

Investigation of Process and Design Changes in Horizontal Tank Outlet Pipes During Main Fermentation

Kristina Boee¹ and Dr.-Ing. Christoph Tenge²

1. Tuchenhagen Brewing Systems GmbH, Am Industriepark 2-10, 21514 Büchen, Germany.

2. Technical University of Munich at Weihenstephan, Alte Akademie 3, 85354 Freising-Weihenstephan, Germany.

ABSTRACT

After a fermentation vessel is filled, the product remains in the long outlet pipes of the vessel during the entire fermentation period. We observed the processes that take place in these pipes during the fermentation period. Different developments were observed in the pipes compared with the tank. Product in the pipes fermented much faster than in the tank and underwent negative changes. The yeast autolyzed and released off-flavors, which also affected the quality of the product in the tank. A possible explanation for this development could be the separation of the pipes from the tank during fermentation for immediate cleaning. The effect of this process is illustrated by comparing conventional and alternative (ECO-MATRIX, a novel, patented tank connection concept) tank systems.

SÍNTESIS

Después que se haya llenado un tanque de fermentación, las tuberías de suministro quedan llenas de producto durante todo el tiempo de la fermentación. Se observó un comportamiento diferente en la tubería comparado con lo que ocurre en el tanque. El producto en la tubería fermentó más rápidamente y sufrió cambios negativos. La levadura se autolizó y aportó sabores desagradables, lo que también afectó el producto dentro del tanque. Una posible solución sería la separación de la tubería del tanque tan pronto como se llene, para que la tubería sea lavada de inmediato. El efecto de este proceso se ilustra mediante la comparación de métodos convencionales con este sistema alternativa (ECO-MATRIX, un novedoso concepto, patentado, para la conexión de tanques).

Introduction

Many modern brewery cellars have large fermentation vessels that hold up to several thousand hectoliters and are equipped

Corresponding author Kristina Boee is technical director at Tuchenhagen Brewing Systems. She holds a B.S. degree in process engineering and a Dipl.-Ing. degree from the Technical University Hamburg-Harburg, Germany. Boee has 14 years of experience in the beverage and brewing industries. Her personal project contributions include project engineer for process units (wort aeration and yeast pitching); product manager for process units (carbonation, mix processing, deaeration, wort aeration, and yeast pitching); presentations, sales materials, support, and technical developments; project manager for beverage plants (complete integration, new developments, design, engineering, installation, and start up); and technical support for Tuchenhagen North America and process units. Boee studied until 1995 and has worked for Tuchenhagen Brewery Systems GmbH, Germany, ever since, holding such positions as product manager (1996–1998), project manager (1998–1999), head of international engineering (2000–2002), head of engineering with power of procurement (2003–2005), and technical director (2005–present).

E-mail: boee.kristina@tuchenhagen.de

Based on posters presented at the World Grains Summit: Foods and Beverages, San Francisco, CA, September 2006, and the 120th Anniversary Convention of the Master Brewers Association of the Americas, Nashville, TN, October 2007.

* The e-Xtra logo stands for “electronic extra” and indicates that the online version contains supplemental material not included in the print edition. Figures 3–5 and 7–9 are in color online.

doi:10.1094/TQ-44-4-0281

© 2007 Master Brewers Association of the Americas

with a number of long outlet pipes. Processes like filling or cleaning are carried out mainly through valve blocks or pipe fences, and the product frequently remains in the pipes after filling and during fermentation. Process parameters that differ from those in the tank (e.g., temperature and pressure) influence changes in the product remaining in the pipes.

The goal of this study was to investigate differences between fermentation processes in the tank and pipes. Different process parameters should lead to different developments in the tank and pipes, and the impact of these distinct processes on fermentation management and final beer quality can be determined. In addition, an alternative design, the ECO-MATRIX tank outlet, was evaluated to look for possible solutions to this problem. The ECO-MATRIX system is a novel, patented tank connection concept (US Patent 10/467,757).

The trials were carried out during the regular fermentation process in a large-scale brewery. To compare the processes, samples were taken from the pipes and tank during fermentation. These samples were analyzed based on conventional fermentation parameters such as temperature, extract, and pH. Yeast activity was determined using live/dead cell staining. Additionally, the samples that showed the biggest differences were examined in detail using GC analyses.

Materials and Methods

Cellar Equipment

The investigated tanks were conventional cylindro-conical tanks connected via an outlet pipe to a pipe fence (Fig. 1A). Each tank was individually cooled. Tanks equipped with the ECO-MATRIX system were directly connected to the pipe system by

valves directly under the cone (Fig. 1B). The remaining outlet was a short pipe (<1 m). This pipe system can be operated and cleaned separately from the tank.

