Advanced IOT Applications

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Lecture - 35
Sensor types: semiconductor and electrochemical

So, before we do any system design exercise on you know using air quality sensors, we should be familiar with several. So, essentially there should be a good preparation towards understanding the kind of values that you are likely to get. We discussed about the calibration effort which is a major part, lot of analytical methods are available today.

You may have to put a box, which has a lot of sensors you know gather the data and then run through these analytical techniques simple statistical methods like linear regression, linear multivariate regression, then it could be a artificial neural networks all these techniques are you know they give you good predictable result provided you have good quality data and we mentioned that it is important to create this good quality data.

Before we even go further into this you know building a system or showing a demonstration of this, its important to know a few terms and out its important to know when you want to go out and buy a sensor, you will see a plethora of options with you each one having its own advantage and disadvantage.

So, which one will you buy, what are the gas detection technologies which are available and therefore, can be sort of get an idea of what are all possible in this world of air quality monitoring. For that I want you to go back and download what is known as a gas detection handbook.

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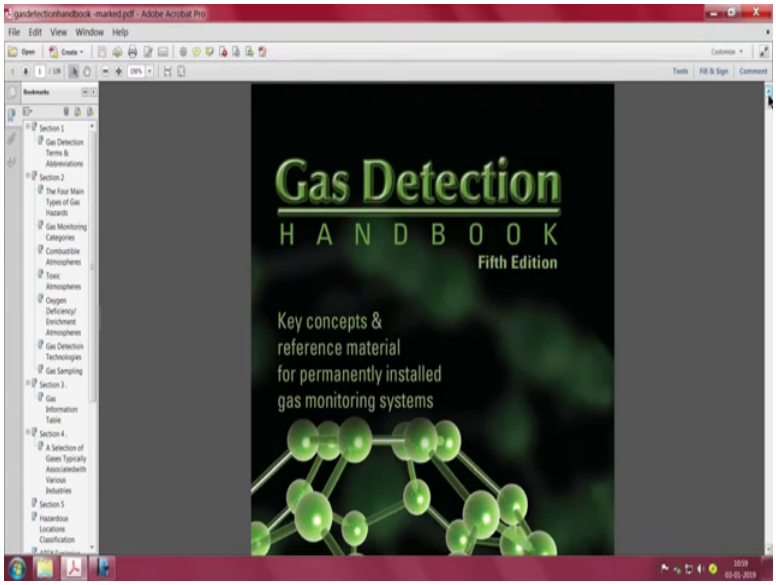

You can see fifth edition of this book is available, freely available you do not have to you just have to download and then you get some key concepts and several nice things to learn from this I learnt quite a bit from this. So, let us run through this and it give you a plan and you can at (Refer Time: 02:29) you can sort of read them through.

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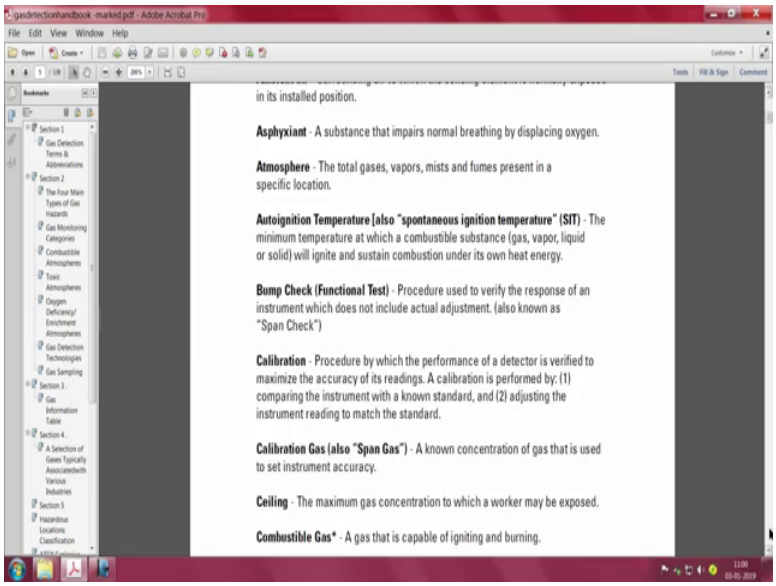

But I would say for example, understanding some definitions some terms are also very very important. For example, if you want to look at calibration right; procedure by which the performance of a detector is verified to maximize the accuracy of its readings.

