

# Wort Boiling by Batch Rectification— Possibilities for Reducing Required Evaporation

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## ABSTRACT

Today, energy costs are very high and are predicted to rise further. Because approx. 2,260 kJ is required to evaporate 1 L of wort (or its water content), it is advantageous to reduce total evaporation during wort boiling. The total evaporation required to achieve the target concentration in cast-out wort is a property of the solution and is determined by the vapor-liquid equilibrium of unwanted flavors in wort and starting concentration in the kettle-up wort. Thus, total evaporation cannot be reduced by existing wort-boiling systems, although this is often asserted. It was theorized that the only way to possibly reduce the required overall evaporation is by fractional distillation or rectification. To test this theory, a new wort-boiling system was constructed using the basics of evaporation and rectification. In this new rectification wort-boiling system, a side stream of wort is constantly drawn from the wort kettle and fed into a rectification column connected to the kettle. Thus, the evaporating vapor and recirculating wort are in direct contact, which concentrates unwanted flavors in the vapor. Because of this, the discharged steam has a concentration of unwanted flavors that is much higher than that produced by normal boiling systems. Test trials were performed with the new wort-boiling system, and its evaporation efficiency was determined. Results of the measurements showed that an equal reduction of unwanted flavors was achieved with approx. 50% less overall evaporation than that required by a normal wort-boiling system. The evaporation efficiency, thus, was doubled. Using this new system, it is possible to reduce the required overall evaporation during batch processing of wort boiling by as much as 50%. If the boiling time is also reduced, the resulting wort has lower thermal stress and a desirable wort protein profile. The required rectification column can be added to nearly any existing wort-boiling system.

**Keywords:** efficiency engineering, wort boiling

## SÍNTESIS

Los costos de la energía son hoy en día muy altos y se pronostica que subirán aún más. La reducción del tiempo total de evaporación del mosto sería muy conveniente debido a que cada litro de agua evaporada consume m.ó.m. 2,260 kJ. La evaporación total necesaria para alcanzar la concentración deseada del mosto final es una propiedad de la solución y es determinada por la concentración inicial del mosto (paila llena) y por el equilibrio de aromáticos indeseables en el vapor y el líquido, por lo que la evaporación total no puede ser reducido por sistemas de cocción de mosto actuales, contrariamente a lo que algunos fabricantes sostienen. Se ha dicho que en teoría sólo se podría reducir la evaporación total mediante una rectificación o una destilación fraccionada. Para intentar verificar este supuesto, se construyó un sistema de cocción de mosto usando los conocimientos básicos de la evaporación y de la rectificación. En este sistema, se lleva una corriente parcial de mosto de la paila de cocción para alimentar una columna de rectificación conectada a la paila. De esta manera se consigue que el vapor desprendido está en contacto directo con el mosto en recirculación, lo que concentra los aromáticos indeseados en el vapor de manera que el vapor desprendido tenga una concentración mucho mayor de aromáticos indeseados de lo que se puede conseguir con un sistema normal de cocción. Se determinó la eficiencia de la evaporación del nuevo sistema de cocción. Los resultados demuestran que se puede conseguir una misma reducción de aromáticos indeseados con 50 % menos evaporación total que con sistemas convencionales de cocción, o lo que es lo mismo, se dobló la eficiencia de evaporación. Este nuevo método hace posible reducir en hasta 50 % la evaporación total necesaria en un proceso por lotes. Esta reducción del tiempo de evaporación reduce la carga térmica a que se somete el mosto, impartiendo al mosto un perfil proteico más deseable. La columna de rectificación se puede adaptar a casi cualquier tipo de sistema de cocción existente.

**Palabras claves:** cocción de mosto, ingeniería eficiente

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## Introduction

Using the basics of evaporation, a new wort-boiling system was constructed. This system is based on the principle of rectification and can be retrofitted into existing systems. By this method, unwanted flavors are strongly enriched in the evaporating vapor. Thus, the discharged steam has a concentration of unwanted flavors that is much higher compared with that of a traditional boiling system. Depending on the boiling method currently employed, an up to 50% reduction in overall evaporation can be achieved, while still maintaining the normal aroma profile of the resulting wort. This system consists of a distillation column that can be retrofitted into nearly any existing wort kettle. The energy savings can be significant.

## Materials and Methods

### Principles of a Rectification Process

The vapor mixture leaving the boiler rises into a distillation column that has a relatively large number of separating stages. In such a stage, the following substance and heat exchange takes place: rising vapors contain the heat absorbed by the runback flowing in the opposite direction, where mainly lower volatiles condense and, therefore, enlarge the runback. The freed condensation heat and rising vapor heat the runback, so that primarily the condensed higher volatile fractions re-evaporate. This process repeats itself in every separating stage—the vapor is continuously enriched with more and more lower volatile compounds (e.g., dimethyl sulfide). Within the distillation column, a specific equilibrium between vapor and liquid is reached. Figure 1 shows an example of the principles of rectification for an ideal two-substance mixture with infinite reflux.

