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R&D: Foundation Stone of Quality

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1. Introduction

There are many definitions of quality. The oldest based on simple fulfilling of desired technical parameters developed into nowadays agreement, that the pivot of interest should be customer and his needs. Modern quality systems define quality as a degree of fulfilling of customers´ demands, or the degree of customers´ satisfaction by goods or services that he had paid for (Juran, 2000).

1.1 The role of quality in success on the market

Quality management systems have been developing since the beginning of industrial goods production. Producers of goods with higher quality had advantages for fight with competitors and high quality products were the main way how to satisfy customers. Although quality products are still necessary for success on the market, quality itself does not make nowadays business. Since the end of eighties new kind of companies appeared. These companies were orientated not only on quality goods production, but mainly on branding.

For these companies quality product was just one fourth of their marketing mix, whose management under certain brand was to satisfy customers. The resting parts of marketing mix are e.g. the price, place of purchase and accompanying services, or promotion quality. The original sense of brand was to label product with the place of origin and name of producer, which together had served as a guarantee of quality.

Due to sophisticated marketing methods can brand nowadays bring to customer whole battery of emotional values, which can sort customers into varying social groups. The satisfaction of customers is not brought only by the product quality, but also by emotions connected with social enlistment of brand (Klein, 2005; Olins 2009).

Brand management added to product new value, which allowed brand keepers to sell for much higher prices than would be the prices of their products without brand. Because not all customers could afford to pay extra price for emotional values and engaging to higher social classes, the byproduct of branding was the polarization of marked and origin of new distribution channels selling products without strong brands. These products are sold for much lower prices and usually have good enough quality to satisfy demands of its users. These so called cheap brands e.g. made up 40 % of German beer marked in 2005 (Verstl, 2005).

Brand management is also the reason why contact of quality department with customers is nowadays mediated by marketing department and quality improvement is often managed by marketing manager.

1.2 Quality improvement

Quality manager can never be satisfied with quality. It is because quality is not static; it is developing together with the development of customers´ needs. The process of developing quality is called quality improvement and it is integral part of modern quality management. As any other management systems, the management of quality improvement is based on the flow of information. There are several model systems for information flow in quality improvement management; of the most famous is Deming´s PDCA cycle (fig. 1) or Juran's quality spiral (fig. 2).

These model systems have in common four basic steps, which also represent four levels where quality is managed in practice. The first level of quality management called "plan" or "product development" step is usually secured by the R&D department or by external consulting expert. This step includes designing of the product with all technical parameters and proposing of production processes with all operation steps and control points.

The second step ("Do" or "Production & process control), usually secured by production department in close cooperation with quality control department, includes production of products by production processes, which are carefully operated by feedback regulation in originally proposed control steps.

The third step where quality is managed is the "Check" or "Final inspection". This step is usually secured by the Quality control department and sampling or evaluation of the results are usually planed and processed with the help of statistical tools, like control charts or histograms.

The last step of information flow at the quality improvement management ("Act" or "Market research") is secured by quality assurance or marketing department. At this step customers´ satisfaction with product is measured. Method can be common market research, like statistic study with questionnaires, or with direct interviews.

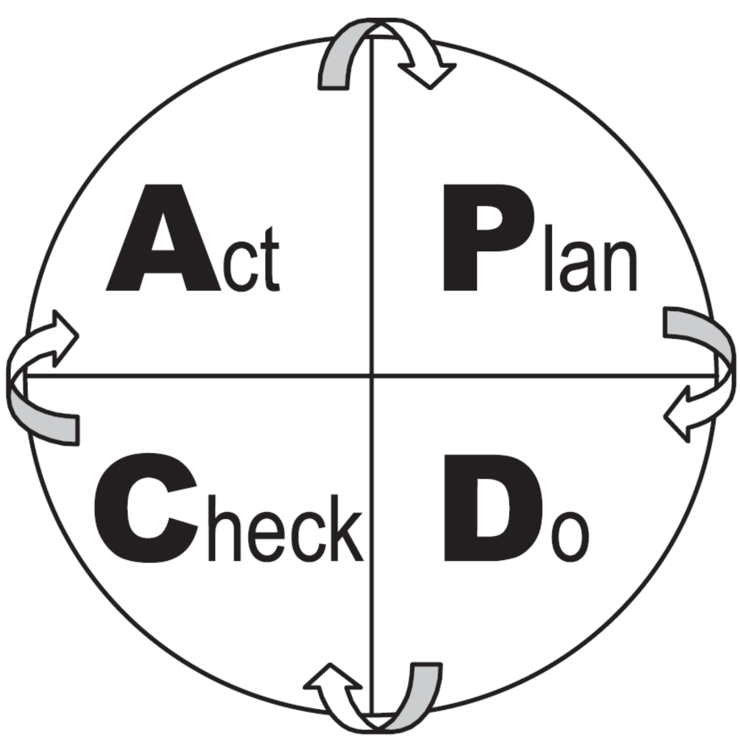


Fig. 1. PDCA cycle.

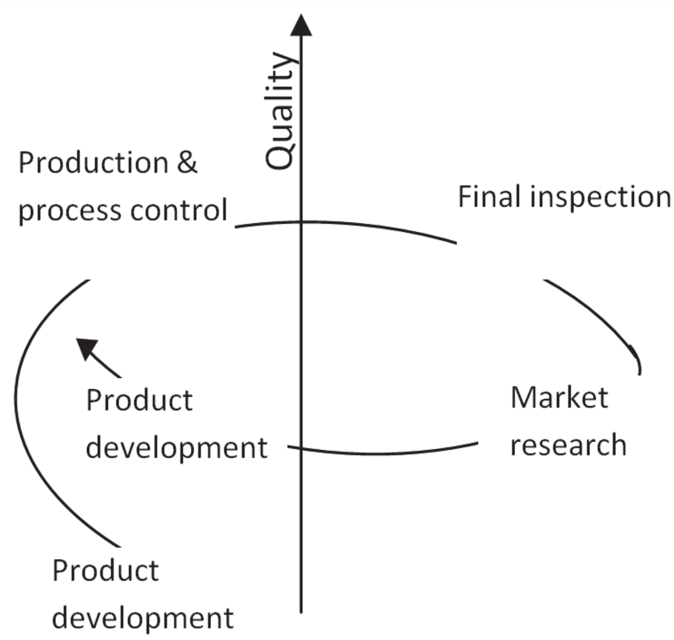


Fig. 2. Juran´s quality spiral.

