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Study of Factors Affecting Strength of Sealing in the Product Packing Process by Utilizing Central Composite Design

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Abstract: This research is to study the appropriate factors to increase the strength of the sealed packets containing seasoning sauce to experiments. This study began with the introduction of cause and effect diagram to analyze the factors that affect the s strength of seals. From the evaluation of several factors involved and found that the 3 factors may affect the strength of seals which are sealing temperature, speed in film feeding, and degree of shut-off valves. Therefore, an experimental design has been conducted by Central Composite Design to analyze the optimal conditions of the packaging, and using Response Surface Methodology to find the best value and it was found that the temperature sealing at 126 ^{o}C, film feeding 18 rpm and degree of shut-off valves at 115 degrees, given the maximum strength of the top and bottom seals. After the application of the experimental result, the strength of the sealing on top increased from 34 N to 56 N or 64.71% more, the standard deviation decreased from 3.14 to 2.92, or a decrease of 7.01% and the strength of seals at the bottom increased from the original 34 N to 55 N, or 61.77% more, the standard deviation decreased from 3.21 to 2.98, or decreased 7.17%. The result of improvement has determined to decrease the waste caused by sealing down from 81.5% to 3.68%, causing the waste of the packaging process reduce from 7.84% to 2.47% or down by 5.37% but the quality of seasoning sauce remain the same. This project has achieved the objective of the study.

Keywords: *The strength of seals, central composite design, response surface methodology*

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I. INTRODUCTION

At present, the industries involved in hire to produce products for various employers, especially the sauce seasoning has grown steadily and have more competitive in terms of quality, price and delivery. [1] Concluded that each organization is trying to develop its own strategy in order to enhance the ability and compete with other operators. Waste reduction in the production process is one way to help reduce production costs. Waste reduction in the production process is one way to help reduce production costs therefore, to improve, develop study and find the appropriate production factor sit will lead to control of production parameters to reduce waste. The company of case studies also suffer from waste in the production process rather than the target especially the forming and packing stages. Due to the sealing of the envelope is not strong enough so that is the cause of leakage. As a result, the sauce that is liquid was flow and comes out. Based on data from January to March 2017 found that all wastes detected in the product packing process were found 7.84%. The highest proportion of Tomato Sauce is 6.61% or a loss worth 84.29% of the total loss value. As Table 1. The purpose of this research is to reduce waste in the product packaging process to 2.5%. Based on relevant research studies found that have been application of experimental design to solve problems in product packaging. Such as [2] has done researched to reduce bubbles in plastic to reduce waste in product packaging process by utilizing Box-Behnken Experimental Design to find the appropriate conditions. The research found that the roller speed of 150 meters per minute, oven temperature 80 degrees Celsius, and plastic tensile 400 New-

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ton make minimal bubbles. [3] has done researched on the reduction of defective products in the package packaging process by utilizing 2^3 Factorial Design to find the right conditions that make the product the least defective. From the research results can reduce the defective product from 6.84% to 2.84% and [4, 5] has researched the application of experimental designs to improve the quality of product packaging by utilizing 33 Factorial Design. To find the right conditions that produce the least waste, from the improvement result was decrease waste 94.07%. Based on studies in related research that leads to a conceptual framework for the study of the optimal value of factors that affect seam strength of sealing. By applying Central Composite Design and statistical analyze methods. Factors studied include sealing temperature; film feed speed, and Shutoff degrees.

