Statistics as Well as Yeasts Are Important in Brewing

BREWHOUSE YIELDS

Application of Statistical Quality Control

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Practically no published information is available on the use of statistical analysis in brewing operations. An attempt was therefore made to demonstrate the application of simple statistical quality control methods to a practical brewing problem—i.e., efficiency of brewhouse yields. Data on brewhouse operations were obtained from six breweries ranging in annual production from 50,000 to 2,500,000 beer barrels. Values for efficiency were calculated for each brew, as well as the maximum and minimum, the average, the standard deviation, and the 95% confidence limit for each brewery. The results, presented in frequency bar charts, indicated a range in efficiency from 91% in a 600,000-barrel brewery to 98% in a 2,500,000-barrel brewery. Another 600,000-barrel brewery revealed considerable variation in yields, warranting further study. A 50,000-barrel brewery showed a satisfactory efficiency of 93.3% and a standard deviation of 0.8%, indicating consistent brewing operations. The use of statistical analysis and control charts points the way to improvement in brewing operations. Brewhouse and cellar processes, and particularly bottle shop operations, represent suitable objectives for statistical quality control.

Although a few individual brewers have applied statistical methods in analyzing data on their operations, there is little published information specifically applying these techniques to brewery operations. There is, perhaps, a general feeling that the statistical methods and control charts used by manufacturing industries are not applicable or practical in brewing. However, statistics has been defined as "mathematics applied to observational data" (*4*), and the brewer must obtain ample observational data, if only for legal reasons. He must list the materials he uses and the volumes and gravity of the beer he produces. Thereafter, application of statistical methods is not very burdensome and certainly need not be avoided. Statistical quality control (*2*) consists of: condensing the information contained in a set of observations, and presenting the essential information in a concise form more readily interpretable than the unorganized mass of original data.

It is a primary purpose of this paper to demonstrate a technique rather than to report on a result. Therefore, a great many assumptions have been made, which may have affected the apparent results. Not all of these assumptions are indicated here, partly because detailed explanations would unnecessarily lengthen this discussion, and partly to aid in preserving the anonymity of the breweries involved.

The technique is simply the application of quality control, by means of simple statistical methods and "control charts," to a practical brewing problem. There are, however, many applications for these tools of management other than the one demonstrated here.

Efficiency of Brewhouse Yield

The subject of the present study is the over-all efficiency of extraction, or yield, in the entire brewhouse operation. The brewery processes covered here consist of: grinding of the barley malt; addition of cereal adjuncts either with or without precooking; subsequent extraction, by means of mashing, of the soluble constituents of the malt and adjunct; separation of the extract or wort; boiling of the wort with hops; straining of the hops; and finally cooling of the wort into starting tanks or settling tubs prior to pitching with yeast for the purpose of fermentation.

Six breweries geographically distributed throughout the United States were kind enough to submit data on their operations. Their annual production rates in beer barrels are about as follows:

Brewery A	600,000
Brewery B	175,000
Brewery C	200,000
Brewery D	600,000
Brewery E	2,500,000
Brewery F	50,000

Each of the breweries involved is considered to be well run and profitably operated. The data were obtained directly from each brewery's records, through the courtesy of their managements, with no attempt to collect special information for this study. This approach is equally applicable to larger or smaller breweries.

The over-all efficiency of the brewhouse may be defined as the ratio of the

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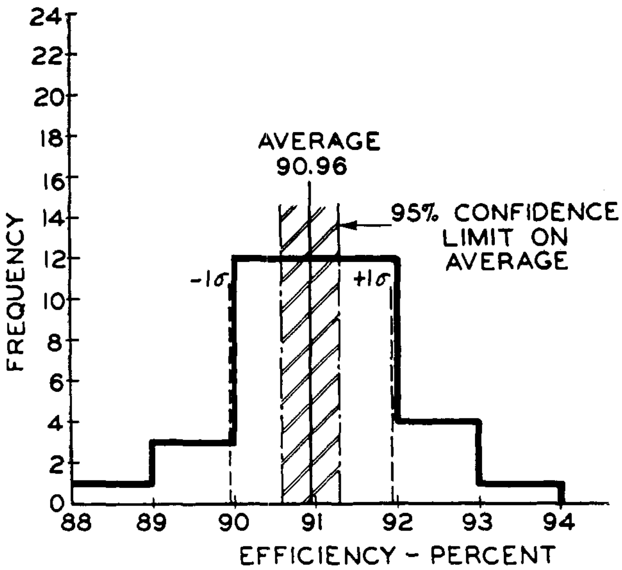