1.3 Quality characteristics

Quality characteristics can be defined technically as inherent property of product that serves for identification, description and differentiation of product form other products and has a quantity and unit. Customer orientated definition of quality characteristic would be a property of product, that satisfy customer.

Quality characteristics can be divided into two groups: real characteristics and measurable attributes. Real characteristics directly correspond to the customer orientated definition of quality and are the reason why customers buy selected product. These characteristics should be evaluated in the fourth step of PDCA or Juran´s quality spiral. Their disadvantage is problematic measurement and evaluation and that is why real characteristics are usually translated into measurable attributes in the first step of quality improvement process.

Measurable attribute suit more the technical definition of quality and although not corresponding directly to customers' satisfaction they can be quite easily measured and evaluated during production and by feedback effect serve in the second and third step of quality management.

2. Case study: beer foam stability

The case study of this chapter for illustration of quality improvement in practice will be beer foam stability. It is a measurable attribute, which closely describes real quality characteristic called foam appearance. Foam appearance is one of the most important quality parameters of beer, because it is a visual parameter and visual parameters are ease to evaluate by almost all customers, who are much surer by what they see than what they taste.

Foam stability is not the only attribute describing foam appearance; the others are e.g. foam density, creaminess, color, or ability to cling on beer glass. Although these technical parameters have their meaning for foam appearance, stability is the most important parameter because when foam is not stable, it disappears and there is nothing to judge.

Assignment for this study is was to improve beer foam stability without changing any other beer quality and production parameters, which most often include raw materials. Complexity of this quality parameter much differs from common example situations like screw production.

2.1 Procedure of foam quality improvement

The general procedure of quality improvement has several steps. Whole process starts with bibliographic research, because many of the basic questions have been solved before by someone else.

The second step should be the verification of bibliographic result under the specific conditions of the company. With good luck this can be the end of quality improvement.

If bibliographic results do not help, the third step should be the start of own primary research. There cannot be given general instruction on this step, but there is one way that occasionally helps and was useful also in the case study of this chapter. It is to develop your own analytical method, of which results closely corresponds to customers sensation of the quality parameter and simultaneously can be used all over whole production line to evaluate how the quality attribute develops during production.

The fourth step can then be to use the new analytical method to find weak points of the production line and find a way how to control these processes to improve the quality problem. Results of the method can then be used for feed-back regulation of selected processes parameters in second step of the quality improvement information flow described by PDCA or Juran´s quality spiral.

The last step of the research would be identical with the third or fourth step of quality management. With the help of sophisticated statistical tools should be precisely evaluated the extent of quality improvement and the economical balance of quality profits and costs.

2.2 Bibliographic search

The research usually starts with bibliographic search. In many cases the same problem has already been discussed either in academic or applied research.

Academic sources

Academic research offers several solutions for foam quality improvement, mostly based on reductionist analytical approach. The idea is that foam stability can be increased by addition of foam stabilizing material to beer. There have been described several foam stabilizing substances, but less methods how to increase the content of these and not change beer taste or composition. Of the most discussed are bitter acids and proteins (Evans, 2002).

All of hop bitter acids can increase foam stability, but the most effective are chemically reduced derivates. Their production stars with extraction of α-bitter acids from hop by organic solvent or supercritical CO_2. The second step is isomerization of α-bitter acids in alkali and high temperature conditions and the third step chemical reduction of iso-α-bitter acids into di-, tetra- or hexa-hydro-iso-α-bitter acids. Most often discussed are tetrahydro-iso-α-bitter acids, produced under the brand Tetrahop.

Tetrahop is used in downstream processes as additive in milligrams per liters of beer. There are several problem of this way of improving foam quality. Major is that although foam stability is increased, foam structure at the end of foam collapse has unnatural appearance resembling polystyrene foam. Next problem is harsh character of Tetrahop’s taste, which is far away from fine taste of natural hops. Probably the least important problem is that the chemical preparation of Tetrahop collides with Reinheitsgebot, German beer purity law saying that beer can be only made from water, barley malt and hops. Improving foam quality by simple increase of natural hop components would have negative effect in change of bitterness intensity, one of the most sensed sensory attribute of beer.

The role of proteins in foam stability has been the most studied part of foam quality in academic research. There have been described several proteins that influence foam quality, mainly hydrophobic proteins like protein Z, or lipid transfer proteins (LTP). Protein Z represents proteins with high molecular weight (relative molecular weight 35 000 – 50 000) and LTP have relative molecular weight 5 000 – 15 000. Proteins, which together with bitter acids and ions build up the framework of foam bubble walls, come to beer from malt.

A lot of studies on which malt contains more of these foam promoting proteins were driven by the idea, that change of malt specifications could be a way for a brewer how to fix problems with foam. The problem of this approach is that changing malt specifications can substantially change some of the other important parameters of beer, e.g. color, fermentability and final degree of attenuation, or the essential character of beer taste, which is hidden in the unfermented remainder of malt in the beer body.

Although foam stability has been in focus of academic research for quite a long time, there have not been found a practical recipe how to improve foam quality and not change any of the other beer parameters, including beer raw materials and composition.

Applied sources

There are far less papers written from applied research compared to academic research. The reason is not only the evaluation of academic research quality by the quantity of published papers, but also historic transfer of applied research from goods producers to service and suppliers companies, who more carefully guard their knowhow and do not publish much of technical papers.

Although it is quite hard to come across this kind of publication, they are of great use because they usually look for practical solutions. Contrary to academic research, which usually looks for answers on questions "how does it work", applied research usually solves questions concerning what can one do to economically solve a problem.

For our case study of foam stability can be found sporadic publications recommending some practical solutions like optimization of the malt grinding, correct choice of lauthering tun, sufficient separation of sediment after wort boiling, or consistent rinsing of bottles at the end of washing (Haukeli, 1993).

3. Improvement of foam stability

The assignment of the research was to improve foam without changing any other quality characteristics, especially beer appearance and taste, which is secured by constant specifications of raw materials. That is why trials with alternative malt specification, hop dosage or use of any additive to beer as discussed in the academic research was excluded from the design of this study.

3.1 Foam stability measurement

Foam collapse can be divided into three stages from the macroscopic point of view. The first is the drainage of beer out of wet foam, where significant upward movement of beer-foam interface can be observed. The second stage is the collapse of dry foam and is accompanied by significant decrease of foam surface. The third stage is the break-up of the last foam layer, which results in the appearance of a "bald patch" on the surface of the beer.