Now, calibration is performed by comparing the instrument with a known standard and adjusting the instrument reading to match the standard. Essentially it is simple for where you checking whether the detector is performing well.

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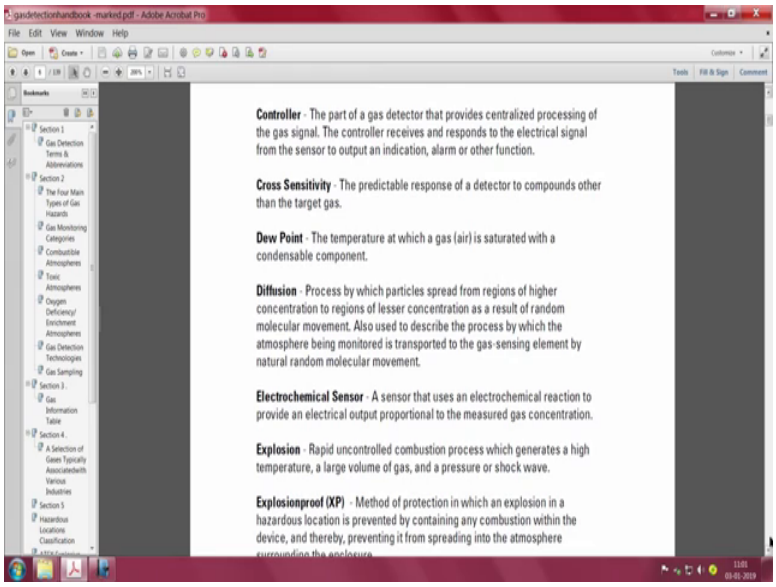

Quite like that when you look at in this area of gas air quality, gas detection and all that cross sensitivity I mentioned this so, many time and absolutely critical to understand what it means. The predictable response of a detector to compounds other than the target gas. Major problem biggest bottleneck, a bighorn in the detection of a particular you know you know pollutant right.

So, that is a big problem. In fact, if you buy sensors you have to see how much of its is cross sensitive to other gases and therefore, it is important for you to know this term very well and understand that any system design has this problem in air quality. Perhaps all these reasons as I mentioned earlier are really cause the cause for IOT not taking off for the purpose of air quality, large scale highly special monitoring of you know air quality monitoring has not taken off because of this.

So, cross sensitive sensitivity is an issue. Then there are different types of sensors electrochemical is one of them. A sensor that uses an electrochemical reaction to provide an electrical output proportional to the measured gas concentrations. This is another important term that you will come across. You will come across semiconductor, you

come across electrochemical and you will come across IR techniques and so, on we will see them as we go on a very quickly.

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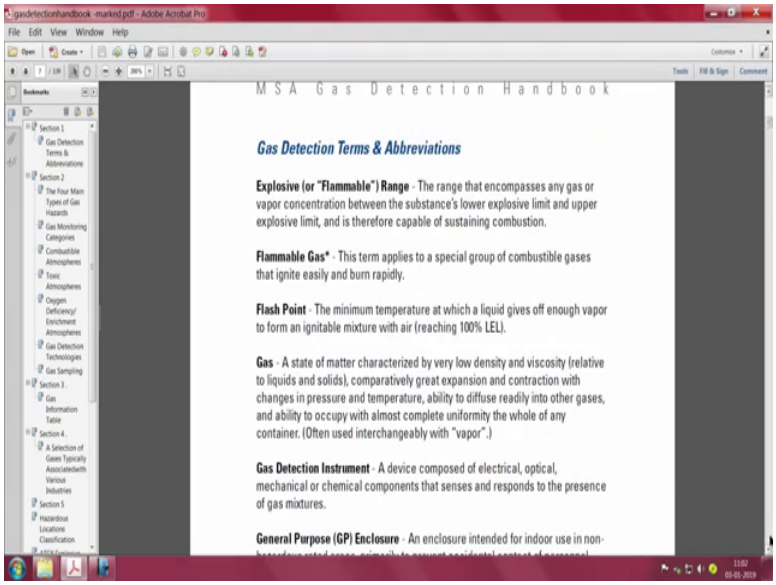

So, then these are important then you can read them as you go along. Definition of PPM; the most common unit of measurement for toxic gases at 10000 parts per million gas concentration level equals to 1 percent by volume exposure. So, its important you understand this definition. Sink it in PPM is defined here relative density is also here, then threshold limit value also important, then vapour and vapour density this is also important vapour pressure.

