Quality Control and Improvement with MINITAB
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Lecture - 30
Two-factor symmetric Design, Robust setting, Two–way ANOVA

Hello and welcome to session 30 of course on Quality Control and Improvement with MINITAB. I am Professor Indrajit Mukherjee from Shailesh J. Mehta School of Management, IIT Bombay. So, earlier in the last session what we have seen is that we have taken two categorical factors and we have seen the influence on the CTQs like adhesive strength and we have taken and we have seen that the interaction is not so significant.

So, we have experimented and we have analysed the data like this. So, and the same thing we will do for another experimentation to see that when there is a continuous variable what else we can do.

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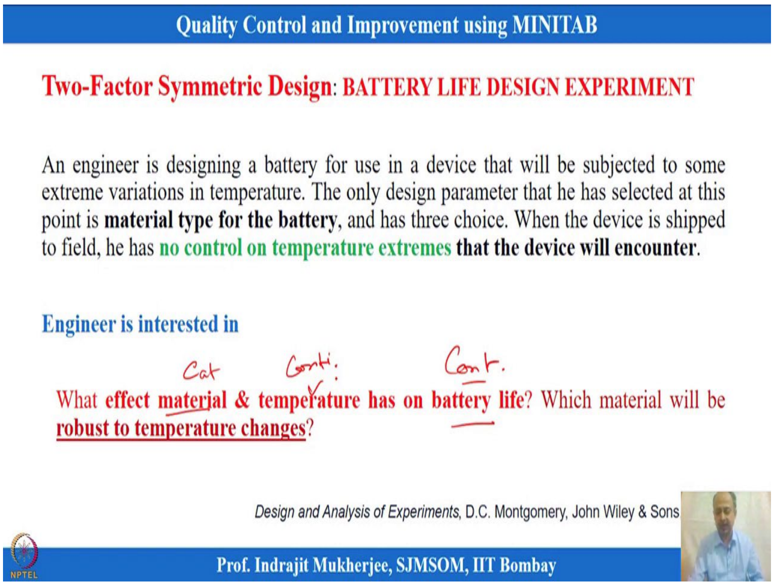

So, this case, battery life experimentation, is taken from Douglas Montgomery's books on Design and Analysis of Experiments and in this case engineer is interested to maximise the battery life and two factors are considered over here. One is the material type and another is temperature. Temperature is a continuous variable, but material type is a categorical variable. Battery life is also a continuous variable.

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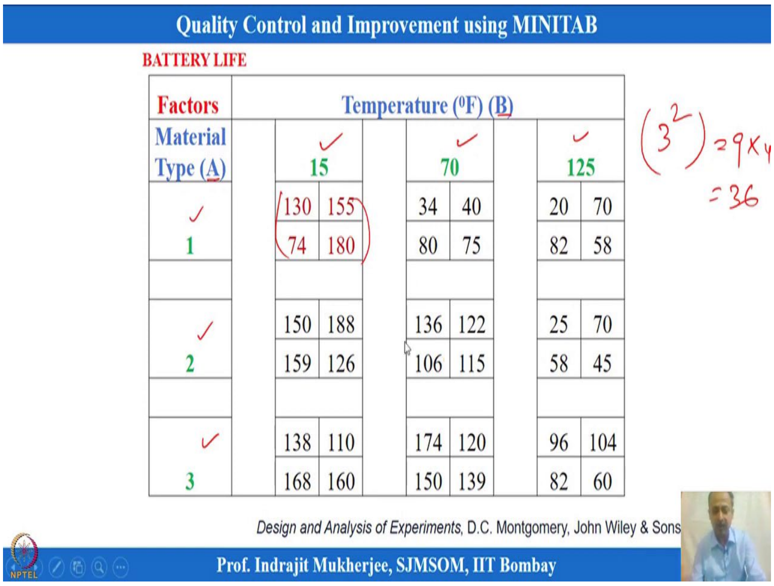

An experiment was conducted at three levels in each for material type which is factor A and this is a temperature which is factor B, is at three levels. This is a symmetric design because levels are same for material type and also temperature. So, this is a balance design we can also see that number of replicates is same. Total number of experimental trials is 9 over here and in each trial I have 4 replicates over here.

So, $9 \times 4 = 36$, number of observations we are having and everything is done keeping in mind that it is randomized experimentation. So, what we will do is that we will just see how to analyse this data. So, one is categorical, one is continuous variable in the predictor side and CTQ is continuous variable over here. So, all assumptions normality assumptions and everything is true whenever I am doing design of experiments. So, we have to verify that one whenever we get the residual and we have to cross check all the assumptions that we have done in regression also ok.

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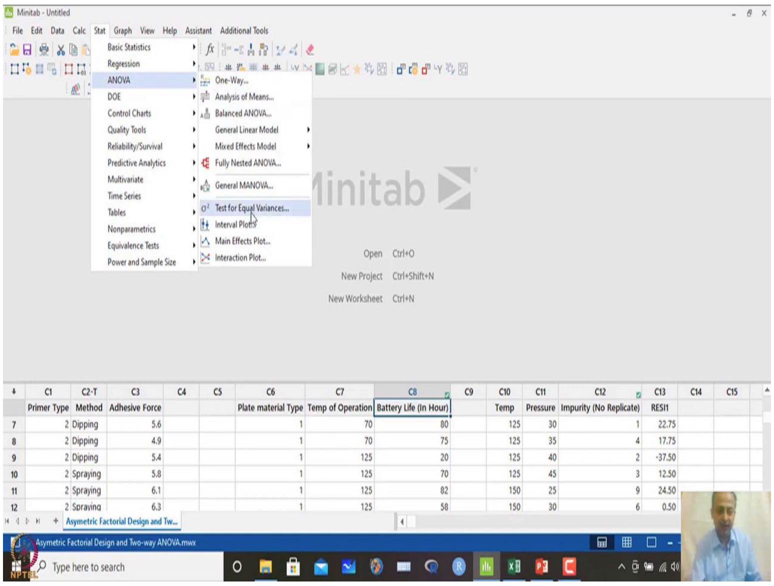

So, in this case what we will do is that this data is in MINITAB and I have already located this data over here C6, C7, C8 this is plate material temperature and battery life over here. So, first we can see that whether the variance is same throughout for every plate material and temperature combinations whether the variance whether the variance is same or not. So, that check or we can do that. So, we go to ANOVA analysis over here and test for equal variance. Response is battery life over here and the factor is plate material and temperature over here.

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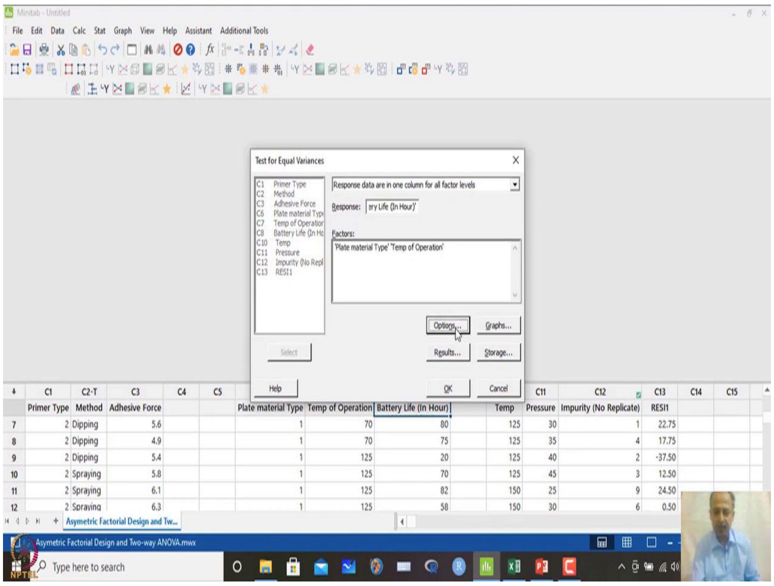

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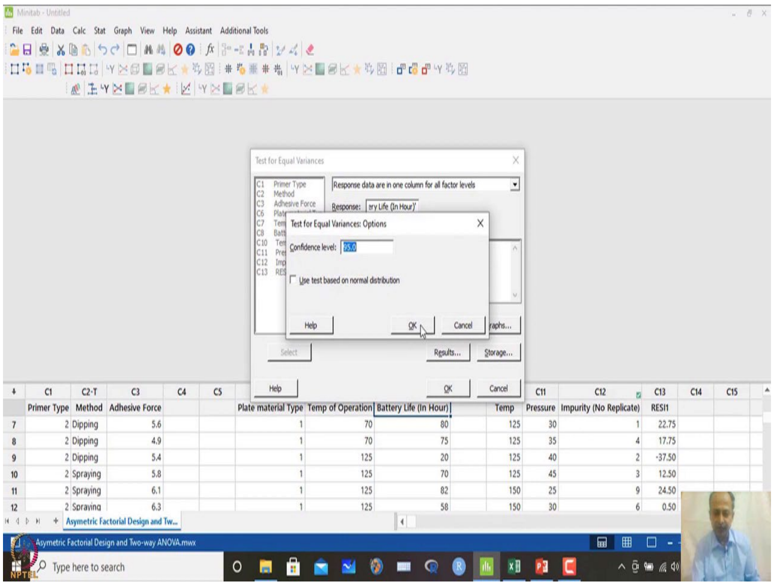

In options we will go for other than normality. So, we can also do normality test which will give me result by Bartlett tests.

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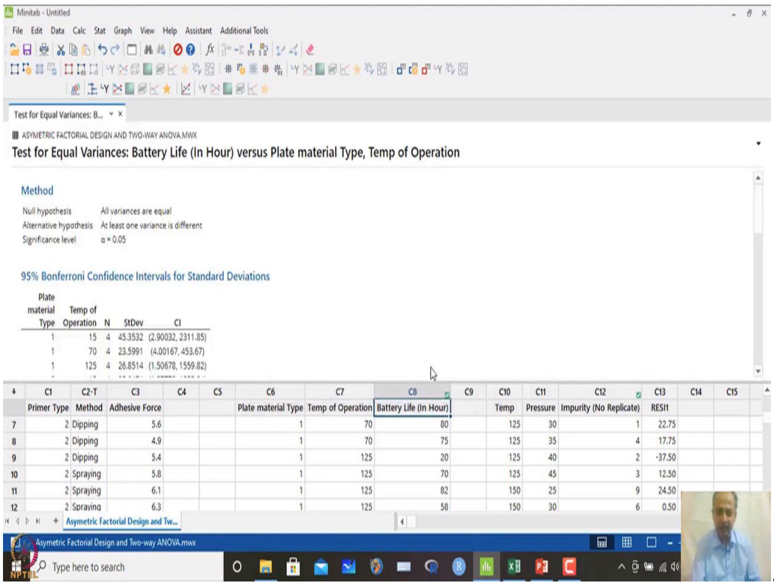

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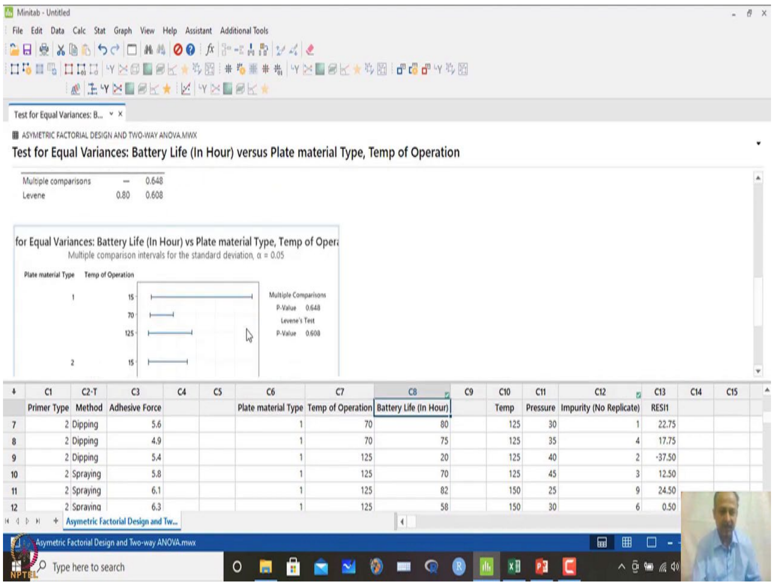

So, in this case if I go with this and this is the Levene’s test and multiple comparison test that we have done.

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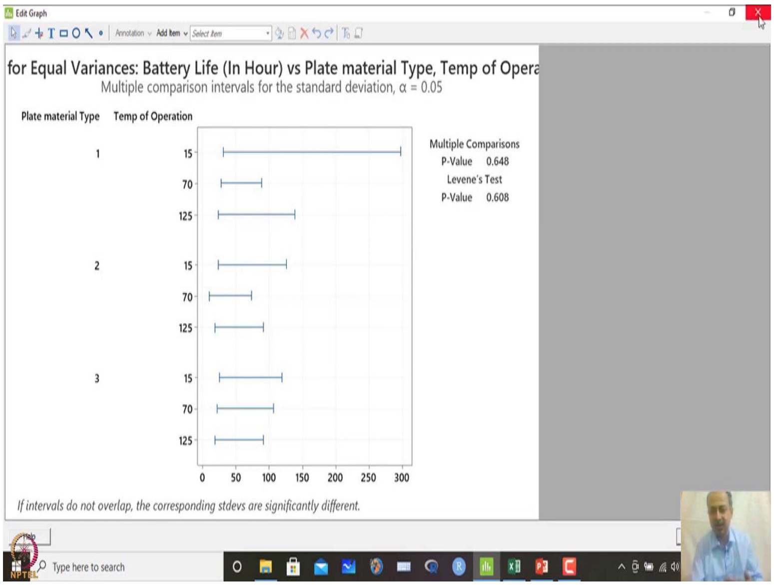

So, we can take any of this over here. So, I will go by Levene's test let us say and 0.608 is quite significantly more than 0.05. So, in this case we can say that there is no as such deviation, but at 15 although we are seeing, but overall results it is showing it is not so significant the variance is not changing significantly ok throughout the experimentation. So, we are satisfied with this. So, immediately what we will do is that we will go for ANOVA analysis or balanced ANOVA.

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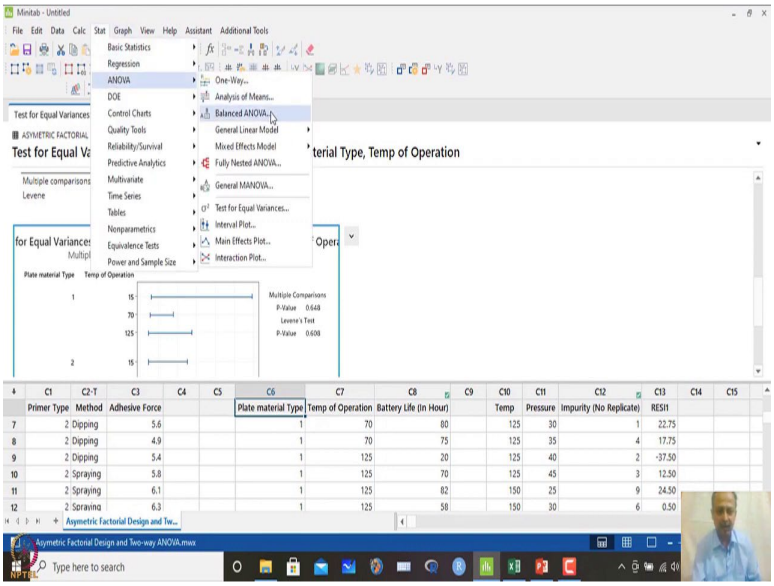

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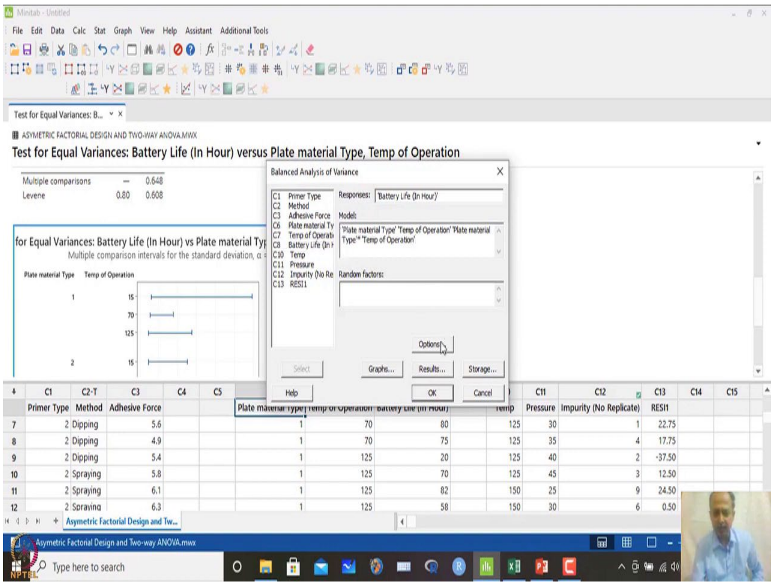

When I select balanced ANOVA, I will write which is the response. So, I will give response, I will give plate material and temperature over here and also plate material and interactions also I want to see. So, multiplication of this with temperature of operations over here.

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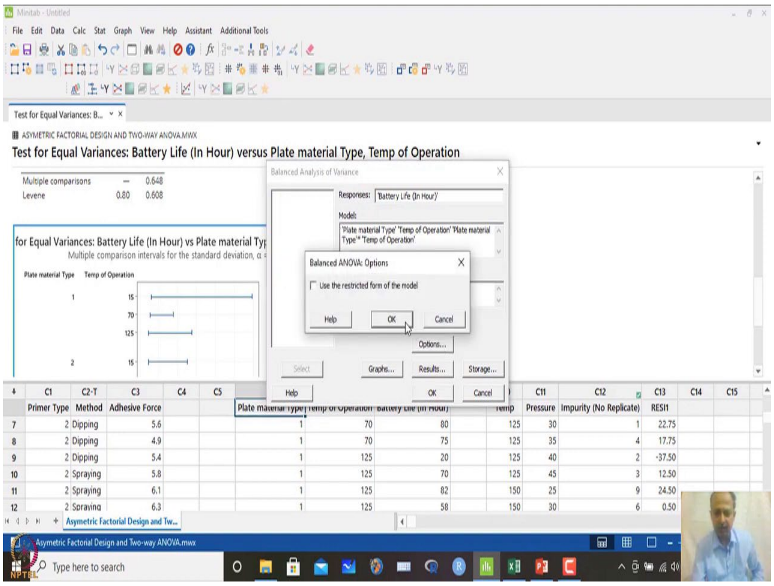

So, in options I do not have to do anything.

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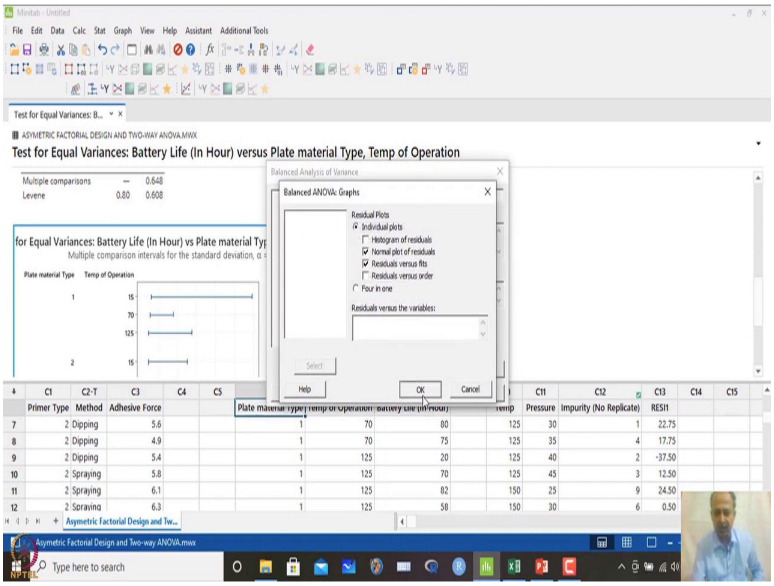

And in graphs where we can see normal plot and the residual plots versus fit and storage what we can do is the residual we can save and then we can click OK over here.

