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Statistical Evaluation of Process Variability on Vanilla and Chocolate Ice Cream Manufacturing Process

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Abstract: ***This paper represents a detailed assessment of process capability (Cp) and product consistency (Cpk) of Vanilla and Chocolate ice cream manufacturing process by applying certain quality tools such as X bar charts, R charts and fishbone analysis. Variable sampling plan was conducted to collect samples of Vanilla and Chocolate 80 ml, 500 ml, 1 L, 2 L and 4 L product volumes. Cp and Cpk of all ice cream products were lower than 1.0. Therefore, process variation is too high. This situation calls for either to reduce process variation or to widen the tolerances. Also for all products mean value of the mass in g/l was off target. Then the process should be adjusted to perform at the target value. Therefore it can be concluded that the manufacturing process of vanilla and chocolate all volume sizes are statistically incapable. The key root causes determined for the focused problem are no dosing mechanism in the filling machine, changes in filling volume, no proper method for monitoring weight of the product, random checking of product weight, changes in overrun and poor monitoring of overrun change.***

Keywords: Process Capability, Product Consistency, Overrun, Fishbone, Mass in g/l

1. Introduction

Overrun is the measurement of air that is whipped into the ice cream in the ice cream machine and is calculated as the percentage increase in volume of the finished ice cream [1]. So, if 1litre of ice cream mix produces 2 litres of frozen ice cream, 100% overrun will have been achieved. Most commercial ice cream has an overrun of 75-100%, whereas the overrun of super-premium ice creams may be as low as 20%.

In industrial scale measurement of mass in grams per liter represents the overrun of an ice cream product. According to the Specification for ICE CREAM (1st review) – Sri Lanka Standard 223:1989 UDC 663:674, minimum requirement of mass in g/l is 475 [2].

Marshall and Arbuckle (1996) held that an increase in overrun will decrease the size of ice crystals [3]. Hartel stated that low overrun induces the formation of coarser ice crystals in ice cream compared with the same formulation made at higher overrun, because air cells may provide a physical impediment to ice crystallization during freezing [4].

Flores and Goff (1999) have suggested that a low amount of air (overrun below 50%) does not influence ice crystal size and that a certain amount of air (overrun over 70%) is necessary to have a noticeable impact on microstructure [5]. However, Flores and Goff (1999) found that when the volume of air reached a critical volume (over 80%), increasing overrun had less impact on the overall microstructure. Too high overrun can have a negative impact on ice cream quality: too much air will dissipate flavour and produce ice cream that is fluffy in texture and light in weight [5].

Tight control over mass in g/l is essential in ice cream operations, since it is directly tied to yield. Tight control over the rate of incorporation of inclusions is also important, as it is also tied directly to yield and profit. On the other hand, if mass in g/l is lower than desired, this could lead to loss of desired quality or even to produce that does not meet the legal requirements for weight of food solids.

Even if a continuous freezer in which the overrun is automatically set is in operation, it is important to whether it continues to perform accurately. When packages are being filled on a processing line, package weights should be closely monitored. Deviations can be attributed to variations in mass in g/l of the ice cream (which would require freezer barrel adjustment) or variations in the fill level of the package (which would require packaging machine adjustment).

Accordingly, statistical analysis of mass in g/l of ice cream products is critical parameter for a large scale manufacturer in order to sustain the quality of the finished product also to retain and achieve the customer satisfaction. Therefore, this research was aimed to critically analyze the variation in terms of mass in g/l of both vanilla & chocolate ice cream products (80ml, 500ml, 1l, 2l & 4l), root causes for the variation regarding mass in g/l parameter & finally to suggest the remedial measures to minimize variation in the case of existence of any variation.

2. Methodology

2.1 Development of sampling plan and data collection

This study was carried out to determine the process capability and process performance index of manufacturing of two ice cream product categories which are Vanilla and Chocolate. Study was conducted for the volume sizes of 80 ml, 500 ml, 1 L, 2 L and 4 L. With the discussions of process owners, it was determined minimum production run time for all the products is 3 hours and accordingly variable sampling plan was carried out to collect the samples.

Sample size of 150 for a one volume was determined since the production volume for a one batch varies with number of factors such as product category, production plan, capacity of aging vat, freezer capacity and speed and etc. Samples of 150 from each volume size were collected in the following sampling manner.

