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Impacts of steam injection technology on volatile formation and stripping during wort boiling.

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INTRODUCTION

In the drive to reduce energy usage in brewing, wort boiling remains an urgent target for optimization, as it represents one of the most energy intensive stages of the process.

Boiling drives a number of key changes in wort, including sterilization, isomerization of hop α-acids, trub formation, enzyme inactivation and the stripping of flavor-active volatile components. The utilization of novel, low energy techniques or technologies to replace existing practice has the potential to impact on final product quality and must be demonstrated to match the performance of existing technologies in this regard. It is particularly important to determine potential effects on wort volatile formation and stripping, to ensure that there are no downstream impacts on finished beer flavors.

The PDX wort heating system (Pursuit Dynamics, Huntingdon, UK) claims to reduce the energy required for wort boiling whilst maintaining efficient stripping of volatile compounds. The PDX wort heater can be retrofitted into existing brewlines and acts by injecting culinary grade steam into the flow of wort in order to create a multiphase flow and enhance energy transfer efficiency (Figure 1).

In the present study, the volatile formation and stripping characteristics of the PDX wort heater were investigated for three different product lines; a lager, a stout and an unfermented malt drink.
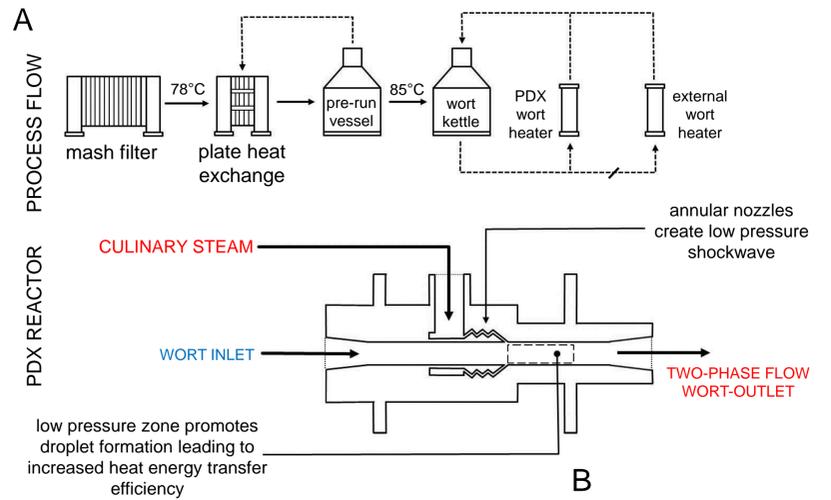

Figure 1 (A) Diagrams displaying the process flow of wort from the mash filter to the kettle and a cross section of an individual PDX reactor. (B) Photograph displaying the PDX heater retrofitted into a Ghanaian brewery, highlighted with (i) wort inlet (ii) main culinary steam line (iii) steam connector to PDX reactor (iv) PDX reactor (v) wort outlet.

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EXPERIMENTAL

WORT PRODUCTION

The PDX heater was installed in parallel to an existing external calandria (control condition) in a 1 million hL brewery in Ghana. To allow direct comparison of the trial and control conditions the same brewline was used to produce all samples, with heater selection controlled using a single electronically operated valve. (Figure 1). In order to control the dilution rate in the trial condition the wort was passed through an in-line heater in order to reach 85°C, the preheated wort was then transferred into the kettle. After 20% of the wort had been transferred to the kettle, IKE was added manually. Samples were taken from 3 different product lines: a stout (grist: malted barley and unmalted sorghum), a lager (grist: malted barley and unmalted maize) and an unfermented malt drink (grist: malted barley and unmalted barley). Additionally, final product samples were acquired for each product type.

WORT VOLATILE ANALYSIS BY GC-MS:

SOLVENT EXTRACTION METHOD: Sample (20 mL) was extracted into 2 mL dichloromethane (DCM) with 100 µL 3-heptanoic internal standard (1 mg/mL) for 1 h at room temperature. The DCM layer was transferred to a glass vial for analysis by GC-MS (Figure 2). Sample (1 µL) was injected in splitless mode (splitless time: 1 minute, split flow: 25 mL/min) using an AS3000 auto sampler. The injector was held at 250°C with an initial oven temperature of 40°C that was increased to 250°C at 8°C/min. Helium (18 psi) was used as the carrier gas to elute the sample volatiles from the ZB-WAX column (30m x 0.25m ID, 1 µm film thickness). The DSQ II mass spectrometer was operated in selected-ion mode. Peak area data were calibrated against a standard curve in order to determine compound concentrations.

SOLID-PHASE MICROEXTRACTION METHOD: Sample (5 mL) was pipetted into a 20 mL headspace vial with 100 µL 2-butanol internal standard (100 µg/mL) and crimp sealed. Headspace was exposed to a solid-phase micro extraction fibre (50/30 µm DVB/CAR/PDMS stableflex SPME fiber assembly; Figure 2), and equilibrated for 10 min at room temperature. Samples were analyzed by GC-MS in selected-ion mode. The equilibrated SPME fiber was exposed to the injector port (230°C) and desorbed for 10 min. The GC was operated in splitless mode with an initial oven temperature of 37°C (held for 2 min) that was increased 18°/min to 150°C. Separation used a ZB-WAX column using a helium carrier gas (18 psi).