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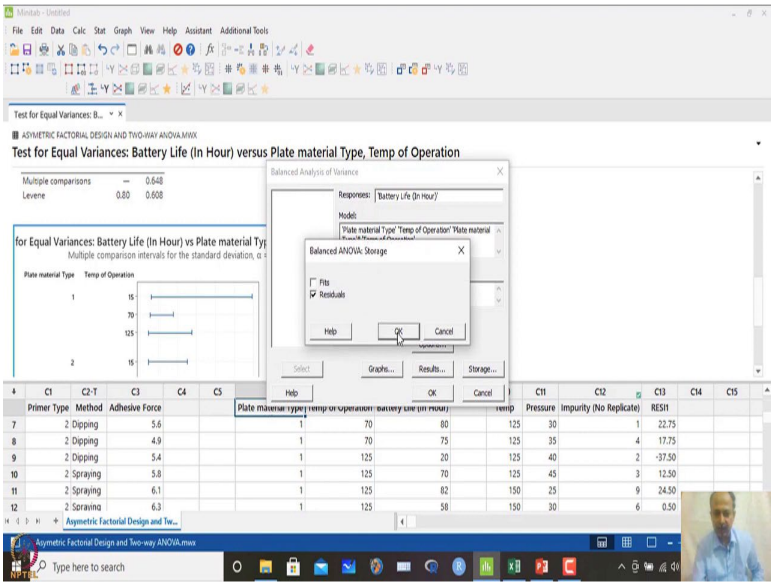

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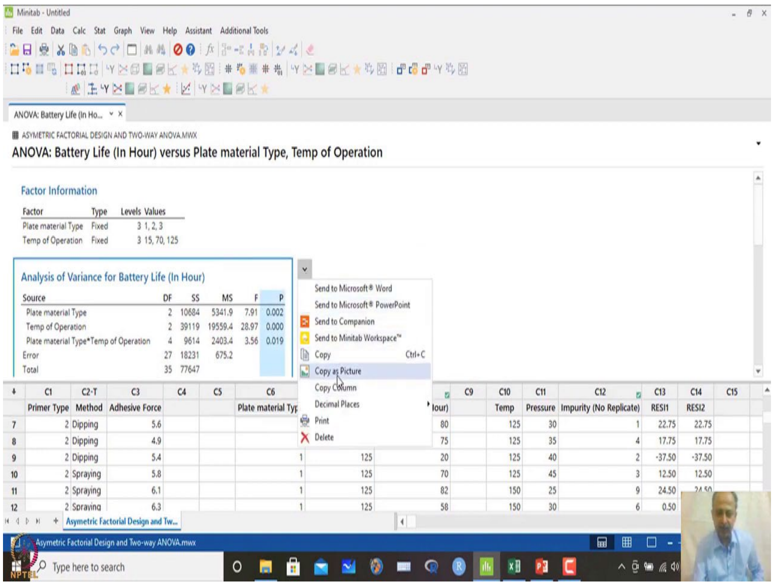

And then we can see the ANOVA analysis that is given over here. So, in this case I will copy this one and take it to excel and try to see enlarge this one and see what is the result outcome.

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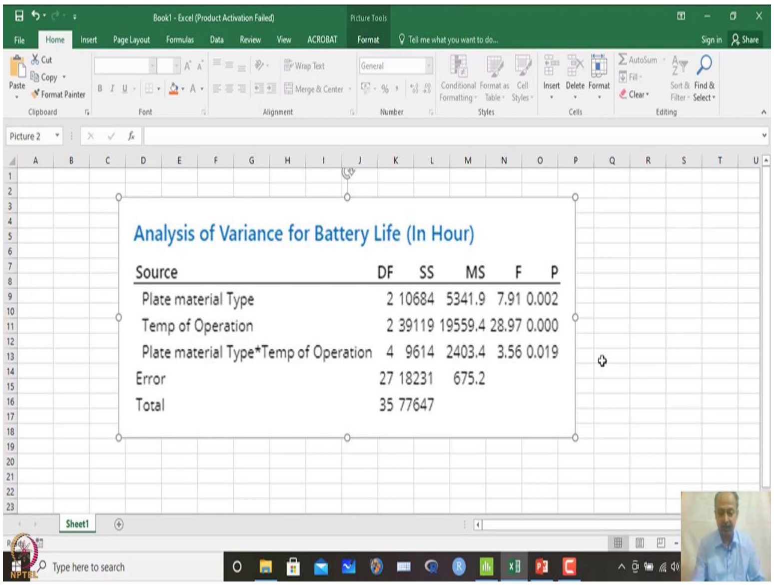

And it is saying that when you are changing plate material type, this is having a significant impact on the battery life. So, there is at least two levels where when I change the material from 1 to 2 or 2 to 3 like that. So, it is impacting basically the mean expected value of the battery life and temperature is also when I change that one it is also significantly influencing like that.

And also we can see that the interaction between plate material type and temperature of operations is also significant because this is also less than 0.05. So, interaction is prominent individually they are prominent so that means, all need to be considered when we are trying to determine what is the optimal combinations like that.

Whenever interaction is prominent in that case we cannot ignore this interaction between the variables while we are determining the optimal combination of plate material and temperature like that ok.

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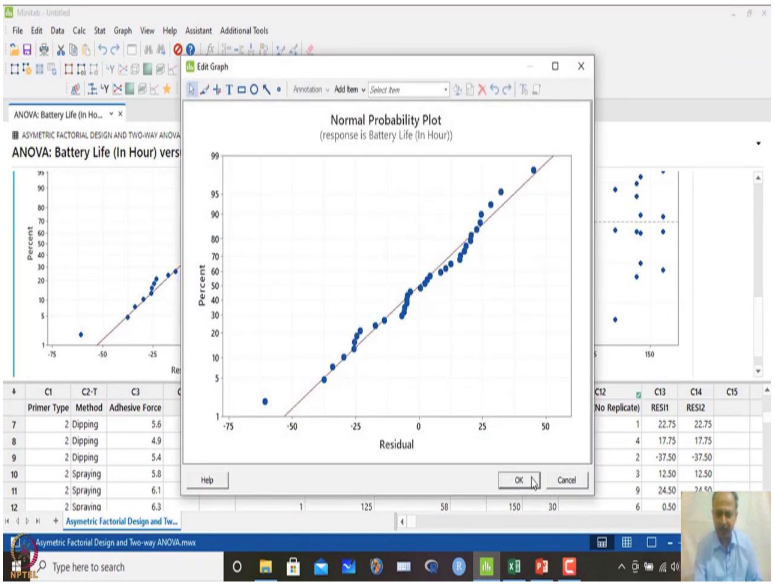

So, what we have to do is that whenever we have seen this one and normal probability plot seems to be satisfactory, there is no problem as such we can also check that one because C14 is the residual. So, we can just check that one whether everything is fine.

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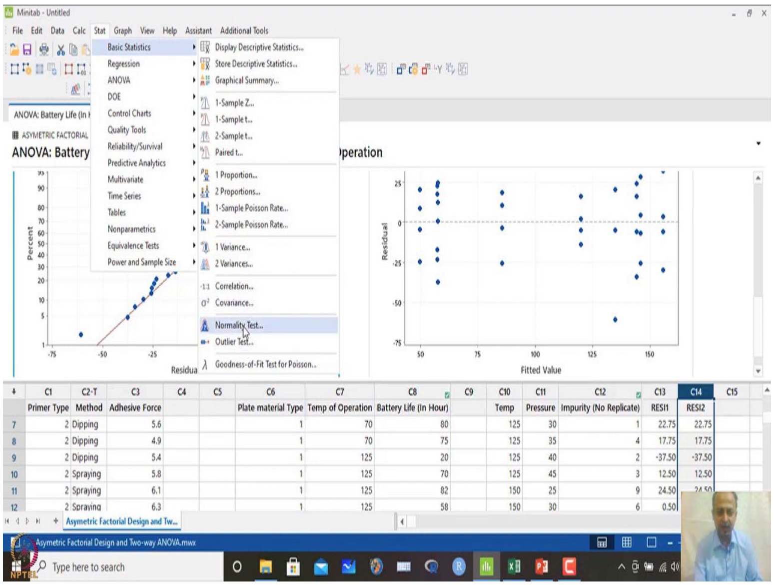

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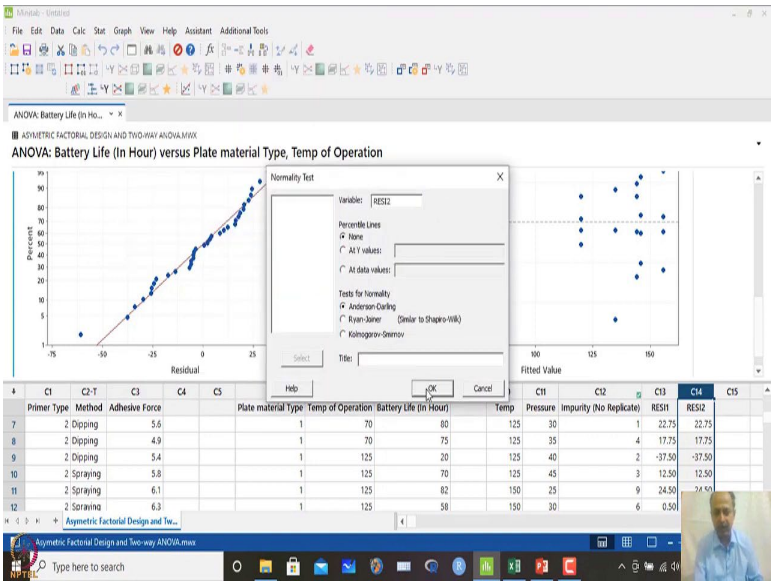

So, in this case normality test we are doing and residual 2 that because earlier there was some other residual that was same.

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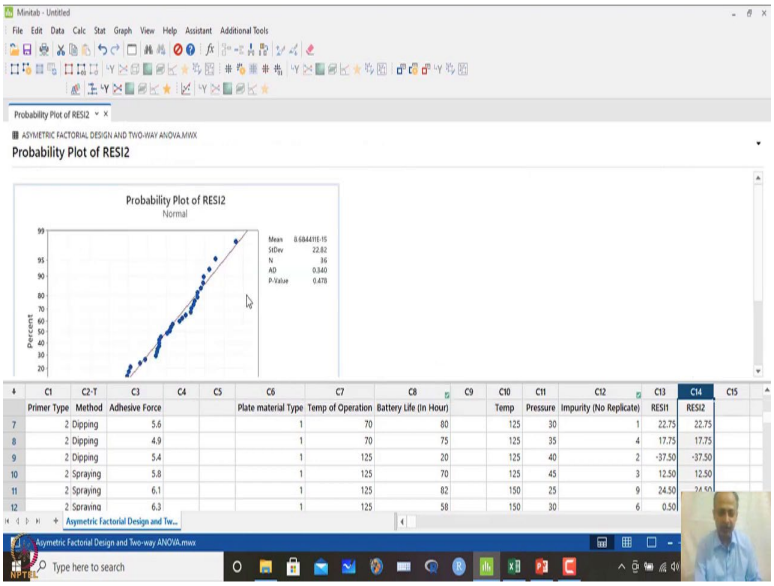

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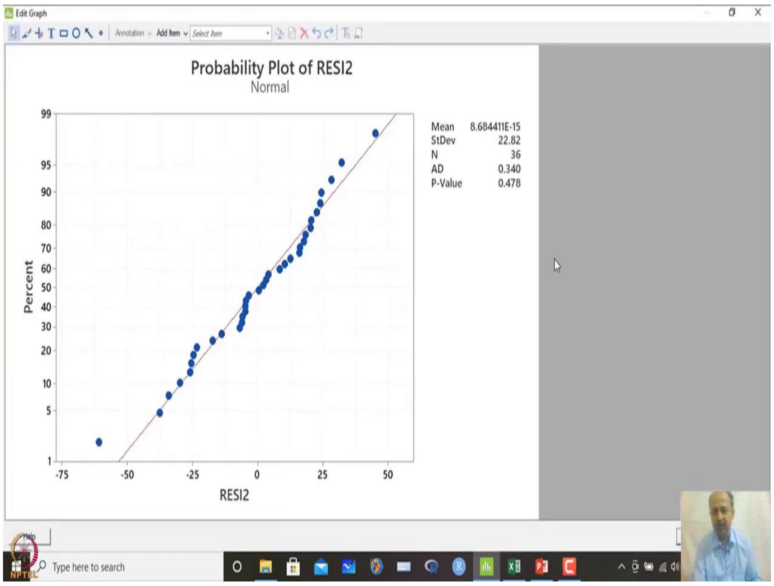

So, in this case what we are seeing is that p value of this is more than 0.05. So, it is satisfactory basically. So, without have any problem in normality assumptions like that.

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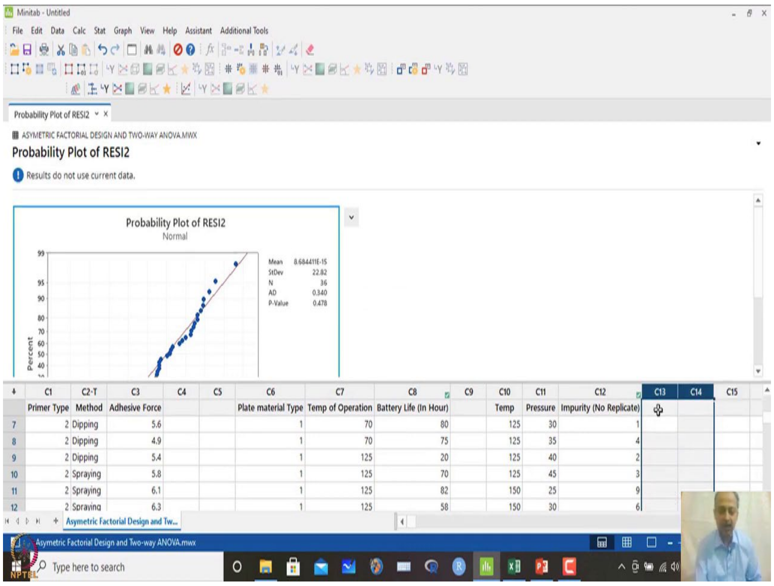

So, we can delete this two over here and then what we can do is that.

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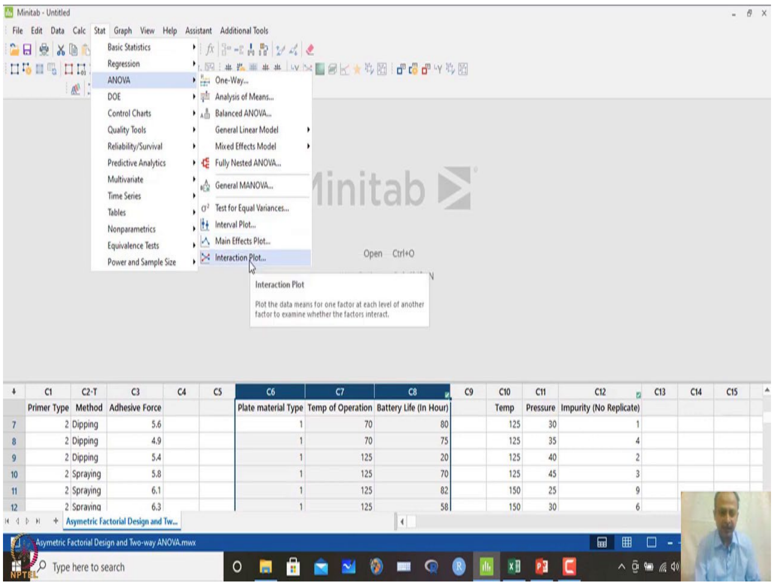

We have done this one and so, we can see 2 plots over here; one is known as main effect plot, one is known as interaction plot. So, what we have to do is that to get the best possible settings that we have to see. So, in this case I have to go to *stat*, *ANOVA analysis* and there will be a main effect plot and one interaction plot over here because interaction is prominent I am going by interaction plot.

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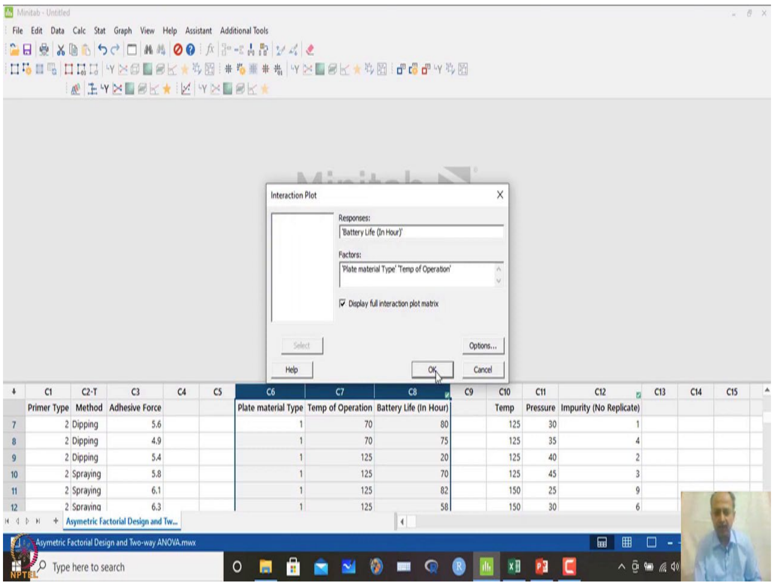

So, what I will do is that I will mention which is the response and I want to see where the response is maximized and then I will give the two variables one is plate material and one is temperature over here. And I will click display full interaction plot over here similarly what we have done last time also.

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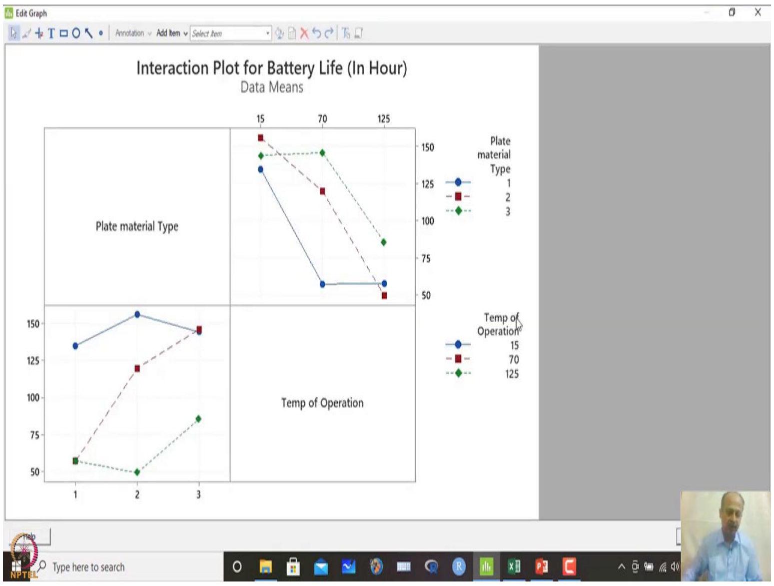

So, in this case I clicked OK and whenever the interaction is present you see that the graphical representation is some more different as what we have seen not similar to the what we have seen when we were talking about adhesive strength maximization.

And what we will see if there is interaction you can expect that these lines will cross each other. So, what you are seeing is that lines are crossing each other. So, in this case what is expected is that whenever such kind of scenario of interaction is prominent the lines will cross each other basically and they will not be parallel they will not be parallel like that.

So, over here I will see one half of this. So, let us see upper right hand side over here. So, in this case what you see is that to maximise the battery life this is the highest point that we are observing this brown point that you are seeing over here is 15.

And this line shows plate material type 2. So, plate material type 2 and 15 degree gives you the best combination over here. So, this is gives you the best combination nearest to this is we have material type 3 and 15 degree that is also. So, what we are seeing is that we are seeing maximum temperature maximum battery life condition is appearing when we are taking a combination at lower temperature at 15 degree and material type 2 or 3.

So, in this case there is no problem in seeing this one although this plate material type 2 is the preferred one. But we have to make a multiple comparison test and figure out whether this is different from this one. So, whether this point what combination of 15 and 2 is different from 15 and 3 like that. So, we have seen multiple comparison test that is possible and we can see that one and but we have to consider over here something else.

In the problem it was mentioned that which material will be robust to temperature change while we are selecting. So, if you see this diagrammatically over here what do you observe for material type 3?

There is a flat region from 15 to 70 over here; that means, this battery life does not change much if you are following plate material type three over here, but if you are taking plate material 2 the slope of this line is drastically falling what we can see as compared to material type 3. So, the slope is higher than material type 3. So, material type 3 is more robust within the temperature zone of 15 to 70 like that.

