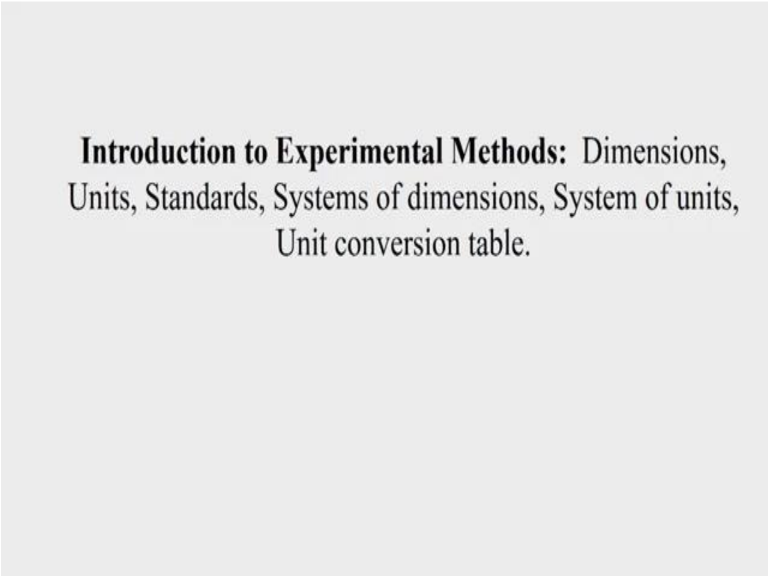
Experimental Methods in Fluid Mechanics
Dr. Pranab Kumar Mondal
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati
Lecture – 2
Dimensions, Units, Standards, Systems of dimensions, System of units, Unit conversion table

(Refer Slide Time: 0:36)



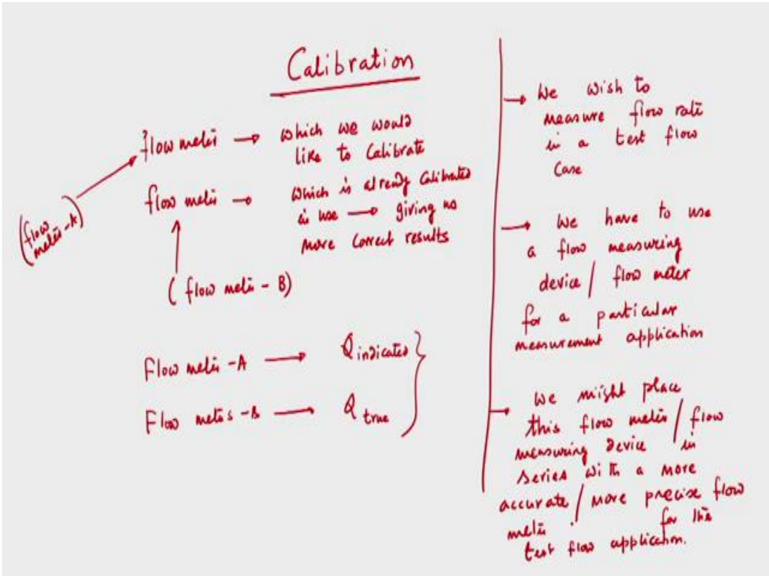
Good afternoon! We will continue a discussion on Experimental Methods in Fluid Mechanics. Today, we will discuss about the dimensions, units and unit conversion table, systems of dimensions, systems of, system of units. So last class, we have discussed about several terms which are important, when, these are important to capture while we are capturing data from experiment, experimental, during experiments.

Many a times we need to analyze experimental data and during that time we need to know those terms, at least accuracy, precision and because we will be doing statistical analysis of experimental data. We will learn how we can fit curves, how we can remove data from the captured data and why we will be dealing those, that time we need to know what do we mean by error and what is the uncertainty. And before we go to do the statistical analysis, we need to a priori about the accuracy and precision of those, of the instrument and equipment.

So, today, I will be discussing another important terms, that is calibration. So this is another important term in the context of experimental methods, I mean in particular, whenever we are using any device, any instrument to measure any data in any condition, we need to know whether that particular device or instrument is giving us the correct results or not. How can we check it?