So, what I want you to lookup is this oxygen for example, people talk so, much about under low pressure, the oxygen content also comes down. While you talk about this 20.95 percentage of air is oxygen and 78.09 percent is nitrogen all that you say, but that is under highest one atmosphere right. But as you go up the atmosphere pressure comes down and as pressure decreases at greater heights the oxygen also comes down. So, this by volume percentage volume if it comes down by how much humans affected is something that this chat is telling you.

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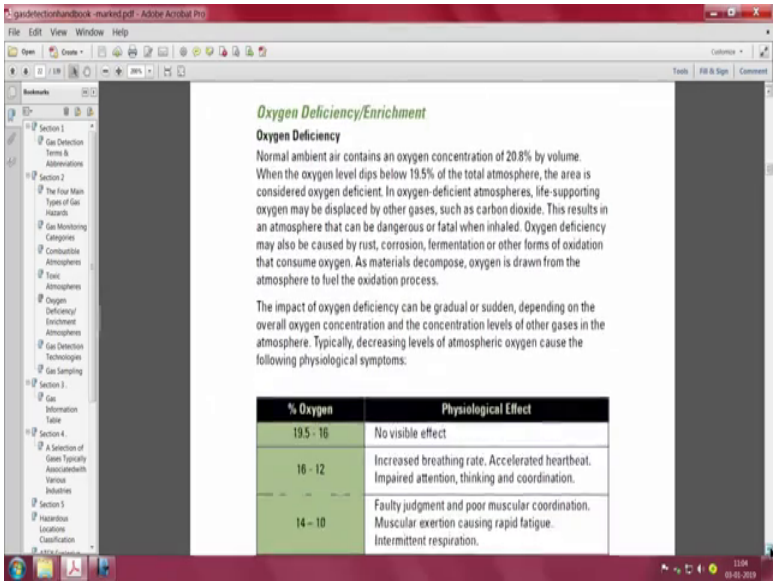

You can see ambient air oxygen 20.8, oxygen level dips to 19.5 of the total atmosphere you are already saying its oxygen deficiency. So, we are very sensitive to the amount of oxygen that we you should have in the air for us to breathe normally ok. Life supporting oxygen may be displaced by other gases such as carbon dioxide, in the event that it comes down from 20.8 to 19.5.

Other bad pollutant gases may occupy the you know the displaced gas which is essentially oxygen. So, really that is a problem. You do not want CO 2 increase at the cost of reduced oxygen right. So, that is the problem and if there is too much of CO 2 it can be dangerous or fatal.

So, oxygen deficiency you know is an issue all right. So, let us see this next chart here. From 20.8 if it comes down to 19.5 to 16 not so, much, but we are already having a problem.

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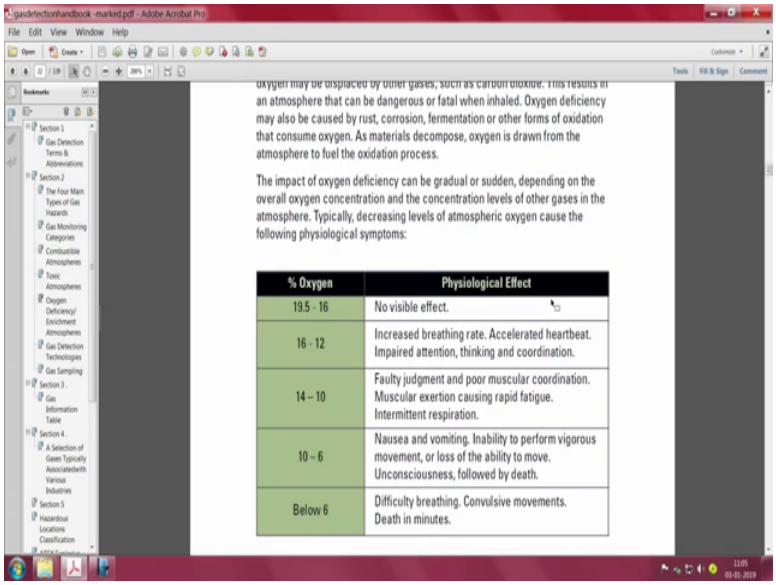