Figure 1. Frequency bar chart for brewery A

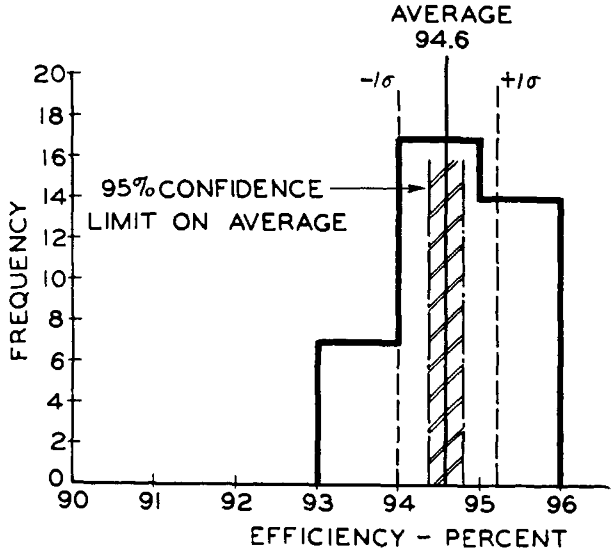


Figure 2. Frequency bar chart for brewery B

total extract received in the starting tub for a brew or series of brews to the total available extract from the brewing materials used. The first step in accurate evaluation of brewhouse yield is to secure accurate data on the available extract from each extract-contributing material used in each of a substantial number of individual brews. The second step is to secure accurate data on the extract available in the starting tub.

The ideal situation is, therefore, when one brew is made in a single brewhouse unit and transferred without blending into one or more starting tubs where accurate volume and gravity measurements can be taken. It is further necessary to have the laboratory yields of each material used in each brew. In practice, for many good reasons, this ideal situation seldom exists, and did not exist in any of the six breweries studied, although brewery C closely approached this situation. A few of the deviations are mentioned in the discussion of the results obtained.

In some cases physical conditions, in some cases the brewhouse practice, and in some cases a failure to appreciate the value of accurate information limit the possibilities of collecting data for individual brews. It is not essential to have individual brew data, if grouped brews will furnish accurate information. If five brews are made per day and collected in three tanks, data on total daily input and output can be collected, and will prove most useful in an analysis of efficiency—in brewery A, for example, two brews were collected in one starting tub. However, some minimum information must be obtained if operations are to be properly interpreted.

Evaluation of Data

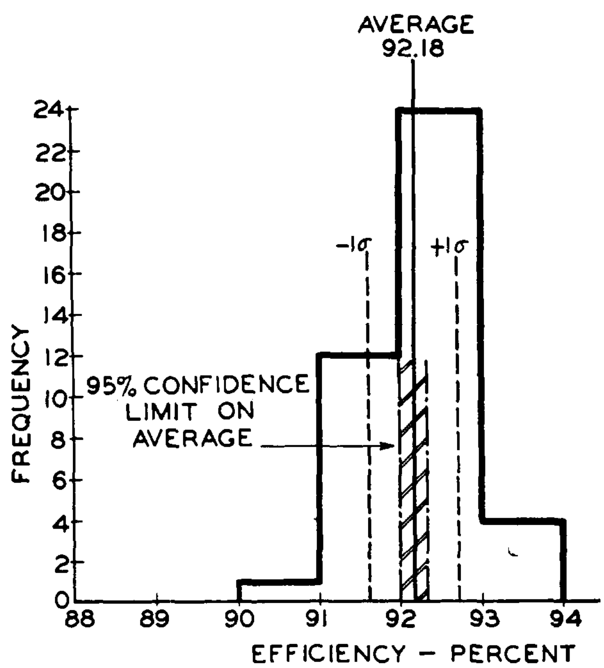
The laboratory as-is yield (fine grind) of each car or lot of material should be obtained at the time of receipt. Variations in moisture content may affect this value at the time of use. The extent of this variation is minimized when the time between analysis and use is reduced. In this report, any such variation is neglected.

