Materials and Energy Balance in Metallurgical Processes

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Module No. # 01

Lecture No. # 02

Measurement of Quantities

This course is on material and heat balance in metallurgical processes. Material and heat balance is regularly and routinely done in a plant to take a stock of the inputs and outputs of the raw material.

It is required to perform an analysis of the various sources from where the material is entering and the sources from where material is exiting in order to keep an account of the loss of material, if at all it occurs during the process. Material balance is very important and the first step to perform energy balance. Both material and energy balance are required to be done in order to find out the flow of material or the path of flow of the material and energy; in order to identify the loss of material, if at all it occurs; and the loss of energy, if it occurs; and to find the ways to optimize the utilization of raw materials and utilization of energy. Now, material and heat balance has become very important, considering the energy conservation of the processes.

Hence this material and energy balance is routinely done in a plant to identify the methods, where the flow of material energy can be optimized.

This course develops problem solving skills; and it sees to that after going through this particular course, you are able to feel the material and energy requirement of the process. To meet this objective, what I have done is, I have collected problems from various sources and I have tried to present the solved and unsolved problems, both.

But my appeal to all of you is that you may see the problem, but the solution, please see only after you have attempted them yourself.

Also, you will see that some concept of the processes I am going to tell you during the lectures, but the details of the process, that, I will be omitting because I am going to stress more upon the material and heat balance; and to perform the material and heat balance.

So the basic concepts I will be illustrating, but if you want to know the more details about the process, then I request that you go through the references that I will be giving you from time to time and get a feel of that process.

Because, my objective for this particular course is to give a quantitative feel about the material and energy balances in various metallurgical processes, in particular metal extraction and refining.

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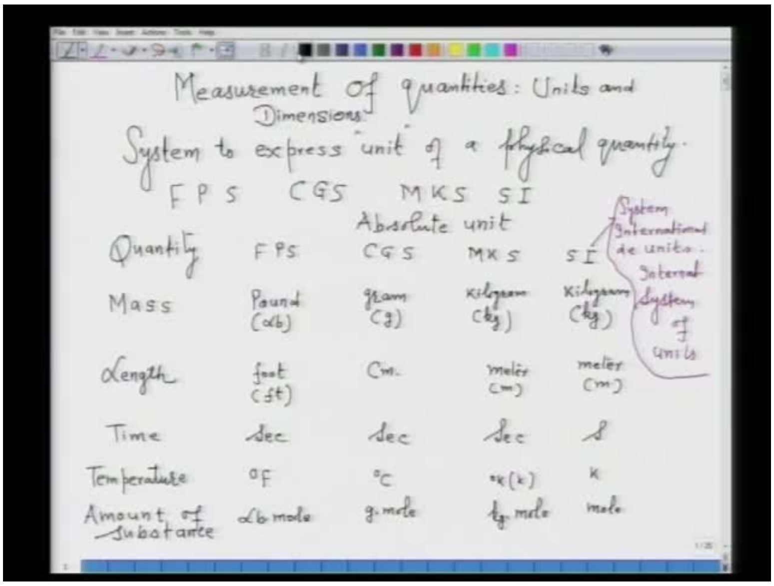

Now, as such, the first lecture that I am going to give you is on the measurement of quantities, units and dimension. I have experienced, over the long years of teaching to the students, often there are mistakes in finding out the units; in deriving the units; in knowing the units.

So, I have thought, let me introduce to the basic concepts of units and dimensions. Now, as all of you know, all physical quantities need unit, in order to compare the magnitude of the physical quantities from different sources.

You do require to express the physical quantity in terms of a unit. There are different systems of expressing the unit of the physical quantity.

Essentially, there are 3 methods, acually 4 methods to express the unit of any physical quantity.

The systems to express the units of a physical quantity: we have systems like FPS, which all of you know - that is feet, pound and second; another is CGS – centimeter, gram and second; still another MKS system - that is meter, kilogram and second system; and last is the SI unit.

So, these are the 4 different ways or system that have evolved, in order to express the magnitude of the quantity.

Now, I am giving the table; for example, if I write here, quantity; I put here, absolute unit; and then first I put say FPS system, CGS system, MKS system and SI system. Now here, I will like to differentiate between the 2 types of units - one is the fundamental unit – fundamental units are those units from where the units of other physical quantities can be derived. And second are the derived units - that is, utilizing the fundamental units, one can derive the units of other physical quantity.