And for that, we need to know what do we mean by calibration? Why it is so important in the context of experimental analysis and knowing that it is very important and integral with the experimental methods, experimental techniques, how we can do this particular things, I mean calibration for, to check the effectiveness or accuracy of a particular device.

(Refer Slide Time: 2:43)



So, today we will discuss about what do we mean by calibration. This is, I will write the definition, of course, but before that we need to know why it is so important. I mean, we should discuss about this taking an example, but at least we should know why it is important. So, I will discuss briefly about it. Suppose, we wish to measure flow rate in a test flow condition and for that, we used to use a flow meter, for that particular measurement of that particular measurement application.

So, what can we do? So that means I can, I would, we wish to measure flow rate, so I am writing here, say we wish to measure flow rate from, or in a test flow condition, in a test flow case. So, basically, we are doing test say liquid is transporting through a pipe or through a channel, we would like to measure flow rate and that measurement if you would like to do, what you need to do? Essentially, we have to rely on a particular instrument, a particular device, that device or instrument will give us reading.

So, for that, what we have to do? We have to use a flow measuring device. So, basically, we have to use a flow measuring device, flow measuring device or flow meter. We have to use a flow meter for a particular measurement application. What is that measurement application? That is, I, that is what I said that maybe liquid is flowing through a pipe, we need to measure the flow rate. So for that, what we have to do?

So, we have to rely on the flow meter or flow measuring device and we have to record data from that. So what we will do? We have to, we might place this flow meter or flow measuring device in series with a more accurate or more precise flow meter in series for the test flow application. What we have to do? That is what I told that I have taken example, I would like to measure flow through a pipe.

We have to rely on the flow measuring device or flow meter. What we will do? We will place the flow meter or flow measuring device by which I will record data in series with a more accurate or more precise flow meter for the test flow condition, for the test flow condition, knowing a priori that the more accurate flow meter or precise flow meter gives us the correct results.

So while we are thinking that okay, we can place one meter, the meter which we would like to calibrate. So we would capture data that meter is used in that flow condition, we will capture data using that flow meter and our objective is to calibrate that flow meter. Since, we would like to calibrate it and that is why we need to place it in series with another meter. That meter will give us, and we know that the meter, that meter is giving more accurate, more precise results. So this is what is done.

Now, what we will do? So if we start experiments, then since these two meters are connected in series in that, in the test flow case condition in this test flow application, so we can, we will, rather we will get data from both the meters. That means we will get data from the meter which we would like to calibrate and also we will get data from the meter which is giving us more accurate, more precise result because we know that this meter is accurate one.

So, knowing fully that the meter is calibrated, that meter is giving correct result, we have placed that meter. So, now we have two different meters. One meter, I am writing one flow meter which we would like to calibrate, which we would like to calibrate. Another flow meter which is already in, already calibrated with other flow meter and that is in use. And we can expect that this flow meter giving us more correct results.

So, this flow meter, say I can give name flow meter B and this flow meter which we would like to calibrate, I can give name flow meter A. So our objective is to know what do we mean by calibration. Then we will discuss what, we would go for calibration at all and if you would like to have calibration of a particular instrument, what, how I can do, we can do? So, these two flow meter because we will be using flow meter which we would like to calibrate and the flow meter which is already calibrated.