The methods for determination of as-is yield (fine grind) are subject to errors of about ±0.5%. Scales used in weighing ingredients, whether in bulk or in containers, are seldom accurate to within ±0.5%. These and other variations may be cumulative or may average themselves out. The measurement of volume of liquid in a brewery is a subject on which the final word has not been said. The degree Plato (per cent extract) is frequently measured by unskilled personnel or by inaccurate techniques. All these variations will affect the accuracy of data. Again, the errors may be minimized by carefully following standard procedures. The methods of analysis of the American Society of Brewing Chemists are most valuable in this regard *(2)*.

There is, nevertheless, a point in studying data as collected, even though they may appear unsatisfactory. An incidental advantage is that some form of statistical control of brewing operations can very effectively highlight the desirability of collecting sufficient data in the correct manner. Certainly, no brewer today would gainsay the necessity for accurate monetary accounting; and operational data are, or should be, just as carefully collected and used. The method of approach to the problem is as important as the gross results obtained. It cannot be said from this study that brewery D, with a possible apparent efficiency of about 96%, is necessarily getting more extract from its material than brewery A, with an apparent average yield of 91%. This could be demonstrated clearly only if the accuracy of the data from each brewery were compared. It can be stated, however, that the variation in results in brewery D from 90.4 to 98.1% should be investigated, and that brewery A should check the accuracy of its data, which, if correct, indicate an operation of low efficiency. If a 600,000-barrel brewery using a bushel of malt per barrel can increase its yield by 3%, it can save about $36,000 annually on its malt bill alone. It can also be concluded that brewery E, although it has the highest average efficiency of the six breweries included in the study, does not have as small a variation from brew to brew as brewery B or C.