So what I am going to write in this particular table is the fundamental unit in all these 4 systems; so these fundamental units can be used to derive the units of other physical quantities.

These fundamental units are: one is the mass; in FPS system, it is expressed in pound and you must have seen in various books it is written as pound. In CGS system, it is expressed as gram and in short, it is written as g. In MKS system, mass is expressed in kilograms and the the short form is kg. In SI system also, it is expressed as kilogram, this is called kg.

Another fundamental unit for the quantity is length; in FPS system it is expressed in feet or foot and shortly it is written as ft; here it is in centimeter; here it is in meter or you write as meter; and S I units also in meter.

Third is the time; in all, whether FPS, CGS, MKS and SI, the time is uniform; that is, in seconds; it is expressed as second here; it is also second here; it is also second; in SI, it is not written sec, but it is written simply as s.

Another is the temperature; temperature in FPS system is in degree Fahrenheit; in CGS, it is degree Celsius; in MKS, it is degree Kelvin or sometimes it is written as Kelvin; and in SI also, it is written in Kelvin.

So another fundamental unit is amount of substance; though it has come in mass, but sometimes, this is also express amount of substance; in FPS system, it is pound mole; in CGS system, it is gram mole; in MKS system, it is kilogram mole; and in SI units, it is simply written as mole.

Now, this SI, I am just writing this separately, SI means System International de units, which means International System of units. That is what this SI system means.

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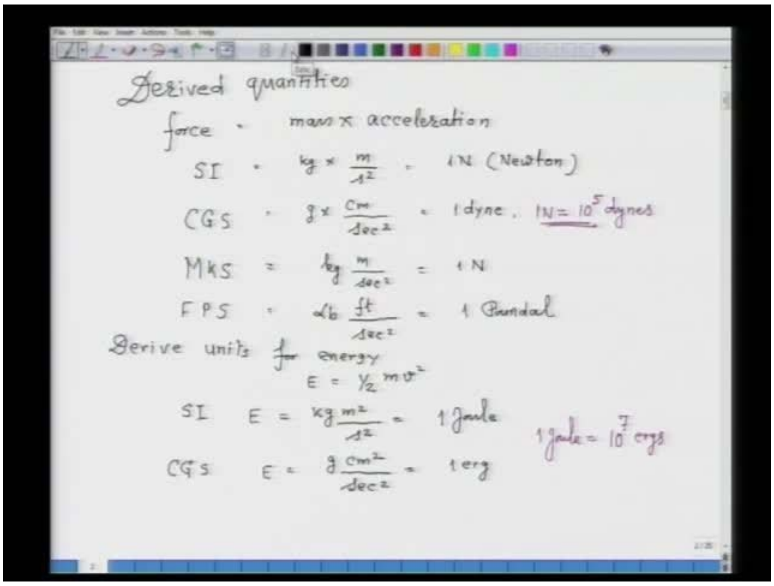

Now there are some derived quantities. Now these derived quantities are those, utilizing these fundamental units, one can derive the units of other physical quantities; for example, you want to derive the units of area, volume, heat transfer coefficient, mass transfer coefficient and so on. So, by utilizing the fundamental unit, one can derive the unit of other physical quantities.

For example, we derive the unit of force; force is equal to mass into acceleration; so in SI units, that is equal to kg into meter upon second square; and that is equal to 1 Newton.

So, you know mass - kg and acceleration - meter upon second square; we are getting kilogram, then meter and second.

They are the fundamental units and utilizing the formula and units of the variable, which is in the formula, one can obtain, for example, unit of force. In CGS system, that will be equal to gram into centimeter upon second square; and that is equal to 1 dyne.

And also here to note 1 Newton is equal to 10 to the power 5 dynes. So that is in CGS system; or similarly, in MKS system; this is a kilogram, meter and second square; now, in most cases SI and MKS units, they are more or less the same. That is equal to 1 Newton.

In FPS system, the unit of force will be pound feet upon second square; and that is called 1 poundal. Similarly, say for example, you want to derive the units of energy; let us derive units for energy; so all that we have to do is write down the formula. Say, energy E; that is equal to half m v square; m is the mass, v is the velocity; so in SI system, E will be equal to kg meter square upon second square; and as all of you know, that is 1 joule.