TABLE 1
SHOWS ALL WASTES IN THE PACKAGING PROCESS (JANUARY-MARCH 2017)

Product	Production Number (Pack)	Waste (Pack)	Waste (%)	Loss Worth Product Type (USD)	Average Per Month		
					Production Number (Pack)	Waste (Pack)	Loss Worth (USD)
Tomato Sauce	4,306,770	393,840	6.61	18,880.87	1,435,590.00	131,280.00	6,293.63
Chili Sauce	733,106	32,110	0.54	1,539.36	244,368.67	10,703.33	513.12
Chili Tomato Sauce	458,515	23,476	0.39	1,125.45	152,838.33	7,825.33	375.15
Salad Sauce	366,409	13,443	0.23	210.08	122,136.33	4,481.00	70.03
Another	91,673	4,382	0.07	644.50	30,557.67	1,460.67	214.83
Total	5,956,473	467,251	7.84	22,400.26	1,985,491.00	155,750.33	7,466.76

A. *Objectives*

To study for find the appropriate factor level to increase the strength of sealing packaging sauce seasoning. In order to reduce waste, the product packing process is reduced to 2.5% by applying design experiments Central Composite Design.

II. RESEARCH METHODOLOGY

A. *Study and Problem Definition*

The company of case studies is a company was hired to producing food sauce It consists of 4 main units as follows: (1) Operations Department, responsible for production, transportation and warehousing, maintenance, and marketing. (2) Technical Department, responsible for product development and technical support, Quality assurance and information. (3) Accounting Department, responsible for accounting and finance. (4) Personnel department, responsible for recruitment. Personnel training and compensation. This research was study in the production department of the Operations Department. Which the seasoning sauce has tomatoes are the main ingredient in addition, a mixture of spices, by use a steam sterilization process through a double boiler. Then do the sterile packaged by hot packing with forming machine, packing and automatic sealing. The steps can be summarized as following:

1) Preparation of raw materials, the staff will prepare raw materials and weigh the raw materials to use in mixing with various recipes. For prepare the tomato juice, which is the main ingredient in the production, uses a grinder and a filter machine, for spices to be mashed and chilled at 5-10 ^{o}C.

2) Mix and disinfect, start by mixing the ingredients by volume, steps and time according to technical department has set. Then the steam sterilization through two-tier pot controls the steam pressure at 3 bar at temperature 110 degrees Celsius for 80 minutes. Then release the product by the closed pipeline to the tank waiting.

3) Hot packing, to prevent the danger of contamination and the growth of microorganisms in the packing process so that use hot packing. Set the sauce temperature packing to about 90 ^{o}C. with the forming and packing machine automatic seal. For film used as NYLON/LLDPE laminated plastic film, the total thickness

80 mm put the sauce in bag while it hot and sealed immediately. The operator will check the seal by observing it, if there is a blemish the leak or crack of the seal have to stops the machine and adjusts the setting temperature of sealing, adjusting the press interval, film feed speed and shutoff degrees to solve such problems.

4) Cooling, Packaged products are transported by belt pass through the cold room about 5 degrees Celsius to reduce the product temperature.

5) Perform quality checks randomly, for example, [6] the microbes detect the amount of microorganisms, yeast detection, and sealed the packing, the leak and the blame of the packing etc. From Table 1 Show all waste of products in the product packing process. (January-March 2017) all wastes detected in the product packing process 7.84% the highest proportion of Tomato Sauce products 6.61% or accounted for a loss of 84.29% of the total loss value. Therefore, this research has chosen Tomato Sauce to study because it is the product with the highest loss ratio.