Sampling

Samples were taken from five different tanks. Three tanks were equipped with a longer tank outlet of 9.6 m (pipe volume 75.8 L), and two tanks were equipped with a shorter outlet of 3.1 m (pipe volume 23.7 L). The length describes the distance between the tank cone and the connection to the pipe fence. In addition, four tanks equipped with the ECO-MATRIX system were investigated (pipe length 0.8 m; pipe volume 6.3 L). Daily

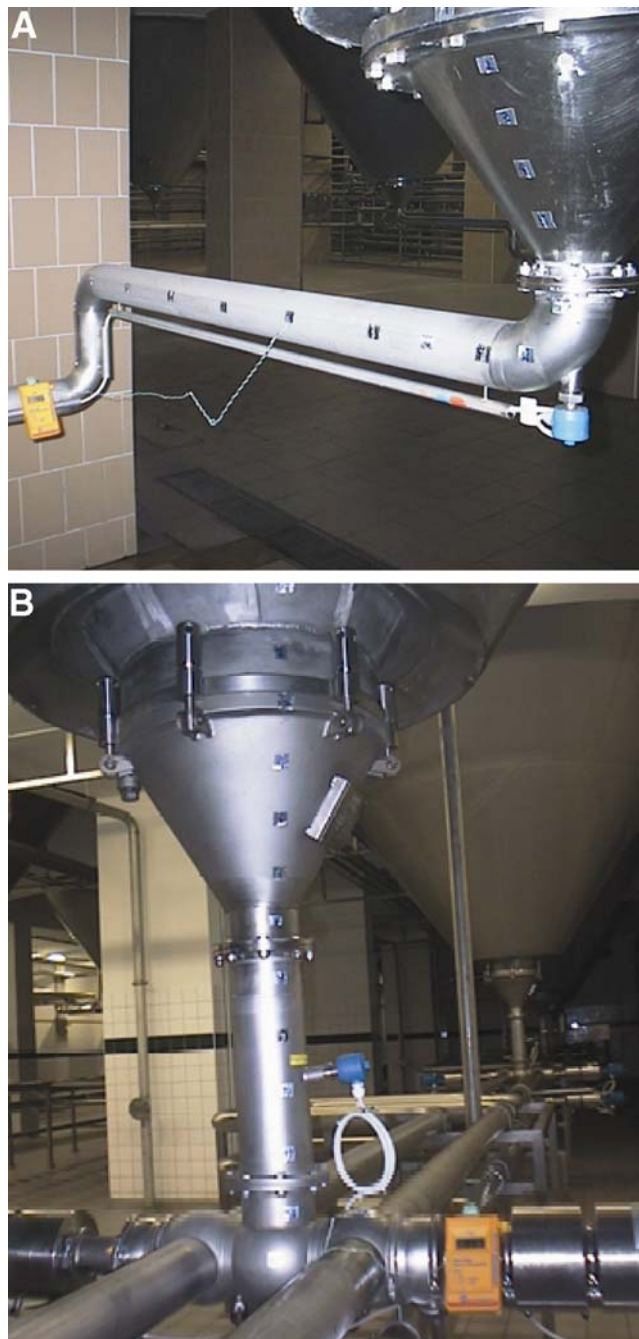


Figure 1. Tanks, outlet pipes, and sampling points. A, Conventional system; B, ECO-MATRIX system.

samples were taken after trub removal (approx. 18 h after filling) and before the first yeast crop.

Analyses

All analyses were carried out according to the instructions provided in the MEBAK guidelines (Table 1).

Results and Discussion

By comparing the results from the tank and pipe samples, we determined how the fermentation process developed in both reaction spaces. The conventionally equipped tanks were looked at first.

Conventionally Equipped Tanks

Temperature development depended strongly on the ambient room temperature. The desired fermentation temperature was

Table 1. Parameters analyzed following MEBAK guidelines

Parameter	MEBAK section
Degree of attenuation	II, 2.9.5
pH	II, 2.14
Yeast viability	III, 10.4.4.1
Volatiles	III, 1.1.1/III, 1.2.1
Fatty acids, esters	III, 1.1.3



Figure 2. Temperature distribution in the outlet pipe.