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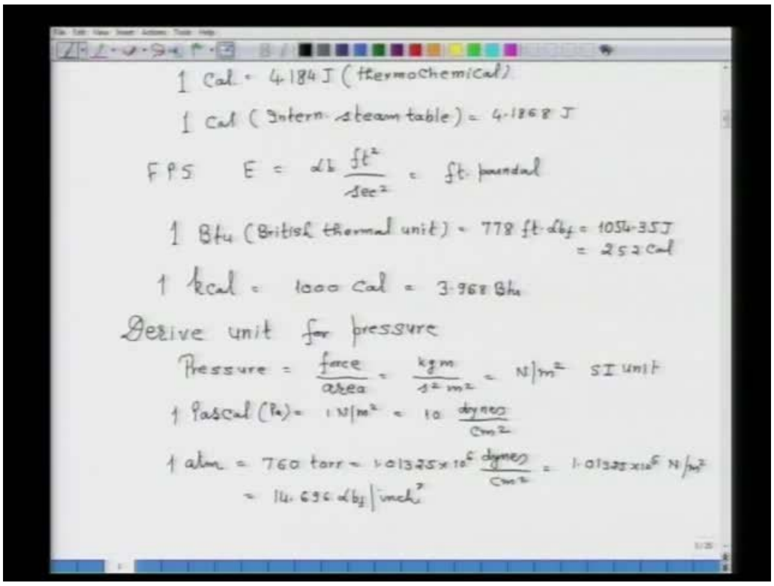

Similarly, in CGS system, energy will be gram centimeter square upon second square; and that will be equal to 1 erg and also the interrelation: 1 joule is equal to 10 to the power 7 ergs; that is also to be remembered. Also here, remember that 1 calorie is equal to 4.184 joule. Sometimes, in some books, it is also given one 4.183, but you can write 4.184; and this is, when you call thermochemical. Now, also, 1 calorie, in international steam tables, that is considered to be equal to 4.1868 joule; there is a slight difference; that is it.

Now similarly, the energy to express in FPS system, we say, E that is pound feet square upon second square; and that is written as feet poundal. Here are some of the important relationships: 1 Btu - Btu stands for British thermal unit; that is equal to 778 feet pound force. That is equal to 1054.35 joule; and that is also equal to 252 calorie.

Now, mind you, these inter-conversions are many times required; and many times we are confused on what values should be used, so, you should be able to derive these from the basic quantities. Also to remember, 1 kilocalorie is equal to 1000 calorie; I do not need to write that, all of you know, that is also equal to 3.968 Btu.

Now I purposefully included the FPS system, because many old books; they are still very good; the problems and the various quantities in them, they are given in the FPS system; in many good books.

So, that is why I thought to include, in my lecture, the FPS system also. Now, let us take third example. Derive units for pressure. Again utilizing the fundamental units, we define pressure. All that you have to define is the terms of the formula, that is, force upon area. Now, we can obtain the unit; so force - kilogram meter upon second square; area is in meter square.

So that becomes Newton per meter square in SI unit. Now similarly, some relations; say 1 Pascal, that is written as Pa, that is equal to 1 Newton per meter square. And that is also equal to 10 dynes per centimeter square. Also to know, 1 atmosphere is equal to 760 torr; that is equal to 1.01325 into 10 to the power 6 dynes per centimeter square; and that is equal to 1.01325 into 10 to the power 5 Newton per meter square. And that is also equal to 14.696 pound force per inch square. Now also to remember here, say 1 millimeter mercury that is equal to 1 torr, because very often we use these units in vacuum; and for very low pressures, we express in millimeter mercury. That is equal to 0.01934 force per inch square. And that is also equal to 1.333 into 10 to the power 3 dynes per centimeter square. Also many times, 1 bar is also a unit; 1 bar is equal to 10 to the power 6 dynes per centimeter square. Now, dynes per centimeter square is the unit of pressure in CGS system; that is equal to 10 to the power 5 Pascal and that is equal to 0.98692 atmosphere.

