**	0.014	0.010	***0.043***
	BF		96.36	96.58	**96.47**	0.161	0.110	102.30	103.00	**102.65**	0.495	0.350	***0.038***
	BG		7.73	7.69	**7.71**	0.030	0.020	7.58	7.58	**7.58**	0.000	0.000	***0.097***
	BH		55.33	55.59	**55.46**	0.186	0.130	58.80	59.30	**59.05**	0.354	0.250	***0.050***
	BI		14.06	14.07	**14.06**	0.011	0.005	14.08	14.15	**14.12**	0.049	0.035	***0.392***
	BJ		13.77	13.76	**13.77**	0.008	0.005	13.68	13.73	**13.71**	0.035	0.025	***0.256***

[2]This is the QC sample (a commercially available lager), the value is the mean of readings taken at Campden BRI between February 2013 and July 2013

By applying a factor of 1.05 to the Beermaster data, statistical analysis using the two-sample *t*-test and the one-way ANOVA test suggested that in the majority of cases and based on current data there is no statistically significant evidence (p-value >0.05) for a difference in colour measurements for beer and wort when using the Beermaster versus the reference colour method.

Bitterness Analysis

Samples were analysed for bitterness content using the Beermaster and the UKAS accredited spectrophotometric method (Campden BRI Method AM/003 based on EBC Analytica 9.8, 2004)

Table 9 Summary of bitterness analysis results for ten different wort samples

		Measured[1]	Thermo Scientific Method					Campden BRI					
Analysis	**Sample**				**Mean**	**Std Dev**	**SE Mean**			**Mean**	**Std Dev**	**SE Mean**	***P-Value***
Bitterness	WA		41.83	42.03	**41.93**	0.141	0.100	33.65	33.70	**33.68**	0.035	0.025	***0.008***
(BU)	WB	34.00	24.73	22.82	**23.78**	1.351	0.950	29.30	28.75	**29.03**	0.389	0.027	***0.119***
	WC	36.00	25.19	24.44	**24.82**	0.530	0.370	29.65	29.60	**29.63**	0.035	0.025	***0.050***
	WD	26.00	32.84	31.81	**32.33**	0.728	0.520	23.40	23.35	**23.38**	0.035	0.025	***0.037***
	WE	51.00	56.56	63.33	**59.95**	4.787	3.400	55.10	56.30	**55.70**	0.849	0.600	***0.433***
	WF	34.00	39.91	38.48	**39.20**	1.011	0.710	32.50	33.45	**32.98**	0.672	0.480	***0.087***
	WG	35.00	41.95	42.14	**42.05**	0.134	0.095	30.90	31.75	**31.33**	0.601	0.430	***0.026***
	WH	32.00	40.06	41.03	**40.55**	0.686	0.480	27.95	30.00	**28.98**	1.450	1.100	***0.062***
	WI		51.99	53.71	**52.85**	1.216	0.860	51.75	53.20	**52.48**	1.025	0.730	***0.795***
	WJ	32.00	37.9	33.84	**35.87**	2.871	2.000	31.30	32.10	**31.70**	0.566	0.400	***0.293***

[1]These are the Campden BRI mean readings on the fresh pre-frozen worts.

Table 10 Summary of bitterness analysis results for the ten different beer samples

		Measured[2]	Thermo Scientific Method					Campden BRI					
Analysis	**Sample**				**Mean**	**Std Dev**	**SE Mean**			**Mean**	**Std Dev**	**SE Mean**	***P-Value***
	CB44	15.90	18.33	17.66	**17.99**	0.474	0.330	15.63	16.03	**15.83**	0.283	0.200	***0.114***
Bitterness	BA		22.11	21.86	**21.98**	0.177	0.130	17.50	17.90	**17.70**	0.283	0.200	***0.035***
(BU)	BB		15.91	15.51	**15.71**	0.283	0.200	13.18	13.58	**13.38**	0.283	0.200	***0.014***
	BC		20.28	18.47	**19.38**	1.280	0.910	23.40	24.20	**23.80**	0.566	0.400	***0.140***
	BD		25.47	24.01	**24.74**	1.032	0.730	20.25	20.28	**20.26**	0.021	0.015	***0.103***
	BE		15.44	14.83	**15.13**	0.431	0.300	12.38	12.45	**12.42**	0.049	0.035	***0.072***
	BF		26.76	24.56	**25.66**	1.556	1.100	24.20	24.45	**24.33**	0.177	0.130	***0.441***
	BG		20.19	22.33	**21.26**	1.512	1.100	19.85	19.62	**19.74**	0.163	0.110	***0.391***
	BH		23.18	23.14	**23.16**	0.028	0.020	26.80	26.70	**26.75**	0.071	0.050	***0.010***
	BI		17.33	16.92	**17.13**	0.289	0.200	17.20	17.30	**17.25**	0.071	0.050	***0.660***
	BJ		26.14	26.01	**26.08**	0.092	0.065	22.25	22.30	**22.28**	0.035	0.025	***0.012***