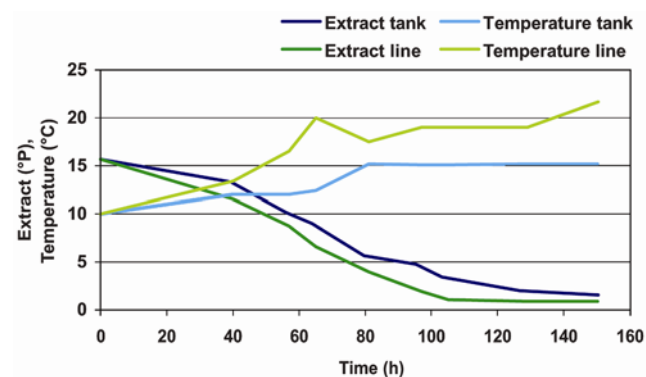


Figure 3. Course of extract in tanks and pipes (longer outlet).

maintained in the tank by cooling. The opposite development could be detected in the pipe. Immediately at the end of the cooling area of the cone the temperature began to rise and adjust to room temperature very quickly (Fig. 2). Thus, the temperature in the pipe was much higher than in the tank, which should have led to different fermentation behavior.

Figure 3 shows the degradation of extract in the tanks and corresponding pipes (longer outlet). A regular course of fermentation was observed in the three different tanks. The extract

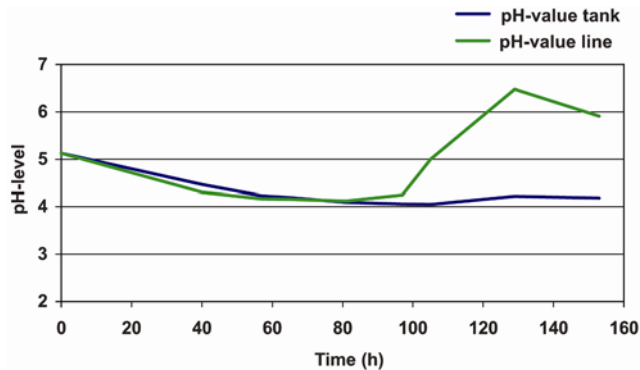


Figure 4. Course of pH in tanks and pipes (longer outlet).

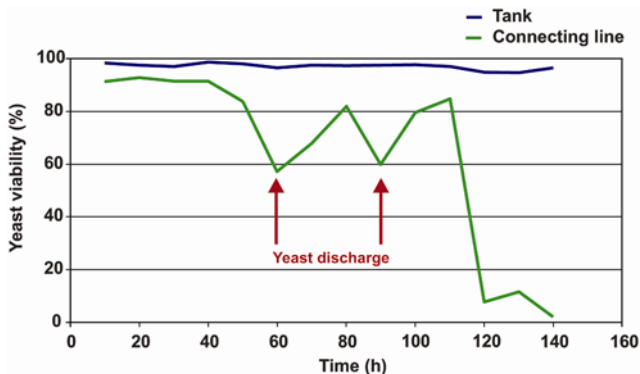


Figure 5. Course of yeast viability in tanks and pipes (shorter outlet).

values in the pipes, however, were totally different. Because of a higher yeast/wort ratio and higher temperatures, the extract was already fermented after a few hours and before the first sample was taken. This implies that for the rest of the fermentation time, the yeast remained in the pipe without any nutrition and at very high temperatures, which could result in a poor yeast physiology and autolysis of the cells. The samples taken from the tanks with shorter outlet lines had comparable results (data not shown).

The pH values of the samples are an obvious indicator of yeast starvation and autolysis. While the tank values also showed regular behavior, the values of the samples from the line increased over the fermentation period (Fig. 4). A release of basic amino acids from the autolyzing cells was responsible for this development. Very high pH values (>6) showed the highly negative conditions for yeast in the pipes. The samples from the tanks with shorter outlet lines had comparable results (data not shown).

Yeast viability underscored these results. Figure 5 depicts living yeast cells over the fermentation period. The samples from the tank showed good vitality. The values of the pipe samples showed a constant decrease, leading to almost 100% dead cells. The strong decreasing phase after approx. 100–120 h corresponded with the increase in pH. Because of the strong



Figure 6. Inner pipe surface after cleaning.