Figure 2 The extraction and analysis of wort volatile compounds using solvent extraction or SPME followed by GC-MS.

RESULTS & DISCUSSION

ANALYSIS OF TRIAL AND CONTROL WORTS

Wort samples were analysed by the Versuchs- und Lehranstalt für Brauerei in Berlin (VLB) in accordance with standard brewing methods. Results showed that the PDX wort heater produced worts which broadly matched the parameters of the control, as is shown for lager wort (Table 1). A 2-tailed t-test, assuming equal variance, indicated that wort colour, coagulable nitrogen, bitterness units, pH and turbidity did not differ significantly between trial and control brews. However, the original gravity of worts prepared using the PDX wort heater was significantly lower than for trial brews (P<0.05) due to the impact of steam injection. In addition, wort total nitrogen, total protein and free amino nitrogen were all significantly higher in the control, relative to trial brews (P<0.05).

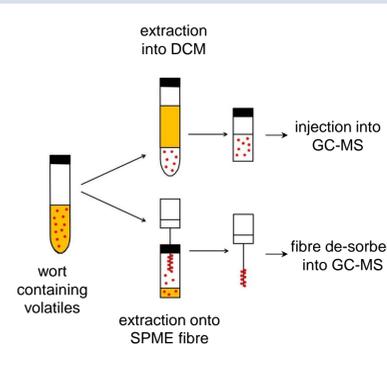Table 1. Analysis of lager worts for trial (PDX heater) and control (external calandria) brews.
Data are the mean ± SD of 4 replicate brews. Parameters which were significantly different (P<0.05) between the two conditions are highlighted in red.

Wort parameter	Trial	Control
Original gravity	13.6±0.6	15±0.3
pH	4.9±0.2	5.1±0
Color	21.7±7.6	16.7±6
Turbidity	15.5±1	17.2±1.3
Total nitrogen (mg/L)	706±11.3	807.3±42.7
Total protein (g/100 mL)	0.4±0	0.5±0
Coaguable nitrogen (mg/L)	27.3±1.5	21±3
FAN (mg/L)	118±7.9	143.7±6.4
Bitterness (EBC)	22.6±2.5	26±2.1
TBI	56.3±4.7	75±6.6

Table 2. Volatile composition of worts at the start and end of boil (stout, lager and unfermented malt drink). Compounds highlighted in red have timecourse profiles plotted in Figure 3.
*DMS-P expressed as DMS equivalent (= DMS_Total −DMS_Free).

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						µg/L					
Product		Stout			Malt beverage				Lager		
Condition	control		trial		control		trial		control		trial
Time (min)	0	75	0	75	0	75	0	75	0	60	0	60
2-phenethyl alcohol	129±32	114±47	107±12	96±6	152±25	144±9	174±33	168±28	106±7	106±7	114±19	91±13
2-phenyl ethanal	145±22	95±28	114±8	99±16	79±15	68±8	99±26	92±17	116±6	108±33	117±18	104±8
benzaldehyde	32±7	12±3	23±3	17±2	11±2	5±1	12±2	13±2	21±3	10±2	21±2	15±3
DMS	183±36	24±10	124±33	27±30	35±16	1±0	35±23	9±5	105±12	19±7	163±35	40±34
DMS-P*	261±125	24±25	155±107	25±22	70±51	15±10	103±67	14±15	209±158	31±11	210±61	24±5
furfural	181±39	282±91	196±42	280±64	205±108	345±44	232±174	519±203	194±36	358±11	228±53	342±112
hexanal	255±85	44±8	107±10	85±36	94±20	43±13	129±36	67±17	117±17	39±8	130±14	76±21
linalool	54±12	8±3	51±15	43±20	9±6	1±1	25±8	12±2	31±2	9±4	32±4	31±21
n-hexanol	72±26	6±5	55±7	39±14	73±23	4±2	94±40	46±12	85±15	11±5	50±14	22±5
β-myrcene	11±5	2±1	23±15	14±17	3±3	0±0	39±32	3±2	30±3	4±1	26±11	9±7
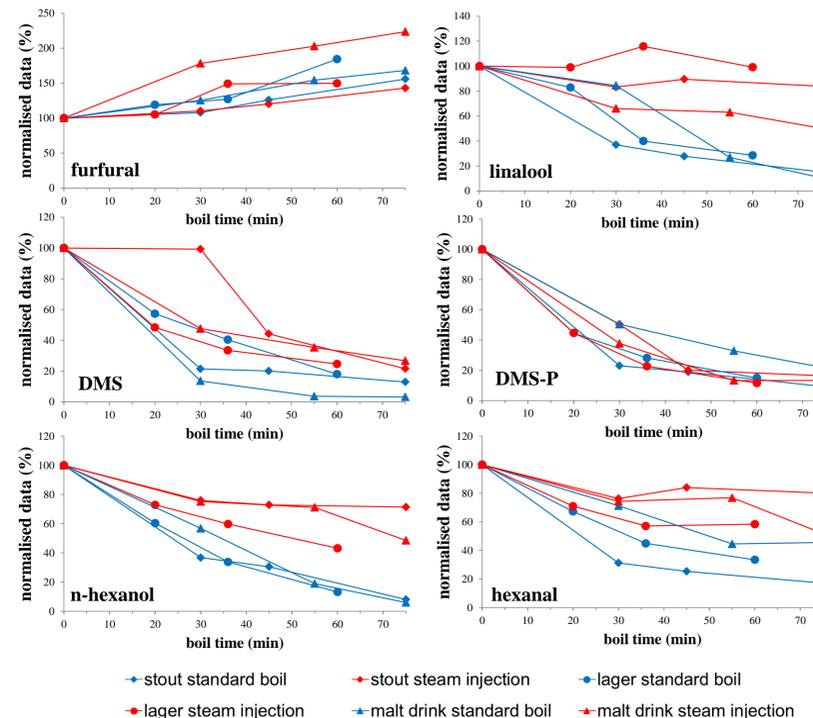
Figure 3. Concentrations of selected volatile compounds monitored through trial and control brews, normalized against their concentrations at start of boil (=100%).

