Introduction

This experiment is about time it takes to boil water. Two different types of materials were taken to boil water. In addition, two different sizes of stoves were taken. Finally, different experiments were taken using one with pan cover and one without.

Objective

The only objective of the experiment is to find out an optimum setting which can help in reducing boil time of water.

Relevant Background

The motivation for this experiment is to reduce boiling time of water so that tea making process can be shortened. There are two types of utensils and stove types in the house that is why they are part of the experiment.

Response Variable

There is only one response variable in this experiment which is time (in seconds) to boil water. Mobile phone's stopwatch was used to measure the time. Time was selected as the response variable so that there should not be any errors based on subjectivity.

Control Variable

Ambient temperature can influence the boiling rate of water. Keeping this in mind, all the observations were taken at fixed temperature of 75-degree Fahrenheit. This has been done using apartment temperature controller (thermostat).

Held-Constant Factor

To get the accurate results, it was required that stove run at fixed level or pressure during all experiments. After each experiment stove and pans got hot. So, to avoid errors every experiment was done after pans and stove retain to room temperature.

Nuisance Factor

One of the nuisance or variation factor was to determine what is the right time to stop the stopwatch. As we know water starts to boil at one side of the pan and then spreads throughout. It is difficult to say when every molecule of water reaches to a boiling point. To overcome this issue, two observations were taken for each setting. In this way two replications were needed.

Proposed Analysis and Presentation Techniques

It is decided to first collect the data at same ambient temperature for all three factors. After that, factorial design was formed in Minitab. Then, design would be analyzed using ANOVA and other graphical tools. Finally, conclusion would be made using factorial plots.

Coordination of the Experiment

There would be only one person conducting and collecting experiment and data. It is because to eliminate errors due to subjectivity.

Trial Runs

Data would be collected in random order to remove bias. Two replications were desired for better accuracy of the results. In this way, there would be two observations taken for same setting.

Design of Experiment

Data

Table 1 represents data that is used in this design of experiment analysis. 8 different observations were taken 2 times for same setting which made up 16 runs. Material, Type of Stove and Pan Cover are the input factors having two levels, whereas Time is the output variable measured in seconds.

Run	Material	Type of Stove	Pan Cover	Time(sec)
1	Iron	type_1	No	330
2	Stainless Steel	type_1	No	383
3	Iron	type_2	No	227
4	Stainless Steel	type_2	No	220
5	Iron	type_1	Yes	315
6	Stainless Steel	type_1	Yes	343
7	Iron	type_2	Yes	210
8	Stainless Steel	type_2	Yes	211
9	Iron	type_1	No	339

10	Stainless Steel	type_1	No	379
11	Iron	type_2	No	213
12	Stainless Steel	type_2	No	224
13	Iron	type_1	Yes	322
14	Stainless Steel	type_1	Yes	348
15	Iron	type_2	Yes	212
16	Stainless Steel	type_2	Yes	204

Table 1: Experimental Data

Factorial Design

Fig 1 represents Design Summary for the factorial design using Minitab. As seen in the figure, there are 3 factors and 2 replications made with a total of 16 runs. There was no randomization as the observations were taken in an unbiased fashion. After that, 2 levels were selected and labeled them as "Text" since the factors were based on qualitative basis. After that, levels were defined accordingly as depicted in Table 1.

Design Summary

Factors:	3	Replicates:	2
Base runs:	8	Total runs:	16
Base blocks:	1	Total blocks:	1

Fig 1: Design Summary

Analysis

'Time' was selected as the response variable when performing analysis on Minitab. Since there were three factors involved, therefore we performed interaction up to 3 levels. Two-sided confidence interval was selected having confidence interval of 95% for the analysis.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	73273.7	10467.7	384.13	0.000
Linear	3	71726.2	23908.7	877.39	0.000
Material	1	1600.0	1600.0	58.72	0.000
Type of Stove	1	68644.0	68644.0	2519.05	0.000
Pan Cover	1	1482.2	1482.2	54.39	0.000
2-Way Interactions	3	1457.2	485.7	17.83	0.001
Material*Type of Stove	1	132.3	132.3	4.85	0.059
Material*Pan Cover	1	100.0	100.0	3.67	0.092
Type of Stove*Pan Cover	1	1225.0	1225.0	44.95	0.000
3-Way Interactions	1	90.2	90.2	3.31	0.106
Material*Type of Stove*Pan Cover	1	90.2	90.2	3.31	0.106
Error	8	218.0	27.3		
Total	15	73491.7			

