MONITORING OF BEER FERMENTATION PROCESS USING ACOUSTIC EMISSION METHOD

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ABSTRACT

The acoustic emission (AE) method has been used to monitor fermentation process in the hopped wort. In the pilot phase of the research, 3 piezoelectric sensors have been placed on the outside of the fermentation tank assembly and acoustic signals have been measured continuously for the entire fermentation period. The sensors' purpose was to “hear” carbon dioxide bubbles emerging inside of the fermentation tank and to pass signals to the AE analyzer/laptop PC for further processing.

Key words: beer, fermentation, tank, cylindroconical fermenter, acoustic emission

INTRODUCTION

Beer fermentation has been monitored using acoustic emission (AE) method that is able to „hear“ small acoustic impulses or noise inside of objects or vessels. The aim of the experiment was to determine whether AE can reliably distinguish fermentation process properties for various beer types. As the temperature of the tank content has been monitored on a continuous basis by an automated system, the AE was expected to provide another parameter of the process.

The technique is unique for its simple concept. No immerse devices are required, no special environment specifications need to be taken into account. If sufficient results are available, automatic fermentation-control devices might be developed including AE monitoring sensors. Similar systems could be used to control vine fermentation process in the future.

Beer Fermentation Process

Fermentation is the process by which fermentable carbohydrates are converted by yeast into alcohol, carbon dioxide, and numerous other byproducts. It is these byproducts that have a considerable effect on the taste, aroma, and other properties that characterize the style of beer. [1]

Cylindroconical fermenters are the most commonly used fermentation systems used today to produce both lagers and ales. As the name implies, the enclosed vessels are vertical cylinders with a conical base and, normally, a dished top. This design allows for easy yeast collection and CIP cleaning. They range in size between 100 and 7,000 hl, have from a 1:5 to a 3:1 ratio of height to diameter, and work under pressures of from 100 to 130 kPa above atmospheric pressure. In fermentation vessels with a ratio greater than 3:1, there is a tendency for increased production of higher alcohols at the expense of esters. Vessel geometry plays an important role in fermentation. As the height-to-diameter ratio increases, so does the mixing of yeast and wort, as well as the fermentation rate. [1]

Acoustic Emission Method

Acoustic emissions are the stress waves produced by the sudden internal stress redistribution of the materials caused by the changes in the internal structure. Possible causes of the internal-structure changes are crack initiation and growth, crack opening and closure, dislocation movement, twinning, and phase transformation in monolithic materials and fiber breakage and fiber-matrix debonding in composites. Most of the sources of AEs are damage-related; thus, the detection and monitoring of these emissions are commonly used to predict material failure. In technical diagnostics, AE method has been used to monitor rotational part status (friction and cavitation of bearings/gears), detection of micro-cracks, pressure vessel defects, tubing system defects, aircraft structure evaluation/testing, and bridge status diagnostics. AE technique has proven useful in fatigue testing and destruction experiments. Major advantages of AE include continuous monitoring of the object, time savings, and forecast abilities of the concept. On the other hand, AE wave source is not always obvious, as the emitted energy may result from several phenomena inside of the part. Further variable factors include shape of the object, surface area, material structure, and homogeneity level. [2]

MATERIAL AND METHODS

In Mendel university, there is a Destila micro-brewery in the food production laboratory of the Department of Agriculture, Food and Environmental Engineering. The Destila system serves for model and/or analysis purposes. It allows for amount modifications of malt, hops, yeasts, and other ingredients. The temperature can be streamlined within the actual brewing process as well. The variable configuration features make the micro-brewery an ideal ground for various research projects. Figure 1 shows the fermentation section of the micro-brewery.

The Destila micro-brewery consists of the following main components: mash tun, cooling system, open fermentation tank, storage tank, cylindroconical fermenter, filtration/racking tank, and accessory (electric, boiler, cooling system, filtration).

In this project, beer fermentation process in cylindroconical fermenter tank has been been subject to AE monitoring. This device allows for combined and streamlined fermentation process as opposed to primary fermentation in open fermentation tank and secondary fermentation in storage tank. The cylindroconical fermenter is made from Cr/Ni stainless steel.

Figure 1: Fermentation part of Destila micro-brewery assembly. Note the cylindroconical fermenter in the foreground with extensive piping accessory (position of SENSOR2). Photo by D. Varner

Three piezoelectric sensors have been glued to the tank body and accessory (SENSOR1, SENSOR2, and SENSOR3). Each sensor featured a different position with relation to the hopped wort inside the tank. The objective of sensor positioning was to establish the closest possible acoustic contact with the actual hopped wort in the tank vessel. However, this has become quite complicated as the body of fermenter features a two-layer welded structure. Reason for this is a convenient glycol-based cooling system that helps to maintain standard conditions for the fermentation process. The concept of sensor engagement was to capture development of carbon dioxide bubbles inside the tank and occasionally register their destruction on the surface of the hopped wort in a way of sound wave.