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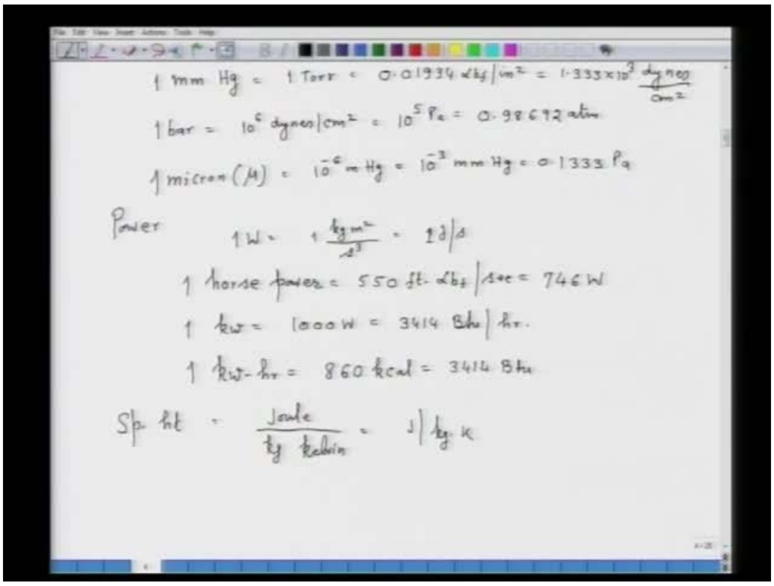

So, this is about the pressure. Now, sometimes very low pressure is also required to be measured, that is, in 1 micron, that is, mu; that is equal to 10 to the power minus 6 meter mercury; that is equal to 10 to the power minus 3 millimeter mercury; that is equal to 0.1333 pascal.

Many times, you require to express the unit of power. So, let us express the unit of power, because these things we will very often require, while formulating the problem of materials and heat balance in metallurgical processes.

Power, 1 watt is equal to 1 kilogram meter square upon second cube; and that is equal to 1 joule per second.

Also, it is expressed, many times, in horse power; 1 horse power is equal to 550 feet per second; that is equal to 746 watt. Many times, we require to express what should be the horse power of the pump or horse power of the motor, in order to transport a particular amount of water from one place to another. And that is why you also require the unit of horsepower. Now 1 kilowatt, all of us know, is equal to 1000 watt; that is equal to 3414 Btu per hour. Also, many times, it is required to express the power consumption in kilowatt hour. So 1 kilowatt hour, approximately, is equal to 860 kilocalorie; and that is equal to 3414 Btu. So, this is about deriving of the units from the basic units. Similarly, you can derive the unit of any physical quantity by utilizing the fundamental units.

The fundamental units are mass, length, temperature and time. These are the fundamental units. Mass you can express in kilogram or kg mole, whichever way you want to express it.

Now similarly, the specific heat; well, I will not be deriving in all dimensions. Specific heat, from the definition, is written, joule per kg Kelvin; that is the amount of heat that is required to raise the temperature of 1kilogram by 1 degree; and it is expressed for example, in joule, kg and Kelvin (Refer Time Slide: 25:32).

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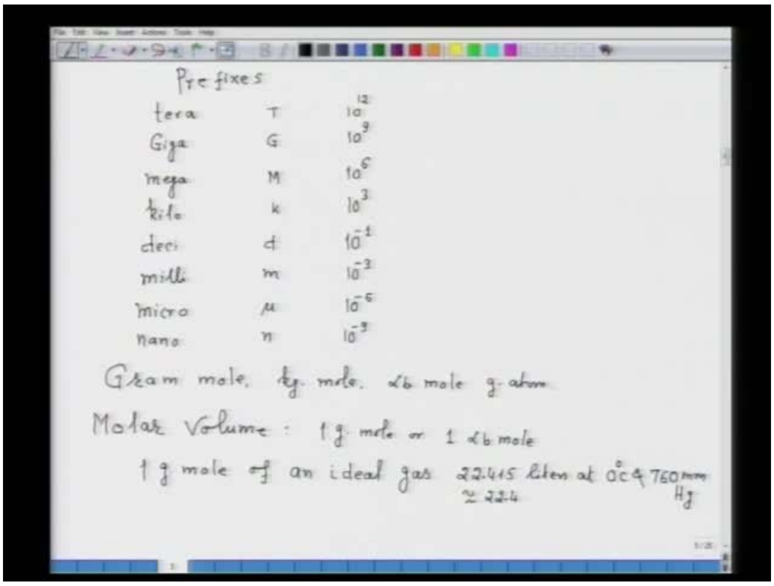

Similarly in other systems - CGS and FPS and MKS, one can derive the units. Now here, some of the prefixes are important. Sometimes there occurs a confusion, so I thought, let me give you. So prefixes, you write tera, it is written as T and its value is 10 to the power 12; giga is a G and its value is 10 to the power 9; mega is M, this is 10 to the power 6; kilo, well, all of you know kilo, I do not need to say, is k, it is 10 to the power 3; then deci, it is d, 10 to the power minus 1; milli, m, which is 10 to the power minus 3; micro, mu, 10 to the power minus 6; then nano, which is now very important, n, the value is 10 to the power minus 9. That is how the various prefixes are there.