Table 2. GC analysis of volatiles, fatty acids, and esters over the fermentation period in the line of a tank with a short pipe

Component	After trub removal	Before transfer	Regular values in beer ^a
Acetaldehyde (mg/L)	28.2	18.3	2–10
Ethyl acetate (mg/L)	8.5	45.6	5–30
<i>n</i> -Propanol (mg/L)	17.4	20.4	2–10
<i>i</i> -Butanol (mg/L)	18.8	15.3	5–10
<i>i</i> -Amylacetate (mg/L)	0.4	1.0	1–5
Amyl alcohols (mg/L)	47.2	55.2	30–50
2-Phenylethanol (mg/L)	16.2	38.5	10–20
Diacetyl (mg/L)	0.39	0.49	<0.1
2,3 Pentandione (mg/L)	0.33	0.38	<0.05
Butyric acid ethyl ester (mg/L)	0.08	0.29	<0.3
<i>i</i> -Butylethylacetate (mg/L)	0.51	0.67	<0.1
2-Phenylethylacetate (mg/L)	0.03	0.45	–
Hexanoic acid ethyl ester (mg/L)	0.56	1.51	0.1–0.3
Octanoic acid ethyl ester (mg/L)	>0.8	>0.8	–
Decanoic acid ethyl ester (mg/L)	>0.4	>0.4	–
<i>i</i> -Valeric acid (mg/L)	1.2	4.8	0.5–1.2
Hexanoic acid (mg/L)	10.2	>11	–
Octanoic acid (mg/L)	2.2	20.2	3–10
Decanoic acid (mg/L)	>4	>4	<0.8
Dimethylsulfite (μg/L)	73	63	30–120

^a Regular values can only be used as a general value for comparison of the results. They can vary widely among different beer types.

yeast settlement in the long outlet pipes, no values could be obtained. Figure 5 shows the values for tanks equipped with a short pipe.

The samples from the pipes were also tested with an immunochemistry assay for the presence of proteinase A. The detected values were all higher than the effective range of the analysis. Unfortunately, no sample material was left for a diluted assay. Thus, only a qualitative statement can be made: the occurrence of proteinase A was detectable and in undesired quantities. A visual and sensory analysis of the samples showed an increase in color and release of off-flavors. Over the fermentation period the aroma became more and more unpleasant, with rotten notes. To show what differences occurred in the chemical matrix over the fermentation period, the first and last samples from one pipe were examined by GC analysis (Table 2).

These results also provide evidence of the uncontrolled fermentation process in the pipe. Some of the fatty acids and the fatty acid esters were already highly concentrated in the first sample due to the beginning of yeast autolysis (e.g., octanoic acid ethyl ester, decanoic ethylester, and decanoic acid). Others, like *i*-valerianic or octanoic acid, increased dramatically over the process time. The volatiles, higher alcohols, and esters showed a slight increase over this period. Specifically, 2-phenylethanol, a temperature indicator, increased due to the uncontrolled temperature in the pipe.

All the data indicate there were two different reaction spaces during fermentation, the tank and the pipe. Analyses showed that these processes varied widely. Fermentation in the pipe was characterized by different process parameters, e.g., yeast/

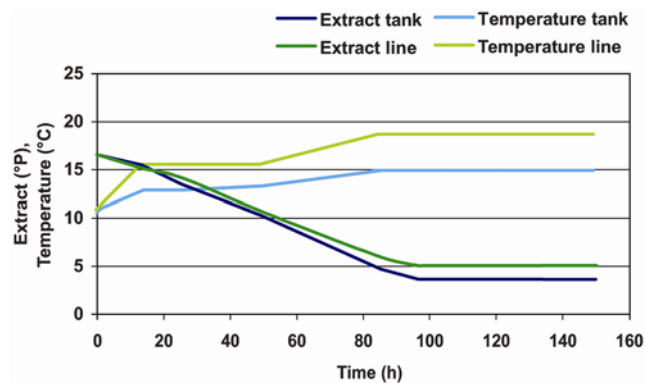


Figure 7. Course of extract degradation in tanks and pipes (ECO-MATRIX).

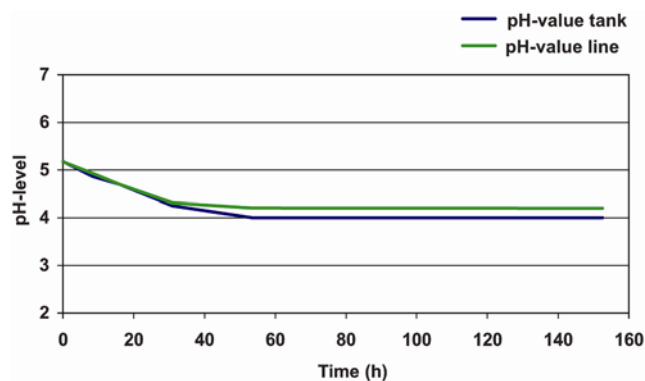


Figure 8. Course of pH in tanks and pipes (ECO-MATRIX).