VOLATILE CONCENTRATION THROUGH THE BOIL

During wort boiling the transient concentrations of volatile compounds are determined by i) their starting concentrations, ii) the rate at which they are being generated by thermally driven reactions and iii) the rate at which they are stripped from wort to the gas phase. In the present trial we opted to monitor concentrations of compounds which represent different generation and stripping behaviours through the boil, as well as some which are of key significance to brewing (e.g. DMSP & DMS; hop-derived compounds such as linalool and myrcene).

Since DMSP is broken down in a thermally driven first-order reaction through the boil, it was interesting to note that the two technologies resulted in similar profiles of DMSP reduction (Figure 3). Furfural is a Maillard reaction product present in kilned malt and which continues to form throughout the boil (Figure 3 & Table 2). Both the control and trial boils displayed similar rates of furfural increase suggesting that the balance between formation and stripping was similar in each case. Compared to the traditional external calandria, the PDX heater showed an apparently inferior stripping efficiency for a number of compounds including DMS, n-hexanol and hexanal (Figure 3), perhaps due to greater generation of these compounds from their precursors.

Hops were added to the brew in the form of IKE. For linalool and β-myrcene the PDX heater resulted in an apparently inferior stripping efficiency, although it is possible that the somewhat lower reduction across the boil was due to a greater extraction of hop compounds from IKE.

FINAL PRODUCT VOLATILE PROFILES

Analysis of in-pack beverages showed only minor differences in the volatile compositions of PDX boiled products, relative to those produced using a traditional boiling process (Figure 4). Fermentation and downstream processing seemed to compensate for the minor differences in wort volatile composition noted post-boil (Table 2). All samples were subjected to sensory evaluation using Diageo standard protocols, and in each case the products of the PDX system were found to conform to the required brand profile.
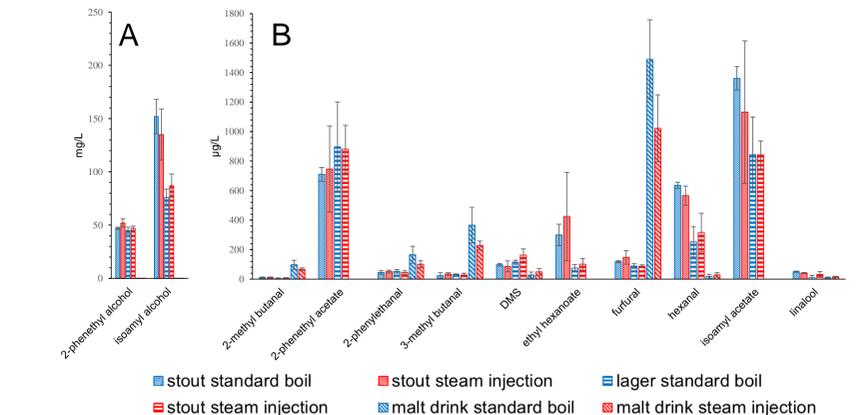

Figure 4. Flavor volatile profiles of finished products that were produced using control (external calandria) and trial (PDX heater) boil conditions. (A) higher alcohols (B) aldehydes, esters, hop compounds and DMS.

CONCLUSIONS

For the external calandria, average steam usage (1.6 bar gauge) during the boil was 2,100 kg, representing an energy usage of 4,572 MJ. For the PDX boils the average steam usage during the boil was 875 kg (2,379 MJ). Thus, the energy savings associated with boiling using the PDX system were of the order of a 50% reduction as compared to the conventional calandria used for control boils. Whilst minor differences in wort quality and volatile composition were noted between PDX and trial brews, these were not sufficient to translate into substantial flavour differences in each of the 3 downstream products, which were flavour matched within acceptable tolerance to the external calandria boiled products.