Fig 2: ANOVA

As depicted in Fig 2, model is significant since p-value is less than 'alpha' i.e. 0.05. Similarly, factors like material, type of stove and pan cover all are significant in the model. On the other hand, 2-way interactions like material with type of stove and material with pan cover is not significant in the model since they all have p-value greater than 0.05. But 2-way interaction of type of stove and pan cover is significant. Finally, 3-way interaction of all factors is also not significant.

Looking at the values of R-squared in Fig 3, model is highly significant and able to define majority of error variances in the model.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.22015	99.70%	99.44%	98.81%

Fig 3: Model Summary

Minitab also gave the Regression Equation as seen in Fig 4. However, it cannot be used because we have qualitative data and regression equations, or analysis are done for quantitative data.

Regression Equation

Time(sec) = 279.38 + 10.00 Material_Iron - 10.00 Material_Stainless Steel
+ 65.50 Type of Stove_type_1 - 65.50 Type of Stove_type_2 - 9.62 Pan Cover_No
+ 9.62 Pan Cover_Yes + 2.88 Material*Type of Stove_Iron type_1
- 2.88 Material*Type of Stove_Iron type_2 - 2.88 Material*Type of Stove_Stainless
Steel type_1 + 2.88 Material*Type of Stove_Stainless Steel type_2
- 2.50 Material*Pan Cover_Iron No + 2.50 Material*Pan Cover_Iron Yes
+ 2.50 Material*Pan Cover_Stainless Steel No - 2.50 Material*Pan Cover_Stainless
Steel Yes - 8.75 Type of Stove*Pan Cover_type_1 No
+ 8.75 Type of Stove*Pan Cover_type_1 Yes + 8.75 Type of Stove*Pan Cover_type_2
No - 8.75 Type of Stove*Pan Cover_type_2 Yes
- 2.37 Material*Type of Stove*Pan Cover_Iron type_1 No
+ 2.37 Material*Type of Stove*Pan Cover_Iron type_1 Yes
+ 2.37 Material*Type of Stove*Pan Cover_Iron type_2 No
- 2.37 Material*Type of Stove*Pan Cover_Iron type_2 Yes
+ 2.37 Material*Type of Stove*Pan Cover_Stainless Steel type_1 No
- 2.37 Material*Type of Stove*Pan Cover_Stainless Steel type_1 Yes
- 2.37 Material*Type of Stove*Pan Cover_Stainless Steel type_2 No
+ 2.37 Material*Type of Stove*Pan Cover_Stainless Steel type_2 Yes

Fig 4: Regression Equation

Fig 5 depicts Pareto Chart of the standardized effects for our three factors and their respective interaction up to three levels. It is also proved from this chart that only individual factors along with interactive factor BC (which is Type of Stove and Pan Cover) are significant.