This division corresponds to measurement strategy focused on the second stage of foam decay. The collapse of the foam accordance to first order kinetic equation is usually expressed as the time dependency of beer volume remaining in dry foam after initial beer drainage.
Kinetic equation can also connect the first two phases of foam collapse as expressed in formula (1),

$$c = c_\infty - a_0 \cdot \frac{k_2}{k_2 - k_1} \cdot e^{-k_1 \tau} + (a_0 \cdot \frac{k_1}{k_2 - k_1} - b_0) \cdot e^{-k_2 \tau} \tag{1}$$

where c is the beer volume or its height under the foam, c_∞ is the total volume of beer after complete foam decay, a is volume of beer bound in dry foam, b is beer freely present in the foam and τ is time. The constants k_1, k_2 describe the foam collapse in the first and second stage of decay, index 0 indicates the beginning of foam degradation (Savel, 1986).
How customers evaluate foam quality was uncovered by qualitative research at which 30 random customers were asked about their satisfaction with beer foam on the beer they were drinking in pubs or bars in the Czech Republic. In contrast to similar investigations, interviewees were not asked a long series of questions about foam quality or served any adjusted beer samples. The intention was to discretely interview the drinkers in their normal pub or bar drinking situation and gauge their opinion of the foam on the beer they were being served. The only question asked by the interviewers during drinking was the unforced question “is everything OK or not with the foam?” At this point, according to the interviewee’s opinion, if there was something wrong with the foam, we visually evaluated the stage of foam collapse, in particular noting the presence of a “bald patch” in the foam, on the surface of the beer.
According to this qualitative assessment of customer perception of foam quality, customers in did not pay much attention to the foam until a problem with the foam is perceived. The beer was seen as problem free so long as there was a sufficient amount of foam to cover the beer surface in the glass. Customers start to be concerned about the foam quality in their glass only once they perceive that there was something wrong with the foam in their glass. This was at the end of foam collapse, when bald patches start to appear on the beer surface. At this point, approximately a quarter of the customers started to pay attention to the quality of beer foam in their glasses. The other three quarters of customers did not have any problems with the foam quality, even at this point. As the break-up of the last foam layer proceeded to produce a substantial bald patch on the beer surface, more customers started to be concerned with foam quality. Once the beer surface was almost completely bald, almost all customers commented that the foam quality was not satisfactory. Thus it can be concluded that for beer drinkers, the early appearance of this bald patch indicates a poor quality beer.
Close to this sensation of foam quality is a method for foam stability measurement called pouring test, which measures foam stability through whole collapse curve and includes the last collapse stages where bald patch appears. It is based on pouring atemperated (8 °C) beer from the bottle to a standard tasting glass and time from pouring to the first bald patch larger than 5 mm appearance is recorded. Although this test is principally very close to the customer sensation of foam quality, it has a disadvantage of low reproducibility.
One of the most spread methods among brewing laboratories is a method called NIBEM. This method is based on recording of the speed of downward movement of foam surface in

the second stage of foam collapse. This method has much higher reproducibility than the pouring test, but is quite far away from the customer perceived foam stability, as can be seen from the low correlation with pouring test (fig. 3).

Disadvantage of both of these methods, NIBEM and pouring test, is that it cannot be used to measure foam stability of samples that do not contain sufficient amount of CO_2 to create foam. NIBEM is slightly less sensitive to CO_2 content of sample than pouring test, because foam is created by flushing of the sample through the jet.

3.2 Matrix foaming potential

The new method for foam stability measurement, which was optimized and tested for foam stability improvement, is called the matrix foaming potential (MFP) and is measured by Foam stability tester type FA by 1-CUBE, Havlickuv Brod, Czech Republic (fig. 4). Foam is created by introducing of a gas into liquid sample and mixing with stirrer. By the combination of gas type, gas flow rate and revolution speed of the mixer there can be prepared foam of various structures, eg. by introducing 0,25 mL/min of air and mixing at 1200 RPM creates very fine foam resembling foam created on draught beer, or introducing 0,5 ml/min of air and mixing at 900 RPM creates medium coarse foam resembling foam on beer poured from the bottle (fig. 5).

Foam stability is evaluated as a time from the end foam generation to the decrease of foam surface over a set distance, which is a distance of electrodes that are in the place of measurement. The MFP value expressed in seconds covers the height of created foam under standard conditions, which corresponds to foaming ability of the sample, time to foam drainage in the first stage of foam collapse and the whole second stage of foam collapse.

As can be seen from the measurement principal, MFP can be used all over the whole beer production line, because even samples without CO_2 can be evaluated. Samples that contain CO_2 have to be degassed prior to the measurement. The MFP measurement has lower reproducibility due to various reasons, e.g. the temperature sensitivity (fig. 6). Regardless the reproducibility this method is much close to real foam quality as sensed by consumers, as can be seen from satisfactory correlation with pouring test (fig. 7).

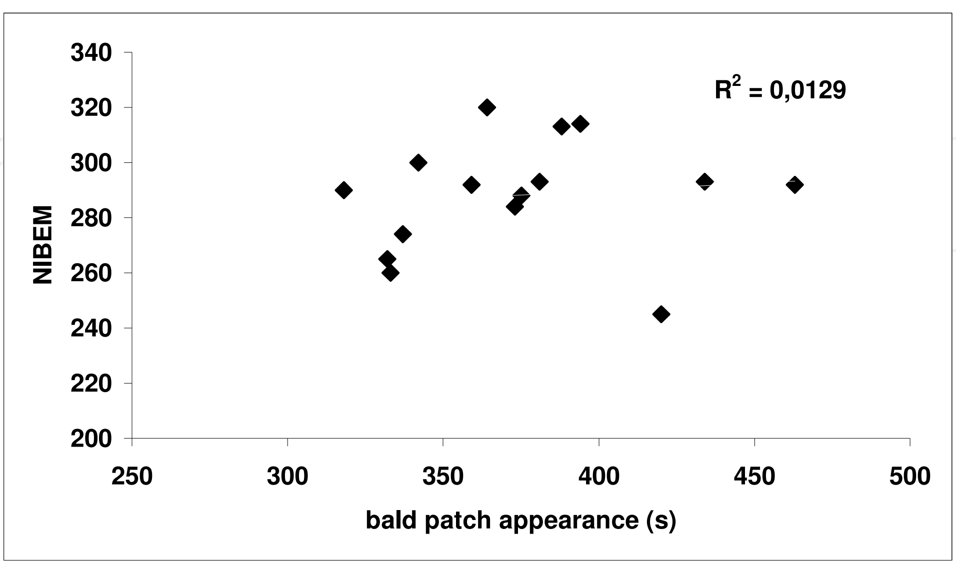


Fig. 3. Scatter plot and regression analysis of NIBEM with customer perceived stability measured by the pouring test.