But if it comes down between 16 and 12 increase breathing rate. Accelerated heart beat impaired attention thinking and coordination 14 and 10 faulty judgment and poor muscular coordination right muscular exertion causing rapid fatigue, then intermittent respiration. 10 and 6 is nausea and vomiting inability to perform vigorous movement or loss of ability to move unconscious followed by death already 10 to 6 below 6 difficulty breathing convulsive movements death in minutes you see as the oxygen level keeps falling the system really goes down. So, critical monitoring means you have to do oxygen monitoring also, to ensure that life is you know all the time there.

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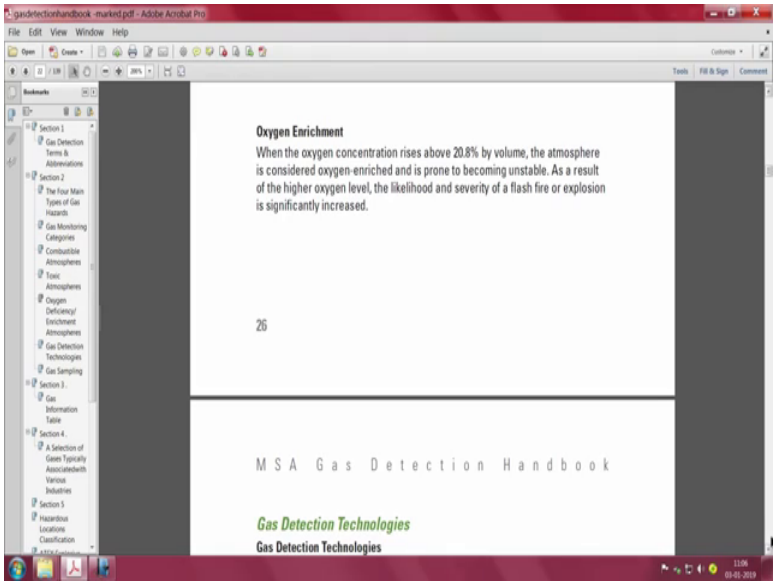

So, we have to look at the gas detection technologies if you have to buy a sensor.

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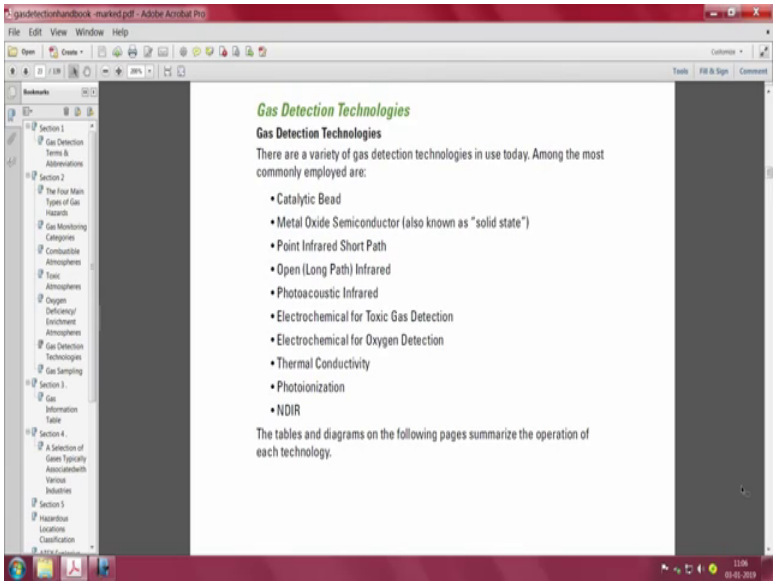

And there are many many types of sensors available among them catalytic bead, metal oxide semiconductor also called solid state; point infrared short path, open long path infrared, photo acoustic infrared, electrochemical for toxic gas, electrochemical for oxygen detection, thermal conductivity, photo ionization, NDIR are all different types of gas detection technologies that are common ok.