B. *Analyze and Determine Solutions to Problems*

Study of current production conditions, from the study of production conditions of the packaging process, Tomato Sauce it is packed in 100 × 120 per/pack square centimeter packing size 100 grams and seam sealing of 4 side from checking the forming step and packing and sealing, it is found that waste is due to various characteristics such as (A) The package leaks from the top and bottom sealing marks. (B) Sauce stains stick on the package. (C) Case leakage from the left and right sealing. (D) Sealing was burn. (E) Misplaced code. (F) Weight does not meet the standard. (G) The size of the package does not meet the other standards. the characteristics of waste from January to March 2017 it was found that the appearance of the package leakage from the top seal most, subsequently, the package was leakage from sealed below and sauce stains stick on the package respectively. From the above characteristics are analyzed for causes the appearance of leakage of packing from top and bottom sealing from relevant people include the department responsible for production and product development and technical support and quality assurance. It was concluded that the package leakage due to sealing was not strong enough. So that do the randomly check the strength of the seal of the products that have been passed check with the 100% by random from the product has leakage from the top seal by random from the product has leakage from the top seal from 100 samples that is a sufficient number of samples. 95% confidence level and the fallibility can be acceptable not more than 2.5 Newton, an average has been sealed strength of 34 Newton. Standard deviation 3.14. And random from the product has leakage from the bottom seal from 100 samples an average has been sealed strength of 34 Newton, Standard deviation 3.21 and from testing result the product good of the testing room has a mean of top seam strength of 52 Newton. Standard deviation 3.14. And a mean of bottom seam strength of 52 Newton. Standard deviation 3.11, The researcher tested the statistical hypothesis of testing result the product good found that the average and variation of strength sealing of top and bottom sealing is not different significantly 0.05, So troubleshooting of waste that leakage package from sealing of the top and bottom are the same problem. This study needs to find the conditions that make highest strength of top and bottom sealing and not less than 51.4 Newton. This value is based on the test results the product good the lowest mean was 51.4 Newton at 95% confidence level.

1) Process capability assessment: This step the researchers was evaluate capability of process to confirm that waste leaked of package from sealed have the variables constant and under statistical control or not. [7] said that the test data abnormality on the control chart from the test method, find out the abnormal data of the automotive industry USA. All data points that plot on the process control chart are in control lines and the data is random from the study found that process data did not show any characteristics. Contradictory to the above assumptions.

2) Analyze and select factors that cause problems: [8] From the problem of sealed packing is not enough strength is expected to be less than 51.4 Newton. will be analyzed for the cause. By brainstorming of those involved by use cause and effect diagram to determine the cause of the problem. Form diagram showing cause and effect cause of waste from sealed is not sufficiently strong, expected to be less than 51.4 Newton. [9] Summarized as follows:

1) Degrees off the shutoff valve of the machine to leave the sauce down the packing will affect the pressure and relate to packing speed include pressing the machine this may affect the sealing in the current work set to 115-125 degrees.

2) Pressing, adjustment of the pressing of the machine is related to the pressure to turn on the shutoff valve off and sealing speed. If set is tight, it will cause a noise in the current operation set to 28-29 mm.

3) Sealing temperature, because the film used today is a flexible two-layer film and weak at high temperature it will be related to packing speed, in the current

work set to 118-122 degrees Celsius.

4) Film Feeding Speed, heat sealing is correlated with the sealing speed, film pulling speed, the speed of the sauce to pack in the current work set to 18-20 round per minute.

5) Sauce temperature, in the actual working conditions of the product packaging process, the packaging temperature is in the range of 80-90 degrees Celsius in order to safety to packaging. Researchers and those involved have brainstormed and consider together and prioritize the cause of the waste. [10] Do conclusions on the use of analytical techniques for waste and the impact of the process (Process FMEA). The result of the analysis is that the number of risk level (RPN) sort by most to least such as the seal temperature is 680, the film feed speed is 510, turn off the shutoff valve is 440, the press range is 80, and the sauce temperature is 70 respectively. Considering the importance of the factors affecting the problem found that there are 3 high scoring factors, [11] The total score of all three factors is 90% of the total score, so that was set to the main factor to study such as sealing temperature, film feed speed, and shutoff valve degrees. The control variables in the experiment such as the press still control at 28-29 mm. the sauce temperature remains the same at 80-90 degrees Celsius, because the researcher and those concerned think it haven't influence on waste. Therefore, the experiment was set up and controlled as described above.