- For a one production run, 30 samples were collected and it was carried out for the minimum production run time of 3 hours
- During run time of 3 hours, for an each hour 10 consecutive samples were collected
- Same procedure was conducted for 5 production runs in order to collect 150 samples

2.2 Determination of Overrun

Method which is conducted to determine the overrun% at the manufacturing premises, is a weight basis calculation which is as follows.

$$\text{Overrun\%} = \frac{(Weight of ice cream mix - Weight of same volume of ice cream)}{Weight of same volume of ice cream} \times 100$$

For overrun determination apparatus called overrun cup is used and weight of ice cream mix filled up to the upper level of the cup has been determined as 143.5 g. Therefore, semi-solid ice cream product which discharges at the freezer machine is obtained to the overrun cup and its weight is obtained. In this manner calculations has been carried out and overrun chart has been developed by the process owners themselves which can determine the overrun % based on the weight of the cup filled with ice cream discharges at the freezer machine.

2.3 Data analysis

Mass in grams per liter (Mass in g/l), was determined for weights obtained for all production runs of all product volumes (10 types) by using Microsoft Office Excel 2010. Also standard deviation, process capability and process performance index were determined for each production run.

Then mass in g/l obtained for 150 samples of all product volumes were analyzed for Histograms and X bar and R charts by using Minitab 16 and Minitab 17 software. Also standard deviation, process capability, process performance index, mean variation and actual Upper control limit and actual lower control limit were determined for 150 samples of all product volumes.

2.4 Brain storming to develop cause and effect analysis

The fishbone diagram is a cause-and-effect diagram that can be used to identify the potential (or actual) cause(s) for a performance problem [6]. Fishbone diagrams provide a structure for a group‟s discussion around the potential causes of the problem. Fishbone diagrams are often used in needs assessment to assist in illustrating and/or communicating the relationships among several potential (or actual) causes of a performance problem. Likewise, these graphical representations of relationships between needs (i.e., discrepancies between desired and actual results) offer a pragmatic tool for building a system of performance improvement interventions (for instance, a combination of mentoring, job aids, training, motivation, new expectations) around the often complex relationships found across potential (or actual) causes [7]. Ultimately after completion of the diagram it is a comprehensive evaluation of the causes of the main problems and also reveals the root causes as well [8].

After conducting the statistical analysis of gathered data, several brain storming sessions carried out with the following process owners to determine the root causes behind the current situation.

- Ice cream R&D consultant
- Ice cream factory manager
- Assistant R&D manager
- Ice cream factory shift managers & production executives
- Ice cream factory quality assurance executives

Based on the discussions carried out fish bone diagram was developed.

3. Results and Discussion

3.1 Results of Mass in g/l variation analysis

There are two formulae to calculate process capability
(a) Process capability ratio (Cp), and
(b) Process performance index (Cpk)

Process capability, for a stable manufacturing process, is the capacity of the process to reach a certain level of quality. For a stabilized process in which factors affecting the standard deviation are properly controlled, process capability, as measured by the quality characteristics of the products of the process, is usually expressed as the mean value plus or minus three times the standard deviation [9].The Process Capability Index (CP) is expressed as a ratio to the specified value. It is used to quantitatively evaluate the adequacy of the process capability - whether the variation in the process is within the limits of the specifications [9].

Table 1: Interpretation of Cp

C_P	Evaluation	Assessment
$C_P > 1.33$	Good	Process capability completely meets specifications
$1.33 \geq C_P > 1.00$	Acceptable	Process capability does not completely meet specifications; process control should be continued
$1.00 \geq C_P$	Inadequate	Process capability inadequate; improvements should be made

Therefore, it can be more evaluated that the process is highly incapable and process variation is too high since determined CP for the process (0.18) is highly lower than 1.0 also Cpk -0.50 <1.0, then mean value of the mass in g/l is off the target.

Standard X, LCL, UCL and Mean variation of Mass in g/l of Vanilla and Chocolate ice cream products are as follows.

- Standard X = 526
- Standard UCL = 545
- Standard LCL = 507
- Standard SD = 9.5
- Standard Mean variation = 524.48 – 527.52

Actual X, LCL, UCL, Mean variation, CP and Cpk of Mass in g/l of all 10 product volumes are given in the following table.