SENSOR1 has been placed on the top of the tank in the initial phase of configuration testing (see Figure 3). Later, a new place was found for SENSOR1: on the bolt head of the temperature gauge fixture. This position is on the side of the fermenter. As the bolt head is directly attached to the gauge rod immerged in the tank contents, SENSOR1 was supposed to get closest possible contact with the hopped wort (see Figure 2).

Figure 2: Position of SENSOR1 on the temperature gauge. Note the yellow rubber band for additional fixing of the sensor. Photo by D. Varner

SENSOR2 has been placed on a carbon dioxide outlet valve assembly (see Figure 3). This part od the device serves as a secondary source of fermentation intensity level. A gauge shows pressure of carbon dioxide in the tank above the hopped wort level. Obviously, the more bubbles emerge from the piping, the more intensive the internal process is. Placing SENSOR2 in the outlet body of the valve was the only way of visual relationship between signal and actual fermentation intensity. Thus, this sensor was initially meant just for support purpose. The actual AE was probably caused by mechanical motion of internal valve components rather than by actual fermentation process.

Figure 3: Position of SENSOR2 on the carbon dioxide outlet valve assembly. The sensor can be seen below the gauge dial, glued upside-down to the bottom of the assembly. Photo by D. Varner

SENSOR3 has been glued to the top of the tank. This position has been chosen due to direct contact with the inside atmosphere of the tank. As opposed to side walls, the top wall of the tank is a single sheet metal plate. As a result, SENSOR3 was expected to easily register the bubbles above the hopped wort level.

Figure 4: Position of SENSOR3 on the top of the fermentation tank (the small one, in background). In the foreground, a big calibration sensor is temporarily glued to the double-wall portion of the tank. After successful calibration of the AE monitoring assembly, it was removed. Photo by D. Varner

The signals from all three sensors was pre-amplified and later processed by the Dakel XEDO AE analyzer. An Ethernet-connected laptop PC with Dakel DaeMon software was used for continuous viewing and storage of the AE data (see Figure 5).

Figure 5: Control laptop PC on top of XEDO AE analyzer. Photo by D. Varner

The data from AE monitoring has been evaluated using Dakel DaeShow software to provide visual representation and statistics. The AE was monitored continuously for the entire fermentation period (see Duration section below).

In general, the fermentation itself was supposed to represent a noise-type signal environment. However, AE events might have been registered as well, mainly in connection with destruction of individual carbon dioxide bubbles.

Acoustic Emission Parameters

Two significant AE signal parameters have been taken into account during the experiment: RMS values and PSD function maximum values. They are described as follows:

- RMS (Root Mean Square) indicates "effective" value or "robustness" of the signal. RMS indicates quantity properties of the AE events (amount of energy). RMS is measured in Volts.
- PSD (Power Spectral Density) of the AE events indicates distribution of energy transmitted over the frequency spectrum. PSD graphs show one or more peaks. Transformation of the signal from time domain to frequency domain has been performed using the Hanning window. PSD is measured in mW/Hz or dBm/Hz for a logarithmic scale.

Additional Parameters of the Brewing Procedure

Temperature – In the beginning of the fermentation, the temperature hopped wort was 7 degrees Celsius. During the first 24 hours of fermentation, the temperature increased to 10 degrees Celsius. Then the control system performed an automatic cooling-based reduction of 1 degree Celsius per day. Thus, at the end of the experiment, the hopped had temperature of approximately 2 degrees Celsius.

Hopped Wort Composition – In this particular brew, the following ingredients have been used: malt 18kg (Czech sort 9kg, Bavarian sort 9kg), Premium granulated hop (100g), water.

Duration – The fermentation lasted from afternoon of April 21st 2010 till morning of April 30th 2010. For all this time, the AE system was active and data was recorded on the laptop PC.

DISCUSSION

Despite expectations, the results of AE monitoring have not produced satisfactory results. The individual sensors provided ambiguous and hard-to-read data that did not correspond to the common fermentation theory (ascending trend, intensive activity, descending trend in the end of the fermentation).

SENSOR1 – produced flat RMS curve with very rare AE events (supposedly bursts of the bubbles). No trends have been visible in the charts.