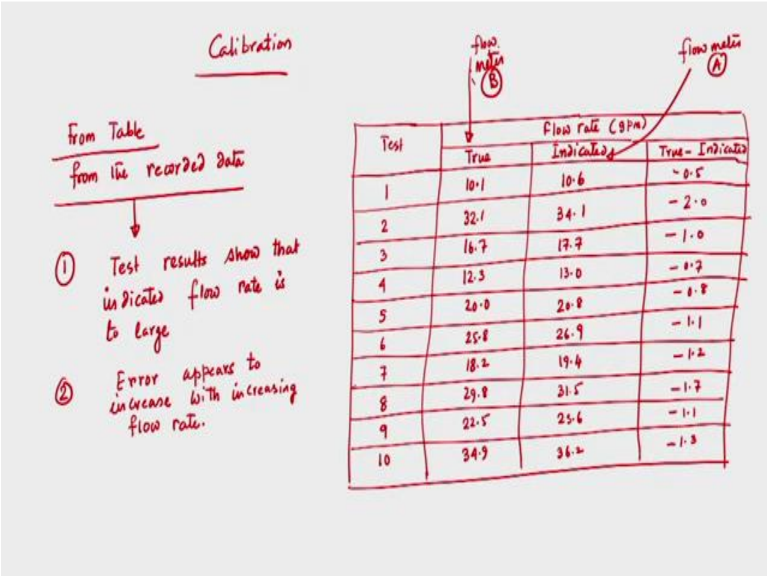
So, for the sake of our understanding we can indicate, we can give the name, flow meter A and flow meter B. So, in the right hand side, we have written that what we will do, we will use these two flow meter in a series in a test flow application. Now again, for the sake of analysis, for the sake of convenient in analysis, say we can assume, so flow meter A and flow meter B, both the meters, both these flow meters will give us data because both the meters are connected and I mean, we will record data from both meters.

So, for the sake of convenient in the analysis, consider in the writing, we can consider the data recorded by flow meter A, say, so I mean that is indicated and flow, data recorded by flow meter B which is already in fact use and which is already calibrated, say the data should be true, I mean correct data. So, mostly we will be using, because our objective is to measure flow rate. So, we can say the flow meter recorded by flow meter A, say this is Q indicated because that is what we would like to know. The performance of this meter and the data will be recorded by flow meter B is Q2.

That means this flow meter we know a priori, this is already calibrated, so we can expect that the data will be recorded by flow meter B are correct results. So, now this Q indicated and Q2 are the flow rate measured by the, flow, our meter. That means the meter we should like to calibrate and the flow meter which is already calibrated and in use. Now, we will discuss in a greater detail. Say, we can take one example; say from the test flow condition, we have recorded data using this flow meter A and flow meter B.

So, for the again to have a better understanding on the analysis, we can now discuss this example. So, let us say we have used these two flow meters and we have conducted say multiple test. And during multiple run, we have recorded, if we have recorded, if we have conducted n number of run, n number of measurements, then we have of course recorded n number of data. That is either Q indicated or Q true value. So, I am now tabulating these experimental results.

(Refer Slide Time: 14:36)



And for that, again to continue with that calibration, so again I am writing that we have one table. So this is one table. And say we have conducted n runs, n number of runs. So, I am drawing this table only to tabulate the experimental data that we have recorded. And this example will give us more clearer picture about this term ‘calibration’. So, this is Q true or I can write true value. So, essentially you have measured flow meter. Say, we have measured; the unit is gallon per minute.

So, we can tabulate true value, that is the value obtained using true meter and another is indicated value, and we can calculate true minus indicated, because we need to know that the value, the data recorded by the flow meter A may not be equal to the data recorded by flow meter B. It may or may not be equal. So that is why we need to make another column. So, another column that we will tabulate the difference between these two measurements, true and indicated.

Say, we have conducted, if we have conducted 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, say we have conducted 10 different runs. So, we have conducted 10 different runs. Probably we have discussed last class that even if we conduct different runs using same instrument in a same flow condition or same application, we will get different results. So, just I am tabulating that what are the different values we are getting from different runs.

And if these two values, that is true and indicated are equal, of course, there should not be any difference. But it is expected that the indicated value will not be equal to the true value. So, there will be a difference between the measured data by flow meter A and flow meter B.

Mind it, the true value, we will get from flow meter B. So, this value will be obtained by flow meter B. And this indicated value will be obtained by flow meter A.

So, I am now, I can tabulate the data. This is the, this is essentially for, this is one typical example for discussion. Say, we have measured true value is 10.1 gallon per minute. In second run, it is 32.6, maybe 16.7, 12.3; 5 is 20.0, 6 is 25.8, 7 is 18.2, 8 is 29.8, 9 is 22.5 and 10 is 34.9. So we can see that as in the first run we got 10.1 true value. Second run again, we got almost three times of that, more than three times. Third, in the third run we got even higher than the first one.