[2]This is the QC sample (a commercially available lager), the value is the mean of readings taken at Campden BRI between February 2013 and July 2013.

The standard deviations of the duplicate samples showed that the precision of the Beermaster to the reference bitterness method was similar for both beers and worts, and was well within acceptable tolerances for such an instrument. Statistical analysis using the two-sample *t*-test and the one-way ANOVA test suggested that in the majority of cases and based on current data there is no statistically significant evidence (p-value >0.05) for a difference in bitterness measurements for beer and wort when using the Beermaster versus the reference bitterness method.

FAN Analysis

Samples were analysed for FAN using the Beermaster and the reference UKAS accredited spectrophometric method (Campden BRI Method AM/017 based on EBC Analytica 8.10, 2002 and 9.10, 2000).

Table 11 Summary of FAN analysis results for ten different wort samples

		Measured[1]	Thermo Scientific Method					Campden BRI					
Analysis	**Sample**				**Mean**	**Std Dev**	**SE Mean**			**Mean**	**Std Dev**	**SE Mean**	***P-Value***
FAN	WA		131.21	132.23	**131.72**	0.721	0.51	146.80	142.10	**144.45**	3.323	2.400	***0.119***
(mg/L)	WB	212.00	201.52	207.94	**204.73**	4.540	3.20	229.90	207.90	**218.90**	15.556	11.000	***0.433***
	WC	208.00	199.52	198.11	**198.82**	0.997	0.70	208.00	207.90	**207.95**	0.071	0.050	***0.049***
	WD	315.00	303.78	300.61	**302.20**	2.242	1.60	279.30	290.30	**284.80**	7.778	5.500	***0.202***
	WE	172.00	186.37	185.02	**185.70**	0.955	0.67	169.70	179.50	**174.60**	6.930	4.900	***0.267***
	WF	269.00	250.41	253.47	**251.94**	2.164	1.50	231.90	240.00	**235.95**	5.728	4.100	***0.168***
	WG	175.00	176.09	175.33	**175.71**	0.537	0.38	177.80	171.20	**174.50**	4.667	3.300	***0.778***
	WH	179.00	188.07	187.43	**187.75**	0.453	0.32	171.20	177.40	**174.30**	4.384	3.100	***0.145***
	WI		168.90	169.30	**169.10**	0.283	0.20	156.20	161.20	**158.70**	3.536	2.500	***0.151***
	WJ	263.00	258.55	259.64	**259.10**	0.771	0.54	231.80	243.40	**237.60**	8.202	5.800	***0.168***

[1]These are the Campden BRI mean readings on the fresh pre-frozen worts.

Table 12 Summary of FAN analysis results for the ten different beer samples

		Measured[2]	Thermo Scientific Method					Campden BRI					
Analysis	**Sample**				**Mean**	**Std Dev**	**SE Mean**			**Mean**	**Std Dev**	**SE Mean**	***P-Value***
	CB44	76.68	69.82	69.46	**69.64**	0.255	0.180	81.33	79.72	**80.53**	1.138	0.81	***0.048***
FAN	BA		60.83	60.96	**60.89**	0.092	0.065	57.10	58.40	**57.75**	0.919	0.650	***0.130***
(mg/L)	BB		28.96	30.30	**29.63**	0.949	0.670	31.80	31.30	**31.55**	0.354	0.250	***0.227***
	BC		12.26	11.76	**12.01**	0.354	0.250	19.60	19.80	**19.70**	0.141	0.100	***0.022***
	BD		34.49	35.61	**35.05**	0.792	0.560	36.20	35.60	**35.90**	0.424	0.300	***0.409***
	BE		96.01	95.09	**95.55**	0.651	0.460	92.10	90.30	**91.20**	1.273	0.900	***0.145***
	BF		71.23	71.71	**71.47**	0.339	0.240	75.10	73.70	**74.40**	0.990	0.700	***0.157***
	BG		58.04	59.06	**58.55**	0.721	0.510	58.00	57.40	**57.70**	0.424	0.300	***0.387***
	BH		26.50	26.61	**26.55**	0.077	0.055	41.10	40.60	**40.85**	0.354	0.250	***0.011***
	BI		112.56	109.59	**111.07**	2.101	1.500	110.70	108.30	**109.50**	1.697	1.200	***0.561***
	BJ		107.97	108.92	**108.45**	0.674	0.480	105.10	102.50	**103.80**	1.838	1.300	***0.184***