Fig. 4. Foam stability tester type FA by 1-CUBE.

Fig. 5. Fine (right) and medium coarse foam.

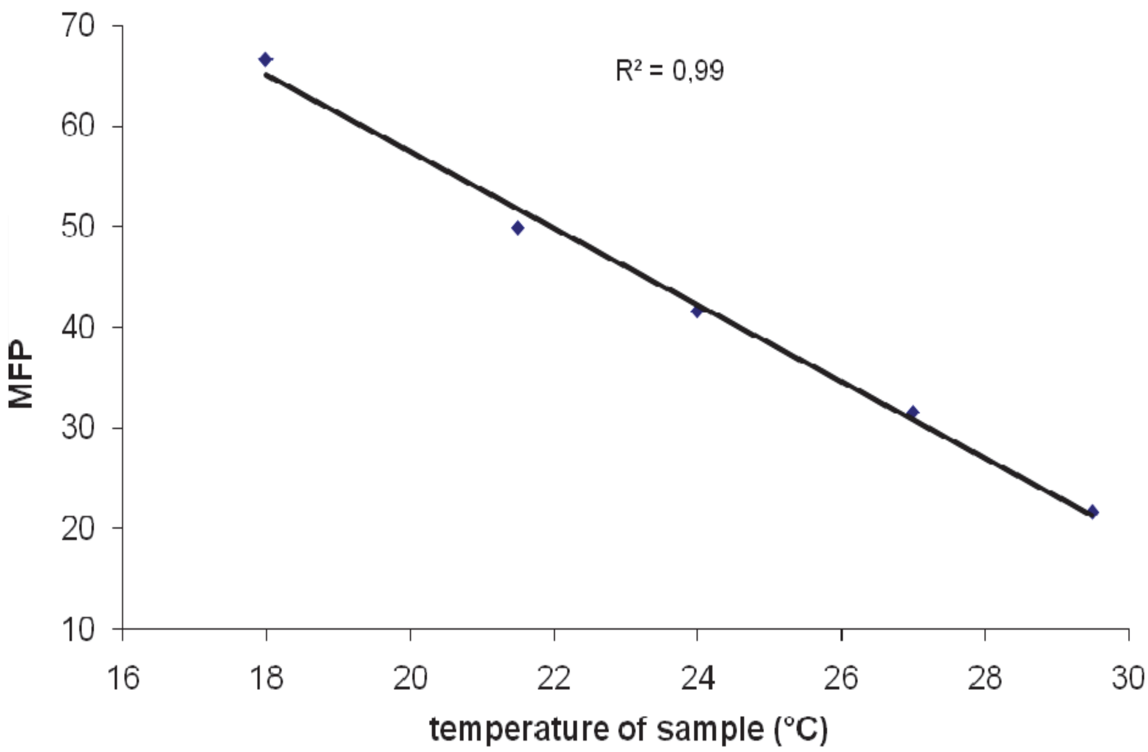


Fig. 6. Temperature dependance of Matrix foaming potential.

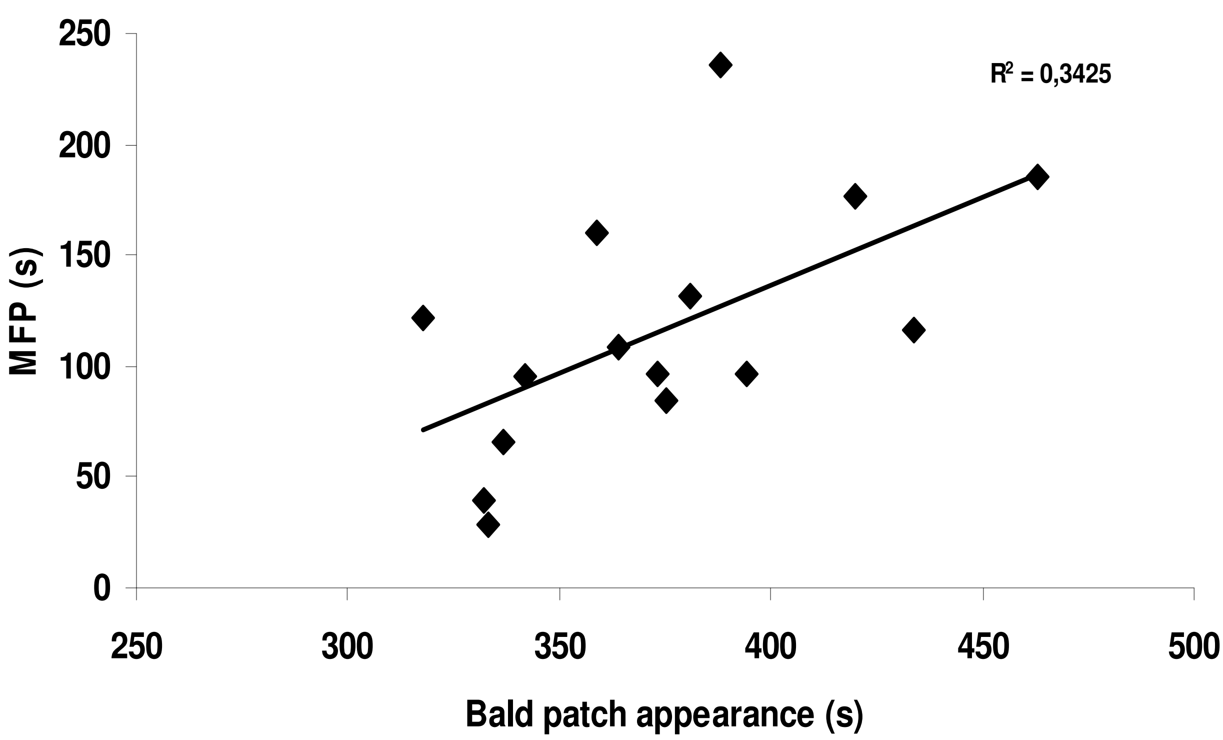


Fig. 7. Correlation of pouring test with Matrix Foaming Potential (MFP).