So, I mean, recorded data are fluctuating. It is increasing, again decreasing, like this. What will be the indicated value? So if we have recorded correctly, correctly means without having any biased results, I mean the results which we have obtained from the indicated, I mean from the flow meter A is not biased with any, I mean previous results. So say, we obtained 10.6. It is expected that the indicated value may not be equal to the true value but it should not deviate from the true value to a large, by a large number.

So, it may not be equal but it will be closer to the true value. Let us see, I mean what are the indicated value. 32.1, then say, we got 34.1, 17.7, then 13.0 for the fourth run, then 20.8 for the fifth number, then 26.9, then 19.4, then 31.5, then 23.6, then 36.2. So, if we have a closer look at this table, we can clearly see that we have conducted 10 number of runs. We have recorded 10 number of data from flow meter B. These are true value because we have to rely on those, because we know a priori that flow meter B is already calibrated, that is in use.

So we have to really rely on the true value. However, if we look at the third column, we can see that the recorded value by flow meter A are not exactly the value which we have obtained using flow meter B. But there I mean the indicated value are almost higher than the true value. Also if we, so I mean I can write that, so what will be the true minus indicated if I just write it here?

So it will be minus 0.5, it will be minus 1.5, it will be 2, minus 2, then it will be minus 1, point 0, point 0, then minus 0.7, then minus 0.8, then minus 1.1, then minus 1.2, then minus 1.7, then minus 1.1 and then minus 1.3. I would now list down the observation which we can see from the, from this table. So, if I would like to list down those, say, from table, precisely from the recorded data, from the recorded data, we can write the followings.

What are those? The test results, so number one, test results show that indicated flow rate is too large, too large, respect to what? So indicated flow rate is too large with respect to the true value. As I said that we have to rely on the data recorded in the first column because those values are recorded using flow meter B, which is I mean expected to give correct results because this is more precise. That is already calibrated, that is in use. Not only that, number two, number two is that the third column essentially indicates if I, if you can recall the definition, one of the important term that we have defined last class, that is known as error.

So, what do we mean by error? That is the difference between exact value, of a quantity and the indicated value for measurement. So, essentially the third column give the error because indicated value and the exact value, we really do not know whether the value is exact or not but again I am telling, I have already told many a times that the data recorded by flow meter B we have to rely on those data because the flow meter B is already calibrated and we have to expect that. We can expect that these data are correct data.

So, if that is the case, then essentially third column represents the data which are nothing but errors. So basically, what we can say? We can see that error appears to increase. So, basically we can see that with, for the first one, error is 0.5, second one, 2.01; 1, 0.7, 0.8, like this. So basically we are increasing flow rate, then error is increasing. Of course, so error appears to increase with increasing flow rate.

So from this example, from this particular example, what we can see that even when you use a flow meter or any device, any instrument to measure any particular I mean data, maybe pertinent to that experiments, so we always we will get the indicated value is not the correct value. How do we know that the value measured by value tabulated in, values tabulated in column are the correct value? Because that is what again I am telling, that is given by the, that is, those values are recorded by the correct meter.

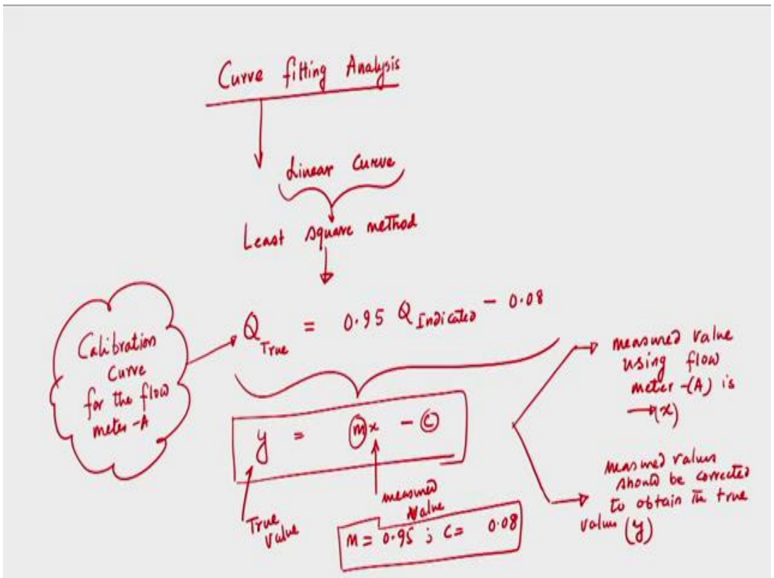
So, now what do we have to do? So, we have to now calibrate because calibrate in the sense, so the flow meter which we would like to calibrate is flow meter A. That will be, that needs to be calibrated because that is not giving the correct results. Because we can, we have seen that the results are too large compared to the true value. Not only that, as the flow rate increases, the error appears to be higher.