Table 2: Statistical data for all product volumes

Product	X	LCL	UCL	SD	Mean variation	Cp	Cpk
Vanilla 80 ml	596.4	528.7	664.2	33.88	590.98 - 601.82	0.19	-0.50
Vanilla 500 ml	561.1	487.8	634.5	36.69	555.23 - 566.97	0.17	-0.49
Vanilla 1 L	497.5	446.3	548.7	25.59	493.41 – 501.59	0.25	0.12
Vanilla 2 L	476.8	443.6	510.1	16.62	474.14 - 479.46	-0.38	1.37
Vanilla 4 L	561.1	472.8	549.6	19.20	508.13 - 514.27	-0.33	0.59
Chocolate 80 ml	571.8	517.9	625.8	26.98	567.48 - 576.12	0.23	-0.33
Chocolate 500 ml	558.5	482.4	634.7	38.06	552.41 - 564.59	0.17	-0.45
Chocolate 1 L	497.4	439.5	555.3	28.96	492.77 - 502.03	0.22	0.11
Chocolate 2 L	487.5	426.9	547.9	30.25	474.14 - 479.46	0.21	0.22
Chocolate 4 L	491.9	449.8	534.1	21.06	508.13 - 514.27	0.30	0.24

For all product volumes, two control charts (X bar chart and R chart) show that the points are not randomly deviate around the center line also not within the control limits for both charts. Therefore it can be further validated that the production process for all products are not in control.

3.2 Cause and Effect Analysis

Based upon the above, Focused Problem Statement is established as follows.

Focused problem statement – Vanilla and Chocolate ice cream manufacturing process is statistically incapable in terms of Mass in g/l from 05/08/2014 to 02/10/2014.

With the developed focused problem statement, brain storming sessions carried out as mentioned under the section 2.4 and the finalized fish bone diagram is shown as follows. All the possible causes are mentioned under each category, however root causes which can generate the focused problem are notified with a right mark. Others are notified with a cross mark.

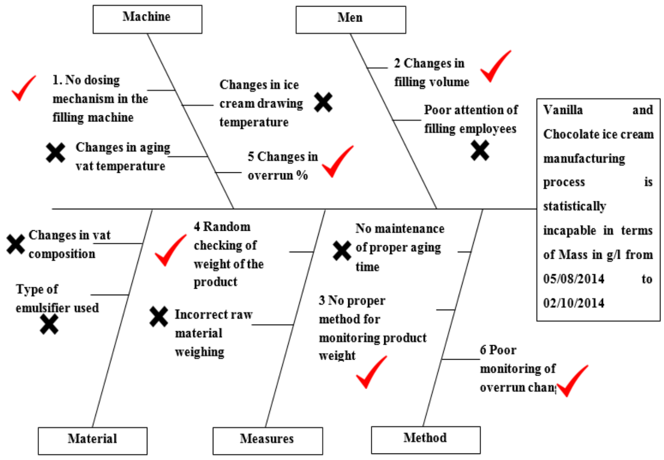

Figure 1: Cause and effect analysis

In the existing ice cream filling process, filling for 500 ml, 1 L, 2L and 4 L except 80 ml are carried out manually by filling employees. There is no dosing mechanism and ice cream is filled up to the upper level of the tub by filling crew. Therefore the filling volume to the tub significantly depends upon the efficiency and accuracy of the filling employee. With changing the filling volume, respectively filling mass in to the tub greatly varies, even though the net volume is considered as the filling volume. Therefore Root cause number 1 and 2 are considered as critical issues which can cause change in the mass in g/l of the product.

Proper product weight monitoring mechanism is not currently carried out in the current ice cream manufacturing process. Filled tub weight is only monitored during the production startup. Hence, if product weight greatly fluctuates, it cannot be determined. No attention to product weight can lead to overfilling or under filling and finally it will result in considerable variation in mass in g/l of the product. Then, root causes number 3 and 4 are considered as significant issues which can lead to the situation of process incapability.

Only in some freezers, overrun fluctuates with time due to poor machine conditions. With changing the overrun percentage, air incorporation to the ice cream mix varies and accordingly product mass in g per unit volume varies. Even though the overrun is measured throughout the filling process, there is no proper mechanism to monitor the overrun change. Due to this factor even if the overrun percentage which is expected to maintain for the freezer machine varies, it is not adjusted to the proper setting with minimum time taken. Hence root causes number 5 and 6 are also considered as the issues which can generate the process incapability in terms of mass in g/l of vanilla and chocolate ice cream manufacturing.