C. Experiments to Determine the Influence of Factors

1) Experimental design Central Composite Design (CCD): In this research use the central design principles, [12] have concluded that as part of the Response Surface Methodology, used in experimental design for quadratic model. and lead to the interpretation of the desired response surface and use and the number of Runs is not much, as an additional test of the 2^k Factorial Experiment. Therefore, the three main factors affecting the response variables to analyze the design of the experiment to find the nearest appropriate point to the best production. The experiments were randomly conducted using a computer program to determine the experimental sequence, [13] by collecting experiments 2 replication in order to get the result to have less variance. Which level of factor shows the results on Table 2. As shown in Table 4. the Analysis of Variance for Top and Bottom Seal Strength. Table 4 and 6, Estimated Regression Coefficients for Top and Bottom Seal Strength using data in uncoded units, Table Table 5 and 7, respectively.

TABLE 2
FACTOR LEVEL OF CENTRAL COMPOSITE DESIGN

Factor	Symbol	Factor Level					Unit
		$-\alpha$	-1	0	+1	$+\alpha$	
Seal Temperature	A	100	108	120	132	140	Degree Celsius
Speed	B	14	16	19	22	24	rpm
Degree Valve	C	103	110	120	130	136	Degree

TABLE 3
EXPERIMENT RESULT

Seal_Temp	Speed	Degree Valve	Seal Strength			
			Top		Bottom	
A	B	C	Y1	Y2	Y3	Y4
108	16	110	39.7	39.3	40.1	38.9
132	16	110	54.0	48.5	54.5	48.1
108	22	110	29.8	34.1	30.1	33.8
132	22	110	50.1	50.2	50.6	49.8
108	16	130	36.4	38.0	36.7	37.7
132	16	130	43.7	43.8	44.1	43.4
108	22	130	27.5	35.5	27.7	35.2
132	22	130	43.7	43.8	44.1	43.4
100	19	120	31.8	30.9	28.6	30.9
140	19	120	47.7	51.2	46.4	51.2
120	14	120	57.8	54.7	54.7	54.7
120	24	120	50.9	47.2	44.9	47.2

TABLE 3
CONTINUE...

Seal_Temp	Speed	Degree Valve	Seal Strength			
			Top		Bottom	
A	B	C	Y1	Y2	Y3	Y4
120	19	103	50.7	53.1	47.8	53.1
120	19	136	41.0	38.1	36.5	38.1
120	19	120	50.8	55.8	47.8	53.2
120	19	120	47.6	55.7	50.7	46.1
120	19	120	54.9	53.5	53.5	50.4
120	19	120	55.6	64.5	48.6	58.0
120	19	120	50.1	54.5	58.5	50.7
120	19	120	50.1	54.9	54.9	53.5

TABLE 4
ANALYSIS OF VARIANCE FOR TOP SEAL STRENGTH

Source	DF	Seq SS	Adj SS	Adj MS	*F*	*p*
Regression	9	2604.63	2604.63	289.40	19.87	0.000
Linear	3	1222.79	1258.16	419.39	28.79	0.000
A	1	917.35	924.63	924.63	63.48	0.000
B	1	102.44	102.44	102.44	7.03	0.013
C	1	203.00	231.07	231.07	15.87	0.000
Square	3	1311.67	1311.67	437.22	30.02	0.000
A * A	1	834.20	961.01	961.01	65.98	0.000
B * B	1	33.85	58.07	58.07	3.99	0.055
C * C	1	443.63	443.63	443.63	30.46	0.000
Interaction	3	70.16	70.16	23.39	1.61	0.000
A * B	1	36.91	36.91	36.91	2.53	0.209
A * C	1	31.08	31.08	31.08	2.13	0.122
B * C	1	2.18	2.18	2.18	0.15	0.702
Residual Error	30	436.94	436.94	14.57		
Lack-of-Fit	6	157.37	157.37	26.23	2.25	0.073
Pure Error	24	279.57	279.57	11.65		
Total	39	3041.56				