Temperature can be expressed in degree fahrenheit or degree Kelvin or degree Celsius. Degree Rankin is also one of the unit; and their inter relationship, I hope you must be knowing, it is very basic.

Now, another thing that is often expressed is gram mole, kilogram mole then pound mole or many a times, we write gram atoms.

To find out the value of gram mole, you divide the mass by its molecular weight. Kilogram mole; gram mole; only the difference of 10 to the power 3; and pound mole, you divide the mass in pound, divide by its molecule weight; so these are also ways of expression of the content of the mass.

Now, it is also necessary to define here, the molar volume. Molar volume is either on the basis of a 1 gram mole or 1 pound mole; and while specifying the volume, one has to specify the temperature and pressure both.

Expression of volume in meter cube requires you to specify what the temperature is and what the pressure is, at which that volume is expressed.

So, 1 gram mole of an ideal gas occupies 22.415 liter or we can approximated to say 22.4, for calculations; and this to remember this is at 0 degree C and 760 millimeter mercury; this point is very important to note.

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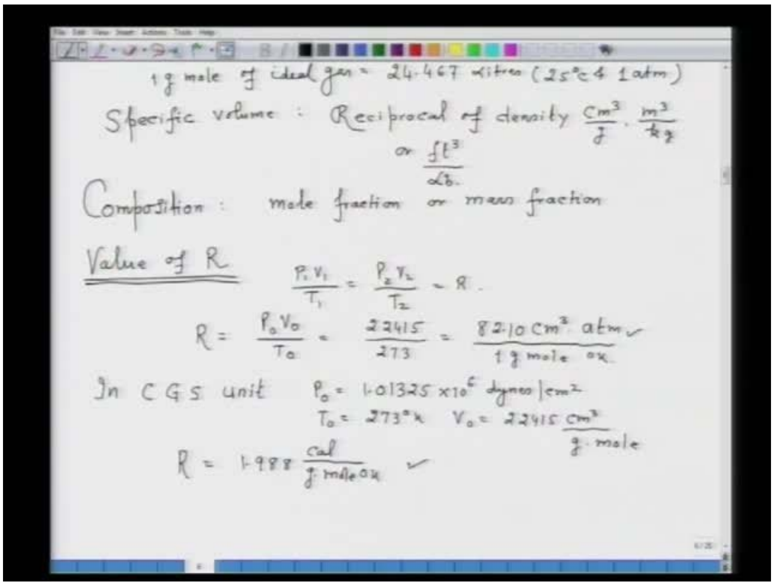

Now similarly, if you want to express, say at 25 degree Celsius, 1 gram mole of an ideal gas equals 24.467 liters; now, here this is at 25 degree Celsius and 1 atmospheric pressure or 760 millimeter, whichever way we want to express. Now remember, to express the volume, accordingly you have to express the temperature and pressure simultaneously.

Another variable which is often used is specific volume; specific volume is reciprocal of density. And that is equal to either centimeter cube per gram; or meter cube, here, it will be per kg; or feet cube per pound. These are ways of expressing specific volume.

Now, composition can be expressed in terms of mole fraction or mass fractions. Its very simple; if you have a different elements in a mixture, then you find out the moles of each element; find out the total moles; and if you divide the moles of an element by the total moles, then you get the moles fraction; similarly, mass; add the total and divide it to get the mass fraction.

Another very important thing that you have to know is the value of universal gas constant.

I will try to derive, because very often, the value of R is needed in dealing with the gases.

The value of R; you know this; very simple; P_1 into V_1 upon T_1; that is equal to P_2 into V_2 upon T_2; and that is equal to R.