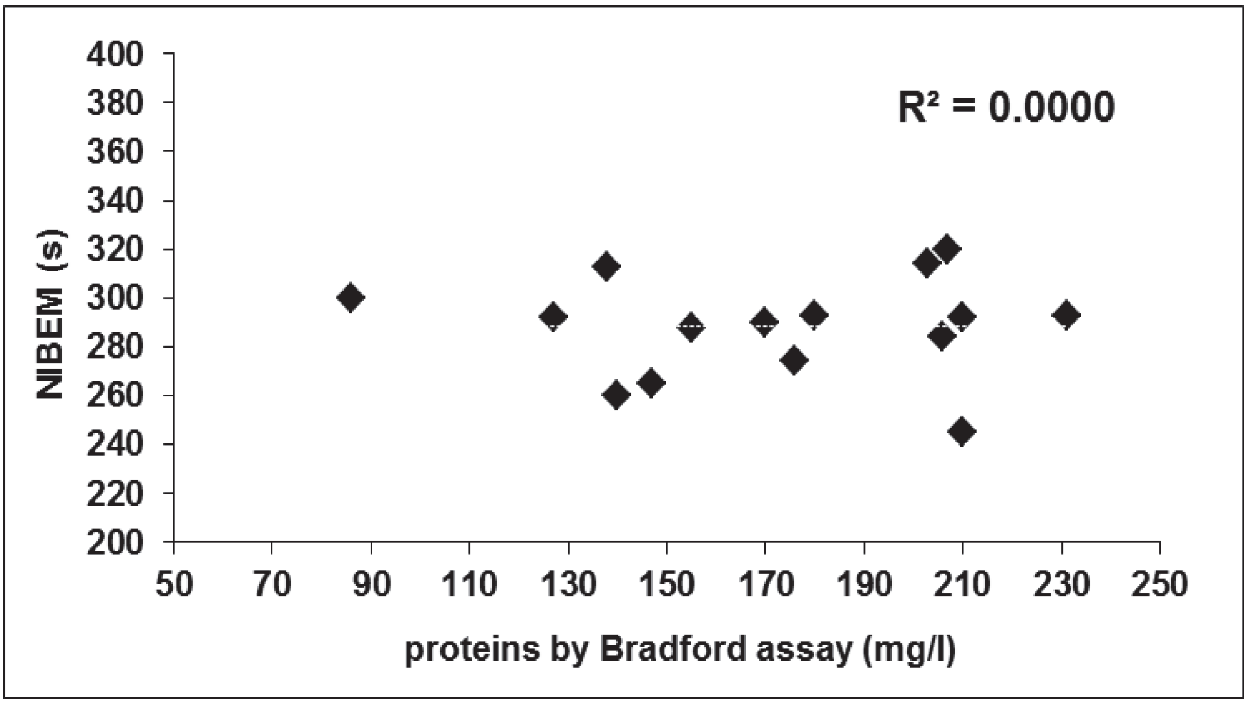
3.3 Foam positive and negative substances

As discussed above, brewers or researchers looking to improve foam quality typically take a reductionist analytical approach. Accordingly, the quality of beer foam generated is tried to be evaluated by measuring the content of foam positive components in beer, and then attempting to modify the brewing process to increase the content of these foam positive compounds to improve foam quality. Most often targeted with such an approach are foam positive components including protein Z, LTP1 and other proteins, and iso-α-acids or their reduced forms. Much more infrequently, the role of foam negative components such as lipids is considered in the technical literature.

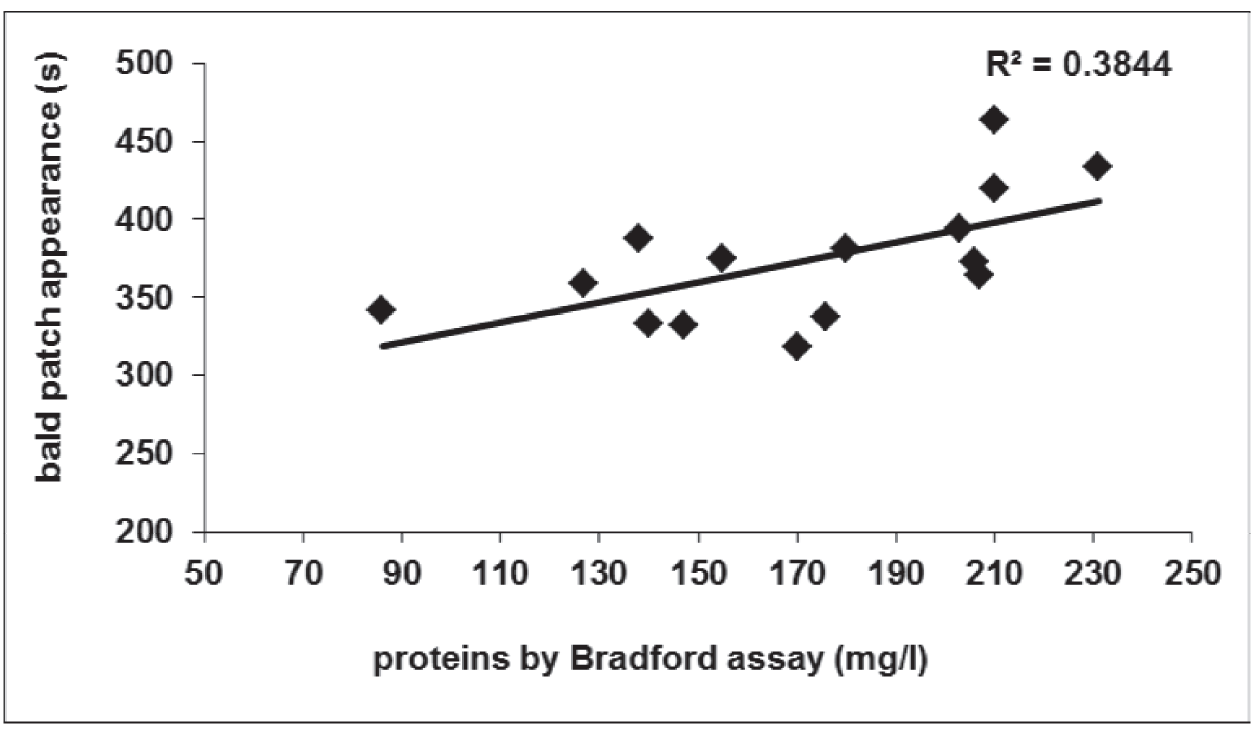
It was observed that beer, even with the lowest content of proteins, could be foamed to 100 % of volume of relatively stable foam by simple foaming technique (Fig 8). A simple approach was to correlate the content of foam positive proteins assessed by the Bradford Coommassie blue binding assay (CBB) with foam stability measured by both NIBEM value and by pouring the beer to a glass from the bottle and measuring the time to bald patch appearance (Fig 9). This experiment was conducted with 15 brands of commercial lagers and showed no association between the level of foam positive proteins in beer or its foam stability with NIBEM (Fig 9A), although there was some association with bald patch formation (Fig 9B) although the slope was relatively low. On the basis of these results it was questioned whether the content of foam positive compounds was as important for the beer foam quality of beer as found in previous studies.