If you are considering that temperature range, it is insensitive to the change in temperature if I change from 15 to 70 any range within this assuming the continuity of the or we can say that within this range we can expect. So, we are just extrapolating our interpretation over here. So, 15 into 70 because we have done one discrete points so, but we can just see the interpolation over here to be more or less flat what we are seeing over here.

So, in this case what we are trying to say is that this is more flat. So, if you have to take reference on robustness now which material I should use I should go for material 3 over here in the range of 15 to 70 and beyond 70 also see material type 3 is giving you higher value of battery life as compared to any other material 2 or material 3, but any how material one is of we can ignore this one.

So, for two what you see from 70 to 125 also it is lower than 70 to 125 battery life what is given by the material 3 over here. So, without much hesitation what we can do is that we can select material type 3 if I want a robust material which is insensitive to temperature changes like that we will go for material three like that.

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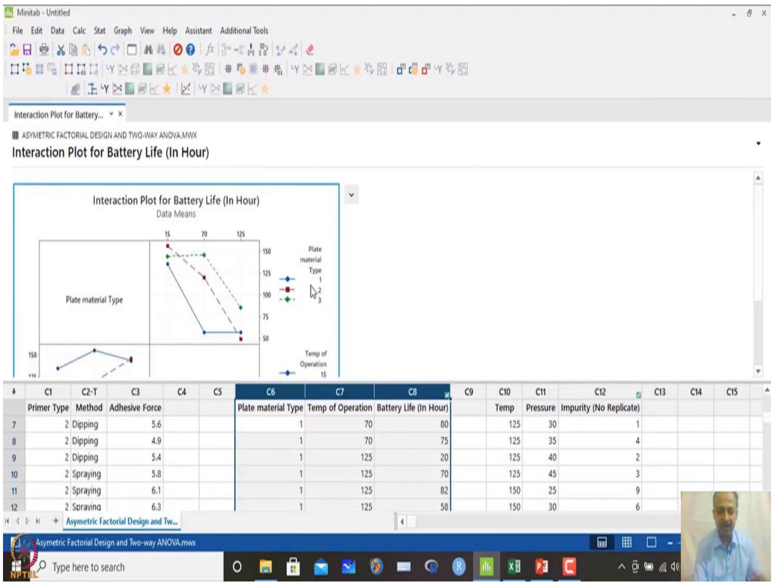

So, this is interaction plot what we can see over here and we can make a comparison test also.

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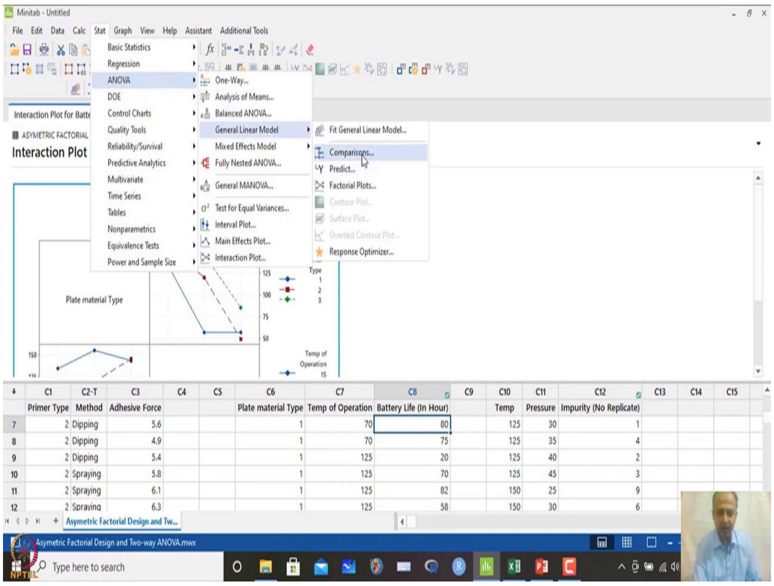

So, if you want to make a comparison test go to ANOVA analysis and then general linear model comparison test over here.

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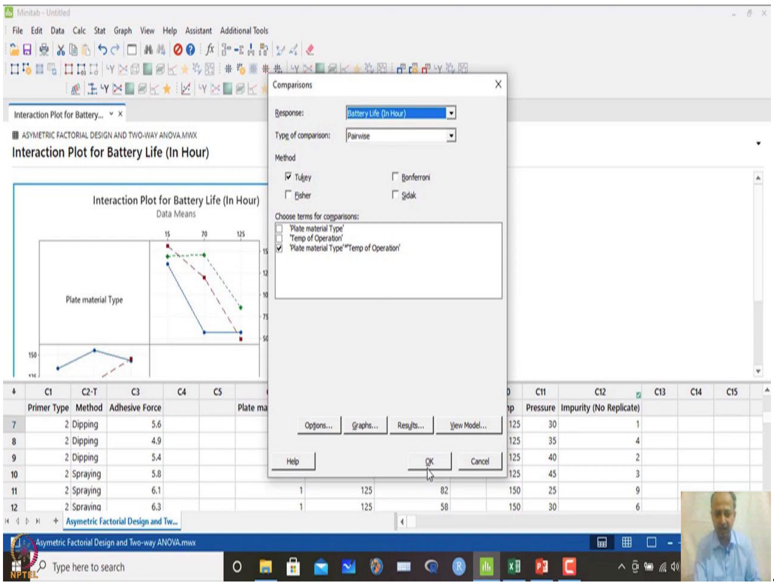

You have to mention that battery life is one to test and I want to see plate material type 3 and temperature and I want to make a comparison because that is prominent what we have seen.

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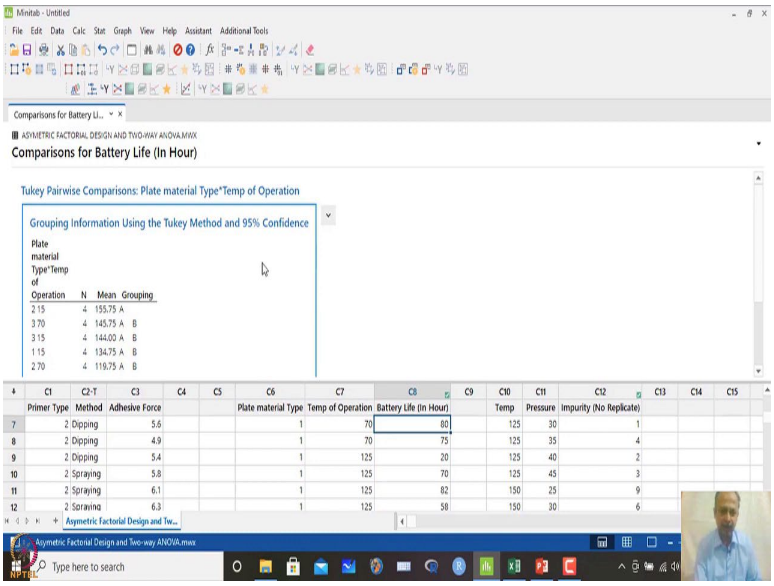

So, here what you can see is that ah grouping information is given.

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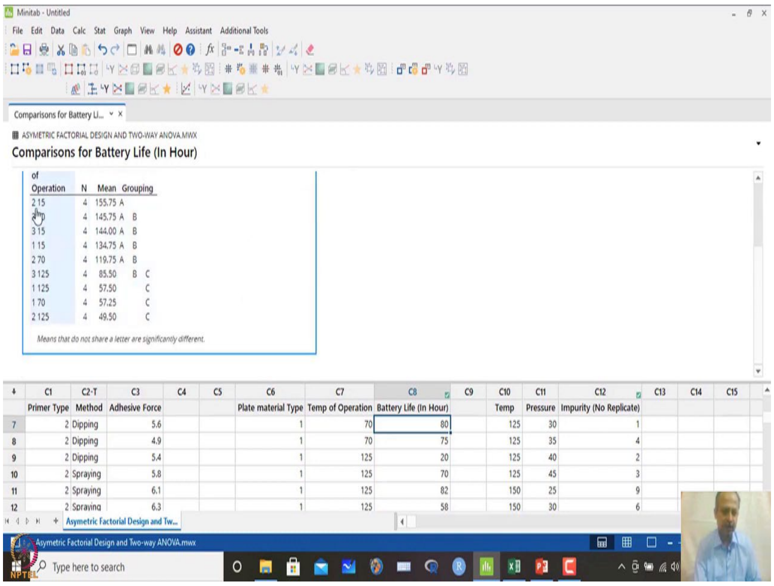

So, 2 and 15 and 3 and 15 are not different as such but based on the robustness assumptions what we are doing is that we are adopting 3 as the material type because although there is no significant difference because letter code remains same. So, but we will select 3 because that is more robust with the change in temperature like that. So, this comparison test is also possible to see which levels to select which combination of the levels to select like that is possible.

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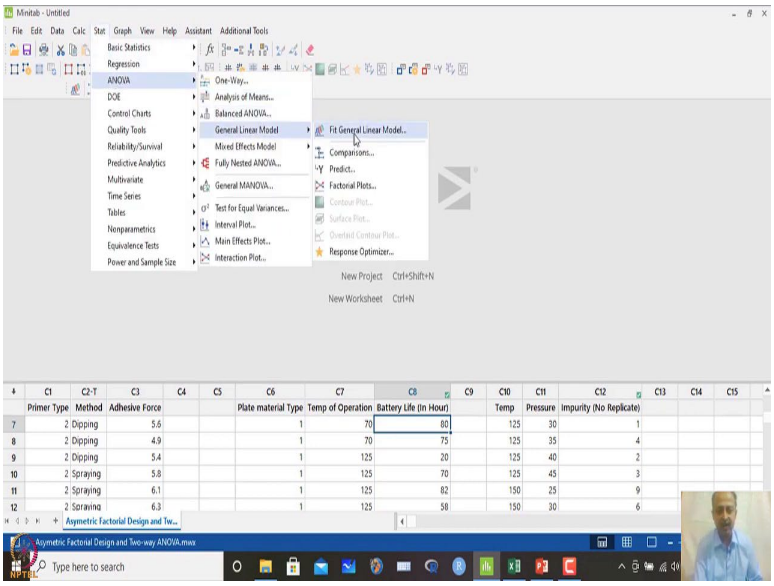

And also we can fit a regression model that we told that we can do general linear models like that fit general linear models over here.

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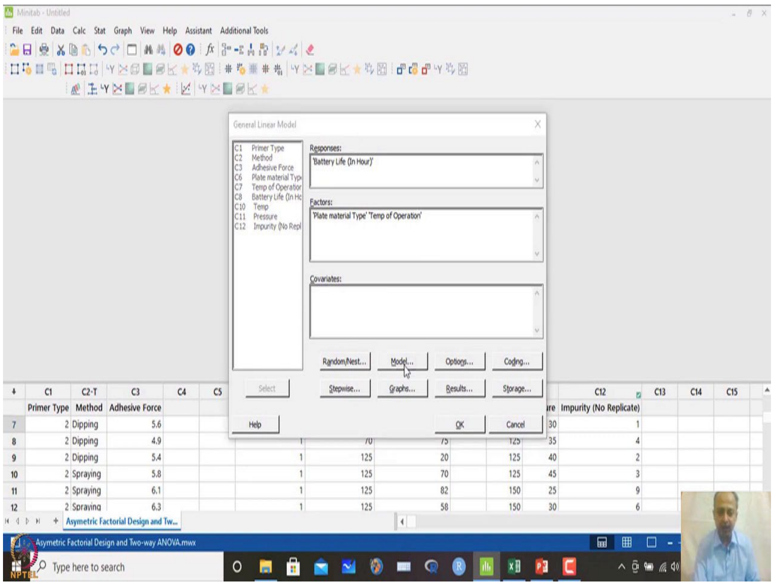

So, I have battery life which I want to predict and plate material type and temperature is done and we want to select the models that interactions also is selected over here what you can observe.

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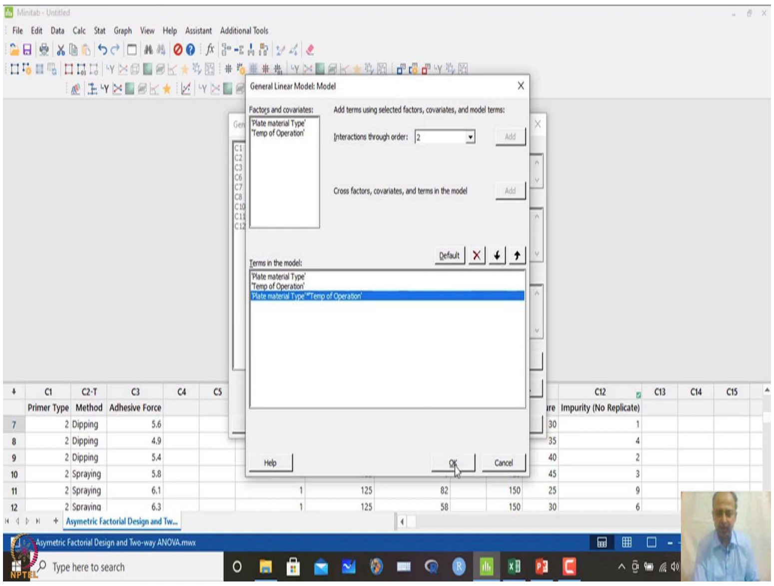

And I click OK over here.

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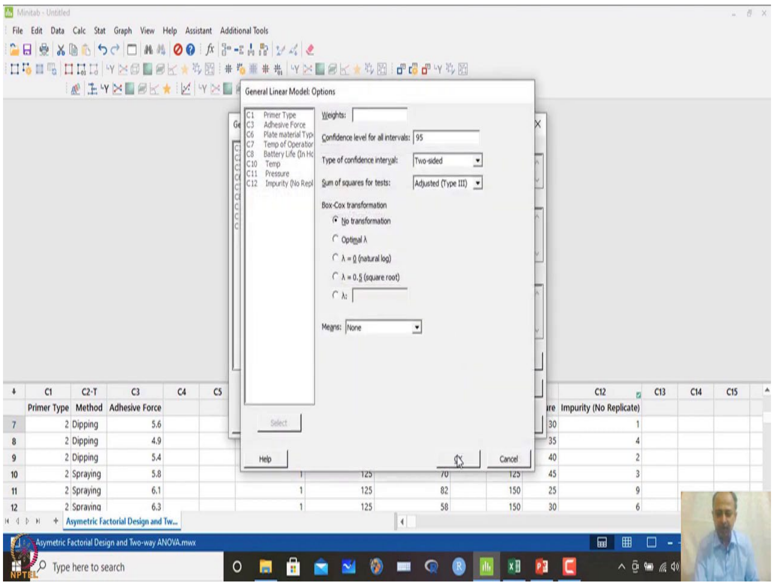

So, in options we have not given anything. So, that is not required.

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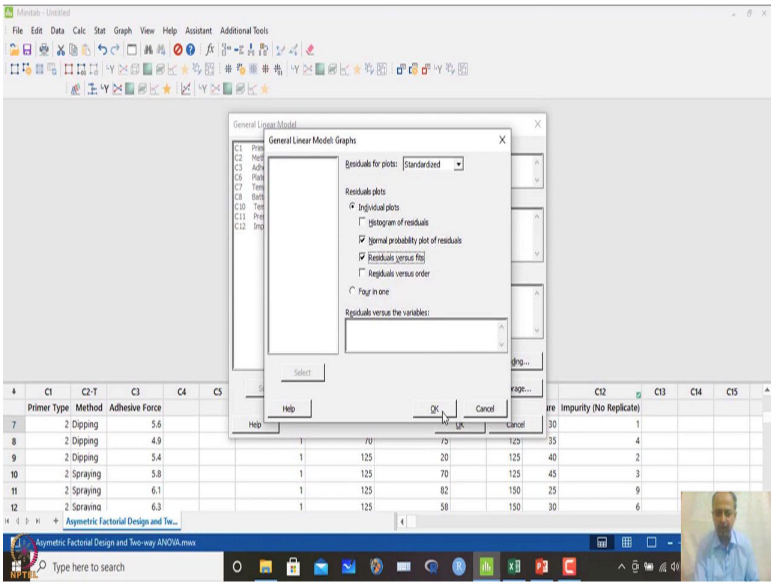

And in graphical representation this normal standardised residual we can do that and we can see the residual plots also and then like what we do in regression.

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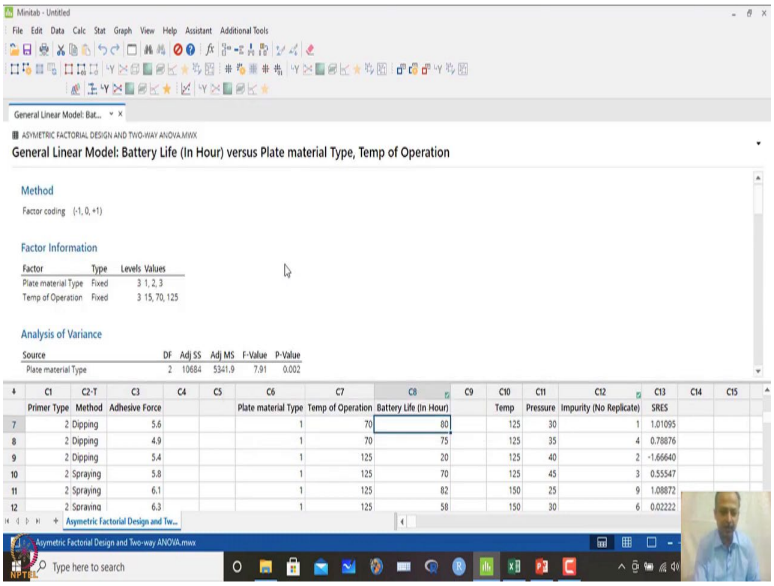

So, if I click OK over here what you observe is that.

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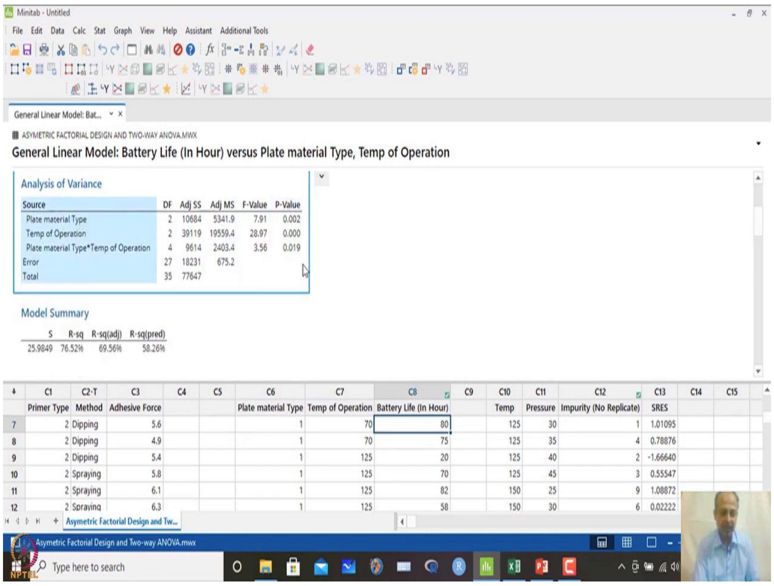

The same results what we have analysis of variance remains same.

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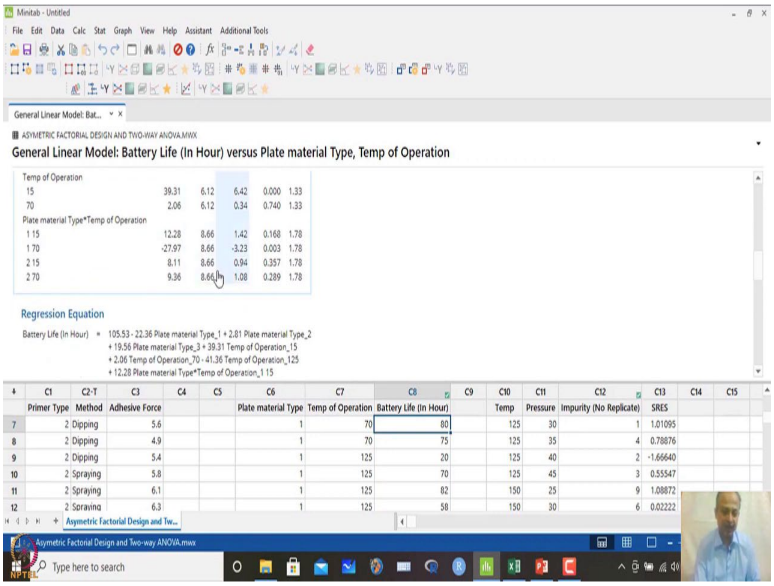

R^2_{adj} is around here 69% and $R^2_{predicted}$ is 58% although not drastically changing like that, but the predictive behaviour is not much what we expect. So, in this case what we have generated a regression model which is significant over here. And we have developed that based on the ANOVA analysis results that we are getting and then what we can do is that is this prediction.