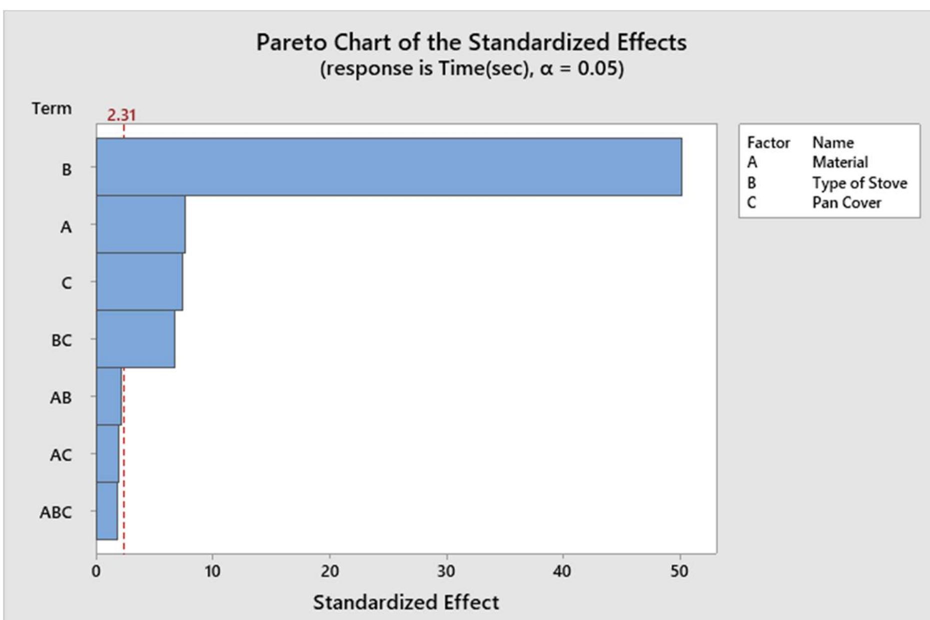

Fig 5: Pareto Chart of the Standardized Effects

Fig 6 shows Normal Probability Plot. This is a decent plot as majority of the residuals lie on or around a straight line. It shows assumption that residuals are normally distributed seem true.