Each brewery was requested to furnish a record of a reasonable number of brews,

Figure 3. Frequency bar chart for brewery C



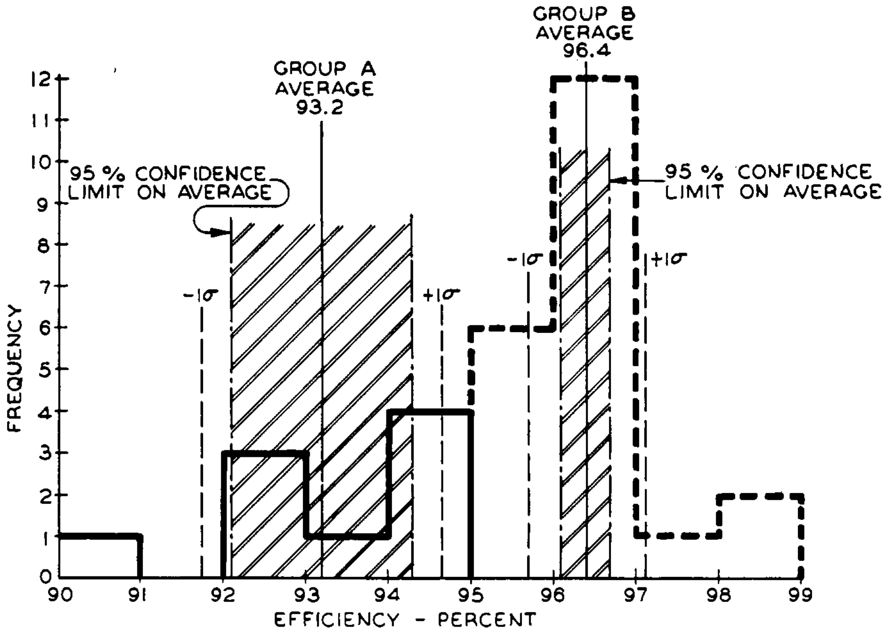


Figure 4. Frequency bar charts for brewery D

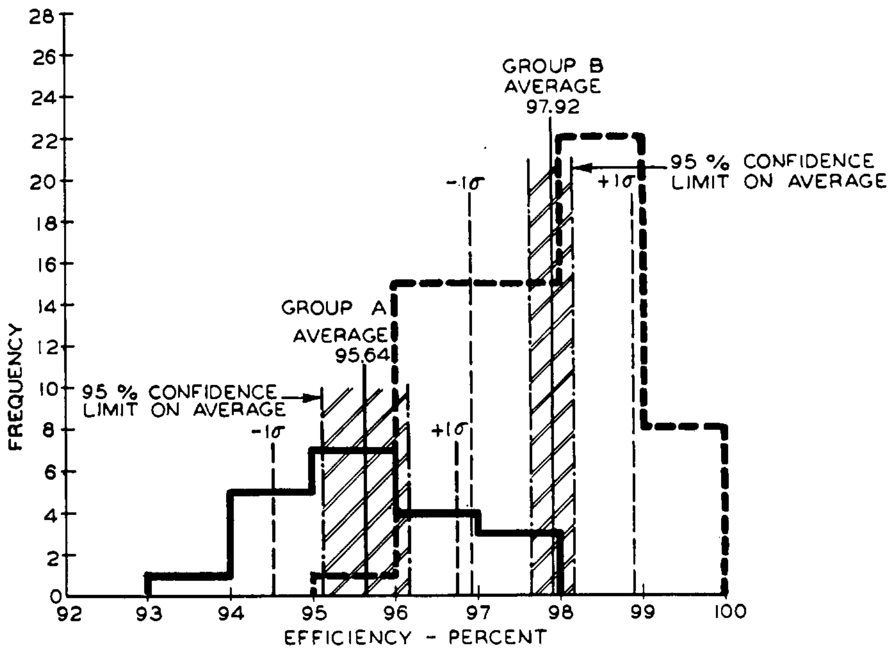


Figure 5. Frequency bar charts for brewery E

indicating: (*a*) the pounds of each malt and extract-containing adjunct used in each brew, (*b*) the laboratory as-is yield of each malt and adjunct, (*c*) the volume of wort received in the starter for each brew, and (*d*) the Plato degree of each brew in the starter. Efficiency was then determined by the formula

$$\text{Efficiency} = \frac{c \times d}{a \times b}$$

where degree Plato was converted to pounds of extract per barrel according to standard calculations and tables (*3*).

Values of efficiency were thus obtained for each brew from each brewery, varying from a minimum of 88.6% to a maximum of 99.6%. Considering efficiency to be the variable under study (although a number of variables are involved), certain minimum data were calculated, which are considered necessary to accomplish the aims suggested by the American Society for Testing Materials (*2*).

Frequency Bar Charts

Figures 1 through 6 show the efficiency distribution as well as the standard deviation, the maximum and minimum values, the average, and the 95% confidence limit on the average. (This last value, computed according to the A.S.T.M. manual, indicates a probability of 95 times in 100 that the average falls within the limits indicated in the chart.)

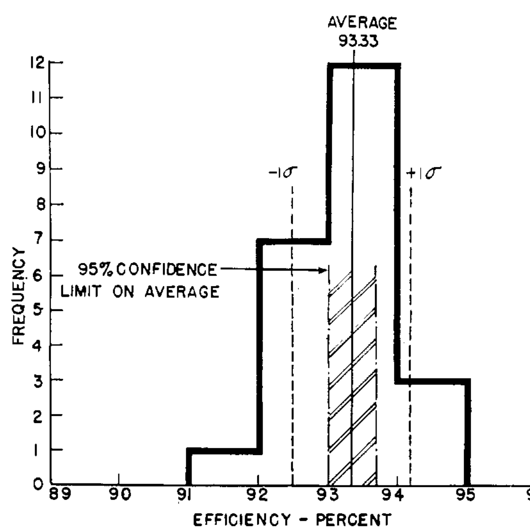
Figure 1 presents results for brewery A, where the efficiency averages about 91% of laboratory yield and the 95% confidence limits are between 90.6 and 91.3%—a spread of 0.7%. The minimum yield is represented by one brew between 88 and 89%, and the maximum by one brew between 93 and 94%. Twenty-four of 33 brews measured are between 90 and 92%, with the standard deviation just about 1%. The data are only fairly consistent, indicating fair uniformity in brews, and the average is low.

Actually, the data here are misleading because the brewer had available only the average laboratory yields, and not the laboratory yields of the materials used for each individual brew. In any case the low yield indicates the need for further checking.