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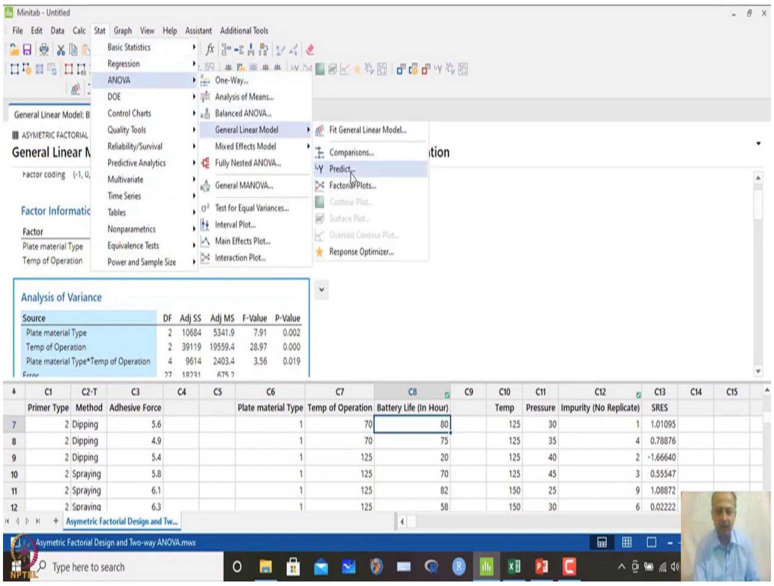

We can predict anything like that. So, I have selected a material type 3 let us say and at 15 degree what is expected. So, I will go to ANOVA analysis and I go to general linear model and predict.

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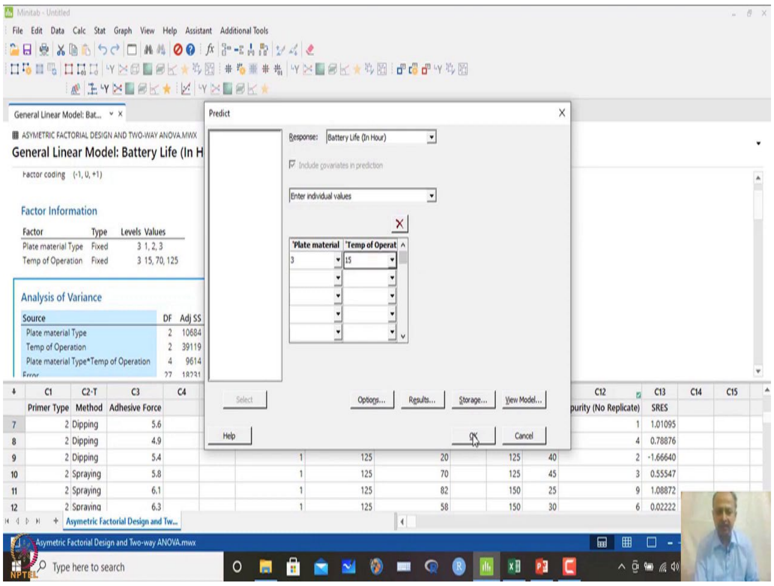

If I go to predict it will say what material type you want to predict. So, I will say 3 and temperature let us say 15. Then I will click OK.

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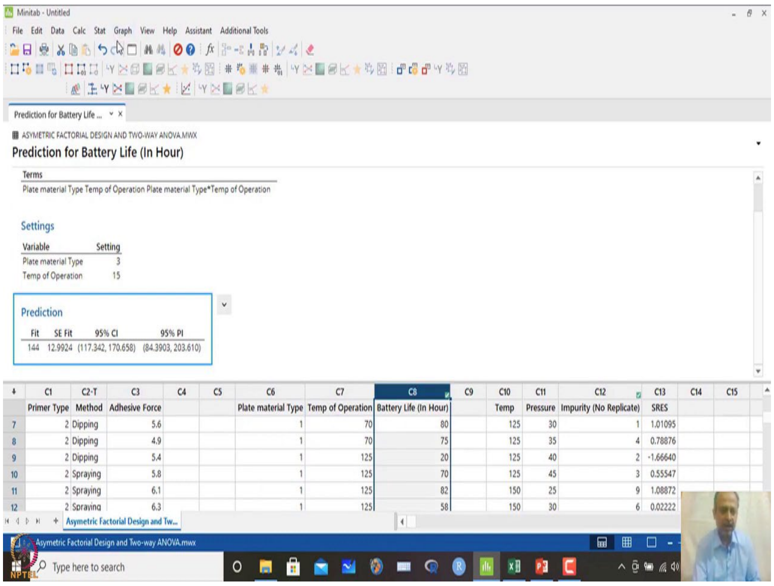

And it will give me some possible values over here. So, this is the predicted fit values. So, the regression model that is general linear model that we have fitted over here it is predicting about 144 is the values and it will give you a prediction interval and confidence interval. So, 144 is expected when these combinations is run at a separate and we can rerun this one.

So, expected value is 144, but there is a prediction interval that is given over here. Now one of the variable is continuous variable over here one is discrete or categorical variable over here and the CTQ is continuous variable that we can see. So, there is another option what we can do is that we can also see graphically surface plot of this.

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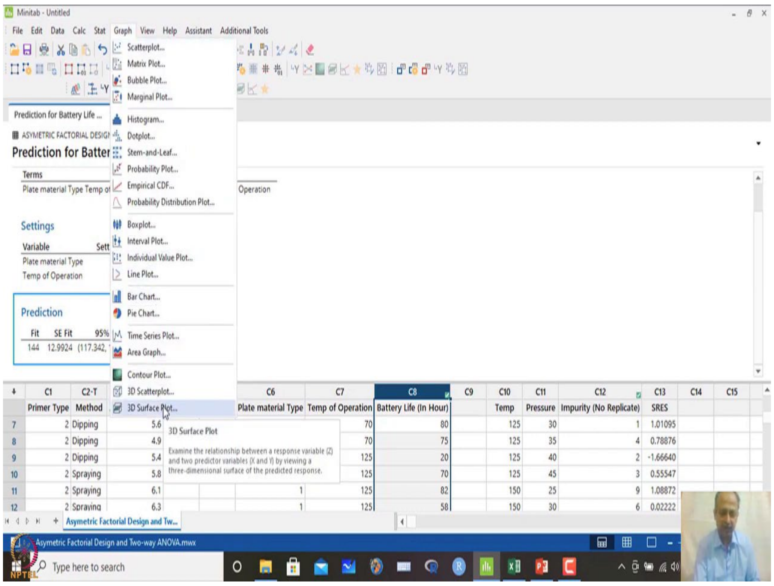

So, we have seen interaction. So, how does it look when there is a interaction how the graph looks in a 3D dimension if we want to see then we can see this by 3D surface plot.

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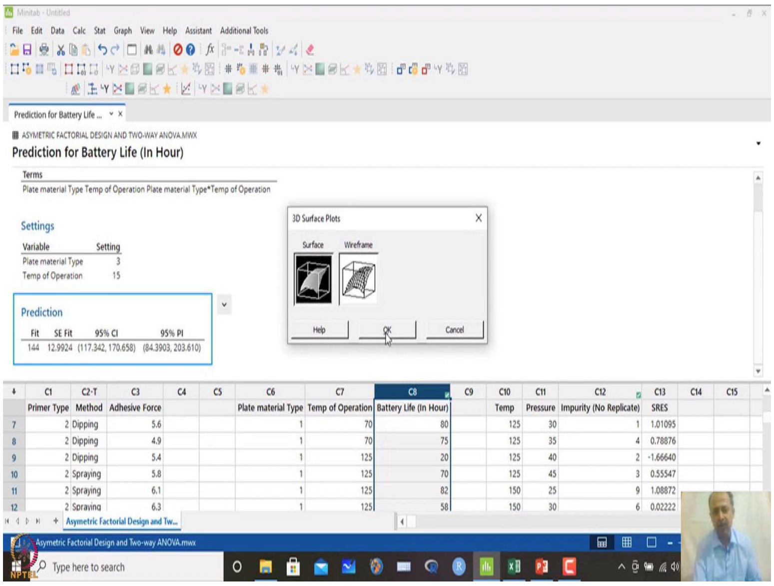

And when you go to the there is wireframe surface like that and I go by surface let us say surface plots like that.

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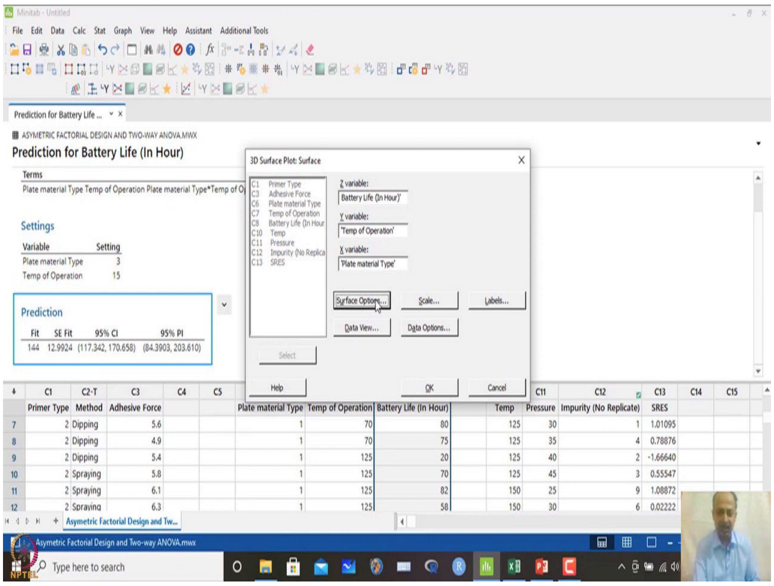

So, battery life is the variable which will be on z axis, temperature of operation on y axis and plate material type on x axis.

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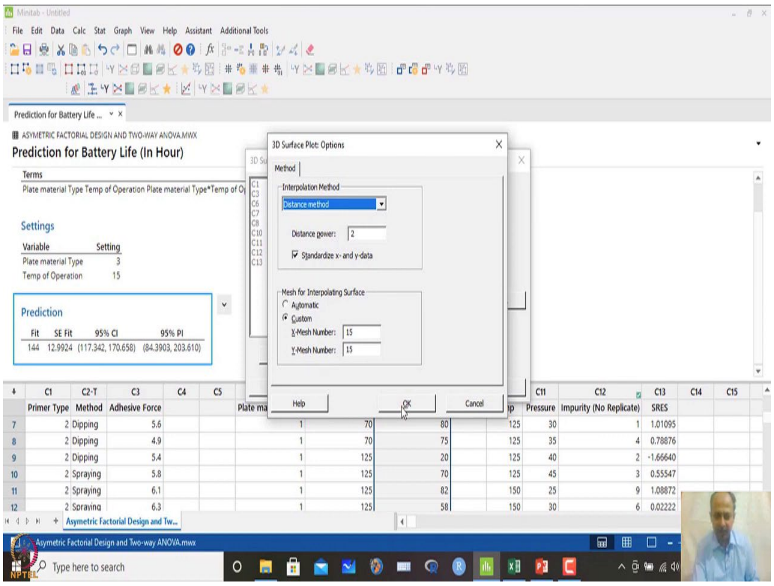

Then surface options over here we can see the methods of this mesh over here Y mesh numbering over here mesh numbering. So, in this case and this is not so, no much required to change the settings over here. If you click ok what will happen is that.

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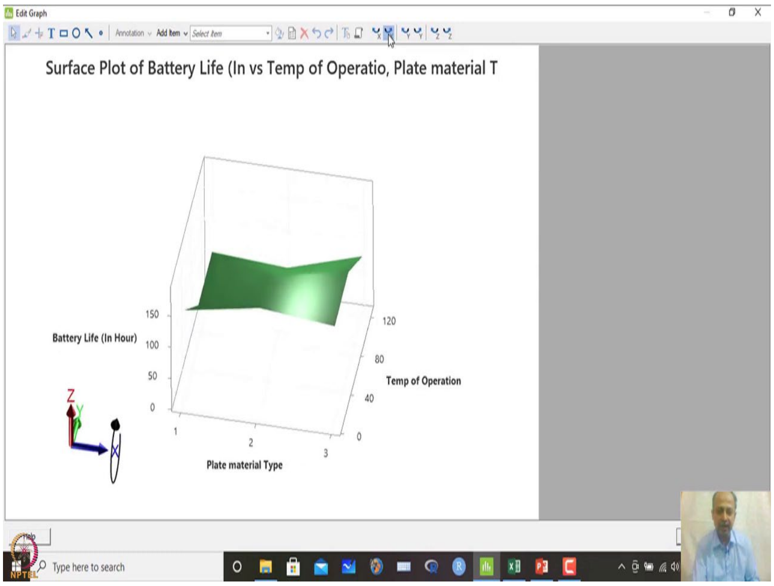

You will get a plot like this; you will get a plot like this and which shows that there is some curvature in the graph what you see over here. So, this can be rotated also. So, you can see rotation on Z axis over here and also you can rotate on X axis.

So, if you see the surface like this. So, you can see that it is not plane surface what is expected because interaction is present. In this case you can expect some amount of curvature that is present in the model. So, that is prominent over here that you can see and you can change the direction over here.

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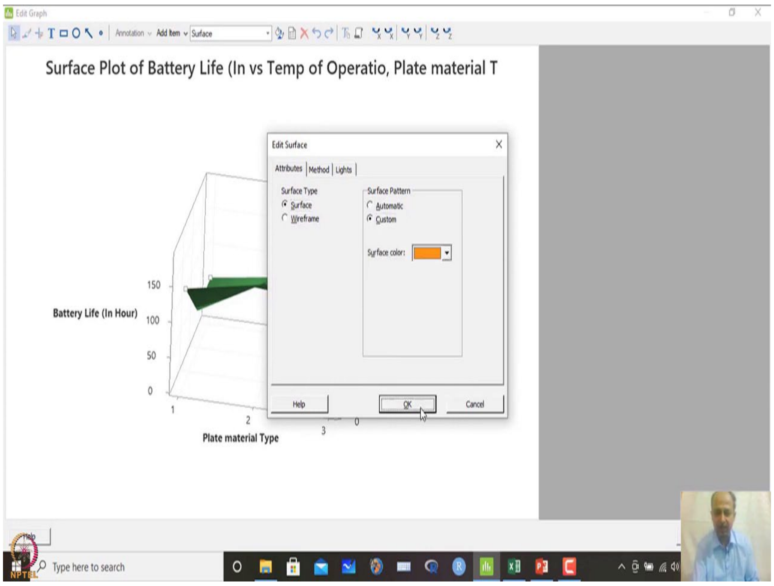

You can also customize the surface.

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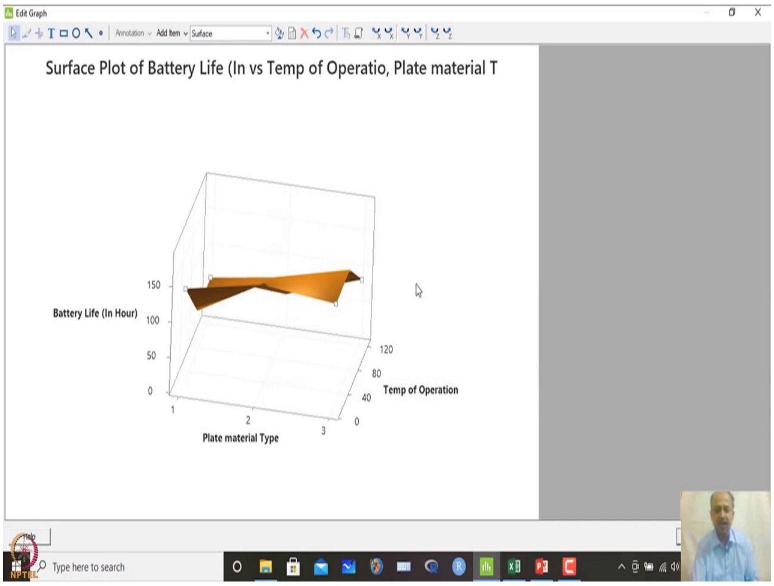

If you want to change the colour, you can. So, you can change the colour then you can see which is the lower surface which is the upper surface like that and the curvature that is present in the surface like that.

So, one is categorical variable one is continuous variable and battery life is continuous. So, we can see the plots of this.

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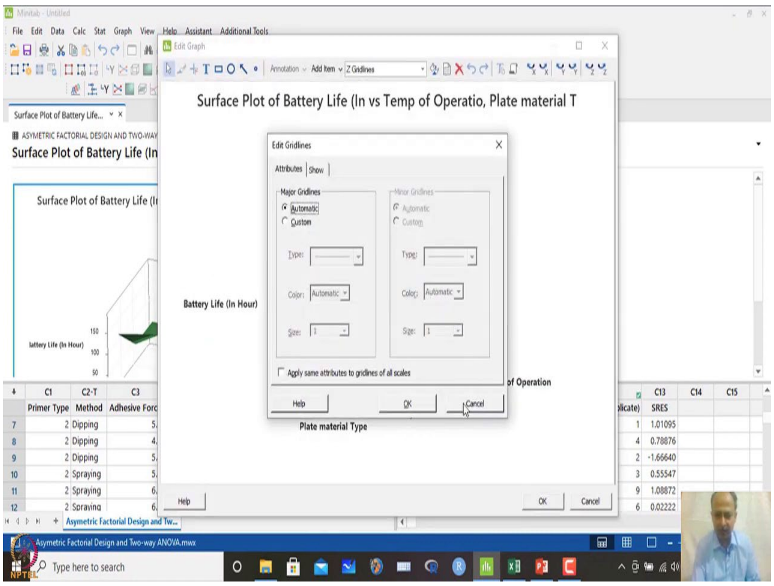

So, what I have done is that I have just changed the surface over here.

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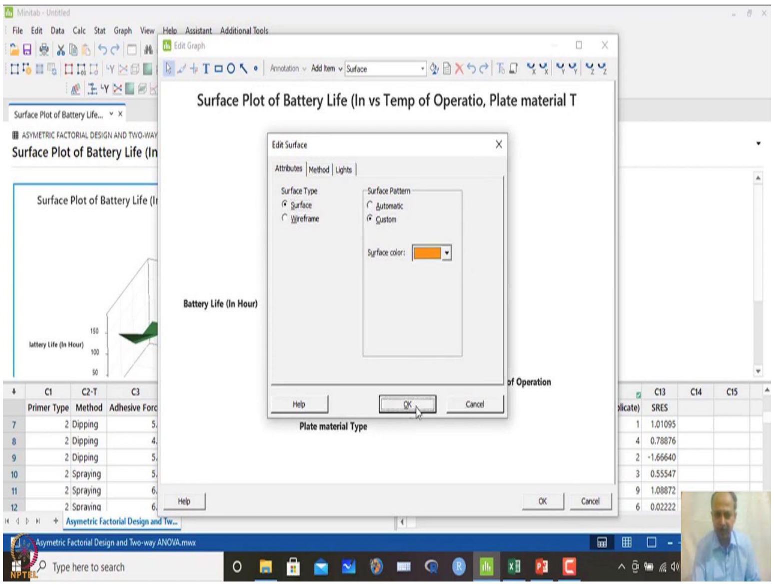

So, customize this one and I have made the surface like this.