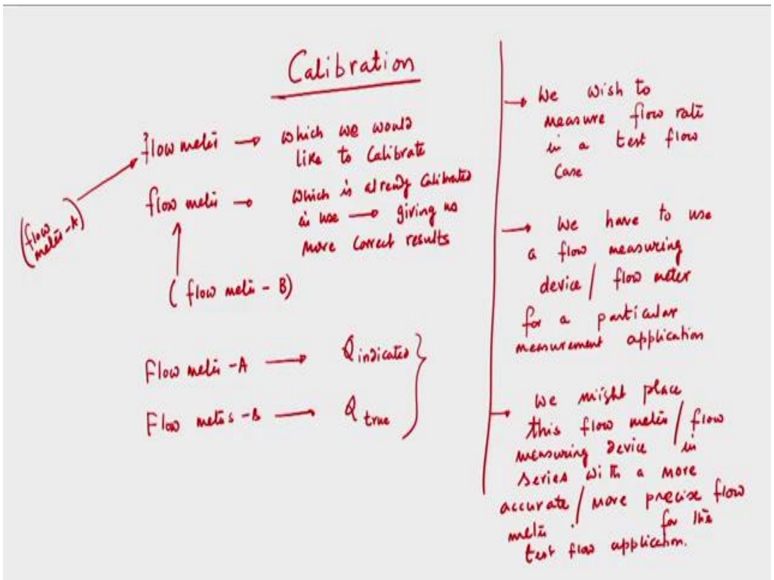
So for that, we have to know, we need to know another technique. What can I do? From this table, from the measured value by the correct meter and the flow meter which we would like to calibrate, we can now have a curve by fitting the data. So, from the data given in table, this table, we can fit a curve. From the curve fitting, from the curve fitted by this data, we can now get the calibration curve. And that curve should be supplied with that particular device, that particular instrument before and student practicing engineer or any other person using this instrument or device to measure in real application he or she should know about this calibration curve.

That means he or she will be using this particular device or this particular flow meter to measure the flow rate. And it is expected that the indicated values are not, since the indicated values are not correct, so at least he has to, he or she has to correct the indicated value to obtain the correct value and that how can someone correct it and for that we need to supply calibration curve. So what we will do now?

From the recorded data we have to now fit a curve. And that curve fitting analysis we will discuss in detail towards the last of this course through statistical analysis. But for the time being, we should know at least that from this data we have 10 numbers, 10 different runs, 10 different true values, 10 different indicated values. From this data, we at least we can fit a curve. And now I will write that if I really fit a curve using this data, we will get that at least for this, for the timing we can discuss that we will follow curve fitting analysis.

(Refer Slide Time: 28:48)





So, basically, curve fitting analysis if we do linear curve, so linear curve fitting analysis, using so we would like to have a linear curve and how do we know that the linear curve will be good enough to predict the data? Because from the table itself we can see that the variation is almost linear. So, we can have linear curve fitting analysis, using a method. That method we will discuss in detail that is least square method. And using this method again I am telling I will discuss in detail about this how we can get a curve from the experimental data.

For this particular application, I can obtain that Q true value is equal to, because we have written that the Q indicated and Q true are the measurements by the flow meter B and A. So, this Q true value will be equal to 0.95 Q indicated minus 0.08. So, essentially, this is a straight line, linear curve. It is Y is equal to m x plus c kind of thing. So, Y is equal to m x minus c. So this is essentially follow a linear curve where I need to know y that is the true value.