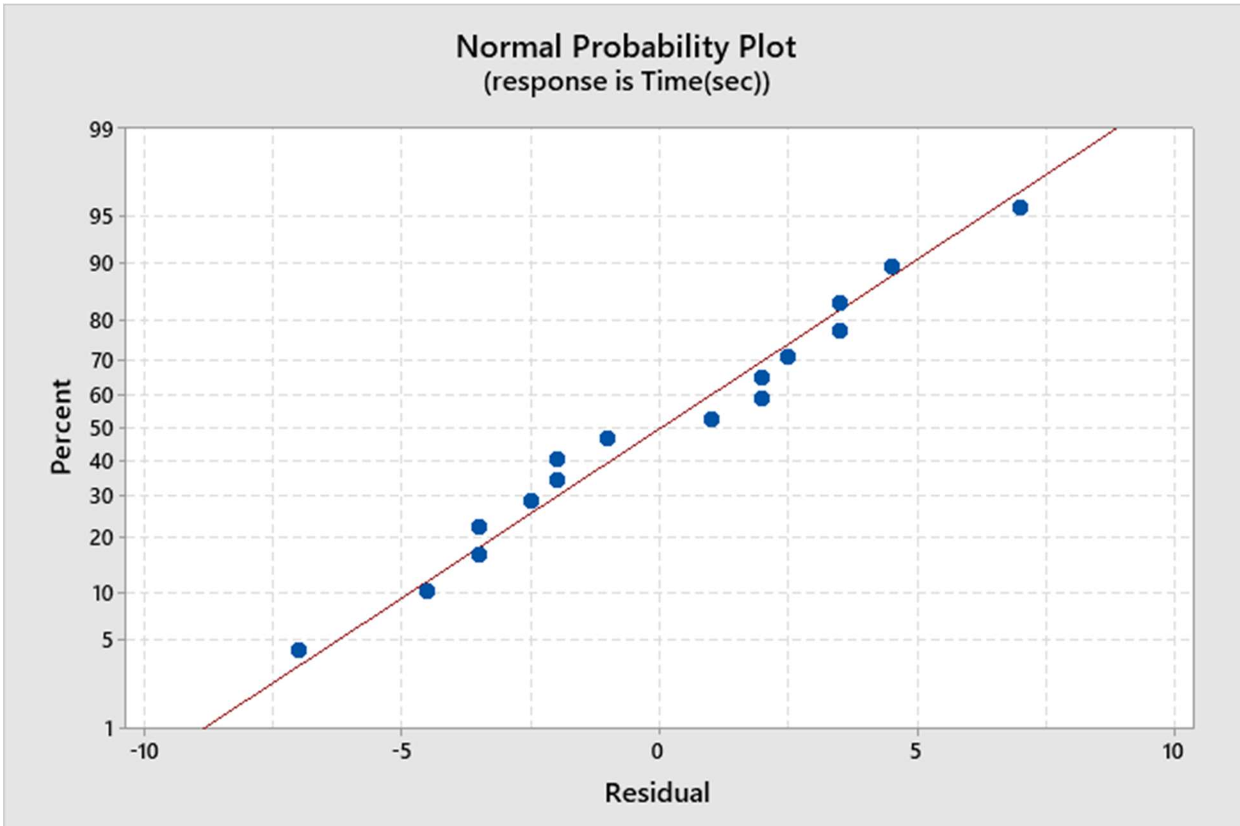

Fig 6: Normal Probability Plot

Fig 7 shows Residuals vs. Fitted values graph. It can be seen from the graph that assumption of constant variance seems legitimate. Residuals going up and down in somewhat similar fashion which prove their constant variance.

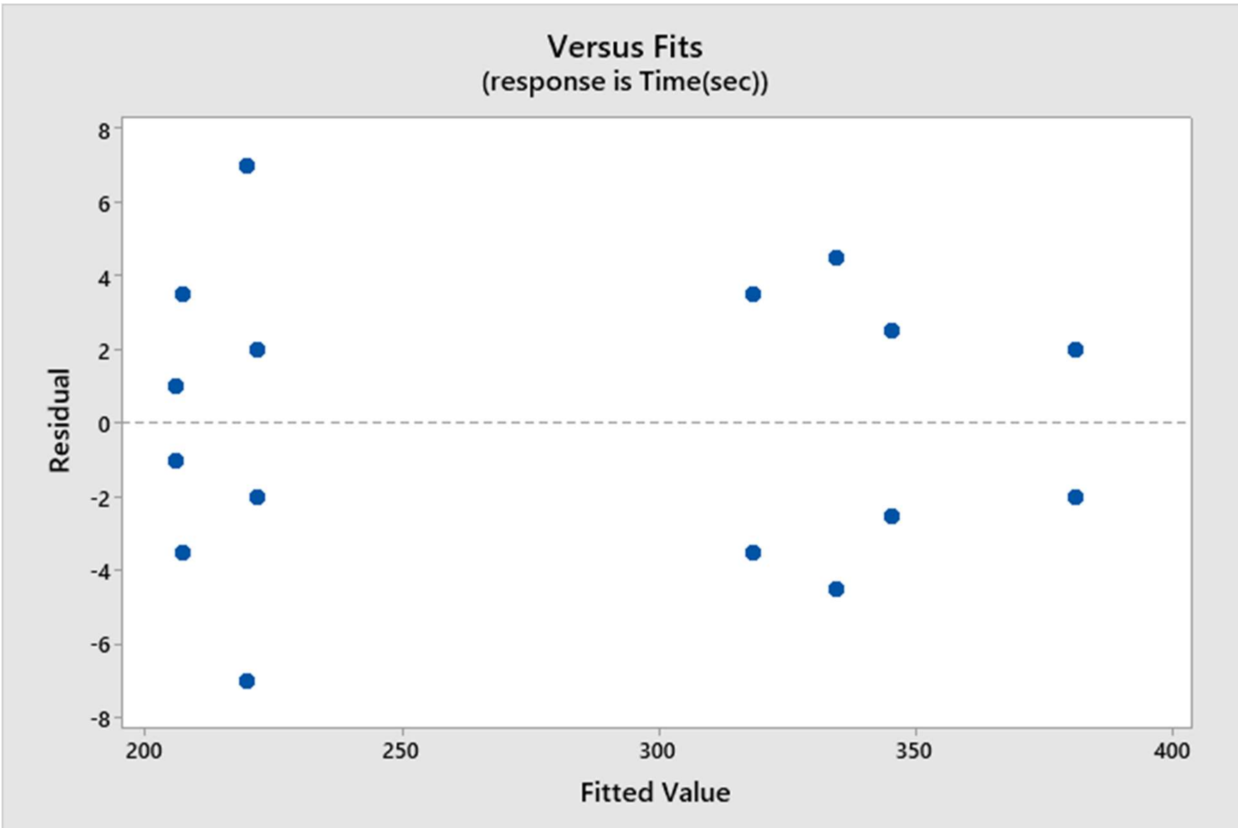

Fig 7: Residuals vs. Fits

Factorial Plots

Factorial Plots which show effect of Individual and Interactive Factors on response variable, is a great tool to analyze the results.