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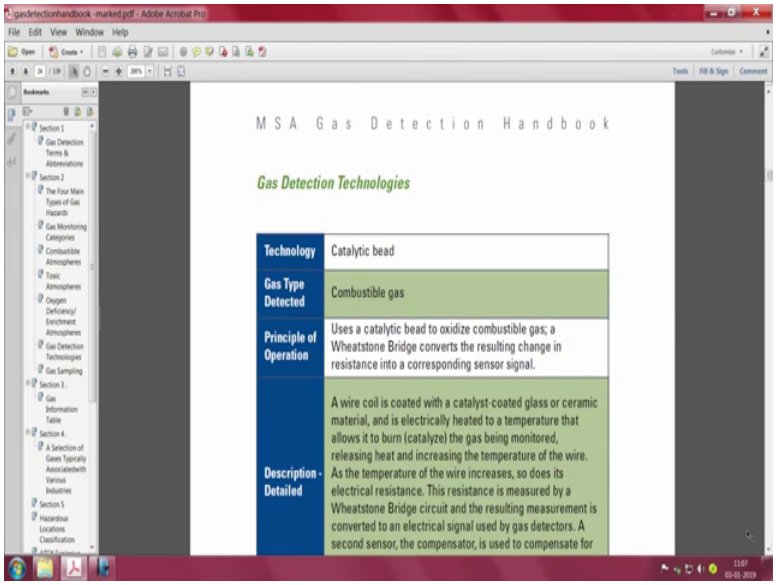

So, you can go through this manual, it will tell you what technology and for what type of gas this technology is best suited. So, you can go on reading this you can see that it will also tell you about the technology. Among them is metal oxide semiconductor a most popular, because in silicon you can make them are you can make gas sensors and perhaps a hot topic everybody wants to make the best silicon gas detection sensor so, that its made cheap and large scale monitoring is possible only if you have a mass metal oxide not mass metal oxide semiconductor based devices.

So, you can see a semiconducting material is used and principle of operation is pretty state forward. It is made of a metal oxide that changes resistance in response to presence of. So, you can see is the most important sentence that changes in changes resistance in response. All the effort is measurement of change in resistance in response to presence of gas and then you this change is measured and translated into some concentration and you start reading from there.

So, the principal is mentioned here, a semiconducting material is applied to a non conducting substance between two electrodes, the substrate is heated to a temperature. See this if you read this carefully, you will follow the data sheet very easily this is important.

What does it mean by reading this sentence? It says temperature at which the presence of gas can be can cause a reversible change in the conductivity of semiconducting material, that is when no gas is present oxygen is ionized on to the surface and sensor become semi conductive. When molecules of the gas of interest of present the replace the oxygen ions, decreasing the resistance between the electrodes.

This change is measured electrically and is proportional to concentration of the gas being measured. So, you can see oxidation and reduction principles are applied on the semiconductor material, because you are talking about oxygen ions being replaced right and being replaced with the molecules of gas of interest right and then there are two electrodes and it says that all this reaction is possible only under heated condition.

So, what should a semiconductor sensor have very straight forward you should have a heater to heat it, then they will be an electrode one electrode and another electrode. Then you will have oxidation on one side reduction on the other side; that means, giving up of oxygen for ions and accepting a oxygen ions. One will measure one type of gas the other will measure the other type of gas. NO 2 and CO can be measured by the same sensor because oxidation and reduction process happens right there.

So, you can measure both simultaneously, but all this is possible only if there is a under certain temperature condition; that means, you have to heated, you want some heated condition which means they should be a heater means what? You need to pass it must be some sort of everything is a chip by the way right everything is inside silicon; that means, there must be a small resistor right inside and by the way making a passive on silicon is quite straight like you know resistors and capacitors are easy inductors are hard to build on silicon.

So, people do not attempt that they try to put inductors outside and all, but that things are all changing you know that is in all in the v l s I word let us not get into that. But the point is you need a resistor and that resistor is something that you can put it, and then you have to connect to one external resister apply a certain voltage this heater will heat and a temperature is maintained and when you pass the target gas, the oxygen ions will get displaced and on the other side some other part the oxygen ion is accepted.