We can find out R; that is equal to P_0 into V_0 upon T_0; so if you express say P_0 as atmospheric pressure; and V_0 if you express a 22415; if you divided by 273; so that will become equal to 82.10 centimeter cube atmosphere; since I have taken 1 gram mole of the gas, 1 gram mole into degree Kelvin.

So, this 82.10 centimeter cube atmosphere per gram mole upon degree Kelvin; in CGS units, if you want to express, then you have to express P_0, that is equal to 1.01325 into 10 to the power 6 dynes per centimeter square; T_0 - 273 degree Kelvin; and V_0 that is equal to 22415 centimeter cube per gram mole.

So all that now I have to do is substitute and if I substitute and solve, I will be the getting value of R, which will be equal to 1.988 calorie per gram mole degree Kelvin

All these values, you have to substitute say P_0, T_0, V_0 into R is equal to P_0 V_0 upon T; and you get R, in CGS units, 1.988 calorie per gram mole per degree Kelvin.

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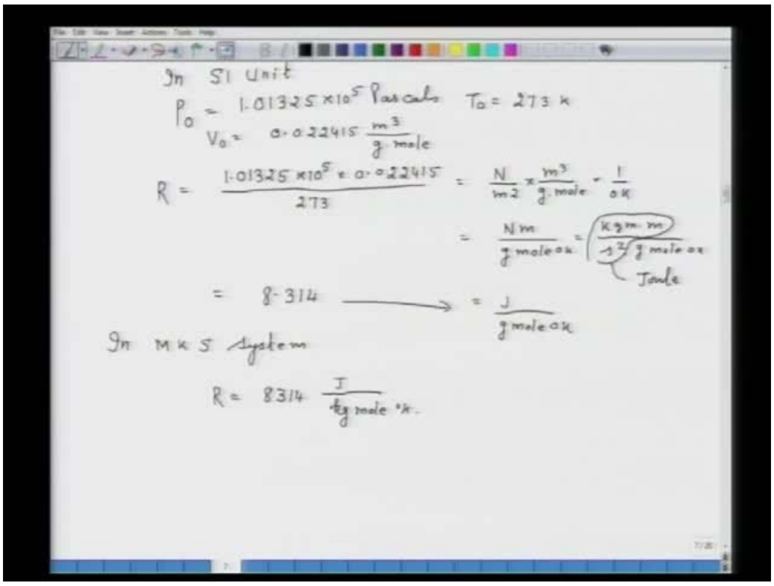

So the value of R; let us derive in SI units; P_0 is equal to 1.01325 into 10 to the power 5 Pascal; T_0 - 273 Kelvin; and V_0 that is equal to 0.022415 meter cube per gram mole.

So I am substituting the value; R is equal to 1.01325 into 10 to the power 5; into 0.022415 divide by 273; and I will try to derive the units. That is equal to Newton per meter square, unit of P; then I substituted V, in meter cube per gram mole; and then I divide by one upon degree Kelvin.

So if I solve this side of the unit, then it comes, Newton meter upon gram mole degree Kelvin; and Newton meter we know that is kilogram meter into meter upon second square, gram mole, degree Kelvin; and this you know kilogram meter square upon second square, this is joule. So the unit has become joule upon gram mole degree Kelvin; and if I solve here, that will be equal to 8.314 joule per gram mole degree Kelvin. So, this value of R, we are able to derive by utilizing the fundamental units; kilogram, meter second and degree Kelvin.

That illustrates that in order to derive the units of any physical quantity, if one uses the fundamental units, which is mass, length, temperature and time, one can in fact derive the units of almost all physical quantities, as I have illustrated over here.

Similarly, if I want to drive in MKS system; and this, I will leave to you to derive these units; get R that is equal to 8314 joule upon kg mole into degree Kelvin.

Try to derive this units in terms of MKS systems; also try to derive in case of in terms of CGS system and so on. This is about the units.