Figure 2, presenting the data for brewery B, represents an almost ideal situation. The average of 94.6% is reasonable for the equipment in this particular brewhouse. The minimum and maximum values lie between 93 and 96%. The confidence limits are between 94.4 and 94.8%—a spread of only 0.4%. The standard deviation is only 0.6%. Again, complete data were missing and there was no certainty as to which adjunct lot was used in each brew, so an average adjunct yield figure was used. However, the maximum adjunct laboratory yield, with the minimum extract in the cellar, would cause an error of −0.1%. Conversely, the minimum adjunct yield, with the maximum extract in the cellar, could have caused an error of only +0.1%. In this case the fact that two malts were used in each brew was neglected. Because the exact quantity of each was not known, the laboratory yields for each brew were averaged. This procedure apparently did not cause any substantial variation.

Figure 3 shows that brewery C reported relatively uniform operations, with only one brew out of 41 below 91%

Figure 6. Frequency bar chart for brewery F



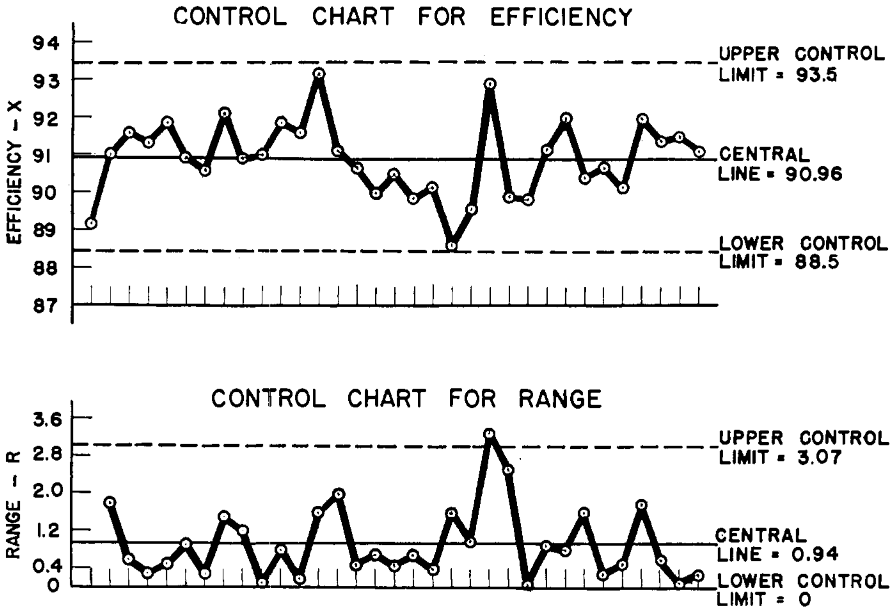


Figure 7. Quality control charts for brewery A

and four brews 93% or above. The average (92.2%) was low enough to warrant further study by the brewery. The 95% confidence limits were 92.0 to 92.3%, and the standard deviation was only 0.6%—the same as brewery B.

Brewery D represents an interesting picture. There are two conditions of operation, which are sufficiently different to necessitate separate handling of the data for each condition. However, data are taken for only one condition each day. It is known that one condition gives consistently higher efficiency than the other, but no record is available that relates the individual efficiencies to the two sets of conditions. For apparently good reasons a rather arbitrary estimate was made that all efficiencies over 95% were the result of one condition. Therefore, Figure 4 is divided into groups, A and B. On this assumption 9 brews were made under group A and 21 under group B. The average yield of group A is 93.2%, but 95% confidence limit lies between 92.1 and 94.3%. The standard deviation is 1.4%—more than twice the value for brewery B or C. The data here are surely insufficient for accurate interpretation, or else, if additional data should confirm a high standard deviation, the variations in operation are substantial in comparison with the other breweries analyzed.

On the other hand, group B reveals a fairly high efficiency—96.4%. The 95% confidence limit is between 96.1 and 96.7%. The standard deviation is 0.7%. Six brews lie in the range 95.1 to 96.0%, twelve brews in the range 96.1 to 97.0%, and only three brews outside these values. If actual results should show that some of the 94.1 to 95% brews really were made under the conditions of group B, and some of the 95.1 to 96.0% brews really belong in group A, the results would show even greater variability.