TABLE 5
ESTIMATED REGRESSION COEFFICIENTS FOR TOP SEAL STRENGTH USING DATA IN CODED UNITS

Term	Coef	*p*
Constant	54.1595	0.000
A	5.8346	0.000
B	-1.9439	0.013
C	-2.9353	0.000
A * A	-5.8293	0.000
B * B	-1.4383	0.055
C * C	-4.0346	0.000
A * B	1.5188	0.122
A * C	-1.3937	0.154
B * C	0.3687	0.702

TABLE 6
ANALYSIS OF VARIANCE FOR BOTTOM SEAL STRENGTH

Source	DF	Seq SS	Adj SS	Adj MS	*F*	*p*
Regression	9	2428.35	2428.35	269.816	25.12	0.000
Linear	3	1299.09	1312.84	437.612	40.74	0.000
A	1	959.67	959.67	959.669	89.35	0.000
B	1	122.52	122.52	122.518	11.41	0.002
C	1	216.90	230.65	230.650	21.47	0.000
Square	3	1058.59	1058.59	352.862	32.85	0.000
A * A	1	664.15	758.40	758.400	70.61	0.000
B * B	1	23.33	40.36	40.356	3.76	0.062
C * C	1	371.11	371.11	371.106	34.55	0.000
Interaction	3	70.67	70.67	23.557	2.19	0.109
A * B	1	37.21	37.21	37.210	3.46	0.073
A * C	1	31.36	31.36	31.360	2.92	0.098
B * C	1	2.10	2.10	2.102	0.20	0.661
Residual Error	30	322.21	322.21	10.740		
Lack-of-Fit	6	84.39	84.39	14.066	1.42	0.248
Pure Error	24	237.82	237.82	9.909		
Total	39	2750.56				

TABLE 7
RESULTS ESTIMATED REGRESSION COEFFICIENTS FOR BOTTOM SEAL STRENGTH USING DATA IN CODED UNITS

Term	Coef	*p*
Constant	52.2881	0.000
A	5.9496	0.000
B	-2.1258	0.002
C	-2.9475	0.000
A * A	-5.1942	0.000
B * B	-1.1982	0.062
C * C	-3.7755	0.000
A * B	1.5250	0.073
A * C	-1.4000	0.098
B * C	0.3625	0.661

2) Experimental results central composite design: From Table 4 and 6, the results of the experimental analysis Central Composite Design found that the factors A, B, C and A * A, C * C, *p*-value less than 0.05 it can be concluded that these factors affect the Top and Bottom Seal Strength, and [14] it can be concluded that the *p*-value of Lack-of-Fit was 0.073 and 0.248 higher than the significance level 0.05. This means that the regression model for Seal Strength is significantly appropriate by R^2 (adj) = 81.32% and 84.77%, respectively. So that the regression model was constructed. And check the hypothesis by Graph Residual Plots found that there was no conflict with the statistical hypothesis. Tables 5 and 7 show relationships that affect the Top and Bottom Seal Strength and the model of the regression equation can be written as a coded unit as the following the Equations are 1 and 1 respectively.

$$Y_{(max)} = 54.1595 + 5.8346A - 1.9439B - 2.9353C - 5.8293A*A - 4.0346C*C \quad (1)$$

$$Y_{(max)} = 52.2881 + 5.9496A - 2.1258B - 2.9475C - 5.1942A*A - 3.7755C*C \quad (2)$$

When $Y_{(max)}$ = Seal Strength
A = Seal Temperature
B = Speed
C = Degree valve

3) Determining the appropriate factors from the experiment: Equations 1 and 2 can find the response to the Top and Bottom Seal Strength was occurred by experiment this is analyzed with the Response Optimizer function the optimum values for all three factors are shown in Figure 1.