So, if I now use flow meter A in real application, if I have this curve with me, then perhaps without any doubt I can tabulate the correct results because I know the indicated value from the actual measurement that is x using the same device. I mean the flow meter A. And what will be the corrected value? The corrected value will be Y. So, I am writing here that is very important, so measured value using flow meter A is x. Then those values are not correct. That is what we have seen.

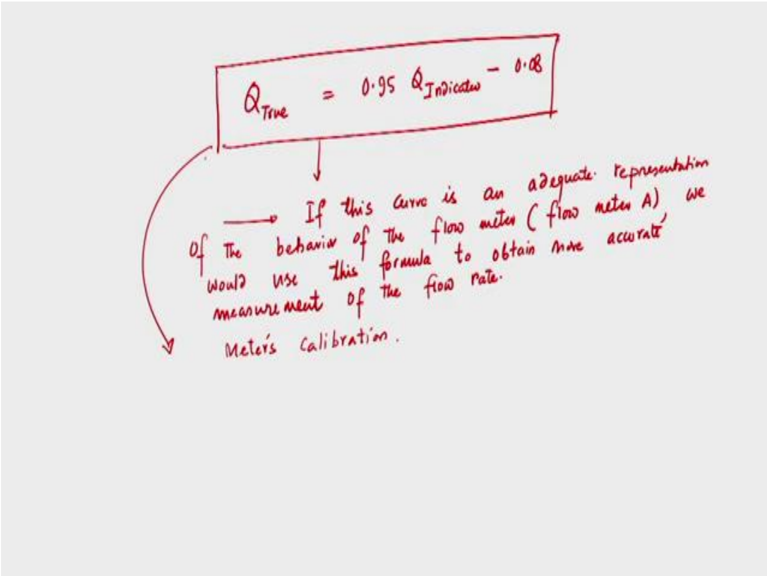
How? Comparing this value with the values obtained by more accurate matter, more accurate device. So, these values are not the correct value not the true value. So, we have to correct the values. So that means measured values should be corrected by a factor to obtain the correct value and that correction method is essentially the calibration curve. So this is the calibration curve for the flow meter A. So this is the calibration curve for flow meter A.

And this calibrated curve should be supplied with that flow meter A and again I am telling if someone would like to use that flow meter for real-life application to measure flow rate, the indicated values that is the measured values are x while the measured values should be corrected to obtain the true value, true values Y. So, Y is the true value, while x is the measured value. And the constant m and c, it is very much important. This constant m and c will vary from device to device, from instrument to instrument.

You cannot say even the company, a particular company which manufacturing this flow meter, the company people cannot say that similar type of instruments, or similar type of device will have, will follow the similar curve. They might follow the linear curve but the constant m and c might differ. So, for this particular case and particular device, the device we have used in real-life practice to measure the flow meter and we have compared that measurement with the measured data from a more accurate method that is we have tried to calibrate it, so how close the measurements are?

That means the data recorded by the flow meter A, how close they are, how close they are means they are how close with the correct value. That is the data recorded by flow meter B. This m and c are constant. And these constants are, m is equal to 0.95 and c is equal to minus 0.0, sorry 0.08. And so basically this constant and this curve should be provided with this flow meter and someone would be knowing this calibrated curve before he or she uses this. Now, again, we should go one step further. By how? So, if this curve, say we have supplied that Y is equal to m x minus c, where Y is equal to Q true.

(Refer Slide Time: 35:44)