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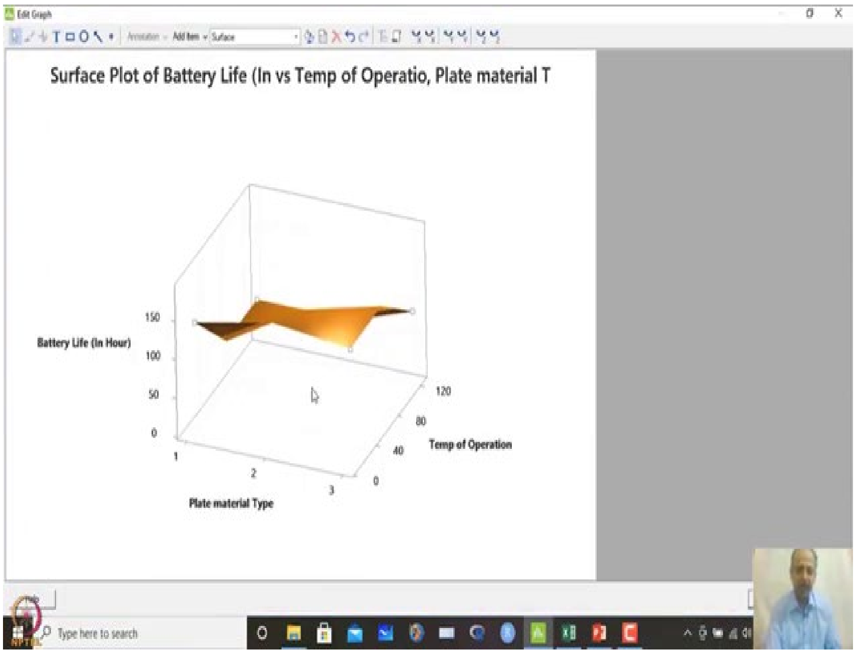

if you take a top view of the surface then what we get is a contour plot. Contour plot is also very important when we are talking about optimization.

So, it is like you are seeing a top view of a mountain.

If you see from the top, mountains will have different surfaces. You will see the altitude along Z-axis. Certain planes will be at same altitude. So, contour plot is an important plot which MINITAB also gives you.

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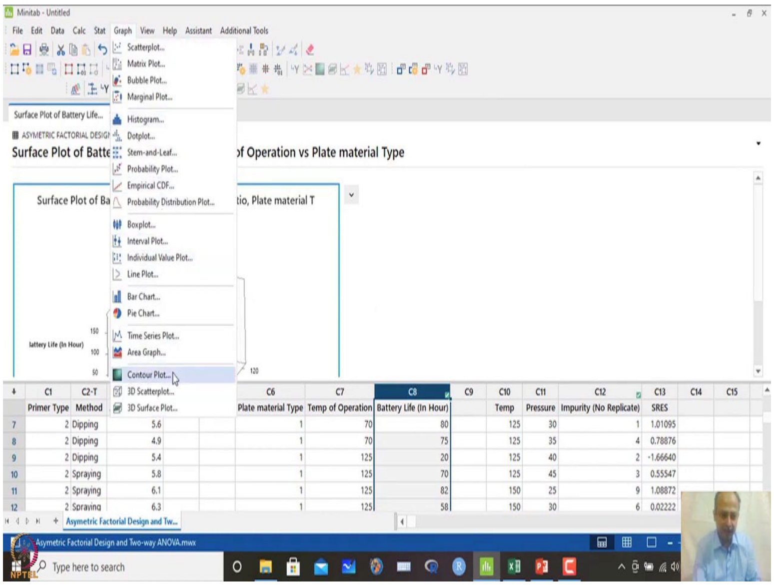

So, you go to *graph* and you go to *contour plot*.

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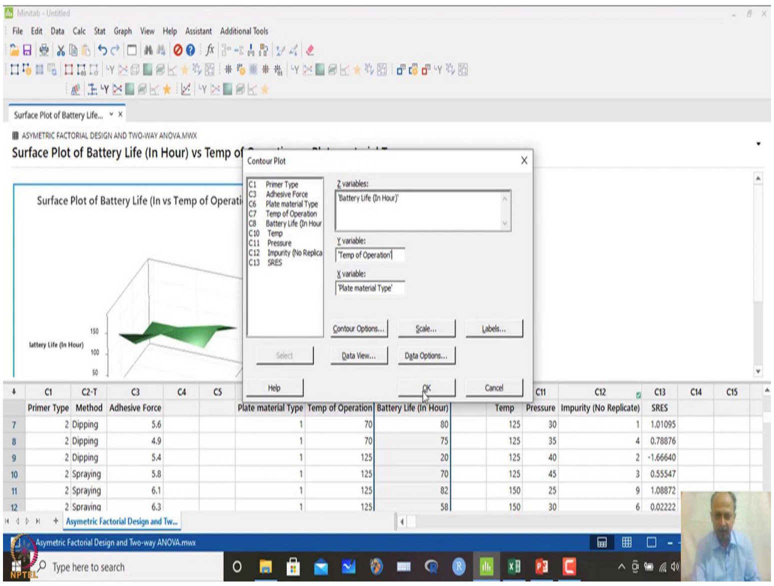

Here you mention battery life and temperature and plate material types. Generally the variable should be treated as continuous variable for the contour plot. But for the sake of simplicity we are doing this. We will take another example where all the variables are continuous and that case it will more relevant, but now just showing you the options that we have.

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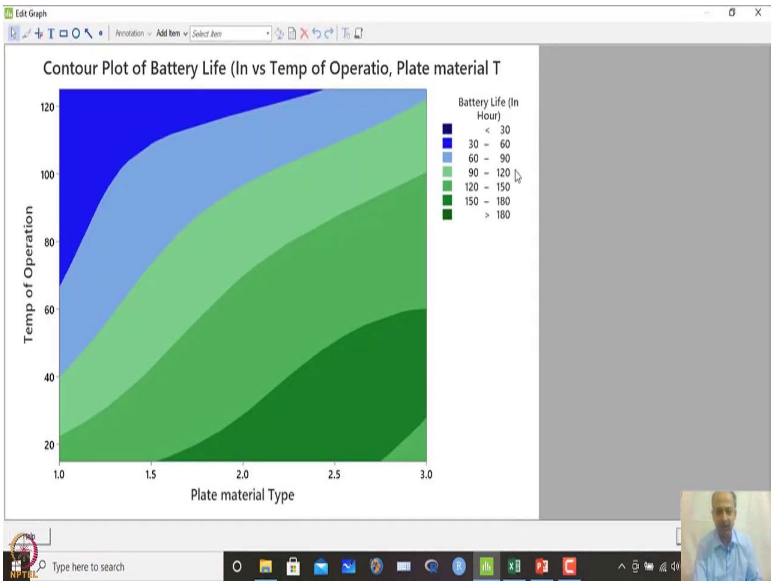

So, here there is an options of contour plot like this. So, where the battery life will be maximized? Battery life is over here on the right hand side. What you see is that greater than 180 what is expected is dark green zone that you are seeing over here, plate material 2 or 3, and temperature range around 15 will maximize battery life. So, contour plot is possible, but one of the variable is discrete over here. So, let us not do this one over here. But I just showed you that there is an option of contour plot which is also used for when defining the region which is where the optimality lies basically ok where to see basically.

So, this is contour plot options is there and these are the things that you can do when one is categorical, one is continuous variable. So, these are the; these are the possibilities what we have then we have another example over here at the end what we are having is that.

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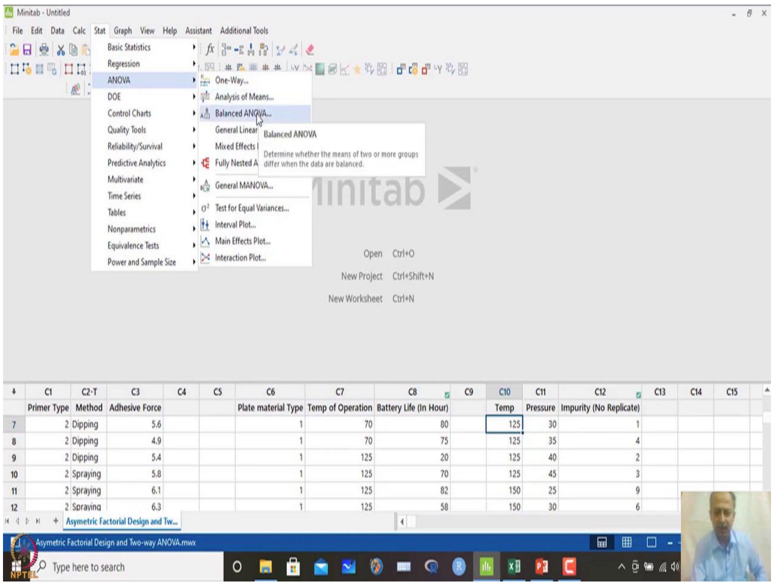

We are having another example over here where temperature and pressure is given. So, this is also another example.

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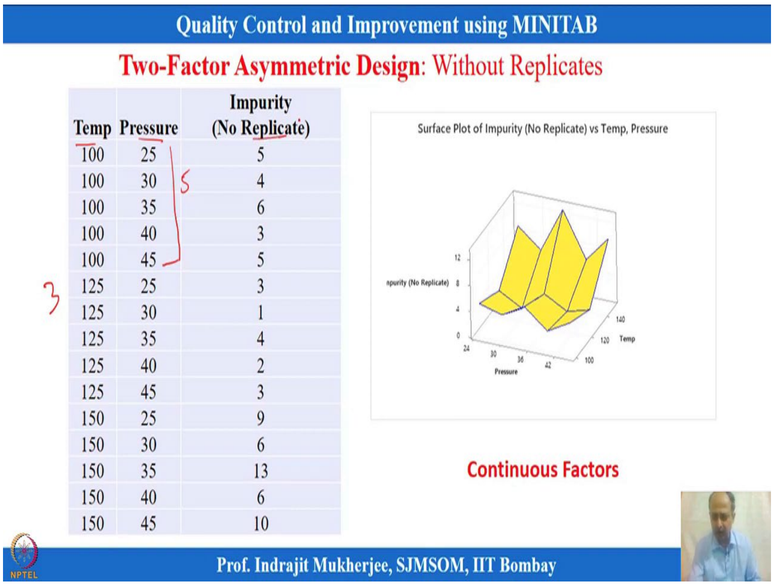

So, this example and this is a two-factor experimentation. We want to minimize the impurities over here. And we have different combinations of temperature and pressure. So, temperature is at 3 levels over here and pressure has 5 levels over here. So, it is asymmetric design what you see over here.

There are 15 experimental trials. There are no replicates. We want to analyse this data. So, in this case this is the data set that we are having temperature, pressure and impurities over here. So, what we will do is that let us go directly to the analysis of variance and let us try to do and see that because there is one replicate.

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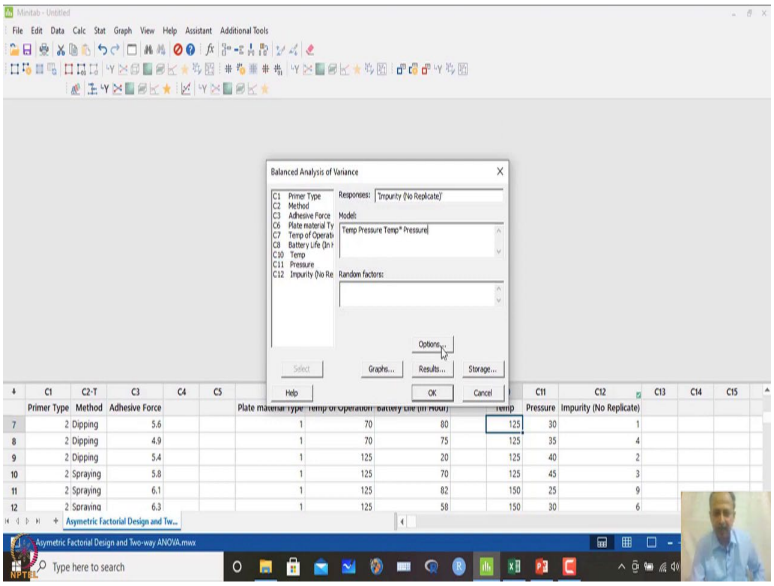

So, we can also go for balanced experimentation over here only thing is that what will be the outcome that is of concern for us. So, in this case response is impurity and the model variables are temperature and pressure over here and let us say I want to estimate the interaction between temperature and pressure.

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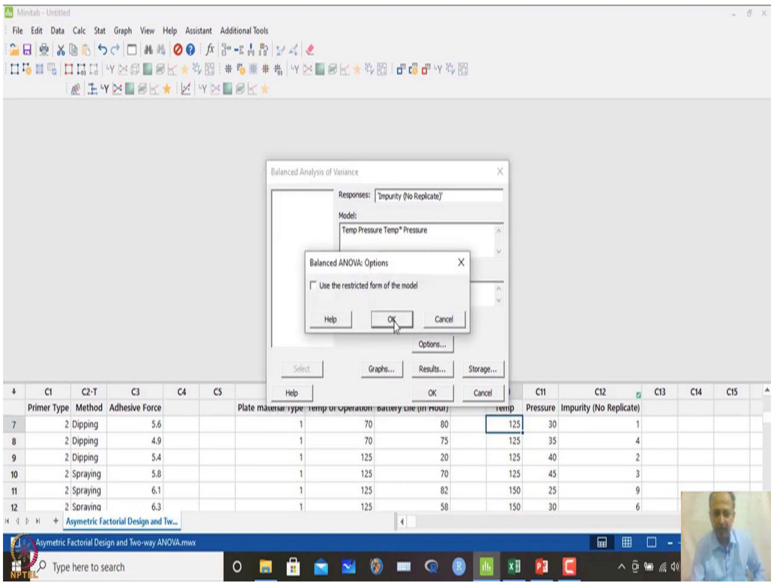

And these options we will give over here and graphical options we will place like this and then we place ok over here.

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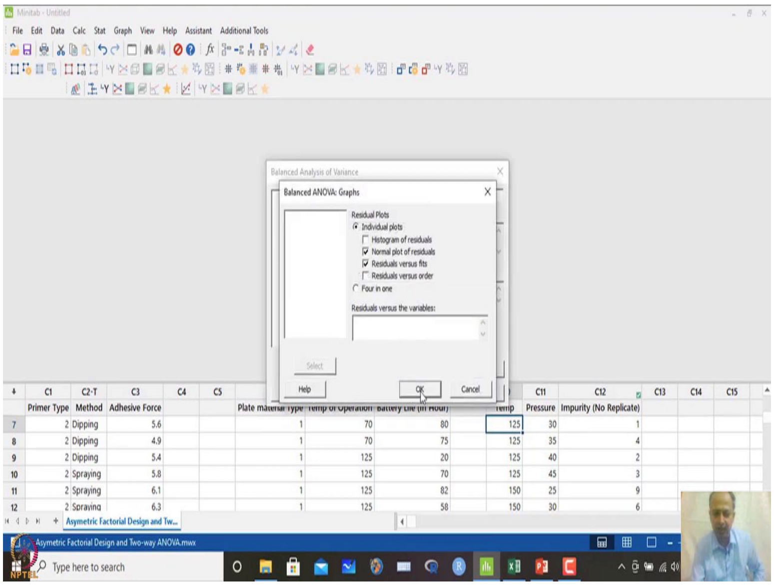

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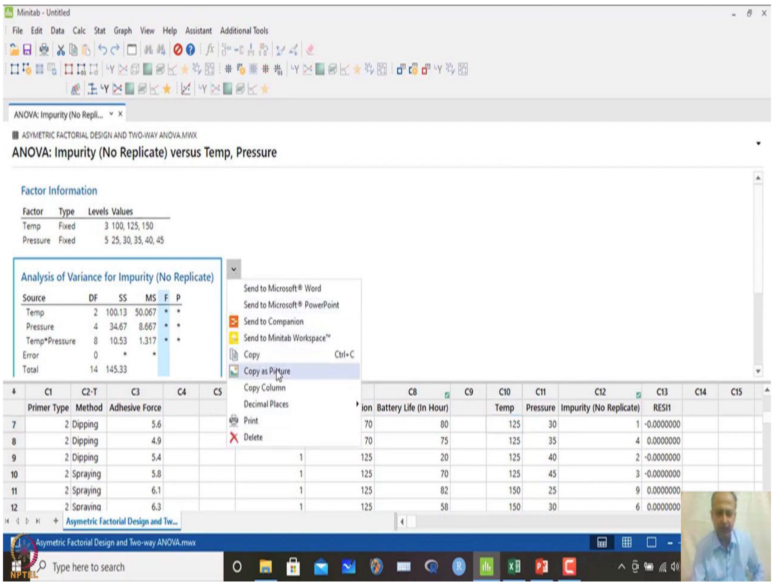

What will happen is that you will see that if I copy this one as picture.

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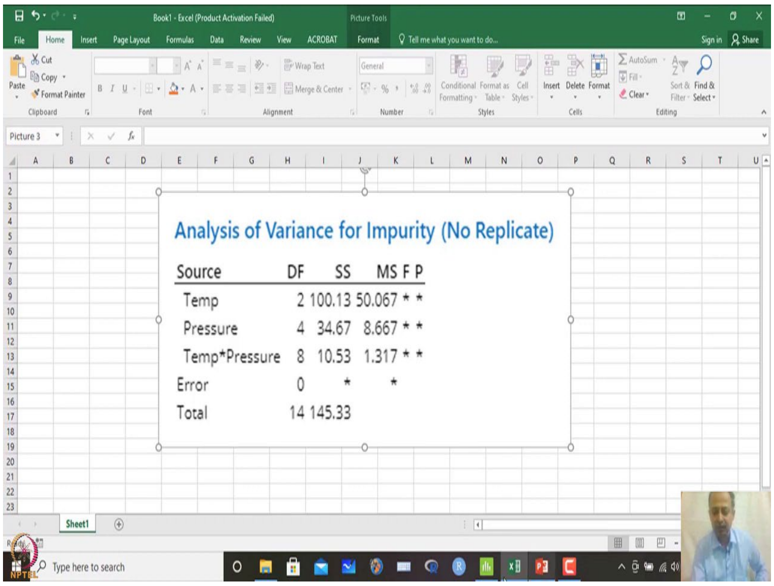

And if I paste this over here you will find the estimation is not possible over here as there is no replicates. So, temperature is at 2 levels over here ok degree of freedom is 2, pressure degree of freedom is 4.

So, total degree of freedom is 6 that is consumed over here by these two factors over here and total 15 experimental trials was done because 5 into 3, 15 trials are done and so, 14 degree of freedom is the total degree of freedom. So, if we subtract 6 from 14, we get 8 degree of freedom.

And if you place temperature and pressure with 8 degree of freedom then there is no error degree of freedom. If there is no error degree of freedom I cannot calculate mean square over here if I cannot calculate mean square I cannot calculate the F values and p values over here. So, it is not possible to see temperature and pressure information over here.

So, in this case we cannot do this. So, we have to confirm now whether the interaction is present or not. So, how do we calculate interaction? It is already given in Montgomery's books how to calculate interaction in case of single replicates what is to be done. So, I am not going to that details. What I will do is that, I want to see whether the interaction is prominent or not graphically whether I can see that one.

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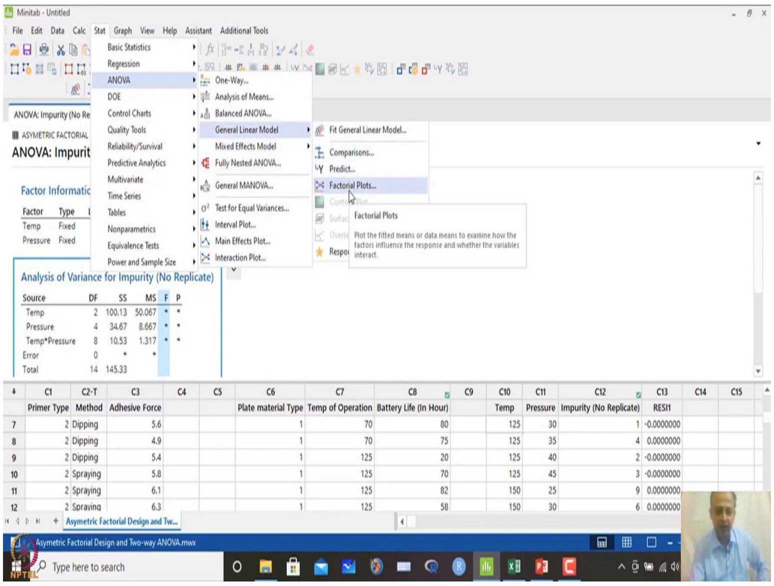

So, if I go to *stat* and *ANOVA* analysis over here. So, interaction plots is possible over here. So, or we can directly go to general linear model and we can go to factor plots also.