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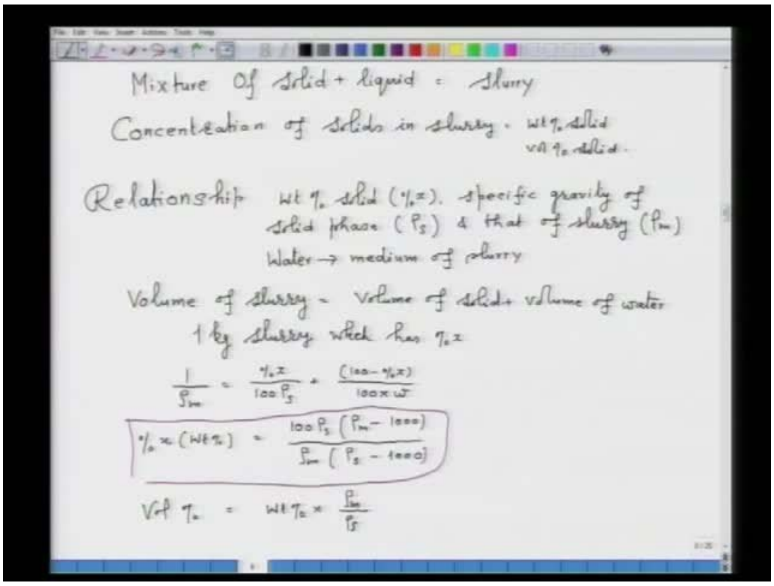

Many metallurgical processes have feed or product streams that contains moisture. That is, the feed is a mixture of solid and liquids. So these mixtures of solid and liquid in metallurgical terminology; this is called a slurry. A slurry consist of solid and liquid and liquid, mostly, it is water that is used.

For transportation purposes of a slurry, it is important to know what the concentration of solid in a slurry is, because you may be using a pump to transport the slurry from one location to another location; this term, slurry, will come very often in my lecture on material and heat balances, so please be clear.

So concentration of solids in slurry can be expressed either as weight percent solid or volume percent solid, whichever way we want to express.

Now, it is also very often required to know what is the weight percent solid in a slurry, because many a times you cannot measure this weight percent solid in a slurry; it is difficult to measure. So you may be measuring by some indirect measurement, say by measuring the density and so on, one can determine the weight percent of the solid in a slurry; and you can convert that weight percent into volume percent of the slurry. So let us derive the relationship between weight percent solid, let us call it is percent x; the specific gravity of solid phase, let us put rho_s; and that of slurry, put rho_m; and we use water as the medium of making slurry.

So we can derive the relationship, it is very simple. For example, volume of slurry is equal to volume of solid plus volume of water.

So, if we take 1 kg slurry, which has solid as percent x, then we can write down this as one upon rho_m is equal to percent x upon 100 rho_s plus 100 minus percent x - that is the amount of water, divide by 100 into w.

From here, we can derive percent x that is in weight percent; that will be equal to 100 rho_s into rho_m minus 1000 because I am using the density of water as 1000 kilogram per meter cube; that divide by rho_m into rho_s minus 1000.

So, utilizing this expression, one can determine the percent solid, if you know the density of the slurry and density of the solid. Of course density of water is known, which is taken as 1000 kilogram per meter cube. Now volume percent of solid in slurry will be equal to weight percent into density ratio. So that is how one can determine weight percent or volume percent of solid in a slurry.

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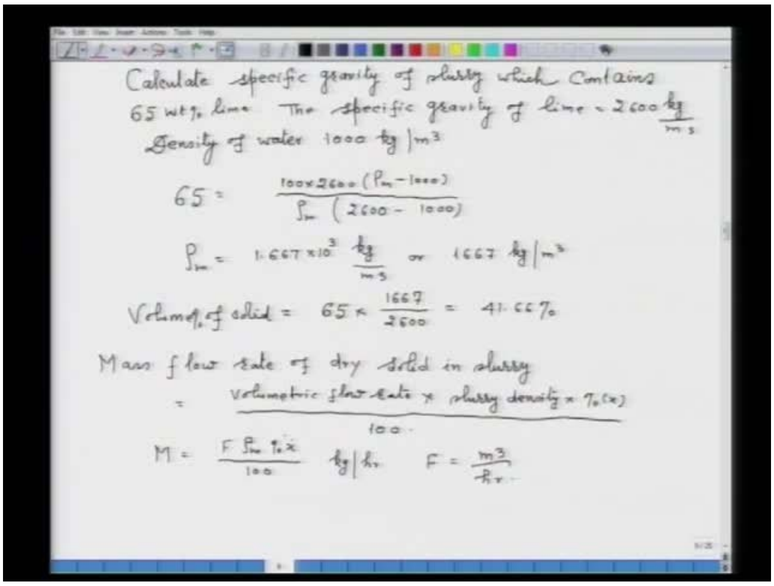

Now just let me illustrate; let us calculate the specific gravity of slurry which contains 65 weight percent lime.