So, you will have oxidation and reduction happening and therefore, you can measure the change in resistance, and the change in resistance is directly proportional to the amount of ions which are getting displaced and that is measurable then that is why they say amperometric methods of measuring they apply that, and then you quickly see the change in that resistance value is directly proportional to the PPM levels of gas PPB or PPM levels of gas that have been passed. So, straight forward, but system design means you should know the principal that is why this particular thing you should understand very very well. So, let us see that part.

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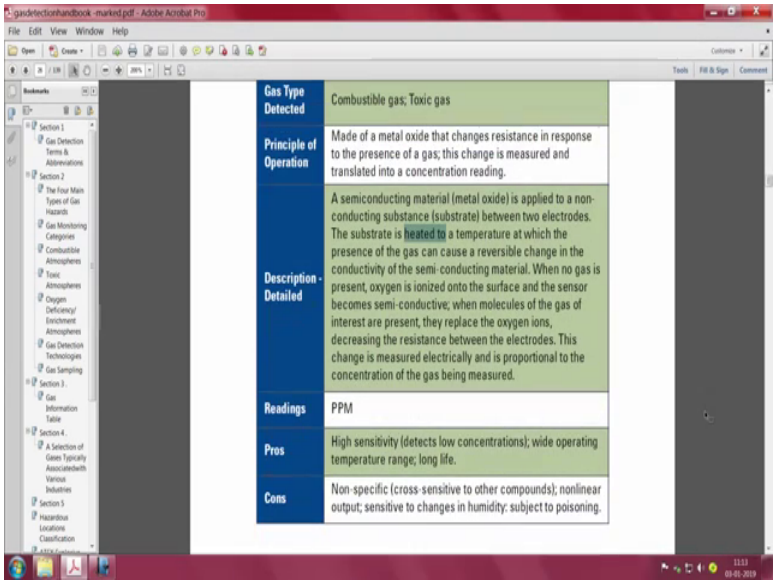

So, here you see this is important again. Prose is high sensitivity detects low concentration levels you can detect very well while operating range long life also that is not a problem, but here is a cons. Look at this non specific; that means, this semiconductor sensor is highly cross sensitive its an issue to other compounds and the outputs are typically are non-linear you get a non-linear output.

So, that paper which we spoke about when we are talking about calibration has to be taken with a pinch of salt. We spoke about linear regression and other techniques assuming that there is some linearity at the output, but semiconductor essentially are not linear they do not give you a linear output, they give you non-linear output. So, it will be some polynomial fit that you will have to worry about some log response perhaps.

Therefore, you may want to even examine where in this whole range of measurement of that sensor where is linearity maintained and apply a linear regression only to that specific section and do not look at the full range of the do not look at the full range, but just look at that specific thing and say is linear here and therefore, I will trust it myself my study only to this range and I will be able to measure accurately, only up to this PPM level and beyond that its not something that we may want to measure.

Therefore, semiconductor sensors can be applied in that way, if you are not interested in very accurate measurement PPB levels, but you want to so, low medium and high something called low medium and high three ranges acceptor is good acceptable or not acceptable.

So, some sort of division if you are able to do and within that range you are able to show that the gas concentration is in any one of these levels extremely good. So, quick and quickly you will be able to get. Because your really not going after essentially you want when you walking or when you are driving or anything you just want to get a first cut whether it is safe to go or not safe to go, that is the first level. Then if you are a real deep scientist, you are interested in going into the details of what is the PPB level that is being there.

So, that is perhaps next step. But for citizens at large people who want to use gas sensors, they do not really care about whether what is actual PPB level therefore, many such applications in the IOT world you should think like that. How will it benefit the common man and how can it be used in a manner that, the you make a rough measurement of it and give a clean chit or low clean chit you say that you can walk you cannot walk. This area is to be band this area can be safe; safe unsafe regions this kind of demarcations if there are available you already extremely good.