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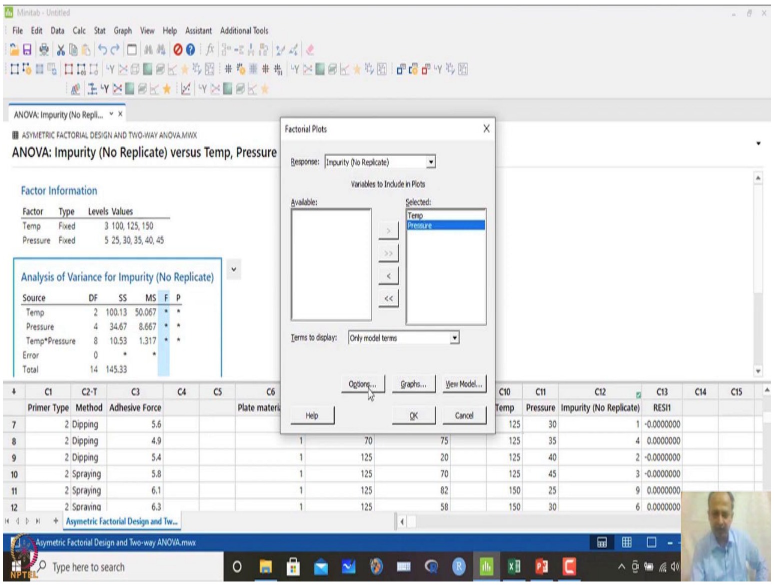

And we can see the plots like that. So, temperature over here. This is this will be impurities that we want to check and then temperature and pressure are the variables.

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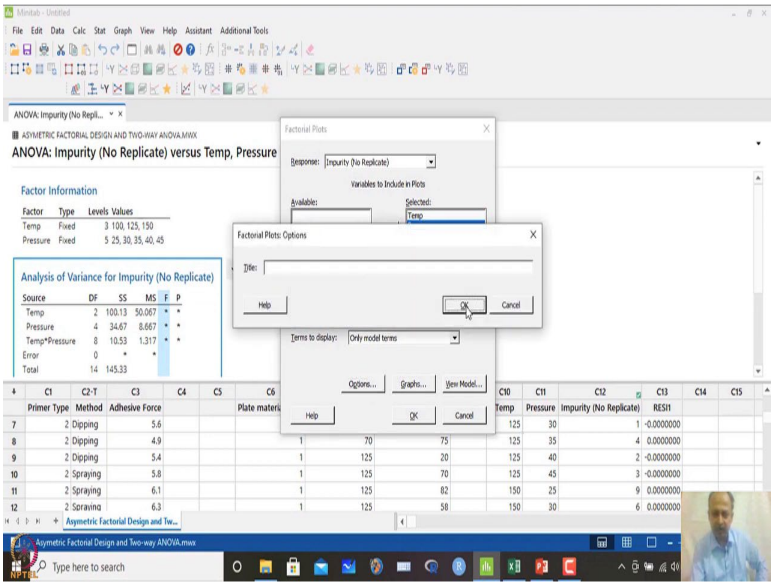

And in options titles we are not doing anything.

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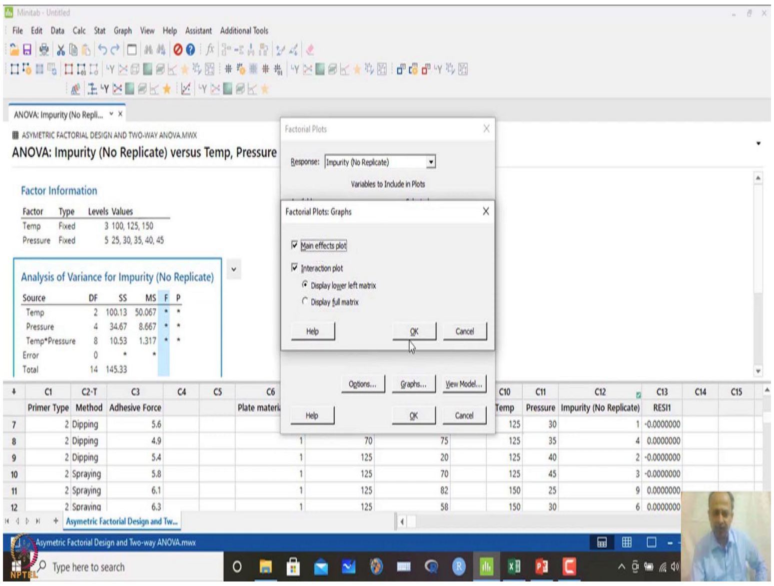

So, graphically we are just defining main effect plot and interaction plot.

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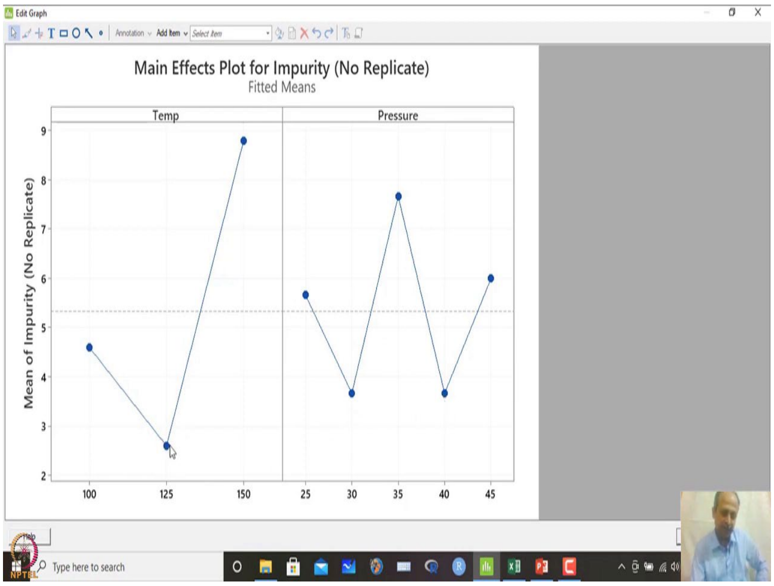

So, we have a zigzag pattern and there are two locations where impurities will be minimized, pressure at 30 or at 40, and temperature at 125 seems to be the condition.

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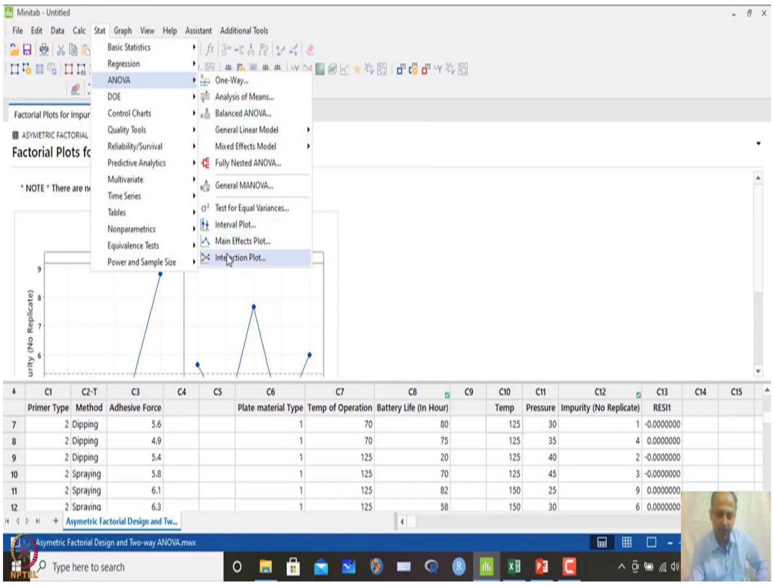

So, in this case interaction plot is not given, but we can go over here and go to interaction plots over here.

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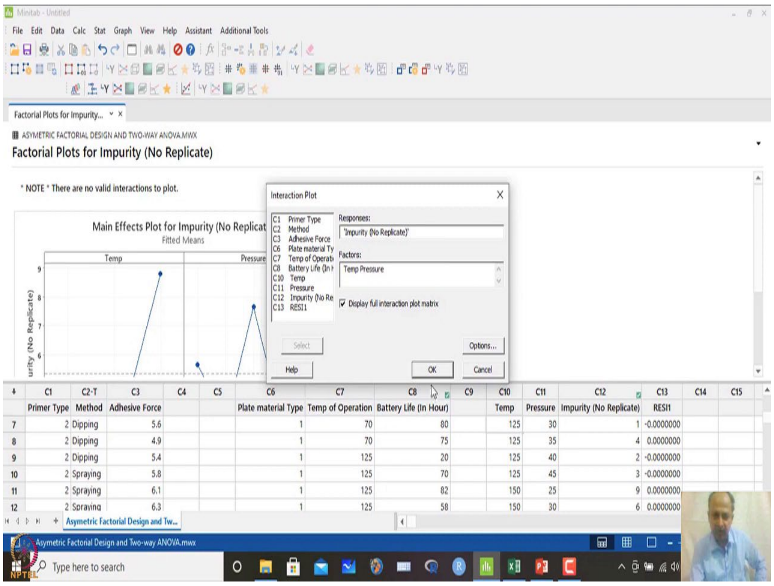

And using this what we will do is that we will use impurities and we will give temperature and pressure over here display full interaction plot.

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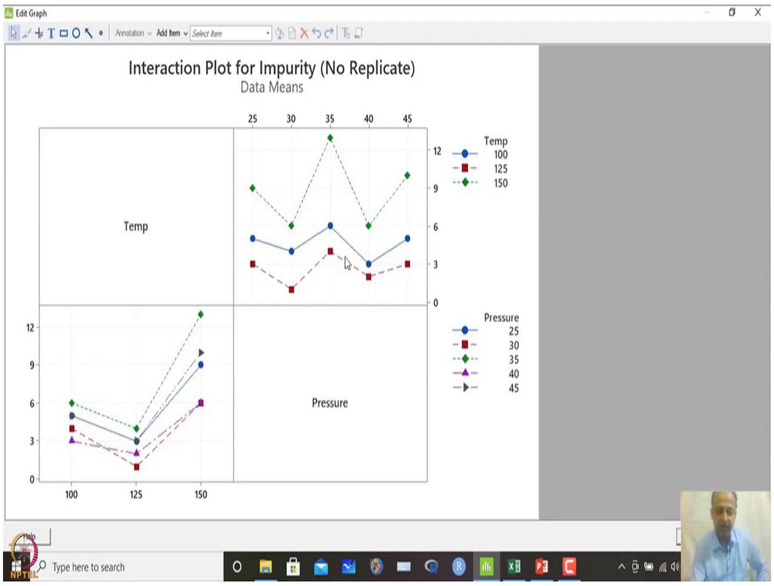

If you do that you will you will find some displays like this in the interaction plot when we are going by that. So, this is the zigzag pattern what we have seen. So in this case what do you see is that patterns are not intersecting each other most of the time that are patterns are more or less parallel like that.

So, we can expect that there is no interactions as such, but in the Montgomery's books also this was proved that there is no interaction between the variables temperature and pressure over here.

So, these things are confirmed by a separate test and MINITAB does not give you options for that. But what I am trying to say is that two variables are there and I can graphically see whether interaction is present or not. And we can also calculate that one using the mathematical model that is given in Montgomery's books.

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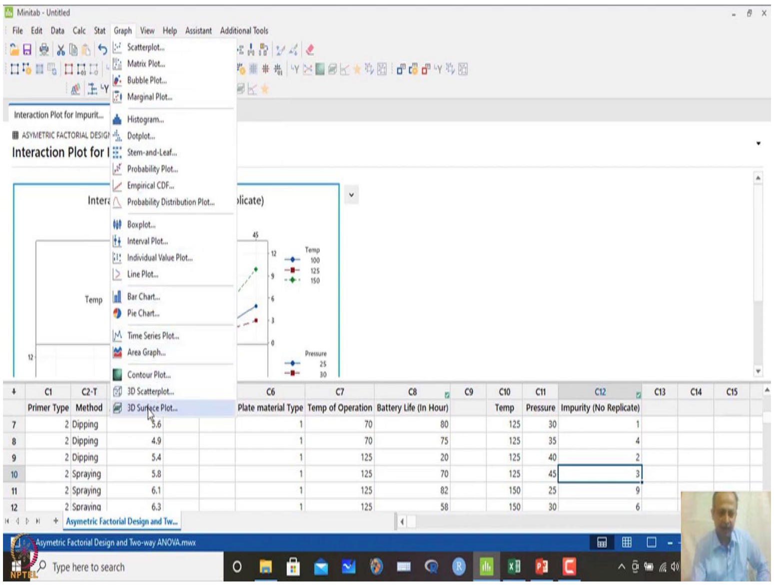

So, in this case we can graphically also see 3D surface plot that we are generating over here.

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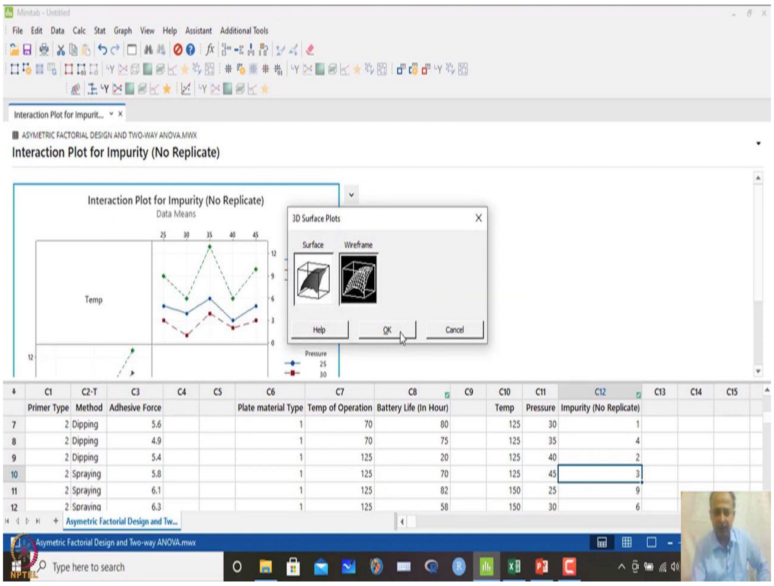

So, in this case may be wire frames also you can use.

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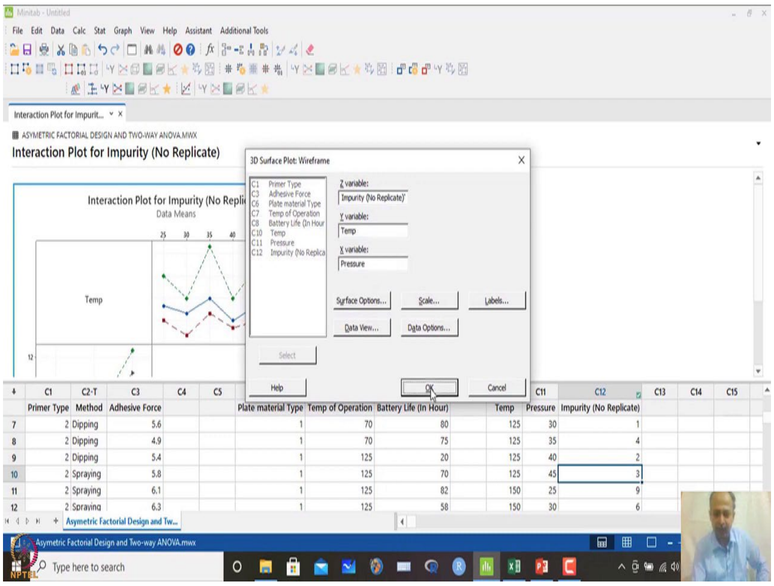

So, instead of this impurity we will take temperature and pressure over here and I click OK.

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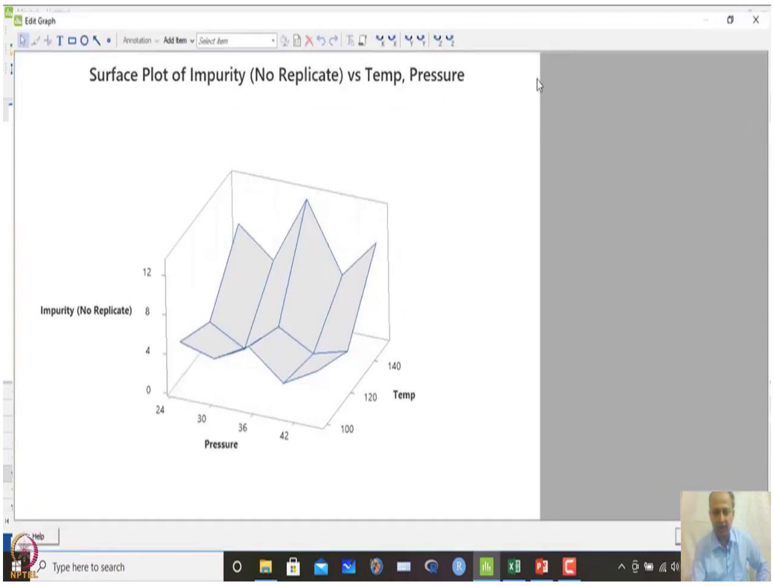

I will get some surface what zigzag patterns that we have seen.

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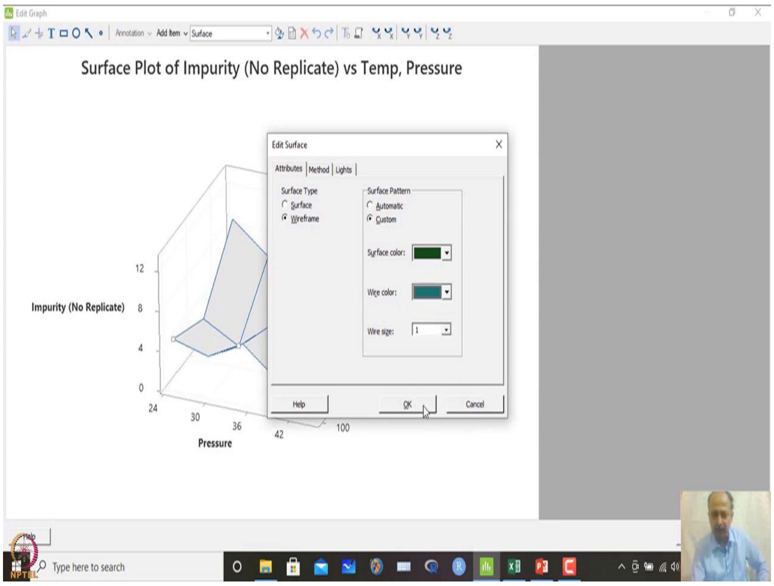

So, in this case these graphs can be changed and I can customize the surface patterns over here. So, may be some colours we can use over here and wire colours also we can use like this and we can click OK. So, this is the surface that we are generating over here.

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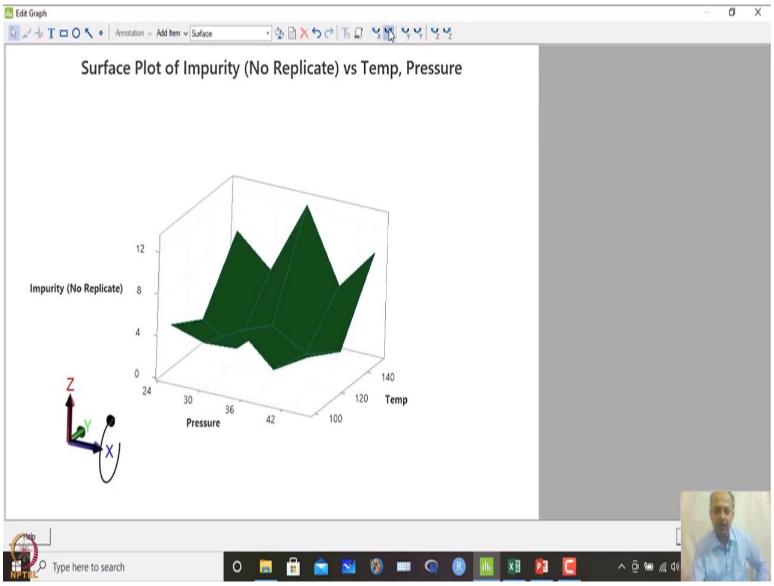

We can rotate the surface and we can see what is happening when I rotate this one. We can change the colour too.