There may, of course, be many reasons for the results shown here. Further data, further studies, may show greater consistencies, and surely such studies appear warranted.

Figure 5 demonstrates graphically the efficiency distribution of brewery E. Here again, as in the case of brewery D, brews were made under two distinct sets of conditions. In this case, however, it was possible to segregate the brews according to the conditions and thus handle each set independently without any arbitrary division. Group A shows an average efficiency of 95.6% and a standard deviation of 1.11%, while group B has an average efficiency of 97.9%, with a standard deviation of 0.98%. This is the highest efficiency shown in these studies. While the average efficiencies of the two groups differ by 2.3%, the standard deviations are substantially the same. This would indicate that although the level of operation differs, the uniformity or variability within groups, as measured by the standard deviation, is substantially the same for the two conditions of operation.

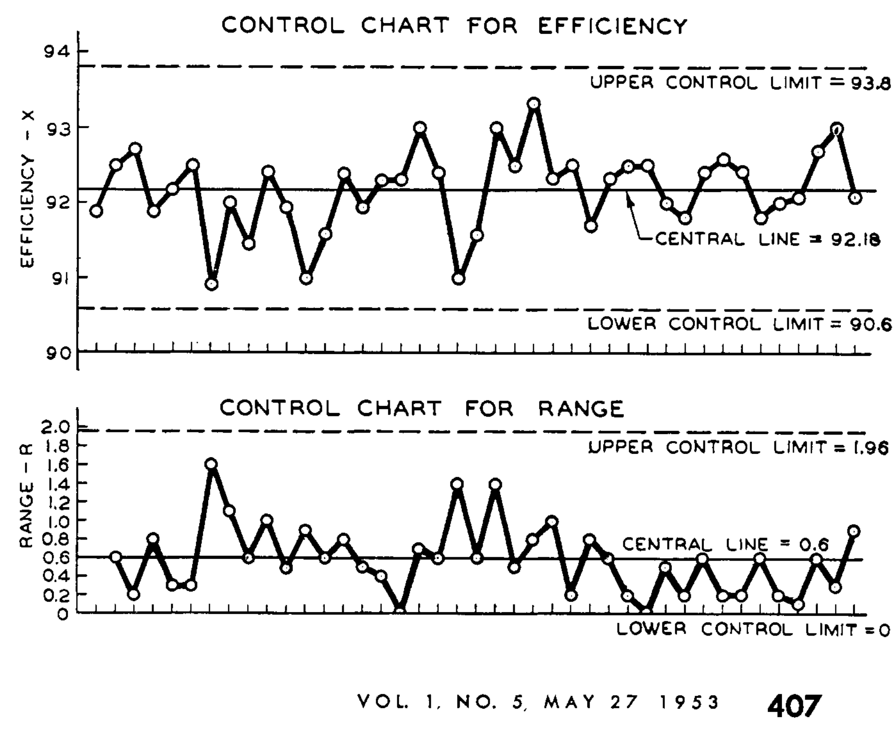
Brewery F is of interest mainly because it is the smallest brewery considered and has a production of only 50,000 barrels annually. Figure 6 shows the efficiency frequency distribution for this brewery. The average efficiency is 93.3% and the standard deviation is 0.8%. Thus, brewery F has an average efficiency higher than brewery A with a production of 600,000 barrels annually and higher also than brewery C with an annual production of 200,000 barrels. The standard deviation of 0.8% would indicate that this plant has a consistency somewhat better than brewery E, whose annual production is 2,500,000 barrels, and not far worse than any of the other plants studied.

Control Charts

For the medium-size or small brewery where only a few brews are made each day (three or less), the most convenient form of control chart is one which shows X, the efficiency, and R, the running range (difference in efficiency between a brew and the brew immediately preceding it, without regard to the plus or minus sign).