[2]This is the QC sample (a commercially available lager), the value is the mean of readings taken at Campden BRI between February 2013 and July 2013

The standard deviations of the duplicate samples showed that overall the precision of the Beermaster in measuring FAN proved better than that of the reference method (especially in the case of worts) and was well within acceptable tolerances for such an instrument. Statistical analysis using the two-sample *t*-test and the one-way ANOVA test suggested that in the majority of cases and based on current data there is no statistically significant evidence (p-value >0.05) for a difference in FAN measurements for beer and wort when using the Beermaster versus the reference FAN method.

SO_2 Analysis

Beer samples were analysed for sulphur dioxide using both the Beermaster and reference method, the traditional Monier Williams distillation/titration method (EBC Methods of Analysis, 1997, 9.25.1)

Table 13 Summary of SO_2 analysis results for the ten different beer samples

		Measured[2]	Thermo Scientific Method					Campden BRI					
Analysis	**Sample**				**Mean**	**Std Dev**	**SE Mean**			**Mean**	**Std Dev**	**SE Mean**	***P-Value***
	230	5.60	4.81	4.94	**4.88**	0.092	0.065	5.60	5.12	**5.36**	0.339	0.240	***0.302***
SO2	BA		3.10	3.00	**3.05**	0.071	0.050	4.80	4.96	**4.88**	0.113	0.080	***0.033***
(mg/L)	BB		5.10	5.10	**5.10**	0.000	0.000	5.76	5.44	**5.60**	0.226	0.160	***0.197***
	BC		0.10	0.10	**0.10**	0.000	0.000	1.12	1.44	**1.28**	0.226	0.160	***0.086***
	BD		1.30	1.30	**1.30**	0.000	0.000	1.60	1.76	**1.68**	0.113	0.080	***0.132***
	BE		11.90	12.10	**12.00**	0.141	0.100	12.32	12.80	**12.56**	0.339	0.240	***0.227***
	BF		0.80	0.90	**0.85**	0.071	0.050	2.40	2.08	**2.24**	0.226	0.160	***0.076***
	BG		4.00	4.10	**4.05**	0.071	0.050	2.91	3.01	**2.96**	0.071	0.015	***0.004***
	BH		2.40	2.40	**2.40**	0.000	0.000	2.24	1.92	**2.08**	0.226	0.160	***0.295***
	BI		1.80	1.80	**1.80**	0.000	0.000	1.60	1.28	**1.44**	0.226	0.160	***0.266***
	BJ		15.10	19.70	**17.40**	3.253	2.300	16.32	16.80	**16.56**	0.339	0.240	***0.778***

[2]This is the QC sample (a commercially available lager), the value is the mean of readings taken at Campden BRI between February 2013 and July 2013

The standard deviations of the duplicate samples showed that the precision of the Beermaster to the reference SO_2 method was similar, and overall the precision of the Beermaster in measuring SO_2 proved better than that of the reference method and was well within acceptable tolerances for such an instrument. Statistical analysis using the two-sample *t*-test and the one-way ANOVA test suggested that in the majority of cases and based on current data there is no statistically significant evidence (p-value >0.05) for a difference in SO_2 measurements for beer and wort when using the Beermaster versus the reference SO_2 method.

Repeatability

Ten samples of a commercially available canned lager were analysed for pH, colour, bitterness, FAN and SO_2 using the Beermaster and the traditional reference methods.

Tables 14-18 summarise the mean and precision data for the analyses.