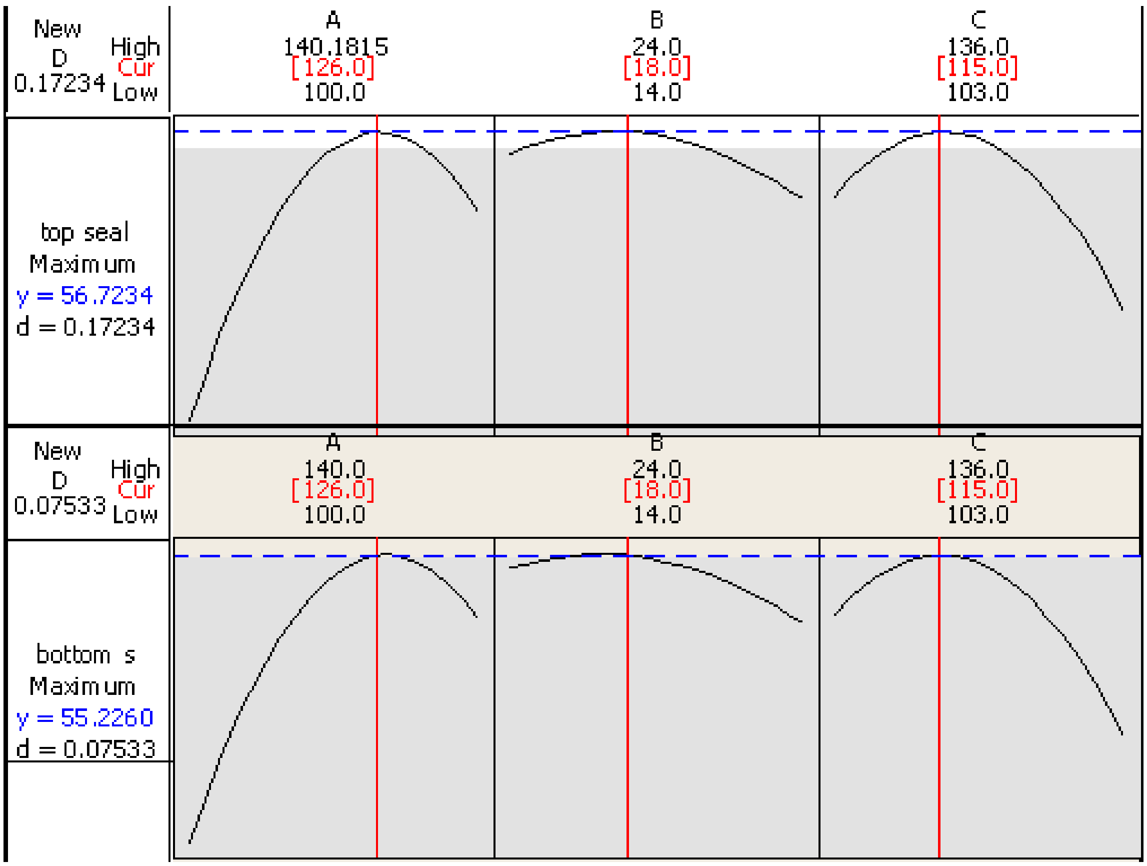

Fig. 1. Optimization plots for the tire data, [15] the current factor settings are top and bottom seal strength seal temperature 126 °C, speed 18 rpm and degree valve 115 degree the goal was to target maximum at 56.7 N and 55.2 N

4) Summary of experiment results: From Figure 1. the results show that the three factors the best fit to the strength values, the top and bottom sealing tends to be the same. Therefore, the factor values for the strength of the top and bottom sealing marks at the highest values are set to be equal to the sealing temperature of 126 žC, film feed speed 18 rpm and degree Shutoff valve 115 degrees. From the average predicted value strength of the top sealing was 56.7 Newton and in the range of 56-57.5 Newton and bottom is 55.2 Newton and in the range 54.5-56 Newton at 95% confidence level.