The specific gravity of lime is given to you - 2600 kilogram per meter cube; take density of water, as it is in the formula, equal to 1000 kilogram per meter cube.

Now when I say slurry that is always, I mean, most of the cases, it is made with water. So it is very straight forward all that we have to do is use a formula. The formula is there; so 65 is equal to 100 into 2600 rho$_m$ minus 1000, upon rho$_m$ 2600 minus 1000.

So all that we have to find out is the value of rho$_m$. So I am leaving the exercise to you, you can do it. Value of rho$_m$ that will come out to be equal to 1.667 into 10 to the power 3 kilogram per meter cube or you can also put it as 1667 kilogram per meter cube. Now, if I want to find volume percent of solid in slurry that will be equal to 65 into 1667 upon 2600 that will be equal to 41.66 percent.

That is how you can find out the weight percent of solid in the slurry or volume percent of solid in slurry.

Now, let us also find out mass flow rate of dry solid in slurry. Now these things are very important, when we enter into the material balance of metal extraction and refining, a large amount of slurry is to be handled and one needs to know what the mass flow rate is.

So this mass flow rate, you can find out; it is the volumetric flow rate into slurry density slurry density into percent x the weight percent solid; and you divide this thing by 100. So if I take it in terms of formula, M is equal to F, which is the volumetric flow rate; rho_m, is the density of slurry into percent x upon 100; that is in kilogram per hour, where F is in meter cube per hour.

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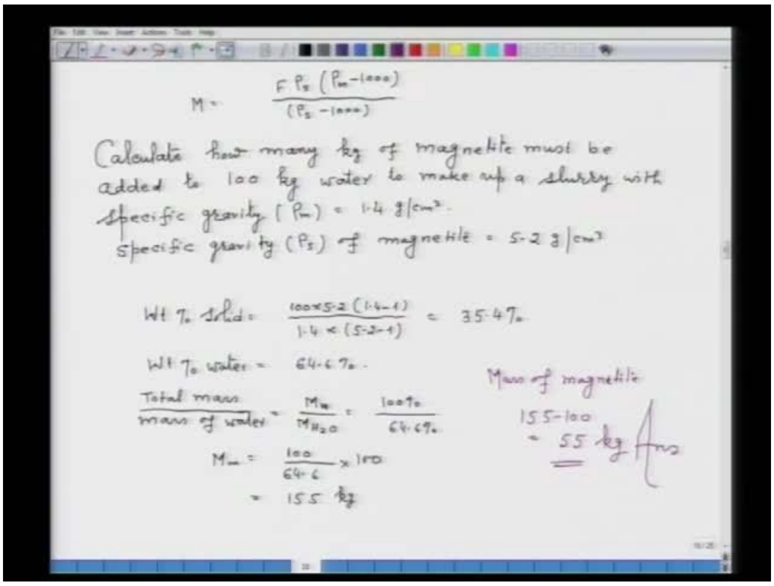

Now if I replace this percentage x from the earlier formula, then I get mass flow rate to be equal to F rho_s rho_m minus 1000 divide by rho_s minus 1000.

So, you can also determine the mass flow rate by utilizing this particular formula. Let me explain to you by solving a particular problem.

Calculate how many kg of magnetite must be added to 100 kg water to make up a slurry with a specific gravity, say rho_m that is 1.4 gram per centimeter cube.

The specific gravity of magnetite is given; that is rho_s of magnetite is given – 5.2 gram per centimeter cube.

So we have to calculate this. You have the formula. So I will try to apply, so that you understand. Weight percent solid, you can straight away find out; that will be equal to 100 into 5.2 into 1.4 minus 1 upon 1.4 into 5.2 minus 1. So that will be equal to 35.4 percent. Weight percent of water is equal to 64.6 percent.

I know the total mass; total mass upon mass of water; that is M_m upon M_{H2O}; that is equal to 100 percent upon 64.6 percent; so from here I can find out M_m that is equal to 100 upon 64.6 into 100. So that becomes 155 kg. This is the mass of the total mixture. So from here, mass of magnetite will be equal to 155 minus 100; that will be equal to 55 kg. That is the answer.

That means, I have to add 55 kg of magnetite, in order to make a slurry of density 1.4 gram per centimeter cube; and this particular thing is often required for various mineral processing operations.