

IEE 572 Design of Experiments (Experiment 2)

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- **Objective of Experiment:**

Water needs to be heated up to 200°F for making noodles. Salt is added to the noodles after it is heated up to 200 °F. the aim of this experiment is to find the effect of size of container (open surface area large/small), Level of hot plate (high/medium), and type of water (normal water/salty water) on the time taken by the water to reach 200 °F

- **Factors:**

1. Size of container (small/ large)
2. Temperature of hot plate (High/medium)
3. Type of water (normal/ salty)

- **Response:**

The response is the time required for the solution to reach 200 degree Fahrenheit.

- **Experiment Type:**

2-level full factorial experiment with 3 factors (2^3), 3 replicates, with blocking.

- **Planning:**

The experiment is conducted with randomization in mind. The order of the experiment is randomized using Minitab. It's made sure that the order isn't trivial. The order includes the two levels of each factor and is mixed to avoid any lurking variables.

Blocking is another concept that was implemented during the planning of this experiment. The solution used involves mixing salt and water. To avoid any error due to different concentration of salt in the solution, blocking was done for every replicate. The amount of salt in the solution was constant (without human error in mind).

- **Experimental Setup:**

Apparatus: Hot Plate with high and medium settings, Water, Salt, Large and small container, thermometer, stopwatch.

The level of each factor in a run is decided based on the order obtained from Minitab. Each combination is carefully applied in the experiment. The time taken by the water to reach 200°F is measured.

Procedure: Water (normal/salty) solution is poured in the container (size large/small) and the level of hot plate is sight to high/medium and stopwatch is started, temperature of the solution is constantly measured and time at which temperature of the water reached 200°F the time in the stopwatch is noted and the hot plate is turned off, solution is disposed, container and hotplate is cooled to room temperature.

- **Results:**

2^3 full factorial experiment with 3 replicates was randomized using Minitab, experiment was performed in the random order given in the below table and response(time) was recorded

↓	C1	C2	C3	C4	C5-T	C6-T	C7-T	C8
	StdOrder	RunOrder	CenterPt	Blocks	Size of container	Level of hot plate	Water type	Response(time in minutes)
1	4	1	1	1	large	high	normal	4.467
2	8	2	1	1	large	high	salty	5.167
3	6	3	1	1	large	medium	salty	11.267
4	7	4	1	1	small	high	salty	7.033
5	5	5	1	1	small	medium	salty	17.250
6	2	6	1	1	large	medium	normal	12.617
7	1	7	1	1	small	medium	normal	21.066
8	3	8	1	1	small	high	normal	8.533
9	13	9	1	2	small	medium	salty	17.650
10	11	10	1	2	small	high	normal	8.267
11	9	11	1	2	small	medium	normal	20.500
12	15	12	1	2	small	high	salty	7.917
13	10	13	1	2	large	medium	normal	12.550
14	14	14	1	2	large	medium	salty	12.133
15	16	15	1	2	large	high	salty	4.550
16	12	16	1	2	large	high	normal	4.567
17	20	17	1	3	large	high	normal	4.383
18	22	18	1	3	large	medium	salty	11.033
19	19	19	1	3	small	high	normal	8.417
20	17	20	1	3	small	medium	normal	20.300
21	18	21	1	3	large	medium	normal	13.033
22	21	22	1	3	small	medium	salty	17.217
23	24	23	1	3	large	high	salty	4.850
24	23	24	1	3	small	high	salty	8.117