### Objectives of the Rectification Wort-Boiling System

As shown elsewhere (3–5), the evaporation efficiency of wort-boiling systems that use an internal or external boiler is always worse when compared with a normal open-boil kettle using heat transfer. In addition, another difference between the two boiling systems (internal and external boilers compared with boiling using conventional heat transfer) must be recognized. While wort brought to a simmer using heat transfer must be mixed homogeneously (bubble-simmer throughout the entire fluid volume), inconsistencies with this method can occur, especially in very large boiling coppers with internal and external boilers. This can lead to parts of the wort being “over boiled” while others remain nearly unboiled. Such inhomogeneities are an

additional cause of the poor evaporation efficiency of such systems.

The primary purpose of the retrofit system is to increase the evaporation efficiency of the systems described above. With the retrofit in place, the advantages of internal or external boilers are still present but with the added advantage of a higher evaporation efficiency. Additionally, overall evaporation can be reduced while maintaining the current product flavor profile, and a shorter boiling time can further improve finished product quality. During the development of such a system, however, the sense of tradition of the brewer on one side and consumer awareness of the product on the other had to be accounted for. It was, therefore, the aim not to develop a plant that can serve industrial requirements, but a system that can be unobtrusively integrated into currently used coppers (brewkettles). Only the boiling time of the new system needs to be identical to the previous system to have all time-dependent processes within the same frame, if this is desired.

### Method of Resolution

Significant enrichment of unwanted substances in the exhaust vapors can be achieved during rectification of circulated wort throughout the entire boiling process. To accomplish this, a partial stream of the wort must be drawn off from the boiling copper and pumped toward the head of a column connected to the copper's steam side. In this way, the vapor ascending from the boiler is in close contact with the reverse flowing wort, which causes an intense heat and mass transfer to occur. The mass transfer is possible because the vapor ascending from the inner or outer boiler contains the unwanted volatile substances in concentrations lower than would be the case with simple atmospheric boiling. Additionally, the use of large coppers can lead to

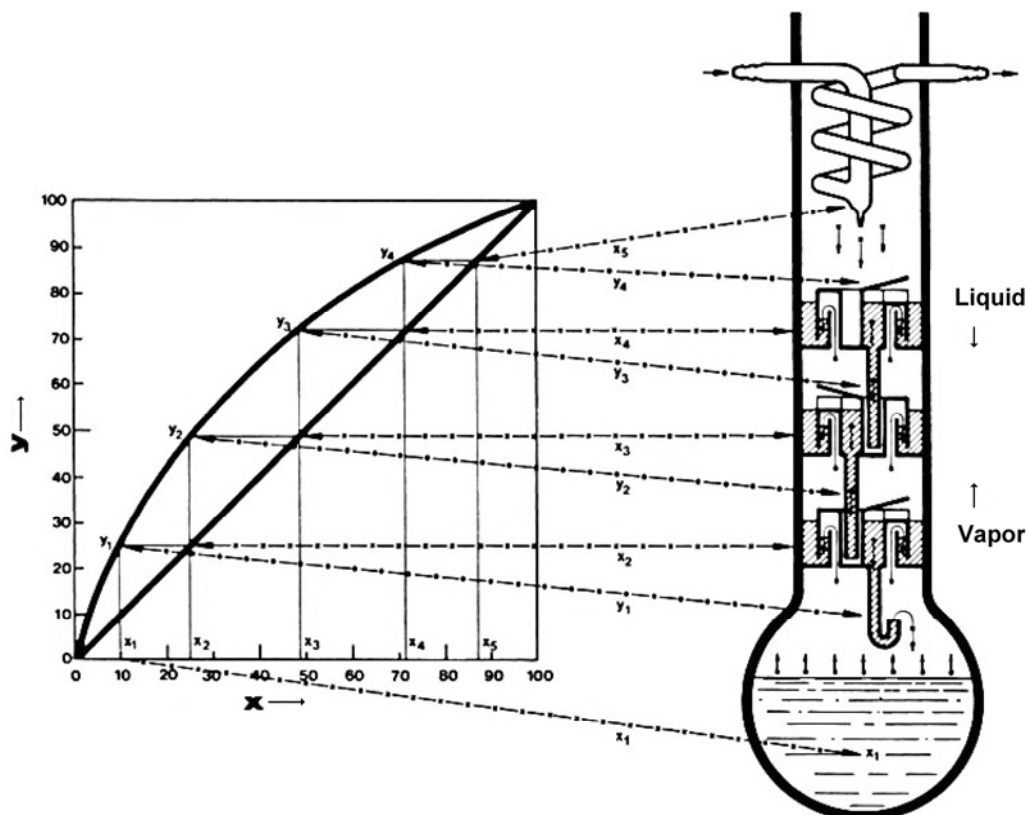


Figure 1. Schematic depiction of the rectification process for an ideal two-substance mixture with infinite reflux (6).