Table 14 Summary of pH analysis results for 10 samples of a single brand of beer

	pH	
Beer	**Beermaster**	**Campden BRI**
BG	4.14	4.00
BG	4.14	4.00
BG	4.17	4.02
BG	4.14	4.02
BG	4.13	4.04
BG	4.13	3.99
BG	4.16	4.05
BG	4.13	4.05
BG	4.13	4.05
BG	4.12	4.05
Mean	**4.14**	**4.03**
SD	**0.016**	**0.024**
95% Confidence Interval for Mean	**4.13, 4.15**	**4.01, 4.04**

Table 15 Summary of colour analysis results for 10 samples of a single brand of beer (*no* factors have been included)

	Colour (EBC)	
Beer	**Beermaster**	**Campden BRI**
BG	7.33	7.53
BG	7.32	7.55
BG	7.39	7.58
BG	7.31	7.58
BG	7.36	7.6
BG	7.30	7.58
BG	7.29	7.58
BG	7.28	7.6
BG	7.32	7.58
BG	7.32	7.58
Mean	**7.32**	**7.58**
SD	**0.032**	**0.021**
95% Confidence Interval for Mean	**7.30, 7.35**	**7.56, 7.59**

Table 16 Summary of bitterness analysis results for 10 samples of a single brand of beer

	Bitterness (BU)	
Beer	**Beermaster**	**Campden BRI**
BG	21.43	19.73
BG	22.94	19.88
BG	22.36	19.78
BG	23.26	20.05
BG	22.24	19.83
BG	21.1	19.63
BG	23.21	19.80
BG	22.44	19.55
BG	21.32	19.38
BG	21.26	19.73
Mean	**22.16**	**19.74**
SD	**0.831**	**0.185**
95% Confidence Interval for Mean	**21.56, 22.75**	**19.60, 19.87**

Table 17 Summary of FAN analysis results for 10 samples of a single brand of beer

	FAN (mg/L)	
Beer	**Beermaster**	**Campden BRI**
BG	57.27	58.00
BG	58.03	58.90
BG	58.54	58.70
BG	58.04	58.40
BG	59.06	57.20
BG	57.20	57.40
BG	58.09	57.60
BG	58.30	57.20
BG	58.85	57.20
BG	58.21	56.90
Mean	**58.16**	**57.75**
SD	**0.596**	**0.706**
95% Confidence Interval for Mean	**57.73, 58.59**	**57.25, 58.26**

Table 18 Summary of SO_2 analysis results for 10 samples of a single brand of beer

	SO $_2$ (mg/L)	
Beer	**Beermaster**	**Campden BRI**
BG	4.0	2.72
BG	4.0	3.20
BG	4.0	3.04
BG	4.1	2.88
BG	4.0	2.72
BG	4.0	3.04
BG	3.9	2.88
BG	4.0	3.36
BG	3.7	3.20
BG	4.0	2.56
Mean	**3.97**	**2.96**
SD	**0.106**	**0.253**
95% Confidence Interval for Mean	**3.89, 4.05**	**2.78, 3.14**

The precision of the Beermaster, as expressed in the standard deviations of the ten replicates showed with the current data and this brand of beer, precision was greatest for pH measurement and least for bitterness. The current data also suggested that the Beermaster was more precise in the measurement of pH, FAN and SO_2 compared with the reference methods used.

Summary

Based on the data obtained during this study, the Thermo Scientific Gallery Plus Beermaster Analyser has been shown to give comparable performance in the measurement of pH, bitterness, FAN and SO_2 to established methods. In the case of colour measurement, the Beermaster had similar precision to the reference method but consistently gave slightly lower results suggesting a factor to compensate for these differences be included in the methodology. When a factor of 1.05 was included in the methodology, the Beermaster was comparable to the established method. Analysis of ten replicates

of the same brand of beer showed that the Beermaster had greater precision in the measurement of pH, FAN and SO_2 compared to the reference methods used in this study. Precision values for all analyses are well within the tolerances expected for spectrophotometers in the brewing industry. The Beermaster is straightforward to use and faster than more traditional methods (in the case of bitterness, FAN and SO_2, significantly faster). The low reagent and water volumes required for analysis not only reduces reagent costs but also reduces the amount of waste produced, thereby providing analysis with a low environmental impact.