- Analysis:**
Analysis of Variance

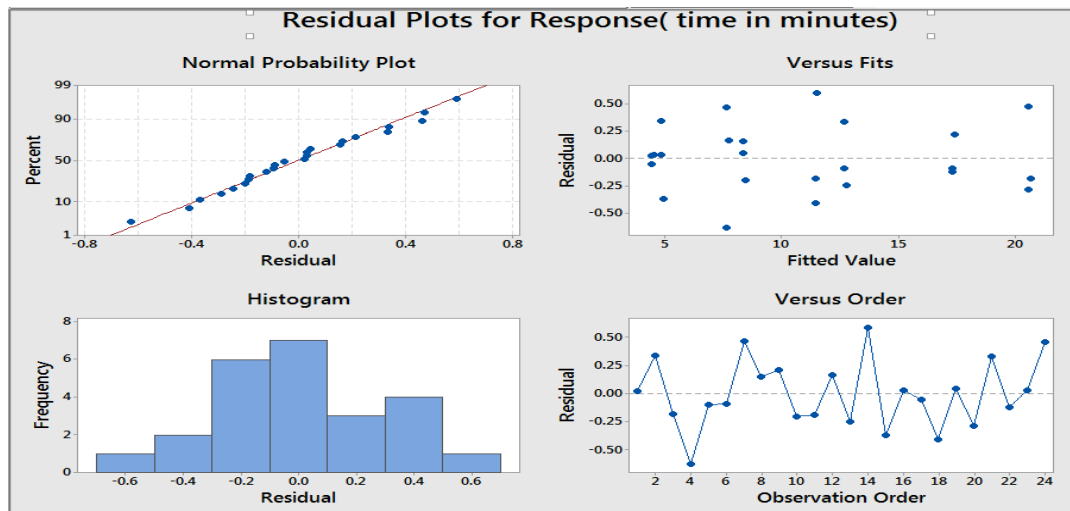
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	703.432	78.159	520.89	0.000
Blocks	2	0.048	0.024	0.16	0.853
Linear	3	674.505	224.835	1498.41	0.000
Size of container	1	158.363	158.363	1055.41	0.000
Level of hot plate	1	507.362	507.362	3381.31	0.000
Water type	1	8.780	8.780	58.51	0.000
2-Way Interactions	3	28.580	9.527	63.49	0.000
Size of container*Level of hot plate	1	18.463	18.463	123.04	0.000
Size of container*Water type	1	3.590	3.590	23.92	0.000
Level of hot plate*Water type	1	6.527	6.527	43.50	0.000
3-Way Interactions	1	0.300	0.300	2.00	0.179
Size of container*Level of hot plate*Water type	1	0.300	0.300	2.00	0.179
Error	14	2.101	0.150		
Total	23	705.533			

From the ANOVA it is clear that blocking and the 3-way interaction will not have any significant effect on the response of the experiment.

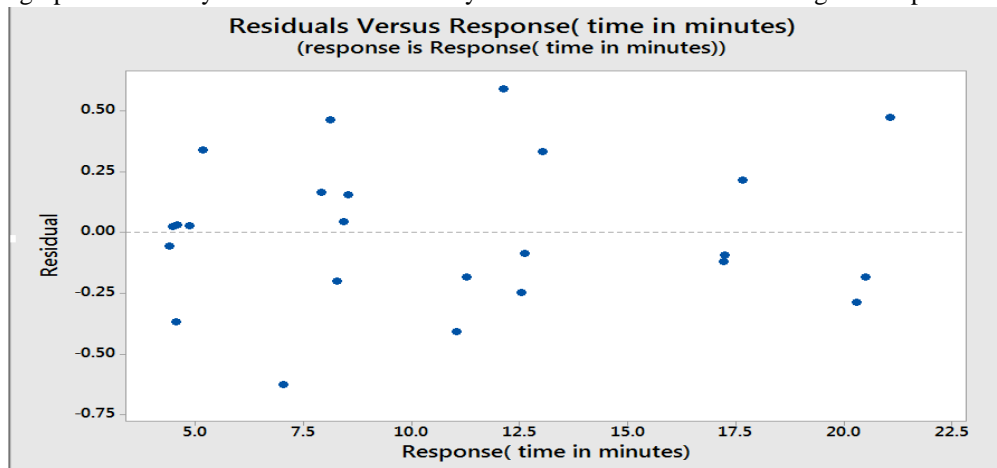
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.387362	99.70%	99.51%	99.12%