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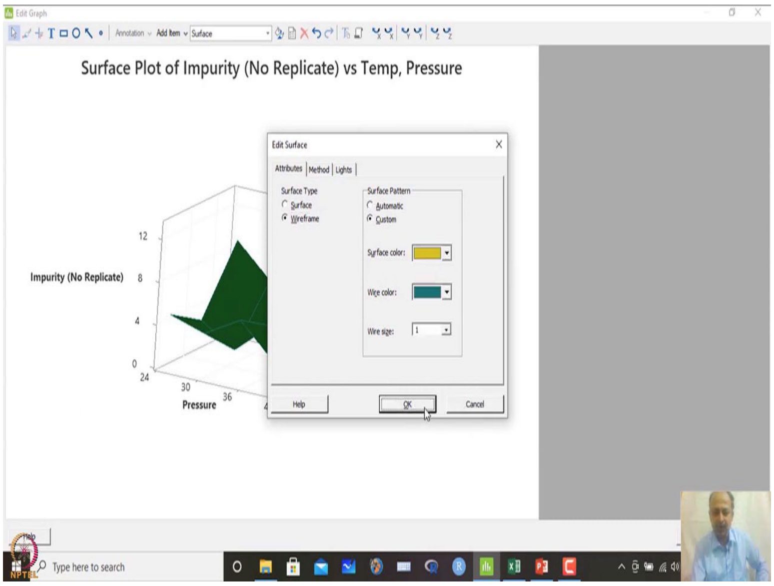

So, this is too dark surface colour we can change it to yellow let us say and we can change this one.

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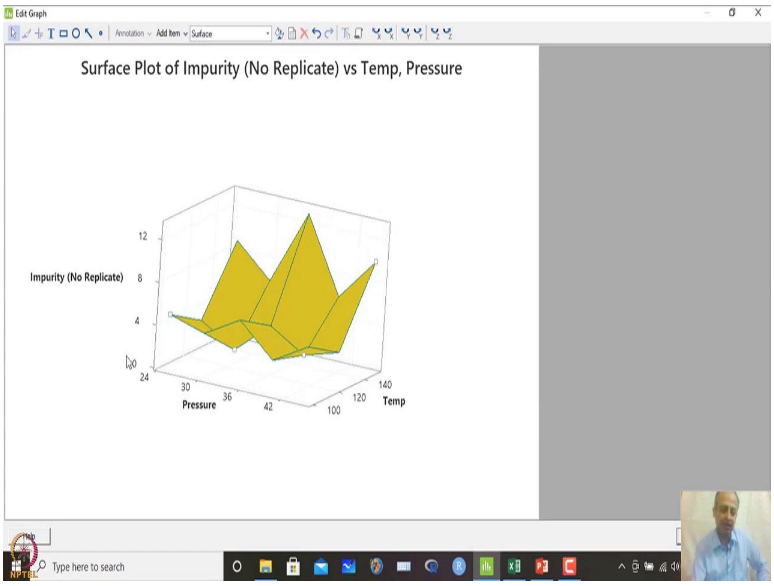

This is the surface that is been generated over here. So, there are two lower peaks that we can see one at 30 and one at 40 approximately around 40. So, this is the surface plot and when you we can also draw the contour plot over here.

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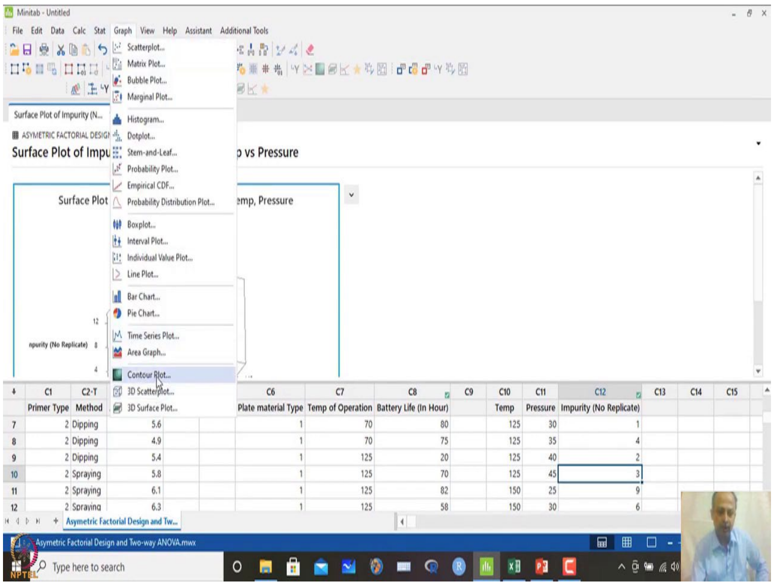

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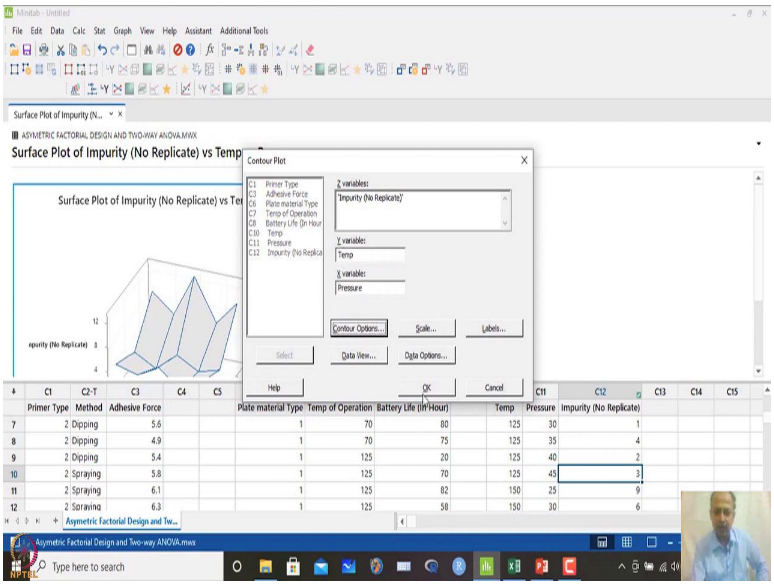

So, when you draw the contour plot it will be more easier to see.

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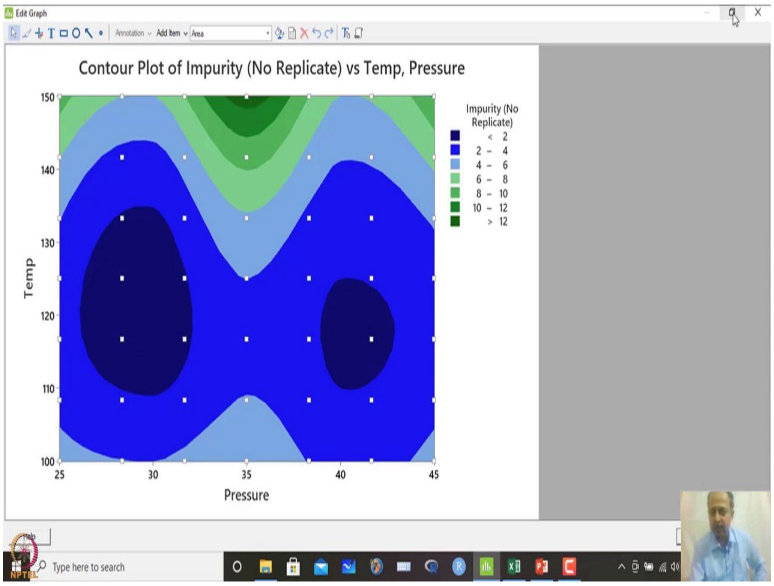

What you will observe is that there are two pressure points over here. So, in this case what you see around 30 and around 40 we are getting a impurity which is less than 2 like that.

This is the darkest position over here. So, around 40 and 30 the optimality is somewhere we can see the combination which is giving you optimality over here. So, in this case the combination can be 30, 125 or 40, 125 like that because what we have seen is that there is no interaction.

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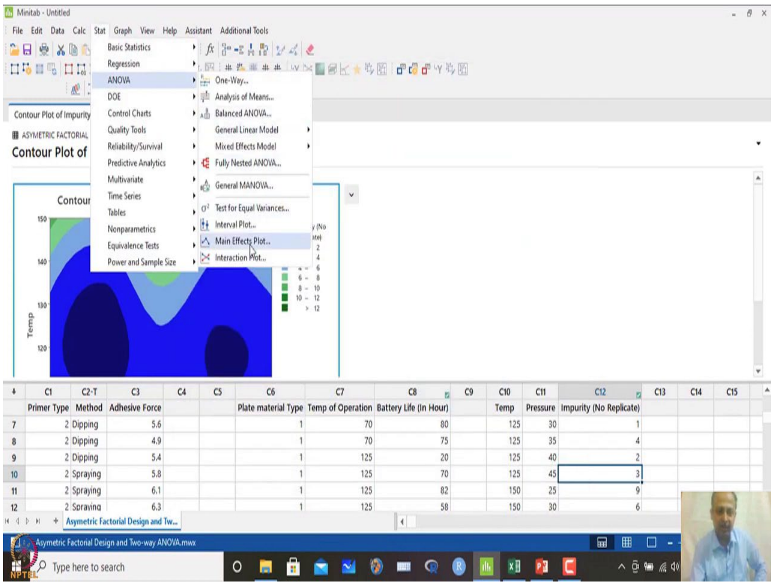

So, we can have a main effect plot and we can see so, in this case ANOVA analysis main effect plot.

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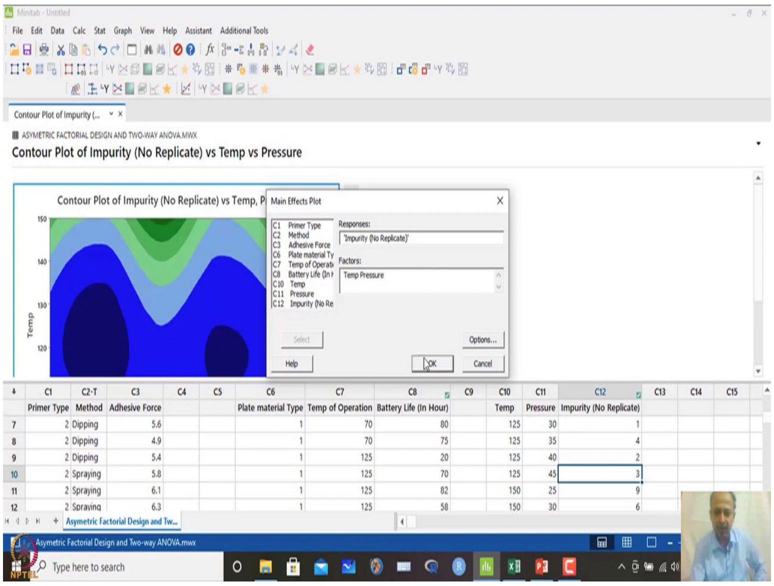

We want to see which is the combination which we should use. So, temperature and pressure like this and I click OK main effect plot.

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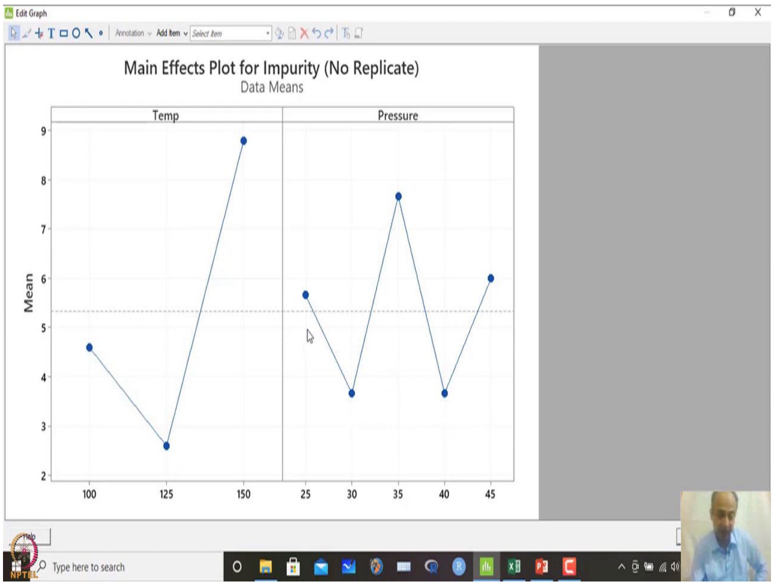

So, in this case 30 or 40 any of these options and temperature is coming out to be this if we enlarge this one the best combination is coming out where I want to minimize the impurities over here. What I can do is that take impurity because interaction is not prominent.

So, temperature is around 125 and pressure can be either 30 or 40 like that these are the two combinations that we can think of ok minute I have gives you another option over here because the variables are continuous over here the two variables are continuous and also the CTQ is continuous over here. MINITAB also gives you an option for optimization of this what should be the combination of temperature and pressure that will give you lowest impurities like that.

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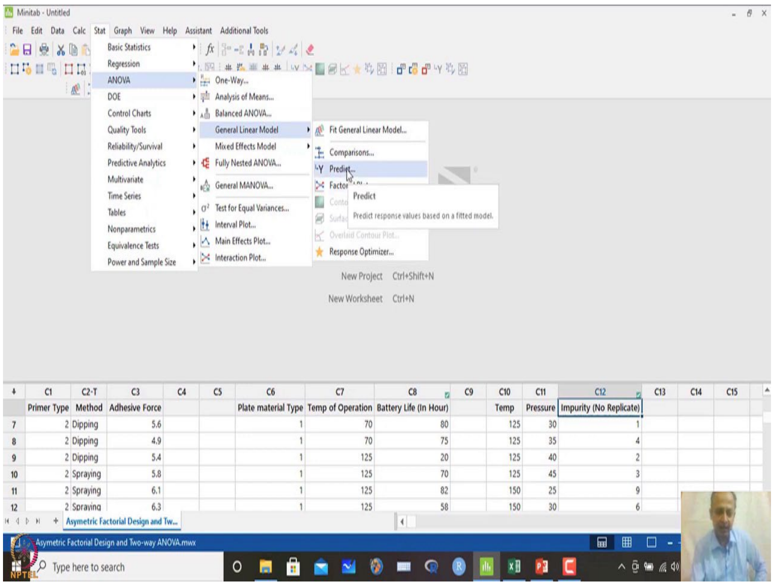

So, in this case what you can do is that in *ANOVA* analysis, *GLM,* there is a option of there is an option of response optimizer over here and there is also a predictor that you can also use over here.

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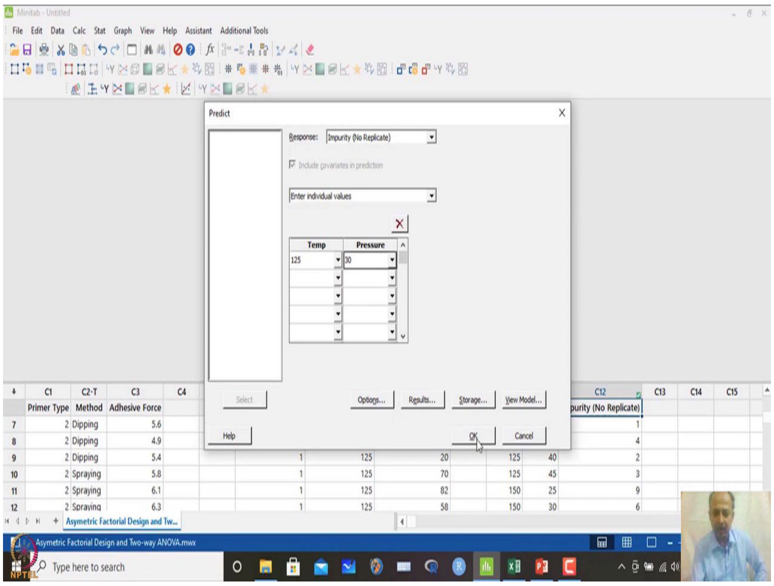

So, I can take a combination of let us say temperature over 125 and pressure is approximately let us say 30 and what is the predicted value.

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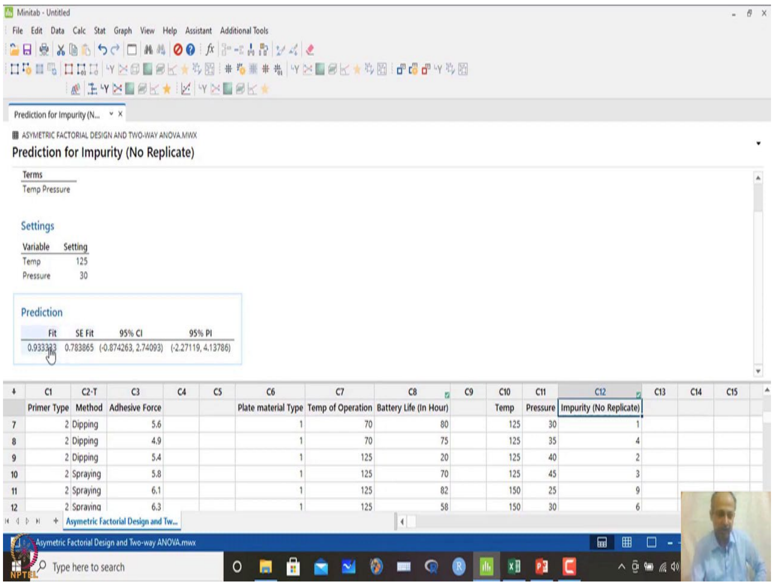

What we can see over here is around fit value is 0.93, 0.933. So, near to we can assume let us say near to one like that. So, impurity is less than two what we have seen in contour plot also. So, prediction seems to be ok.

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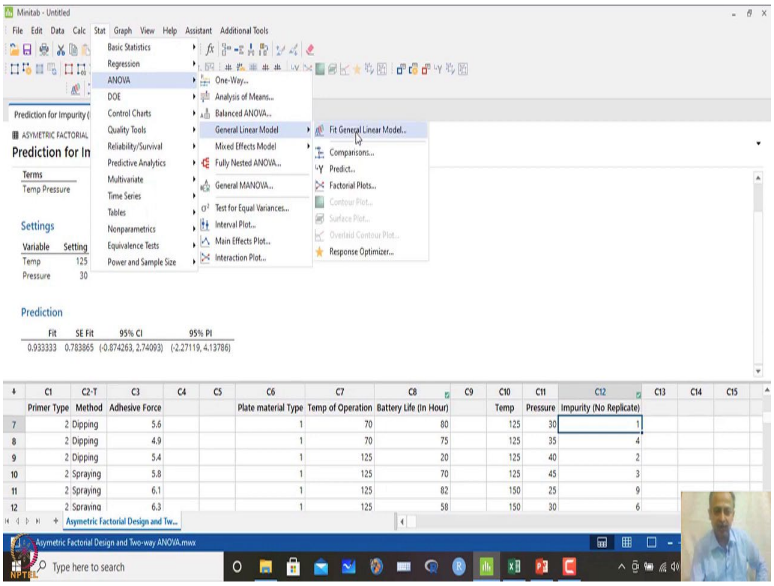

And GLM models also we can develop.

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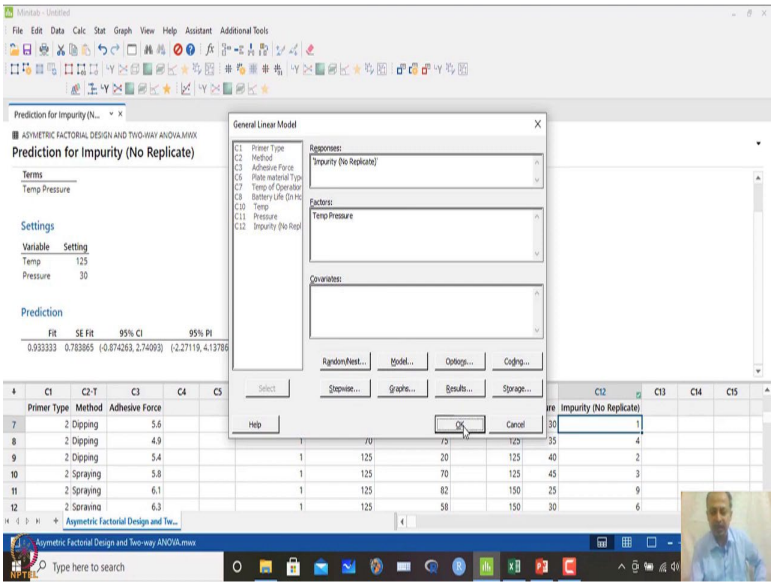

Only thing is that I have to use this impurity over here and I have to see what temperature and pressure over here and the model will not take interaction. So, that is not required.