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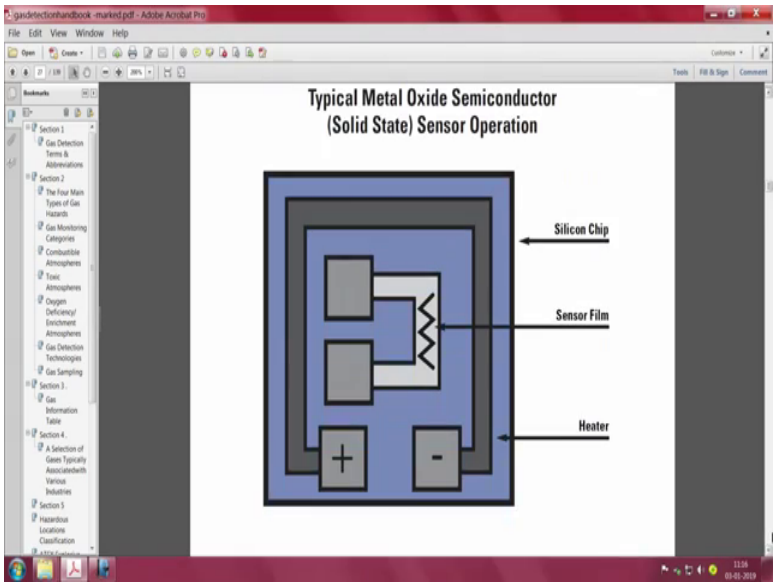

So, electrochemical and semiconductor are most popular. So, you can see that he has given a picture here, there is a silicon chips sensor film heater is there and all of them. Then you have point infrared short path, then you have electrochemical which are also very popular and I think its good to spend time on this part as well. Uses an electrochemical reaction to generate a current proportional to the gas concentration which is what I was trying to say that there is some output current and amperometric methods can be applied here, you basically have a current that is proportional to the gas concentration, then you want to convert the current into some voltage.

So, what will you do? You will put a transconductance amplifier some small of op amp circuit will be there and that op amp circuit will convert that current into some voltage and you measure the change in voltage and say that if there are sum change in voltage that will correspond to the concentration level of gas.

So, in the metal oxide semiconductor part you are changing the resistance, you may you are varying the resistance and that is indicated of the PPB PPM level here it is current which is essentially changing. So, I think I amperometric since its called amperometric its more applicable to the electrochemical sensors not so, much to the actually not applicable to the metal oxide semiconductor gas detection technology at all ok.

So, that is a correction for my side. Sensor is a chamber containing a gel or electrolyte and two active electrodes. The measuring sensing working electrode and a counter

electrode a third electrode is used to build up a constant voltage between the anode and the cathode, the gas sample enters the casing through a membrane, oxidation occurs at the anode and reduction takes place at the cathode. When the positive ions flow to the cathode and negative ions flow to the anode a current proportional to the gas concentration is generated.

So, no different from what a the oxidation reduction method that I mention to you with respect to semiconductor actually same thing is happening here as well and so, let us quickly look back at that to see if there is any difference yes. So, its mentioned here ok. This you can see that this is the same there is a substrate in this case and there are again two electrodes, then you have a substrate heating and you have measurement exactly the same base two electrodes and two electrodes here as well, but they did not mention anything about presence of an electrolyte right.

So, perhaps this is a proprietary technology and each manufacturer may do it his own way, to generate this semiconductor sensors all right. So, principal wise its the same, you could read that and understand better from a particular manufacturer all right. So, before we move on the major advantage of electrochemical is, you see here I would say full marks linear output.

So, you can easily apply several of the techniques that we discussed in the other paper, its highly sensitive, its linear output and easy to handle. Only problem is its has limited shelf life and its lifetime is shortened in very dry and very hot environments. So, if there are extreme weather conditions I do not think the electrochemical sensors are very good, but its very extreme conditions.