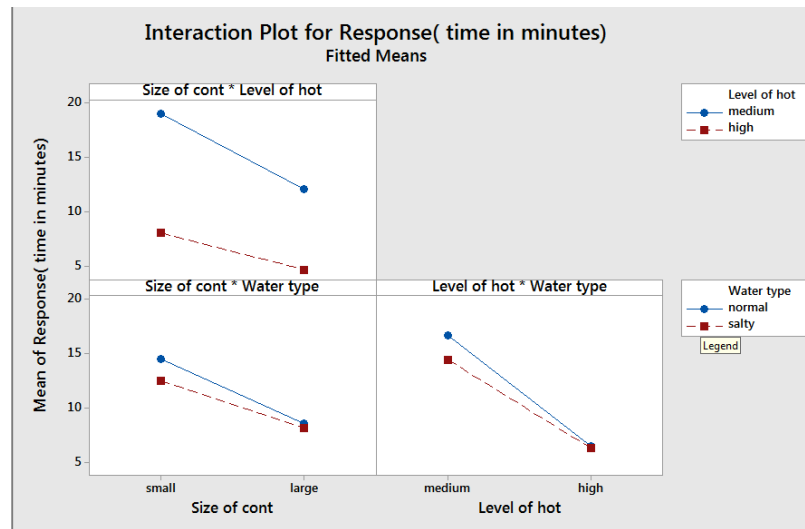
R^2 of the model is 99.7% which indicates that 99.7% of variability is accounted by the model.



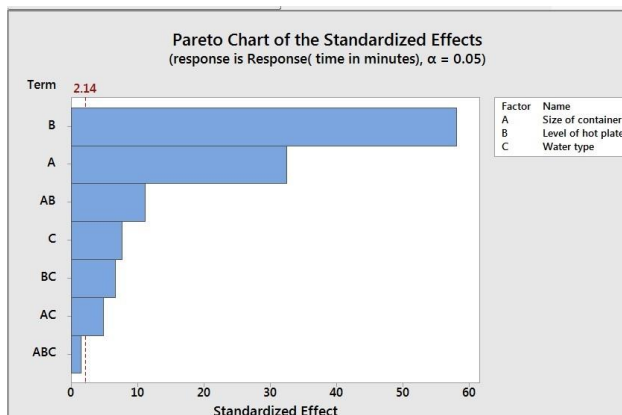
From the above graphs we can say that the data is normally distributed and there is no recognizable pattern in residual plots.



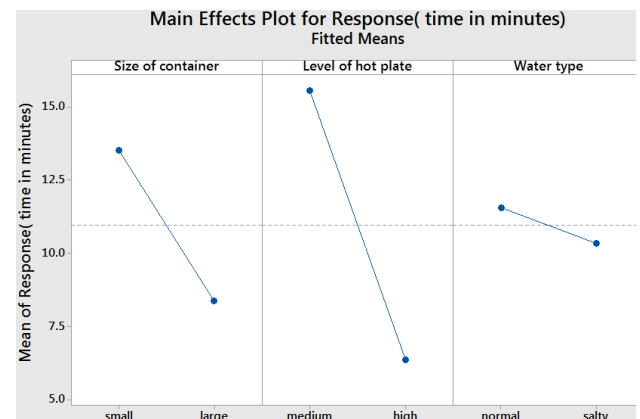
From the above graph, we can conclude residuals are not distributed in any pattern i.e. they are distributed randomly



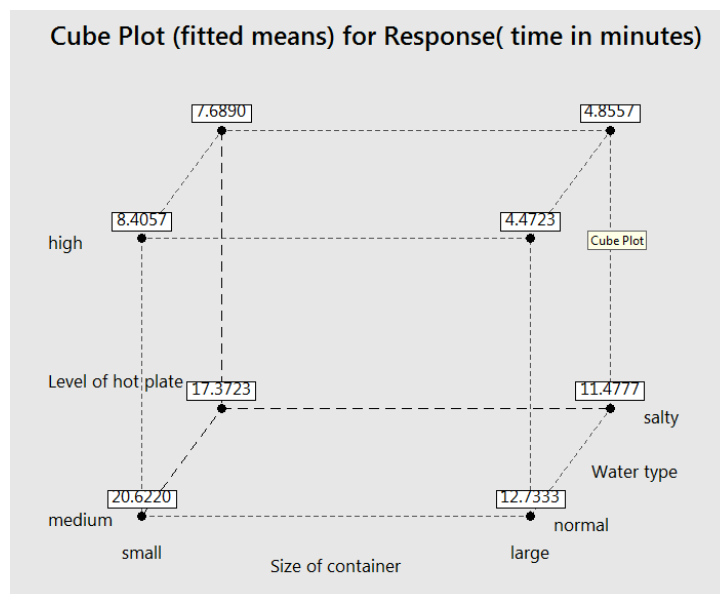
Graph indicates interaction of factors. As seen from the graph there is no three-way interaction and there are no parallel lines in the plot, hence all three two-way interactions are significant.