wort ratio and higher temperatures, which led quickly to extensive degradation of extract, with subsequent starvation and autolysis of the yeast cells in the line. As a consequence, undesirable off-flavors and proteinases were released. Although the volume in the pipe was negligibly smaller compared with the tank volume, quality losses in the finished beer cannot be excluded. The amount of off-flavors would not be detectable if diluted with the tank content. However, proteinase might still affect foam stability negatively. Conditions in the pipe (high temperature and high pH) also may enable growth of bacteria. Higher DMS contents in the pipes compared with the tanks were found in other studies on this topic (*unpublished data*), suggesting contamination with wort-spoiling bacteria. The conditions in the pipe mainly depend on the surrounding conditions. They probably do not differ that much in a cool cellar but would vary greatly in plants with outdoor tanks in hot areas. Thus, the recommendation is to discard one pipe volume at least, despite minor product losses. Additionally, cleaning of the pipes could be critical. Figure 6 shows the inner surface of a pipe after cleaning. The cleaning of the pipe has to be performed together with the tank cleaning. This leads to a very low flow velocity in the pipe and unfavorable fluid dynamic conditions. Only extended cleaning intervals, higher temperatures, and/or a higher detergent concentration will produce satisfactory results.

To solve the abovementioned problems, flushing the pipe after filling should be possible. An alternative pipe system (the ECO-MATRIX system) was also installed in the brewery. The analyses performed with the conventionally equipped tanks were also carried out for this system.

ECO-MATRIX System

The temperature distribution in the ECO-MATRIX system was similar to the conventional system: immediately under the cooling zone the temperature in the pipe adjusted to room temperature.

The degradation of extract was different compared with the conventional system, however (Fig. 7). The tank values were comparable, but the samples from the pipe showed a slower degradation of extract that was still faster compared with the tank but not as extreme as with the conventional pipe. This indicates better intermixing of the contents of the tank and pipe (ECO-MATRIX) during the first fermentation period.

The pH and yeast viability values (Figs. 8 and 9, respectively) corresponded with this development. The increase in pH in the pipes started later than in the conventional system. Additionally, the values were not as high. The same applied to yeast vitality. A later decrease in the pipe samples can be seen.

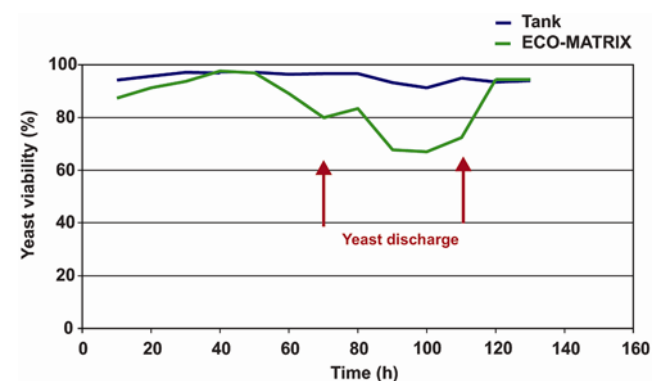


Figure 9. Course of yeast viability in tanks and pipes (ECO-MATRIX).

For the tanks equipped with the ECO-MATRIX system, the results were nearly comparable to the results achieved with the conventional pipe system. But in detail, the parameters observed did not show similarly extreme values. Also, the negative changes in the pipe occurred later in the ECO-MATRIX tanks. Considering the minor volume in the small outlet (only approx. 6 L), this could be considered a short extension of the cone. With the design of the ECO-MATRIX system, the outlet pipe is no longer connected to the tank and can be cleaned individually. This should lead to lower product losses and less required cleaning.

Summary

In summary, the connection of the tank with a long pipe system shows disadvantages if product remains in this pipe over the fermentation period. Because of different conditions in the tank and pipe, two different processes can be described. The tank

shows a regular fermentation pattern, but in the pipe, the fermentation process is accelerated. This results in yeast starvation and the release of off-flavors and other quality-reducing substances. In addition to complex cleaning requirements for these pipes, quality problems may occur. Strategies to separate and clean the pipe after tank filling are recommended. One possibility is the use of a system similar to the ECO-MATRIX system, where the valves are directly connected with each tank. Thus, no product remains in the pipe, which can reduce or eliminate the problems discussed above.

ACKNOWLEDGMENTS

We thank the project partner in the brewery for his expert technical advice and his efforts in carrying out these experiments. Additionally Konrad Müller-Auffermann's efforts in taking and analyzing all samples and collecting data material are very much appreciated.