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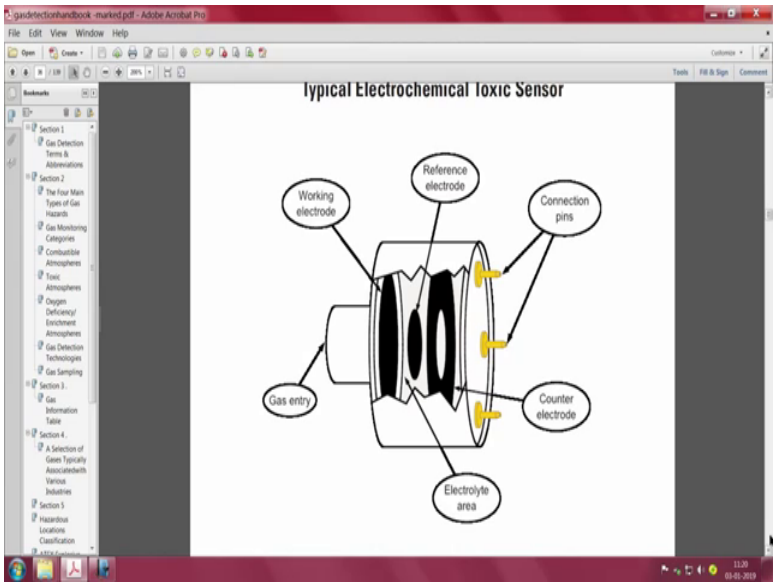

By enlarged I would recommend you to design your systems with electrochemical sensors. Of course, wherever semiconductor is good one may also use them. So, please spend time reading this chart.

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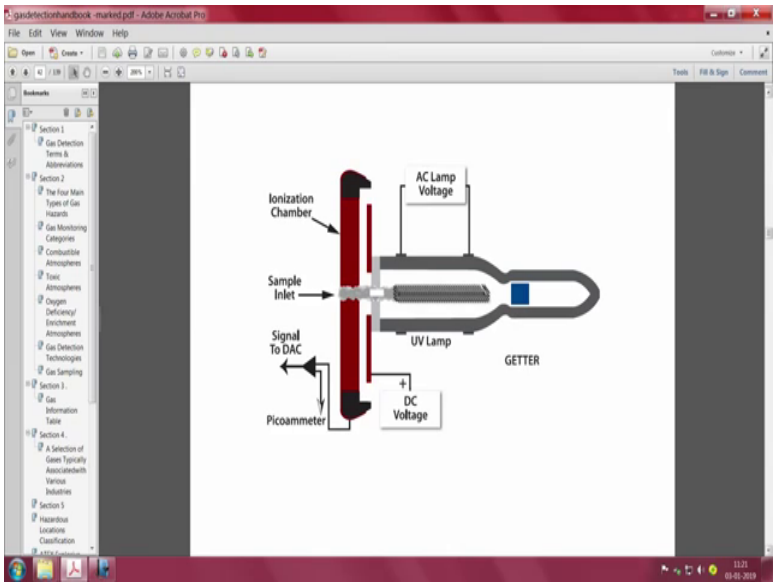

This particular manual and that will help you to you know get into the details of the type of sensors that are available.

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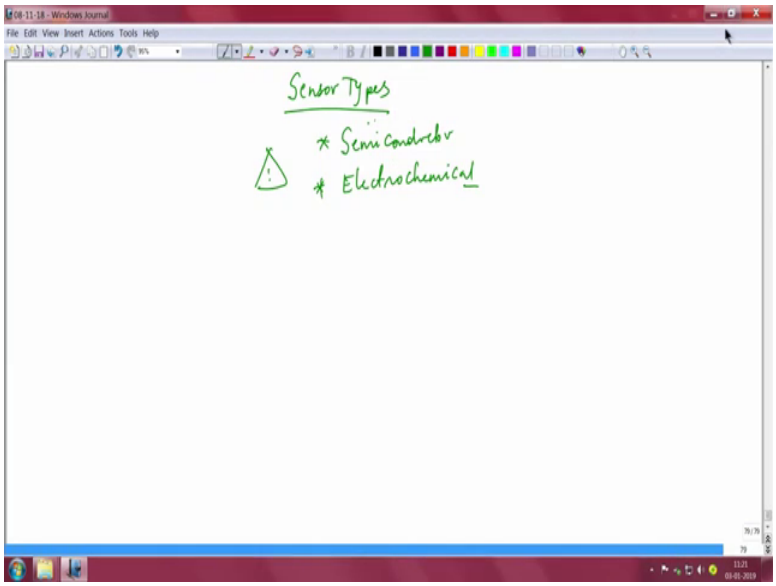

So, semiconductor sensors and electrochemical are important right. Let us now spend some time looking up one of these types of sensors and look at system design around that particular part.