This suggests that the content of foam positive proteins/components may not be limiting with respect to foam quality, a similar conclusion that can perhaps be drawn from the beer dilution experiments of Roberts over 30 years ago (Roberts, 1978).

Fig. 8. Whole volume of low protein beer converted into foam.



(A)



(B)

Fig. 9. Scatter plot and regression analysis of protein content of beer with NIBEM value (A), and time to bald patch appearance (B).

Previous investigations using a "foam tower" have shown that hydrophobic and foam positive components such as LTP1 and iso-α-acids are preferentially concentrated in the foam. To study if the content of beer foam positive proteins/components were limiting, a serial re-foaming experiment as depicted in figure 10 was designed. Degassed beer, created foam by stirrer as in MFP measurement with foaming time kept constant so as to measure the quantity of foam produced. The foam and beer phases were separated by pouring beer from under the foam, refilled the beer phase to original volume by "fresh" degassed beer to keep standard foaming conditions and again created foam with the mixer. The refilled amount was less than 10 % of the total volume. This cycle of foaming and separation was repeated 15 times.

The basic premise of the experiment was that if the content of foam positive proteins/components content was limiting in beer foam, foam capacity (amount of generated foam) and foam stability would decrease with sample order number in the experiment as these foam active components were concentrated in the foam and depleted from the beer. Thus foam positive proteins/components would migrate and concentrate in the foam phase in the earlier foaming and separation steps and so that there would not be a sufficient amount in beer phase in the later steps to generate sufficient amounts of stable foam.

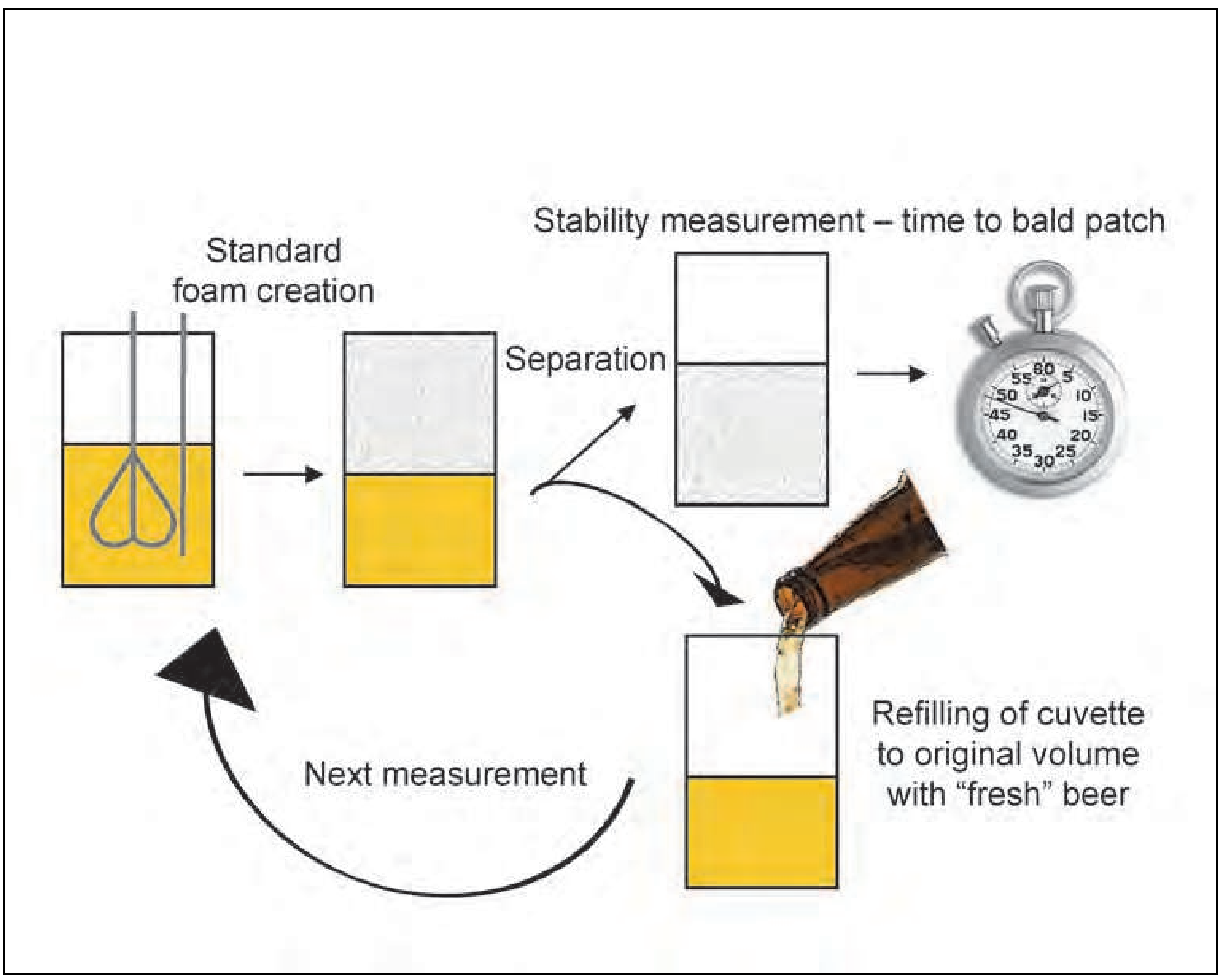


Fig. 10. Schematic of the design of experiment for the serial re-foaming of beer. Fifteen iterations of re-foaming of the beer were undertaken.