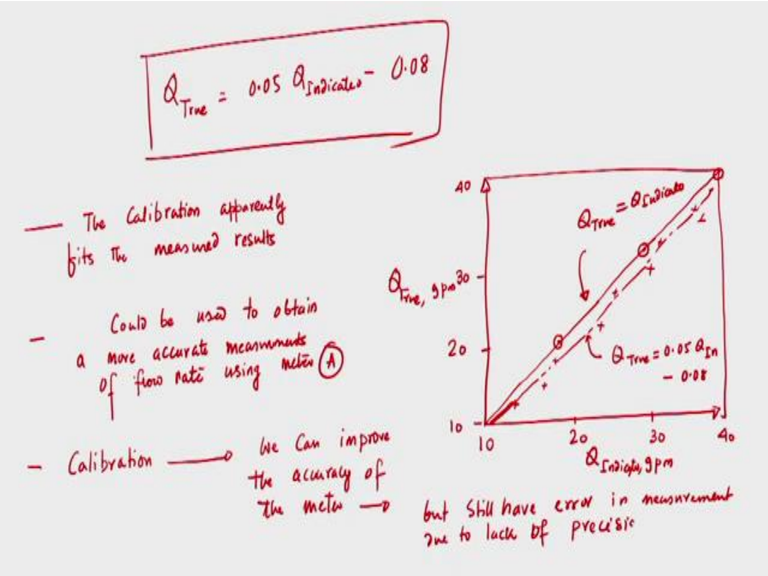
That means if I write again next page, so if this curve Q indicated is equal to 0.95, Q, sorry, Q true is equal to Q indicated minus 0.08. So, now if this curve is an adequate representation of the flow behavior of the meter A, then we can use this formula to obtain accurate result without any further validation, without any further test, without any further calibration, the flow rate in real life. So, that means I am writing here, if this curve is an adequate representation of the behavior of the flow meter, which flow meter?

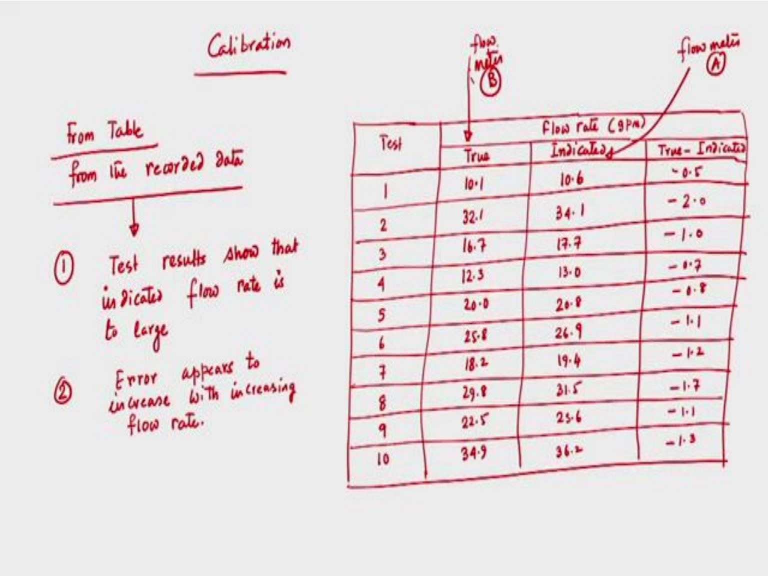
Flow meter A, then we would use this formula without any doubt that we can safely use that device if I have this formula to obtain more accurate measurement of the flow rate. So, this is the, conclusion of this analysis is that we have tested flow meter A, we have, that is we have calibrated. So what is calibration? Before we go to use any particular device, any particular instrument for the measurement in any case, we should know a priori that the device which are, which is giving result, which is recording data, which is capturing experimental results are true.

If to ensure that we need to know, we have to check whether the measured data are close to the correct value or not, again, what are the correct value? So, we need to know a set of values in a similar conditions which are recorded with a more accurate or more precise flow meter. So, essentially calibration is nothing but to check the accurateness of a particular device by comparing their result, by comparing the result obtained from that device with the result obtained using a more accurate or more precise meter.

So, this curve as I said, this is known as meter’s calibration. So this is known as meter's calibration curve. So, as I said, we can go one step further. That means in order to check this curve, again we would draw the following graph. In order to check we can go one step further. That means let us check for graphical representation. So this is a mathematical representation. We have been able to establish one equation that relate the true value and the indicated value through certain constant following a linear relationship. So, now even if we need to check it through a graphical representation, so we can plot this. So if I need to plot it, what I will get? We will get the curve like this.

(Refer Slide Time: 40:40)





So, I have Q true is equal to 0.05, Q indicated minus 0.08. So this is the meter’s calibration. Now, what we can do? We can have a curve. Say, along x axis we are obtaining Q true, that is again gallon per meter. And along y this is Q indicated or we can do it reverse. So this is Q indicated and this is Q true. Again, it is gallon per minute. So, Q indicated gallon per minutes and this is also gallon per minutes.