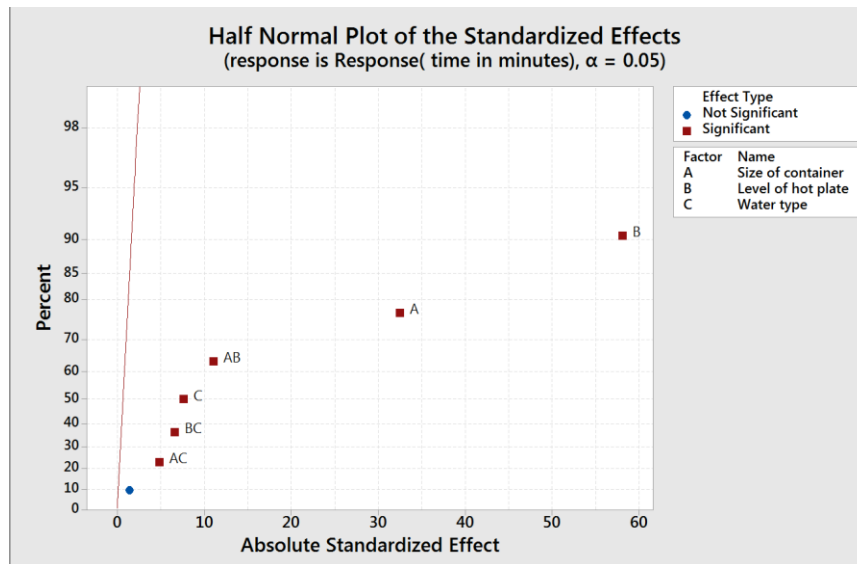
As we can see from Pareto chart of the effects of the factors, the effect of ABC is less than the reference line, we can conclude that effect of interaction ABC is not significant.



We can see from the Main effects plot factor A and factor B has higher effect on the model than factor C, same can be confirmed from effects Pareto chart.



We Can conclude from Cube Plot of response that we can get minimum value of response with large container, normal water and keeping level of hot plate as high followed closely by large container salty water keeping level of hot plate as high.



We can see from half normal plot that factors A, B, C and interactions AB, BC, AC are significant and interaction ABC is not significant. Same can be verified from ANOVA and Pareto chart of effects.

- Verification:**

Once the analysis of the experiment was done and the regression model for the response was generated, one more run of the experiment was done to verify the model.

Response(time in minutes) = 10.9535 - 2.5687 Size of container
 - 4.5978 Level of hot plate

- 0.6048 Water type
 + 0.8771 Size of container*Level of hot plate
 + 0.3867 Size of container*Water type
 + 0.5215 Level of hot plate*Water type

Size of Container	Temperature of hot plate	Type of water solution	Observed Response (y)	Calculated Response (\hat{y})	Residual $\hat{y}-y$
Small	medium	Normal	20.38	20.6220	0.242
Small	medium	Salty	17.11	17.3722	-0.2622
Small	high	Normal	8.16	8.4054	0.2454
Small	high	Salty	7.30	7.6892	0.3892
Large	medium	Normal	12.38	12.7332	0.3532
Large	medium	Salty	11.07	11.3778	0.3078
Large	high	Normal	4.30	4.4726	0.1726
Large	high	Salty	4.45	4.7556	0.3056

We can see that the residuals in the above table are not large and it is in the margin of 2 standard deviations of mean square error, hence we can conclude that the model fairly predicts the outcome of the experiment.

- Conclusion:**

Referring to the cube plot we can deduce that for minimum response, we can use the combination of high level of hot plate, large container and normal water, this combination is closely followed by the combination of high level of hot late, large container and salty water.

From the ANOVA we conclude that all three factors along with the all six two way interactions are significant but three-way interaction of the factors is insignificant. This can be verified from Pareto Chart of effects as well as half normal plot.

The regression model generated predicts the response fairly which was verified by taking one more run of the experiment.

- Problems &Recommendations:**

While conducting the run with salty water, the concentration of salt in the water may affect the response and the data might not be clean. Hence blocking was done along the replicated and separate solution of salt water was made for each replicate.

There are 2 sizes of hot plate available and the size of hot plate affected the readings hence the size of hot plate was recorded for every combination and it was kept same in each replicate. The Hot late should be allowed to cool down completely else it may affect the quality of data.