Figure 11 clearly shows that with serial re-foaming, foam capacity throughout the experiment was unchanged and foam stability, in terms of time till bald patch formation, was substantially increased, being five times higher at the end of experiment than at the beginning. It follows that foam stability was not just determined by the level of foam positive compounds, but it was more the result of compromise or balance between foam positive and negative components. Moreover, as the foam stability increased with re-foaming, it was apparent that both negative and positive foam components were presumably concentrated in the foam, thus separated from the beer to be re-foamed in the next cycle. This unexpected and contrary result could be explained by the following hypotheses. Firstly, Bamforth proposed that "hydrolyzed hordein appears to selectively enter beer foams at the expense of the more foam-stabilising albuminous polypeptides" such as protein Z (Bamforth, 2004). As such, as the level of hydrolyzed hordein is depleted relative to the albuminous polypeptides, foam stability would be seen to improve. However, Lusk et al. found in their foam tower experiments, as the content of LTP1 was depleted, the foam became less "creamy" and contained coarse bubbles, that were not observed in this experiment (Lusk, 1999). Secondly, as LTP1 is concentrated in beer foam and is thought to play a lipid-binding role in beer, both the LTP1 and the foam stabilizing lipids would be removed with the separated foam. An improvement in foam stability would occur if the level of lipids were limiting in the beer relative to LTP1, other lipid binding components and foam positive proteins/components.

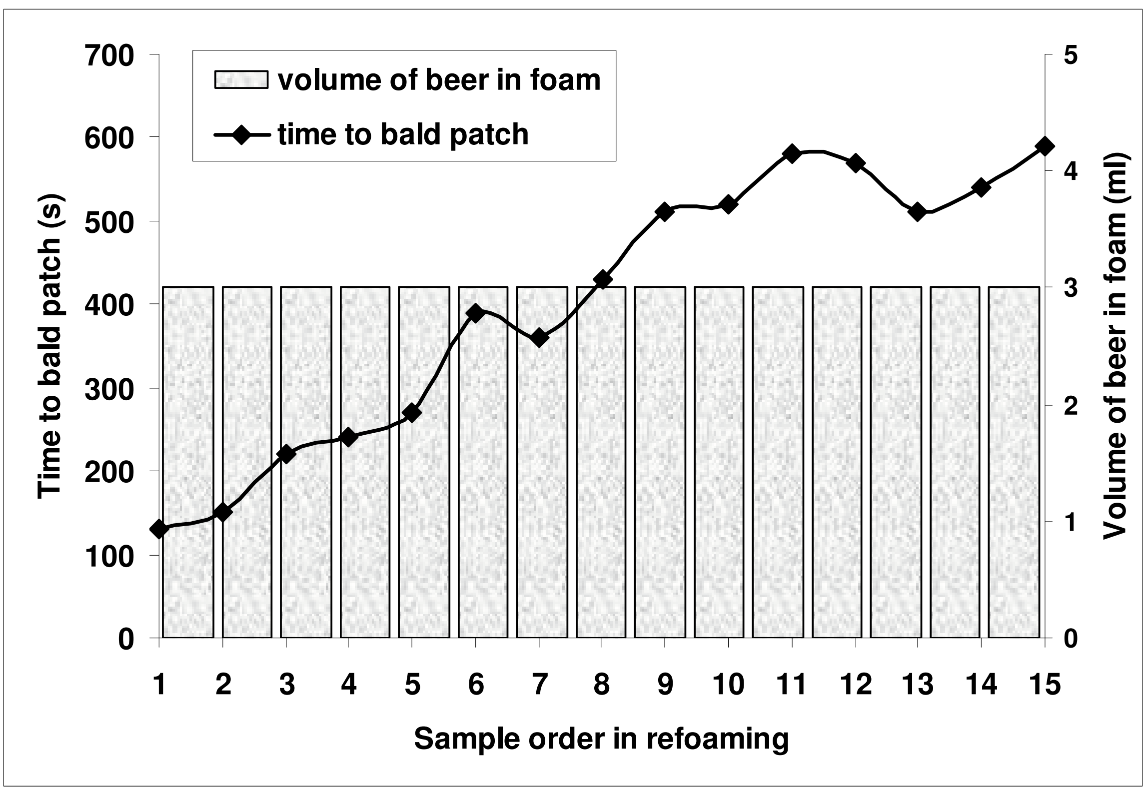


Fig. 11. Results of foaming capacity and foam stability during a serial refoaming experiment with 15 iterations. The volume of beer foam formed was exactly the same for each refoaming iteration, when using a constant time of foaming.

3.4 Practical approach to foam stability

The insights gained from these experiments recommend several practical approaches to foam quality improvement in commercial production. These are based on the premise that by measuring the MFP during and within each production stage, critical points can be identified in the process that reduce foam stability and indicates process parameters that can be modified to improve foam stability, particularly the limiting of the inclusion of foam negative components. One example was to apply MFP measurement during the course of lautering and sparging process. Figure 12 shows, that extended sparging was one of the steps that reduces foam stability. It has long been known that although extended sparging recovers more extract, it also results in the extraction of increasing amounts of undesirable substances such as polyphenols, husk bitter substances, etc , and foam negative materials. Similarly, the MFP analysis was applied during the course of main fermentation (Fig 13). During fermentation, foam stability was decreased to almost a third.