So, if I, so say this is 10, 20, 30, and 40 because if I go back to my previous slide where we will see that the maximum value, recorded value is 34.9 and 36.2. So this scale is good enough for the graphical representation. And similarly we can consider 10, 20, 30, 40. So, this is 10, this is 20, this is 30, this is 40. So, we have a straight line like this. So, this is essentially we can see that when, sorry, I have done the mistake. So, basically say this is 10 and say this is 20 and say this is 30 and this is 40.

So, 10, 10; then again 20, 20; again 30, 30 and 40, 40. So, basically this curve indicates the true value equal to indicated value. So this is not our calibration curve. If I would to superimpose our calibration curve over here, so this curve indicated indicates Q true equal to Q indicated. So, this is not our meter's calibration curve. Here if I would like to superimpose, it is, so true value will be always less than the indicated value. That is what is clearly evident from this table.

So, true value should be always less than the indicated value. So, I mean, we can have, so maybe indicated value, indicated value are like this. So, I have a curve. So this curve is Q true is equal to 0.05; Q indicated, minus 0.08. So, this is the actual meter's curve, which we obtained from our least square analysis by fitting the data, experimental data. And we can see two important things that from the indicated value we have obtained this curve.

So, what can we say from this? The calibration apparently fits the measured results well. So, we can see the calibration that is the curve represented by the dotted line; the calibration apparently fits the measured results or measured values. So this is very important. We can see almost all the points lie on the curve, lie on the line. So, dotted line is the calibration, calibrated curve and whilst the point shown by crossed mark, those points lie almost on the fitted curve. So, the calibration apparently fits all the measured results.

And therefore, this calibration curve could be used. So, this calibrated curve could be used to obtain a more accurate measurement of flow meter using meter A, using a flow meter I can say, flow rate using meter A. Very important. So, another important observation what we can say from is that we can improve the accuracy of the meter through calibration. So, what we can do, but we have seen that we can improve the, so what is the outcome of this calibration? Is that so calibration, why it is done?

We can improve the, we can improve the accuracy of the meter for this particular case, specific to this case or in general of all the instruments or devices. So, we can improve the accuracy of the meter specific to this case, in generic term we can, in generic sentence or in generic, in general, we can improve the accuracy of any device, any instrument. But another important observation is that still but, still have error in measurement. That is quite obvious because all the data points, all the points marked by cross sign are not exactly lie on the line but still have error.

That means if you try to calculate deviation, you will find deviation but it is not that much deviation. So, we can improve the accuracy, we can, you cannot make it 0, more I mean error. We cannot make it error free, but we can improve accuracy but still have error in measurement due to, because of what? Due to, this is due to lack of precision. That is what we have discussed in the last class, due to lack of precision.

So, from our today's understanding we can say that calibration is one of the foundations of measurement. We should know about it before we go to use any instrument, any device for any particular applications, we should know about the, about this term whether the equipment, whether any particular equipment, instrument, device is already calibrated or not. If it is calibrated, then it should be, we should have that calibration curve with us essentially to obtain the correct or true results.

Not only that, it is always unwise to use any instrument without at least a minimum check of its performance whether it is giving correct value, correct value in the sense how much correct it is. It may not approach to the true value but whether it is close to the true value or not. And if it is not the true value then what is the deviation? So one of the key problems that we encounter in calibration is, so I also would like to discuss rather to highlight, to mention this particular aspect, this particular point over here is that one of the key problems that we encounter in calibration is that how do we get the true value of the measured quantity. That is important. How do we get the true value of the measured quantity?

Because again I am telling, we are relying when you are calibrating a device or instrument, we are relying on the data that was given in the first column the true value knowing fully that those values are recorded by a more precise, more accurate meter. But we really do not know that whether that device was giving correct results or not. That means but we have to rely, we have expect that those devices, those equipment are giving correct results. So, this is one of the important problem that we encounter in calibration is that how do we get the true value of the measured quantity.

So, at least someone would have a minimum check on its performance before we go to use any particular device, any particular applications. So, with this, I stop my discussion here today and we will continue our discussion on this subject in the next class. Thank you very much.