Fig 8 shows Main Effects plot for response variable time in terms of its mean against three factors at two levels. Our goal is to have reduce amount of time to boil water. If we must select one setting for each factor, we could select Stainless Steel, type_2 and No Pan Cover to have reduced time to boil water. More specifically, material and pan cover have very little effect on time whereas type of stove has decent amount of effect. So, it is recommended to use type_2 stove always to have reduced amount of boiling time.

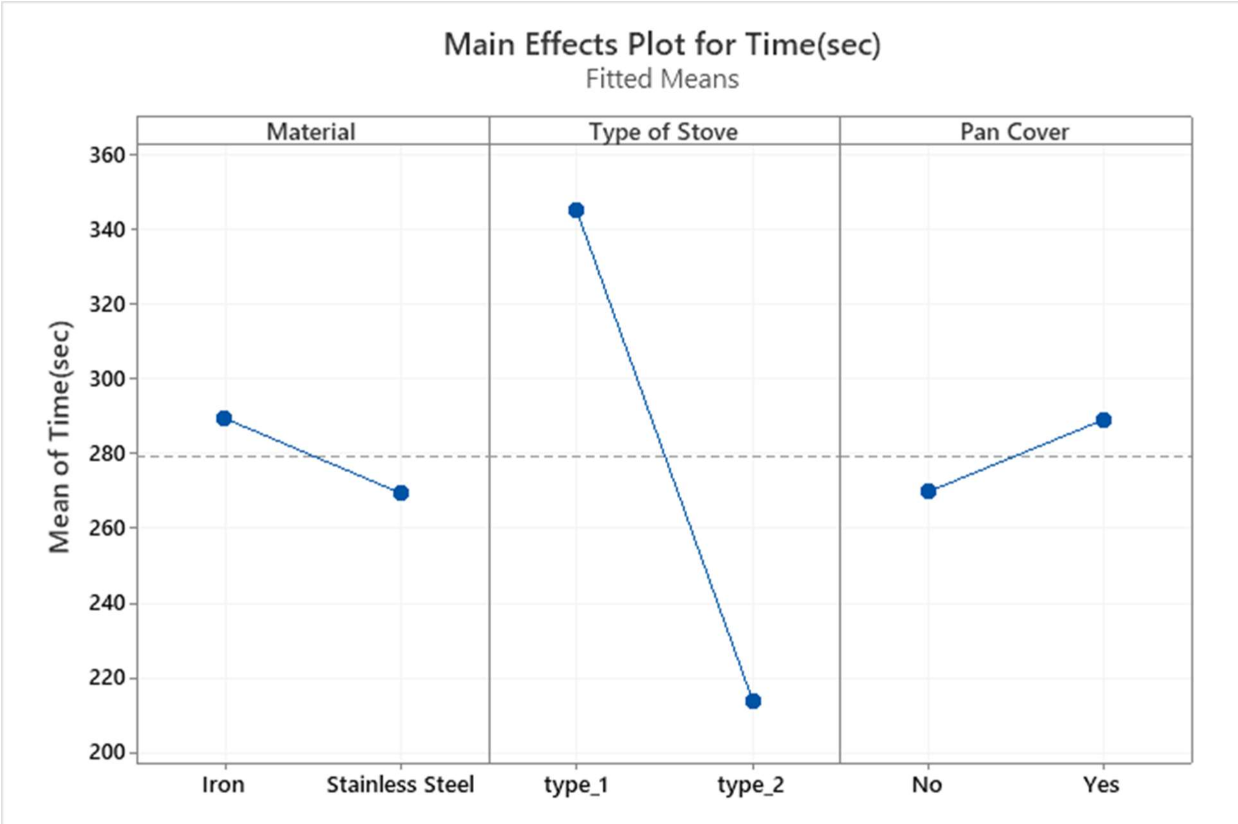

Fig 8: Main Effects Plot

For Interaction Plot in Fig 9, type of stove and pan cover would be looked for, since it is only interactive factor that is significant in the model. It also proves that type_2 setting is most optimum regardless of any pan cover.