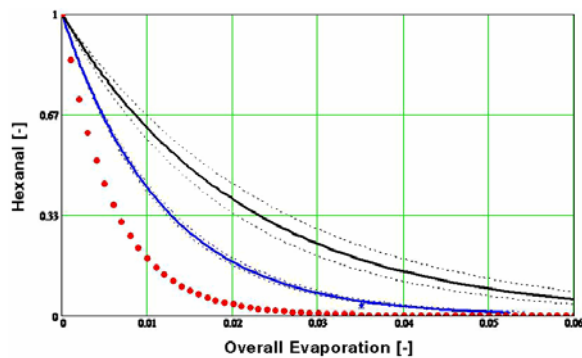
inhomogeneities in the wort to be boiled. As the wort is drawn off from the bottom and sides of large coppers, it is possible for the wort to contain significantly higher concentrations of unwanted substances than the simmering wort in the boiler. This causes an increase in the concentration gradient between the simmering wort and reverse-flowing wort. Using the rectification system, wort inhomogeneities can be adjusted. By means of enrichment of the volatile components in the ascending vapor, the required total evaporation, when compared with that of the former systems, can be drastically reduced.

### Experimental Setup

To confirm the theory that the normally required overall evaporation can be reduced by rectification, a pilot rectification wort-boiling system was constructed for trials. After the calculation of residue curves for the new boiling system, residue values were measured in independent experiments.

### Results

Figure 2 shows that the residue curve for the rectification wort-boiling system (middle line) is much sharper compared with the one calculated for a normal wort-boiling system (upper line). Thus, an identical residue value is reached with approx. 50% of the evaporation that is traditionally required. Because approx. 2,260 kJ is needed to evaporate 1 L of wort, the resulting energy savings are significant (example provided below). The measured residue value for hexanal lies directly on the calculated residue curve, confirming the calculation for this point. The lower line shows the calculated curve for a slightly modi-



**Figure 2.** Calculated residue curves of rectification systems together with a measured residue value.



**Figure 3.** Examples of retrofitted rectification wort-boiling systems (left: nostalgic; and right: modern).

fied variant of the system, which reveals that the evaporation efficiency can be enhanced even further.

### Examples of the New Rectification Wort-Boiling System

The new wort-boiling system has already been integrated into several breweries. Figure 3 shows photos of two installed rectification wort-boiling systems. It can be seen that the new system can easily be retrofitted into nearly any form of commonly used wort-boiling kettles.

### Expected Savings Using the New Wort-Boiling System

A comparison of the energy requirement shows that significant amounts of energy, and in turn costs, can be saved using the rectification wort-boiling system. For example, a medium-sized brewery that uses a copper with a capacity of 200 hL, together with a boiling time of 1 h and a total evaporation of 6%, can save 1.4 GJ of heating energy per decoction when using the rectification wort-boiling system. This results from the fact that only approx. 50% of the primary total evaporation is required (due to the rectification effect) to reach the normally expected residue value. However, to accomplish this, an additional pump is needed. Assuming the energy requirement of the pump is 3 kW and the ratio of ascending vapor to diverted wort is 1/200, the additional required energy consumption is calculated at only 10.8 MJ. Because only a 193.8 hL wort volume is needed to reach the identical amount of cast-out wort (188 hL) at a new overall evaporation of 3%, approx. 6.2 hL less must be brought to simmering temperature after the lautering process. Taking into account the effective heat capacity of approx. 4.1 kJ/kg K, an additional energy saving of 55.9 MJ/decoction is achieved. This calculation results in a total energy saving of approx. 1.44 GJ, or 400 kWh, per decoction. Expressing these savings in euros results in a savings of €60 at a kilowatt hour price of €0.15. Considering that on average 32 decoctions take place during 1 week, approx. €100,000 can be saved during the year. This example clearly points out the significant amount of energy (and costs) that can be saved when utilizing the new boiling system in midsized breweries.

The specific column needed for the new wort-boiling system can be integrated as an upgrade in nearly any commonly used wort-boiling system. Therefore, the investment costs and amortization times are notably less than would be the case for the acquisition of a new wort-boiling system. Deterioration of the finished wort and, thus, of the final beer product relative to other parameters (foam, coagulated nitrogen) is not expected, because the wort is only diverted via a pump. This finding was verified through the use of other systems that feature forced recirculation for the diversion of wort (8–10).

Due to the reduced overall evaporation required when using the rectification system, it is also possible (at equal evaporation rates) to reduce the boiling time to the minimum necessary for the required kinetic processes to occur. This would result in less replication of thermal indicators and, thus, in a drastic reduction in the thiobarbituric acid value (7). Consequently, the quality of the wort would be enhanced further.

## Conclusions

The results of this work show that it is possible to improve the evaporation efficiency of common wort-boiling systems with the use of the described rectification system. With this system, it is possible to match a product's current flavor profile with less overall evaporation. Because the evaporation of wort is the most energy-intensive step in the brewing process, the savings in energy and production costs are significant. This system does not negate all of the recent developments in the area of boiling systems in general. The improvements made by the development of new boiling systems, such as higher heating and vaporization rates, avoidance of pulsation during heating, and reduction of fouling, still remain relevant after the rectification upgrade. After a rectification retrofit, the evaporation efficiency of each of these boiling systems is significantly increased compared with the earlier system. Because of the significant results achieved by this process, the newly developed rectification wort-boiling system, including the appendant process, has been assigned a patent (1,2).

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