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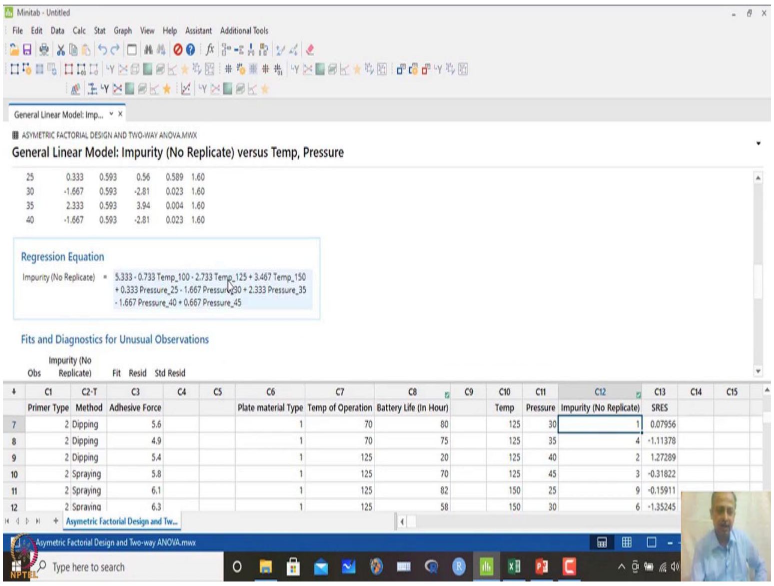

So, in this case we will have a generalised linear model and in this case we can make a prediction out of this.

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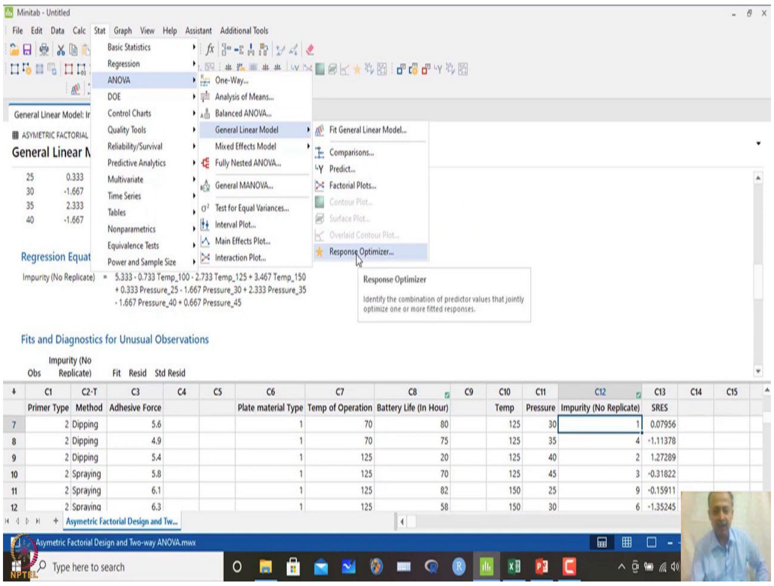

And I know this MINITAB does it automatically for you when I am; when I am mentioning predict. So, it is developing the equations and based on that it is predicting basically. So, what I am interested in response optimization; that means, this is a response surface that is developed with the CTQ and temperature and pressure over here. So, I want to identify which is the optimal condition.

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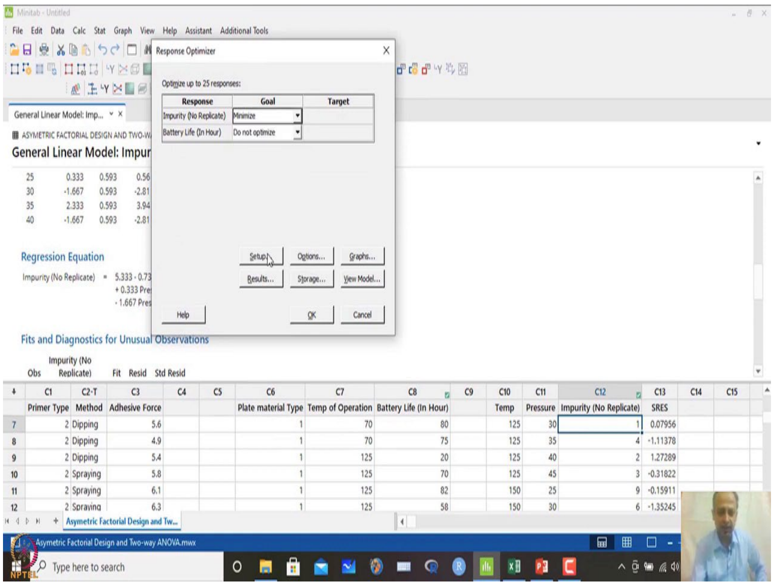

So, MINITAB uses an optimization techniques to do that. So, I want to minimize let us say impurities over here.

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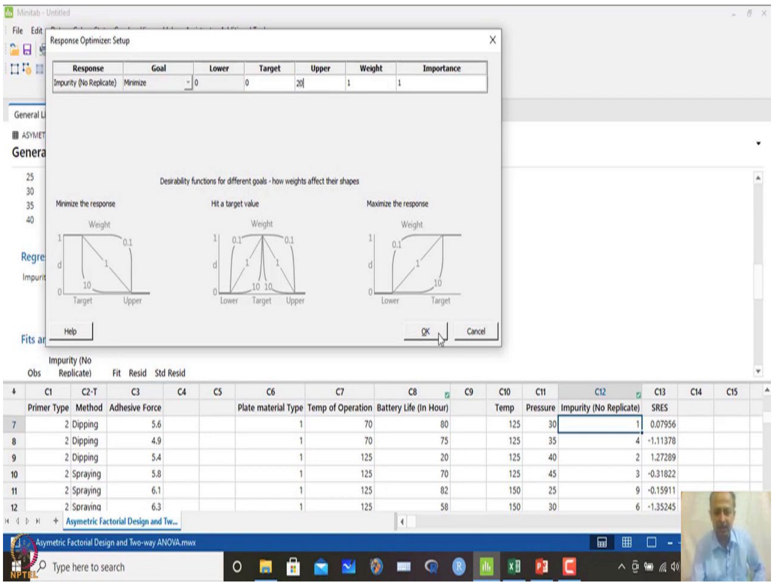

So, in setup what you have to do is that, this MINITAB automatically takes, but you can change the upper limit over here. So, if you want upper limits can be changed and target may be we can make it 0 and this may be upper bound may be 20. And this depends on you. So, there is no as such hard and first rules over here.

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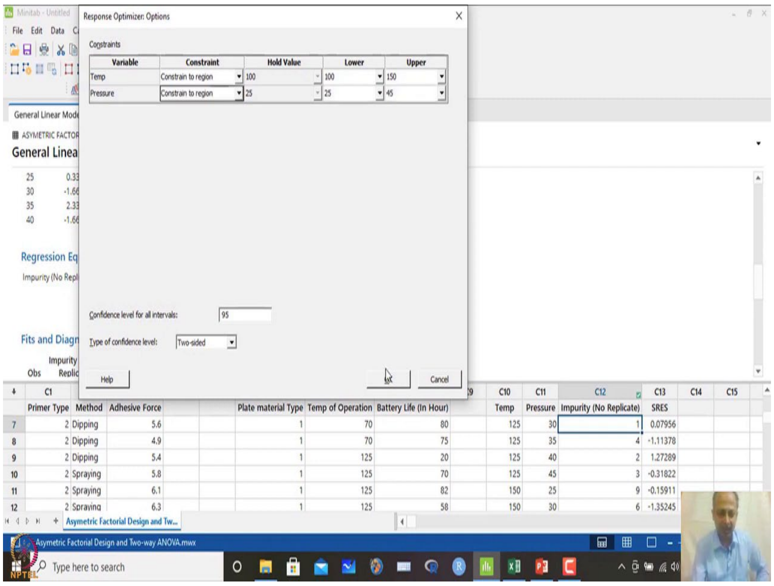

Whether you want to apply constraints over here because optimization we are doing and it will search around the surface that will be generated and based on that. So, I can give constraint to the region. So, within the region of experimentation let us constraint to the region over here.

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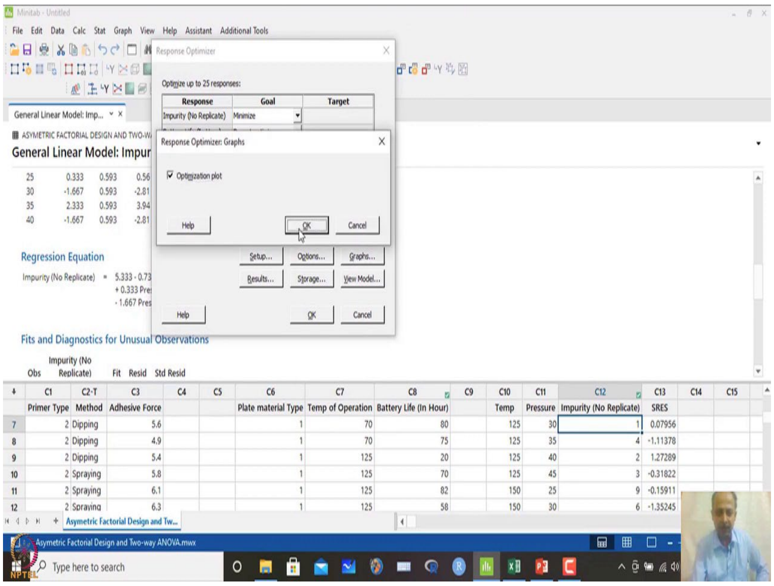

In this case I will click ok and graphically if you want to see optimization plot will be given and if you want to store something we can store and then we click OK what will happen is that.

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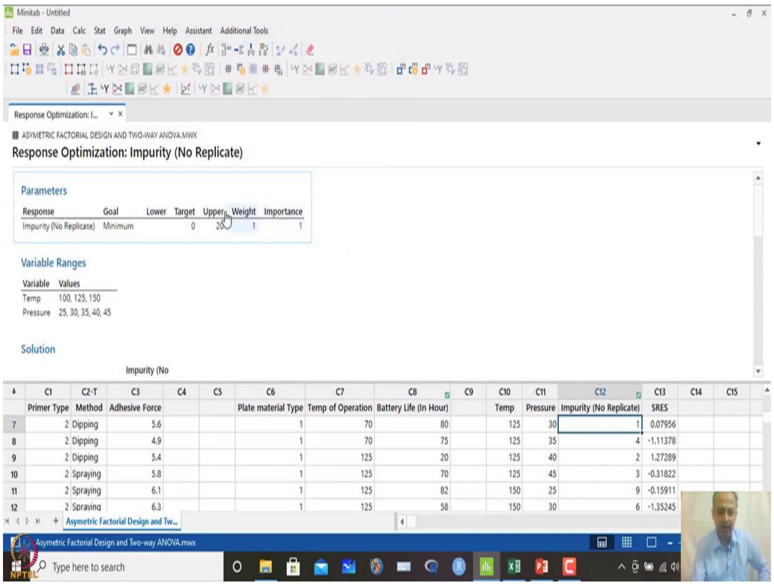

It will give you a best combination like that. So, the best combination that is given by this MINITAB software is solution 1.

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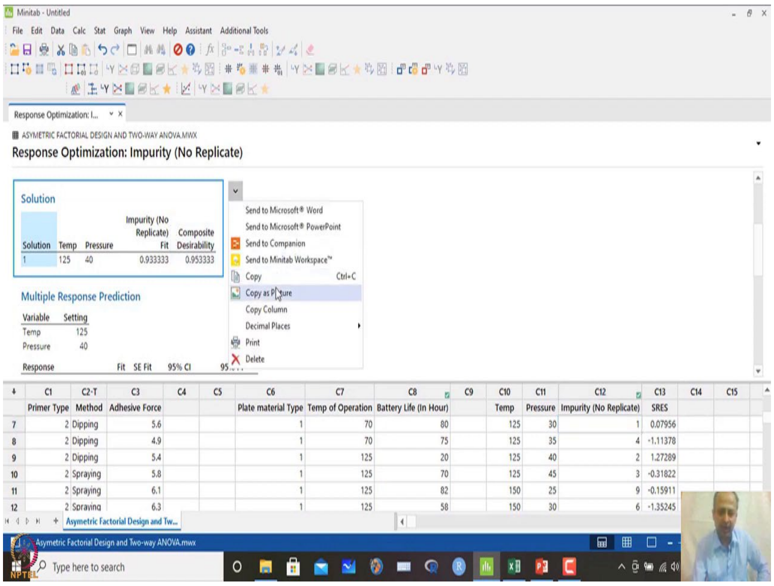

One of the solution is temperature combination of 125 and pressure at 40 that is giving me one indicator over here what I will just highlight over here which we will discuss afterwards.

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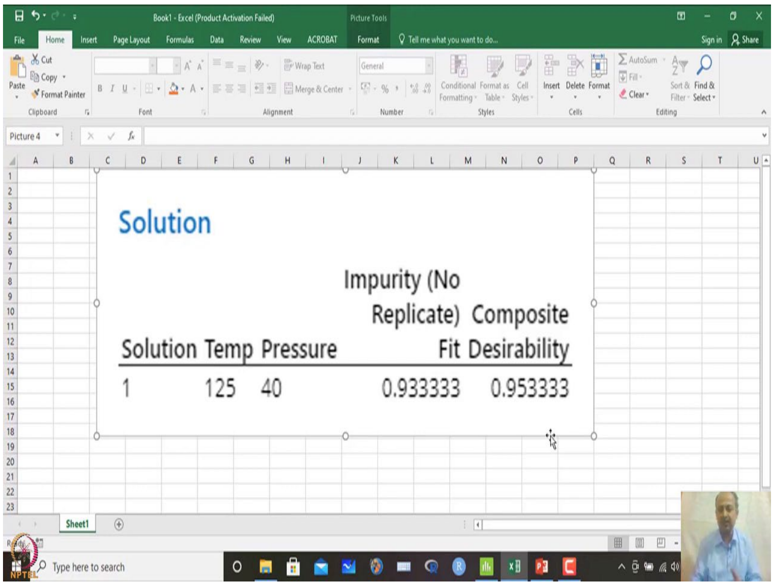

And this is the indicator that MINITAB uses which is known as desirability which is known as desirability and this is the last quantity it is close to one indicates that that is the best solution we are near to the best solution basically ok we are trying to minimize and if the score is near to 1.

So, this is one of the measures that is used which is known as desirability and one of the measure here it is composite desirability, but we have only one CTQs that is why we will get the same measures of desirability and composite desirability over here that we will discuss afterwards. But my intention was to show that MINITAB can give you some solution if CTQ is continuous and temperature and pressure is continuous.

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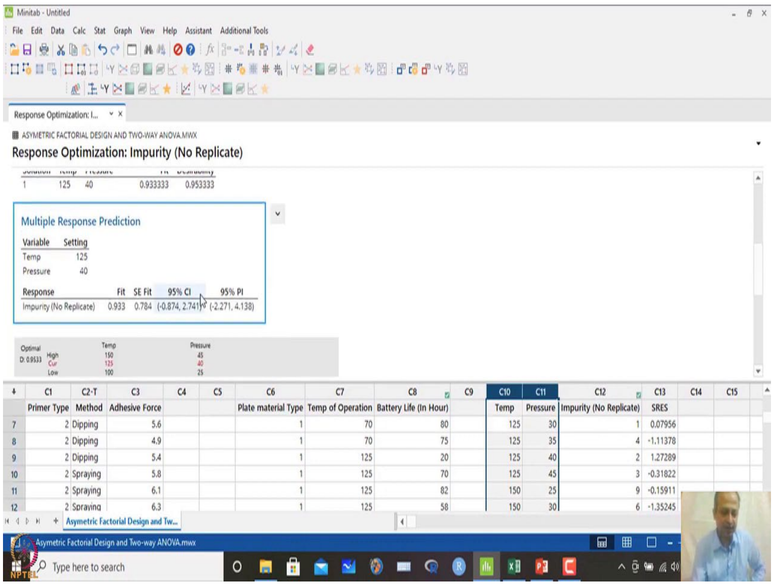

MINITAB can search on the surface using optimization algorithm and it can give you the best possible combination that is temperature at 125.

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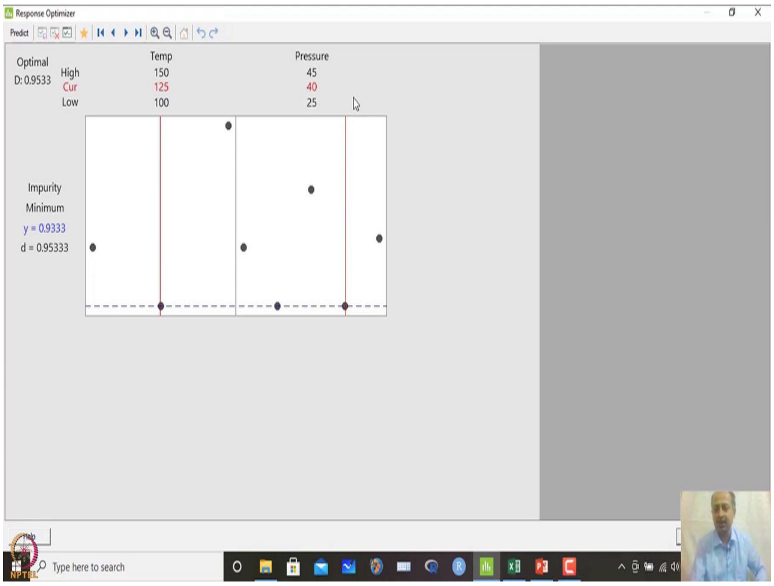

So, this you can see temperature at 125 and pressure at 40.

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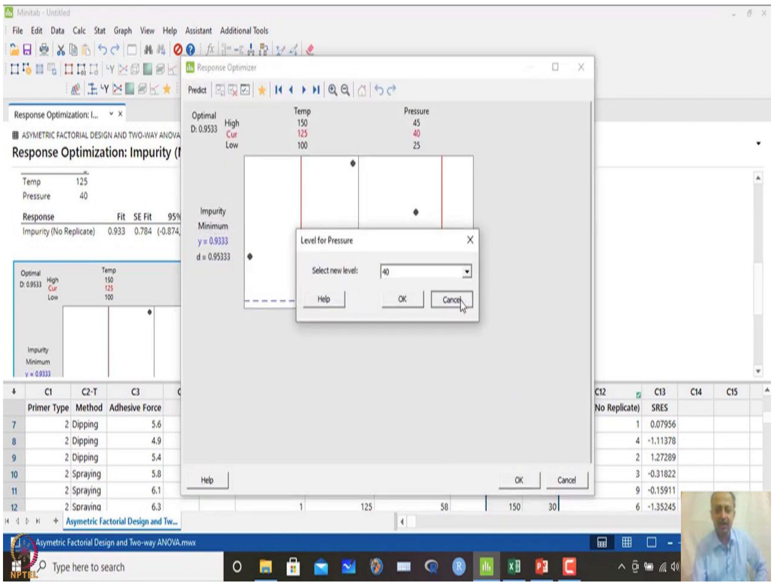

And this you can see that there is a red, red highlights that you are seeing over here that is best combination. MINITAB has figured out like that and it will give you a y values of approximately 0.9333 ok. So, that is near to one we can assume like that impurity is less like that.

So, MINITAB gives you and this is the best option MINITAB using the search algorithm that it is using it will give you some best conditions. So, what we have done over here in two way analysis of variance, we have taken factors which are categorical and CTQ which is continuous.

So, the experiment was done and asymmetric design was used, and in this case there is no replicate basically n is equal to 1 means there is no replicate and how to analyse that one how to figure out whether interaction is there or not and how to see and how to optimize the data sets like that and find out the best combination of temperature and pressure like that.

So, those things are discussed over here more complex relationship and understanding of this theories can be seen using you can see Montgomery’s books like that. So, we will stop over here and we will move on to a new topic. So, now, we are entering into design of experiments, but before that what is required is that we need to know one important topic which is known as measurement system analysis.

So, we will just discuss measurement system analysis and why it is required. Because before I go into design of experiments this is one of the area we should also understand because that is very helpful because if the instruments is not correct then the measurement that we are taking has no values basically.

So, until and unless we measure accurately and that has to be ensured. So, after experimentation this CTQ value that you are getting if the instrument is not correct these values will be different and the results will be different. So, the purpose will not be solved. I will not get the optimal condition and pseudo-optimal condition we will get. So, that is required. So, what is measurement system analysis, we will try to see in our next session.

Thank you for listening.