5) Test to confirm results: [16] When got the optimum condition forming of packing and sealing is achieved the samples were tested to confirm with the 100 samples. The test results showed that. The average seal strength of the top is 56 Newton. Standard deviation 3.01, with mean values in the range 55.5-56.6 Newton and the average of the seal strength of the bottom is 55 Newton, the standard deviation of 3.0 the average range was 54.5-55.6 Newton at 95% confidence level. The average strength of the top and bottom sealing marks was close to the values of 56.7 Newton and 55.2 Newton, respectively. Including the range between the minimum value and the maximum value of the average strength, the top and bottom sealing marks it is greater than the minimum average set at 51.4 Newton. The average and variance of the strengths, sealing, top and bottom seals were tested for difference, before and after the test results, there were significant differences 0.05.

III. RESULTS

From experimental results were Sealing Temperature 126 °C, film feed speed 18 rpm and degree Shutoff valve 115 degrees was applied to the forming process of packing and sealing between May to July 2017. It was found that the average strength of the top sealing crest increased from 34 Newton to 56 Newton, the standard deviation decreased from 3.14 to 2.92, and the average strength of the seal of the bottom is increased from 34 Newton to 55 Newton. The standard deviation decreased from 3.21 to 2.98, and from the average test of strength, the upper and lower sealing are more than the target average mean has set 52 Newton. And the standard deviation decreased. Significantly, the statistical significance was 0.05. It was concluded that the mean of the top and bottom sealing strengths was increased and the variance decreased. By the average strength of the top seal will be in the range 55.5-56.6 Newton and the average the strength of the seal bottom is in the range 54.5-55.6 Newton. Therefore, if set the condition of the factor determines as the result of the research there will be an average of the top and bottom seal strengths not less than 55.5 Newton 54.5 Newton. At the 5% confidence level, respectively. Which is more than the average set at least 51.4 Newton. The result of the improvement is that waste is caused by the sealing cause decreased from 81.5% to 3.68% As a result of all waste of the product packing process decreased from 7.84% to 2.47%.

IV. CONCLUSION AND RECOMMENDATIONS

This research is study the optimum conditions in the product packaging process with experimental design to reduce waste in such a process. From problem analysis was found that all wastes detected in the product packing process were 7.84% the highest proportion of Tomato Sauce products reached 6.61% .The highest proportion of Tomato Sauce products reached 6.61% or accounted for a loss of 84.29% of the total loss value. Therefore, this research has selected Tomato Sauce products as the study of products that have the highest loss ratio. And the waste from the leak package from the top and bottom sealing 81.5% of the total loss by analyzing the leaky characteristics from those involved. It was found that sealing was less than 51.4 Newton. Therefore, study the optimal conditions to increase the strength of sealing packaging sauce seasoning in the packaging process of the product seal maximum strength. By starting to evaluate assess the stability of the process, it was found that all data points were plotted on the process control chart it is in control lines and the data is random. Then, the cause and effect on diagram was analyzed to determine the factors that affect the seal strength and filtering the basics by using techniques to analyze the patterns of waste and the effects of the process (process FMEA).

In conclusion, there are 3 factors that may affect the seal strength are seal temperature, film speed, and degrees off Shutoff valve. The experimental design was designed Central Composite Design to analyze for the right conditions use Response Surface Methodology to find the best value. It was found that the seal temperature 126 žC, film feed speed 18 rpm, and degrees off Shutoff valve 115 degrees give highest strength of top and bottom sealing. after the application of experimental results, the top seal strength increased from 34 Newton to 56 Newton or 64.71%, the standard deviation decreased from 3.14 to 2.92, or decreased 7.01%. And the strength of the bottom seal increased from 34 Newton to 55 Newton, or 61.77%, the standard deviation decreased from 3.21 to 2.98, or decreased 7.17%. In conclusion, the average strength of the top and bottom sealing after the update has increased with an average of at least 55 Newton and a range of 54.5-55.6 Newton. which is the lowest average that is greater value than the minimum average set at 51.4 Newton. As a result of the improvement, the waste caused by sealing decreased from 81.5% to 3.68%. As a result of the improvement the waste of process caused by sealing decreased from 81.5% to 3.68%, as a result, the total waste of the package packaging process decreased from 7.84% to 2.47% or decrease 5.37%. Based on the hypothesis testing it was found to be in accordance with the above mentioned statistical significance of 0.05. The quality of the seasoning sauce remains the same. This research has achieved its intended purpose.