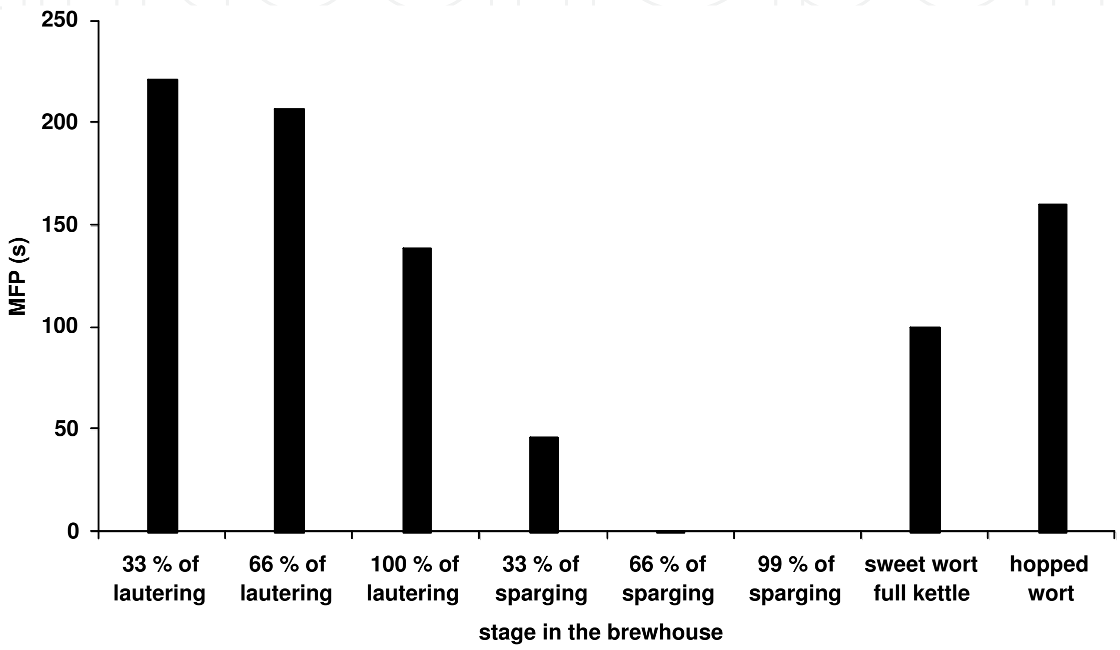


Fig. 12. Matrix foaming potential of wort samples taken during the course of lautering and sparging.

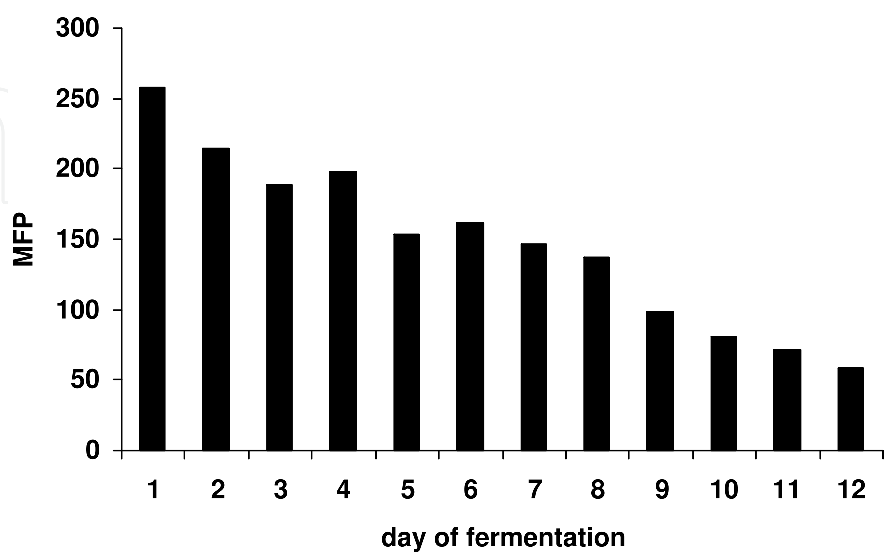


Fig. 13. Matrix foaming potential of "beer" samples during the course of main fermentation.

By this approach there were found several control points for foam stability, of which some fulfilled the demand for not changing of any other beer quality parameter, including raw materials. The effectiveness of these new control points has to be validated by statistical methods, which also serve for control of constancy of other quality parameters after setting new control points.
The most suitable statistic tool is regulation chart, which illustrates the change of foam stability in figure 14 by NIBEM value. Foam stability increased from values around lower specification limit into optimal central zone for NIBEM, MFP increased approximately three times.

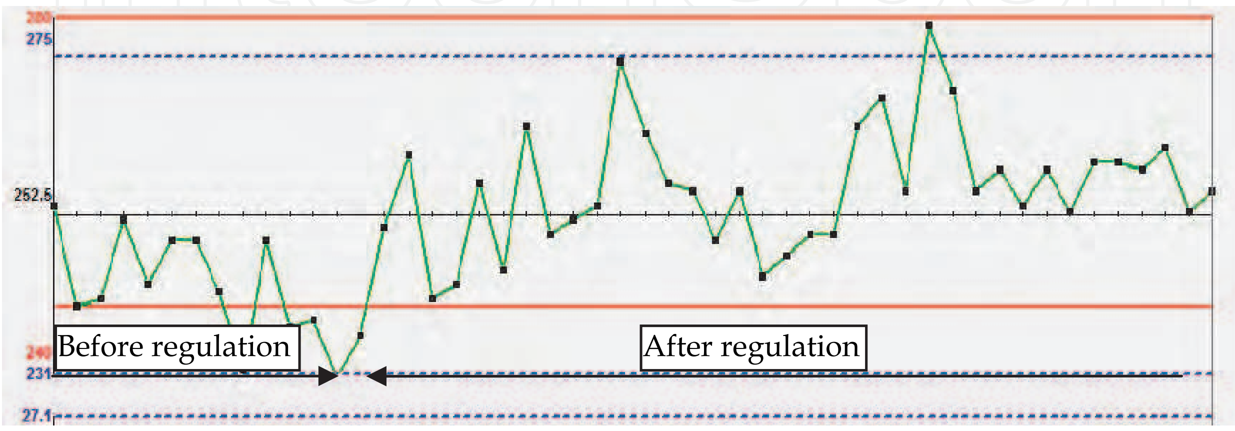


Fig. 14. Regulation chart of foam stability measured by NIBEM during process optimization.

4. Conclusion

Integral part of modern quality management is improving quality. For the task of improving beer foam quality, more successful strategy appeared to be employing own R&D, compared to external consulting expert, even with deep knowledge of bibliographic results on given topic.
The quality improvement procedure included optimization of new method with results close to customer sensation of quality, which could be used even for evaluation of intermediate product all over the production line. By this method weak points were discovered and the success of new regulation was evaluated by control charts.

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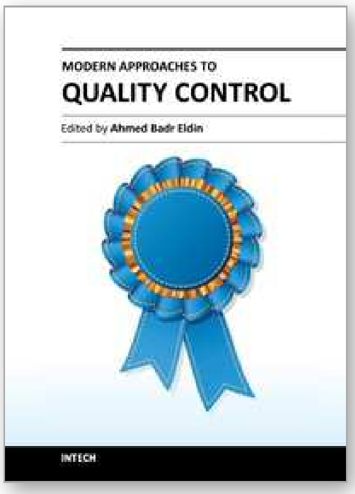

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Rapid advance have been made in the last decade in the quality control procedures and techniques, most of the existing books try to cover specific techniques with all of their details. The aim of this book is to demonstrate quality control processes in a variety of areas, ranging from pharmaceutical and medical fields to construction engineering and data quality. A wide range of techniques and procedures have been covered.