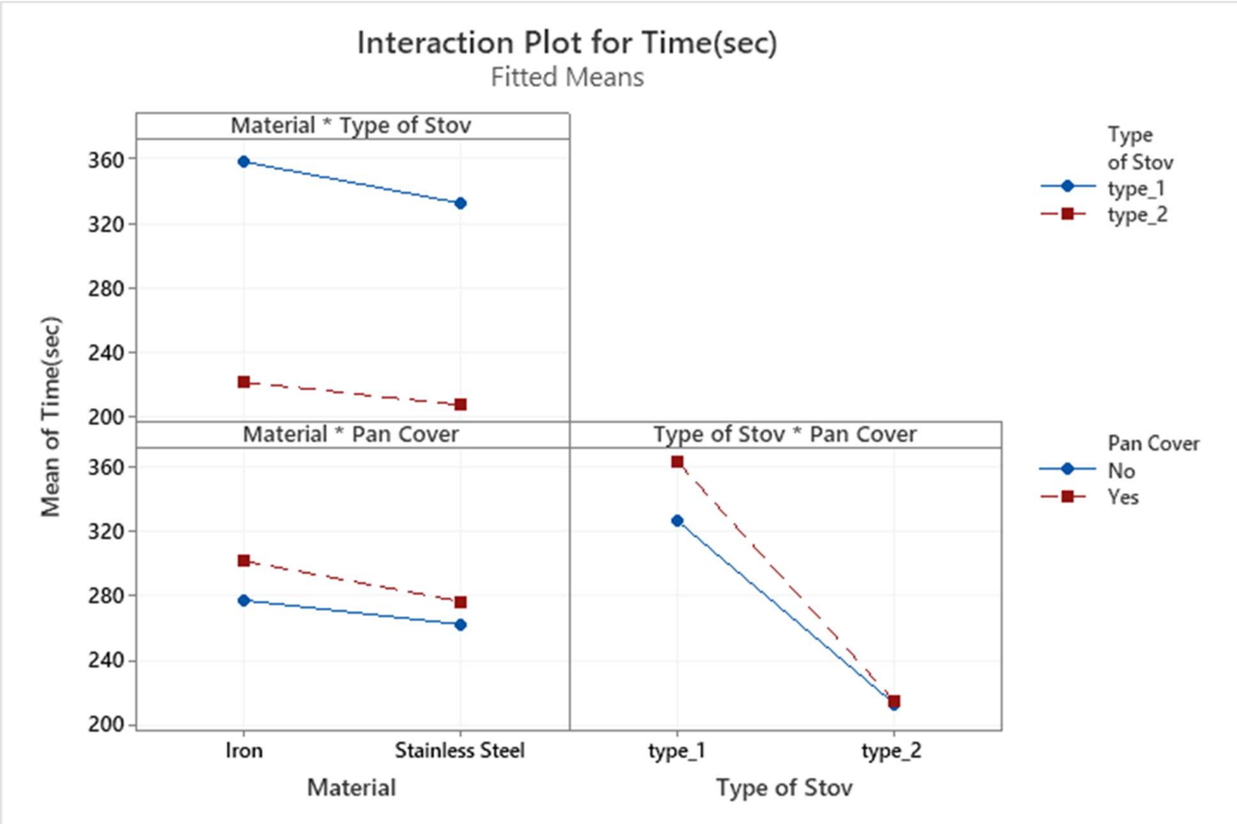

Fig 9: Interaction Plot

Conclusion

It is recommended that given material and pan cover has little or no difference on the boiling time of water. On the other hand, type of stove has created significant difference in boiling time of water. Therefore, one must use type_2 stove to decrease boiling time of water. For the sake of interest, changing of stove type resulted in decreasing mean time from 350 to 210 seconds which is around 2.5 minutes which is a great difference.