- Suggestions, Based on the results of the research, [17] it was set the standards for configuring forming machine components in packing and sealing the machine operator must have a good understanding of the machine operation, should give the basic knowledge needed to be provided to those involved preparation of a standardized work manual and to continually apply statistical process control principles.

- Suggestions, from considering the problematic product of waste of Tomato sauce that have stain on the package still remains the most this issue should be addressed to continue the improvement.

REFERENCES

[1] V. Vichit Tanthasut, W. Rijiravanich, and C. Mahittafongkul, *Industrial Work Study*. Bangkok, Thiland: Chulalongkorn University, 2000.

[2] W. Rijiravanich, *Productivity in the Industry*. Bangkok, Thiland: Chulalongkorn University, 2000.

[3] D. C. Montgomery, G. C. Runger, and N. F. Hubele, *Engineering Statistics*. New York, NY: Wiley, 2011.

[4] D. C. Montgomery, *Introduction to statistical quality control*. New York, NY: John Wiley & Sons, 2009.

[5] H. K. Celik, G. Kunt, A. E. W. Rennie and I. Akinci, "Non-linear fem-based shattering simulation of shelled edible agricultural products: Walnut shattering by nut cracker hand tool," *International Journal of Technology and Engineering Studies*, vol. 3, no. 2, pp. 84–92, 2017. doi: 10.20469/ijtes.3.40006-2

[6] K. Gopal Rao and R. Joseph V, "Reduction of testing of chemical parameter using design of experiments," *Quality Engineering*, vol. 14, no. 2, pp. 301–305, 2010. doi: 10.1081/qen-100108687

[7] K. Kankanok, B. Khamon, and P. Kongrod, "Study of waste reducing in packing process," in *Proceedings of Conference on Industrial Engineering Network,* Cordoba, Spain, 2010.

[8] R. A. Bourque, *Hot-Fill Technology*. New York, NY: Wiley, 2000.

[9] J. R. David, R. H. Graves, and T. Szemplenski, *Handbook of Aseptic Processing and Packaging*. Boca Raton, FL: Crc Press, 2012.

[10] S. Tangsitcharoen and P. Jamchue, "Reduction of bubbles defects in plastic packaging plastic process: Utilizing box behnken experimental design," in *Proceedings Industrial Engineering Network Conference,* Montréal, Canada, 2001.

[11] R. Coles, D. McDowell, and M. Kirwan, *Plastic in food packaging*. London, UK: Blackwell Publishing, 2003.

[12] R. H. Myers, D. C. Montgomery, and C. M. Anderson-Cook, *Response surface methodology: Process and product optimization using designed experiments*. Hoboken, NJ: John Wiley & Sons, Inc., 2009.

[13] P. Chutima, "The experimental design engineering," Chulalongkorn University, Bangkok, Thailand, Unpublsihed master's thesis, 2004.

[14] T. S. Parsana and M. T. Patel, "A case study: A process fmea tool to enhance quality and efficiency of manufacturing industry," *Bonfring International Journal of Industrial Engineering and Management Science*, vol. 4, no. 3, pp. 145–152, 2014. doi: 10.9756/bijiems.10350

[15] M. Guide, *Data Analysis and Quality Tools*. Pennsylvania, PA: Minitab Inc, 2000.

[16] K. K. Chowdhury and E. V. Gopal, "Quality improvement through design of experiment. A case study, quality engineering," in *IFIP Network Conference,* Paris, France, 2000.

[17] G. M. Smith, *Statistical Process Control and Quality Improvement*. London, UK: Prentice Hall, 2000.