SENSOR2 – produced some usable results featuring steep rise of AE events and correlating RMS. However, while RMS shows descending trend towards the end of experiment, the AE events for some reason keep on higher count level. As SENSOR2 measured secondary activity of valve components, this data DO NOT represent actual fermentation-related carbon dioxide development. On the other hand, the quantity of CO2 bubbles going through the valve might proportionally correspond to the fermentation process intensity. A chart with cumulative AE event count versus RMS trend is shown in Figure 6. The extreme rise of RMS at the very end of experiment time-line has been caused by the brewery personnel. Clearly, they have been touching the tank and performing some rich-sound-emitting activities, such as pumping or rinsing.

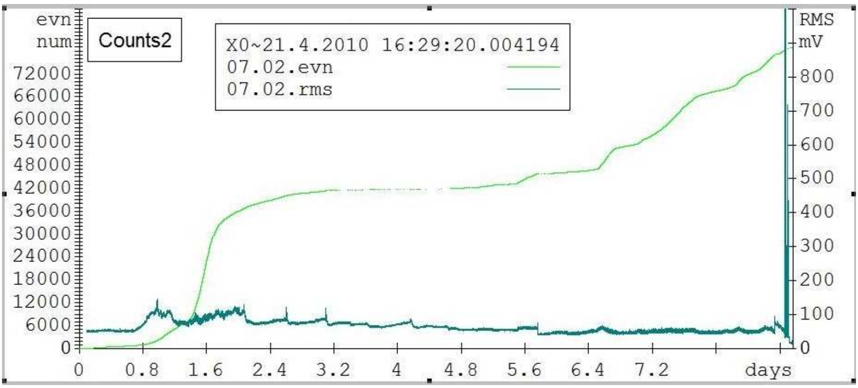

Figure 6: Data acquired from of SENSOR2. Note the green curve of cumulative AE event count (the steeper the curve, the more AE events have occurred) and blue trend of signal RMS values. Plot generated by the Dakel DaeShow software.

As far as the PSD function of SENSOR2 data is concerned, typical spectral distribution in the signal is shown in Figure 7. However, as stated above, this is not a relevant process-related data plot, but rather a secondary process property (probably a mechanical motion of the valve mechanism).

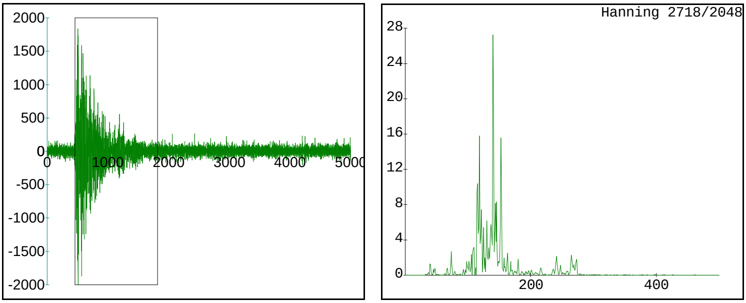

Figure 7: PSD data acquired from of SENSOR2. Note the selection window on the left and corresponding frequency distribution that actually describes some mechanical motion rather than a fermentation-related process. Plots generated by the Dakel DaeShow software.

SENSOR3 – produced flat RMS curve with very rare AE events. No trends have been visible in the charts. Recorded data is similar to SENSOR1 data set.

CONCLUSIONS

The aim of the experiment was to observe possibility of AE being able to monitor fermentation process in a micro-brewery facility. Three sensors have been used, but no satisfactory results have been obtained. The only reasonable AE data come from secondary process (carbon dioxide outlet valve). Possible reasons for the failure might be as follows:

1. Lack of knowledge concerning AE behavior in Cr-Ni steel and signal attenuation.
2. Complex layout of the fermenter making proper positioning of AE sensors complicated.
3. Unavailable data concerning the inside conditions in the fermenter.

For future research, we strongly recommend performing a detailed study of fermenter structure and extensive calibration/verification of the sensors' functionality.

REFERENCES

[1] Beer Fermentation [online]. 2010 , 08.02 [quot. 2010-09-26]. Available from WWW: < http://www.beer-brewing.com/beer-brewing/beer_chapters/ch13_beer_fermentation.htm >.

[2] KREIDL, Marcel, ŠMÍD, Radislav. Technická diagnostika. 1. vyd. Praha : Nakladatelství BEN

[3] BÉLA, Kiss; HORVÁTH, Imre. *Pivovarský slovník : německo-anglicko-maďarsko-český* . Reedice VÚPS. Praha : Luxpress, 1994. 265 s. ISBN 80-7130-033-0.

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