Figure 7 illustrates such a control chart for brewery A. With the exception of one brew whose range fell outside the upper control limit, all brews were within the limits. As long as brews plotted on the chart fall within the limits, the brewer knows that no disrupting elements have entered the brewing operations. If, on

Figure 8. Quality control charts for brewery C



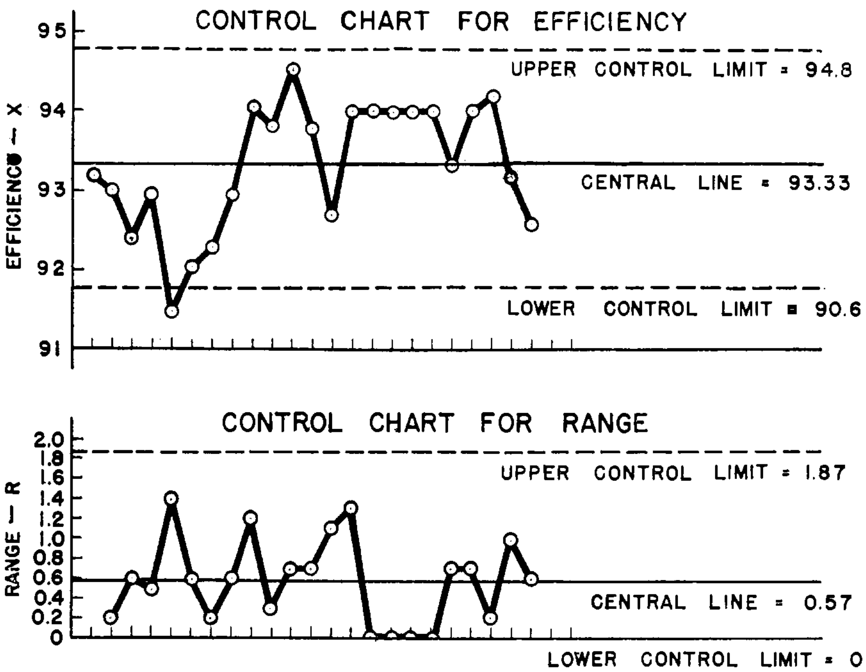


Figure 9. Quality control charts for brewery F

the other hand, brews plot outside the control limits, the brewer should immediately investigate the cause. In this case it might have been faulty weighing of materials, faulty reading of the saccharometer, or something else. Furthermore, the wide limits of 5.0 for efficiency and 3.07 for range confirm the findings shown in the frequency bar chart with respect to the relatively wide variation between brews.

Figures 8 and 9 demonstrate the control charts for breweries C and F. The limits are much narrower than that for brewery A, indicating greater uniformity for breweries, particularly for brewery C. One brew in brewery F, however, fell below the lower control limit for efficiency, probably because of some fault in the brewing process or in measurements. The chart for this brewery also reveals that the first group of brews made during the time period under investigation fell below the central line, indicating low efficiency, while most brews of the second and larger group fell above the central line, showing improved efficiency.

For the brewery that produces four or more brews a day, another form of control chart offers some advantage. In this type, all the brews produced in one day are lumped together and plotted as one point on each of the control charts (an equal number of brews each day are desirable, if this method is to be applied in its simplest form). Thus, the number of plotted points will be reduced and the control limits will be closer to the central line.

For purposes of illustration, the data from condition B of brewery E were used (Figure 10). It is assumed that five brews are made each day. (This is not the actual case, but is assumed here to demonstrate the method.) It is then reasonable to take the five brews for each day and consider them as one sample. New brews are then plotted on the same charts in a similar manner. Any abnormalities will become apparent immediately.

Discussion and Conclusion

A study of the frequency bar charts and control charts offers a great deal to the management of a brewery. Figures 1 and 7 show unsatisfactory yield and only fair uniformity in brewing operations for brewery A. Figure 2 demonstrates both good yield and good uniformity for brewery B. Figures 3 and 8 exhibit unsatisfactory yield but satisfactory uniformity for brewery C. Figures 4 and 5 reveal unique conditions for breweries D and E. Figures 6 and 9 show both satisfactory yield and satisfactory uniformity for brewery F. Finally, Figure 10 indicates uniform operations for one set of conditions in brewery E.

The use of simple statistical analysis and control chart presentation of data can point the way to improvements in brewing operations. The use shown here is only one possibility. The imaginative brewer will undoubtedly see many other useful applications of these techniques.

Most brewhouse and cellar processes lend themselves to statistical quality control. Bottle shop operations are particularly suitable and are being subjected to control chart analysis in a number of breweries. It is hoped that publications along these lines will be forthcoming in the near future.

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Figure 10. Quality control charts for brewery E