4. Conclusion and Recommendations

4.1 Conclusion

Actual average mass in g/l of Vanilla 80 ml, 500 ml, 4 L and Chocolate 80 ml 500 ml products samples were considerably higher than the standard mass in g/l (526 g/l). This situation leads to generate a negative impact on the company‟s profit since it offers more weight to the consumer rather than the expected amount. But if these product volumes use for the manufacturing of more cups and tubs, manufacturer would be able to earn more profit since these two products are considered as the two big cash cows in the company‟s current portfolio.

Vanilla 1 L, 2 L, Chocolate 1 L, 2 L and 4 L products had average mass in g/l which are lower compared to the expected mass in g/l for the products (526 g/l). This situation may create negative impacts on consumer satisfaction since desired quality or even to produce that does not meet the legal requirements for weight of food solids which is 475 mass in g/l.

- Cp < 1.0 for all products, process variation is too high
- Cpk < 1.0 for all products, mean value of the mass in g/l is off target
- Mass in g/l in terms of all the product volumes are not in control and the process is incapable

4.2 Recommendations

Remedial measures for either reducing or mitigating the identified root causes are provided in the following action board.

Table 3: Remedial measures for the reduction or mitigation of root causes for process incapability

Number of the root cause	Remedial measure	Importance
01 & 02	Introduce a Multi Head Net Weight Filling System (cup doser)	A multi-head net weight filler offers more than simply higher filling rates but can also cut down on product loss when the product varies in density . Since this filler contains a level probe, once the product is filled up to the required volume, level probe detects it gives the signal to the regulator controller which ensures proper dosing of product flow. Also settings of filling can be adjusted according to the bulk density of the product. By introducing this dosing or filling system it would be able to reduce fluctuations in filling volume.
03 & 04	Design, develop and implement a net content control procedure	Either can introduce a check weighing, free weighing or manual weighing system for the filling process. By implementing such a procedure it would be able to monitor the weight of the product in a regular manner. Thus mass in g/l will be able to monitor against the company specifications and it will facilitate to take corrective actions in a case of deviation.
05	Design, develop and implement a machine maintenance management system for freezer machines	In order to implement this step, proper training of filling operators and mechanics in the streams of Total Productivity Management (TPM) and Autonomous Maintenance is required. With implementing these management systems employees will be able to properly operate and maintain the machine and hence machine setting fluctuations could be minimized. As a result of that it would be able to minimize the overrun fluctuations and therefore process capability in terms of mass in g/l could be achieved.
06	Develop and implement a proper two way communication method in between quality assurance department and the production.	Mechanism should be developed to reduce communication gaps in between QA and production when a fluctuation of overrun exists. Because even the QA monitor the overrun in a regular procedure, in some cases following corrective actions get delay due to this issue. If it exists for a longer period, it will lead to greater fluctuations in terms of product mass in g/l.

References

[1] W.S. Arbuckle, "Calculating cost and percentage of overrun," in Ice Cream, Springer Science, New York, 1986.
[2] Specification for ICE CREAM (1st review) – Sri Lanka Standard 223:1989 UDC 663:674
[3] R.T. Marshall, W.S. Arbuckle, Ice Cream, Chapman and Hall, New York, 1996.
[4] R.W. Hartel, "Ice Crystallization During the Manufacture of Ice Cream," Trends Food Sci. Technol, 7, pp. 315-321, 1996.
[5] A.A. Flores, and H. D. Goff, "Ice crystal size distributions in dynamically frozen model solutions and ice cream as affected by stabilizers", J. Dairy Sci, 82, pp. 1399-1407, 1999.
[6] G. Watson, "The Legacy of Ishikawa", Journal of Quality Programme, 37(4), pp. 54-47, 2004.
[7] WBI Evaluation Group, "Fishbone diagrams", Needs assessment knowledge base, Accessed From: http://siteresources.worldbank.org/WBI/Resources/213798-1194538727144/9Final-Fishbone.pdf, Accessed by: February 28, 2015.
[8] Balanced Scorecard Institute, „Basic tools for process improvement", Module 5 – Cause and Effect diagram, Accessed From: http://www.balancedscorecard.org/files/c-ediag.pdf, Accessed by: March 2, 2015.
[9] Diploma in Food Quality Assurance, Module 1 /Sec 07, 2007