Hello Everyone, welcome to the third video lecture on the course of CFD using openfoam. this lecture is dedicated to the essential governing laws and their open foam implementations in CFD and HT. the first part is computational heat conduction. this course is brought to you by FOSSEE IIT Bombay. I am Sumant Morab the instructor for this course. along with me professor Janani S Murallidharan is the coordinator for this course.

The outline for today's lecture is as follows. first we will look at all the governing plus which are present for studying computational fluid dynamics and heat transfer. then as a first step we will see in detail the energy conservation law and the terminology which is involved in the formulation of energy conservation law. then we look at finite volume methodology for discretization of particularly energy conservation law involving only conduction as first step. after that we will see how we can implement this particular energy conservation law with only conduction in open form. after seeing the implementation details , as a part of exercise we solve simple 2D heat conduction problem in open form.

Coming to the governing laws which exist in CFD and heat transfer, so basically as I said in the last video lecture that whenever we deal with finite value methodology which is generally used in open form we deal with control volumes which is a subdivision of domain which we are studying. so assuming that the fluid or the solid is incompressible in nature the mass conservation inside a control volume is as follows: so the net amount of mass which is entering the control volume must equal to the must be equal to the net amount of mass which is leaving the control volume period of time delta T . so basically mass cannot get a created and cannot get destroyed within a control volume. whatever is coming in inside a control volume must also leave the control volume for an incompressible fluid. so that is the main gist of this particular equation. now in momentum conservation, the net amount of increase in the momentum inside a control volume it is equal to the net amount of advected momentum which is entering the control volume and also apart from advected momentum we have net amount of viscous and pressure impulse in the positive XY or Z direction. basically we will deal with mass and momentum conservation in our later lectures but as a first step we will see what is energy conservation which is nothing but our first law of thermodynamics, that the increase in the energy within a control volume should be equal to the net amount of energy which is entering into the control volume plus the amount of energy which gets generated within the control. so both these energies that is the energy which is entering into the control volume the net energy which is entering into the control volume along with that whatever is generated inside the control so these both these things kind of contribute to the net increase in the energy within a control volume. so that is the meaning of energy conservation. basically it's again that the energy can neither be add created nor be destroyed. also so there is it should be conserved that is the main implication here.

so before actually going into the mathematical definition of the energy conservation we have to understand some terminologies which are very important so now assume that a family is having dinner or lunch in in a room where in there is a fireclay on the left side which you can see and assume that ice block has been brought from outside for some purpose and it is kept inside the row in one of the corners say on the right side now the ice is at particular temperatures is 0 degrees Celsius whereas the fire in the fire clay is at some higher temperature say 100 degrees Celsius now there are two possible situations so if the wind say is blowing inside the room in the positive direction that is given by the blue color here that is denoted by plus you so then the family members will kind of experience hotel temperature because of the conviction of the heat from the fire clay whereas if the velocity say is in the opposite direction say it is denoted by minus you then the members of the family kind of experienced lower temperature this might be very logical to you but there are some physics which are involved behind this so what is there is no flow inside the room so in that situation the temperature experienced by the family members will be average of the fire temperature and the ice cube temperature if there is no velocity involved so in that case it is a pure conduction process wherein the energy transfer is occurring through random vibration of the molecules basically you can see say that the air molecules which are there in the atmosphere they kind of transfer the energy that is pure conduction whereas if you see pure attraction it is the energy transfer due to bulk motion of molecules say the air is warming OK the molecules are moving with in some particular direction say from left to right that is plus you so then they carry the heat from the fireplace to the family members so in that way the energy transfer here is occurring through advection so in reality there is always a mixture of conduction and advection this is the situation which exists in the world so always there is some amount of flow which is happening and because of that there is advection and also conduction occurs inherently OK so there is no process wherein there will be only pure advection there can be a process where there is pure conduction only assume that there is no there is no flow at all so in those conditions it will be only pure conduction but there can never be a situation where there is only pure advection OK so so only conduction is possible or else in the usual situations uh whichever we deal David usually in our day-to-day activities it is usually conviction that is mixture of conduction as well as advection.

now if we consider energy conservation law, in a continuous form so basically continuous form means we are taking infinitesimally small control volume and say we are writing the equations in terms of partial differential equations so now the energy conservation law which is presented here it is purely for a connection. that is the first part which we are dealing with in today's lecture so. as I said earlier so the rate of change of energy within a control volume which is given by go eat by two T so the rate of change of another G increase of energy stored within a control volume should be equal to the net rate of conducted thermal energy. In the sense you can see in this figure that from the left side there is a energy flux QX with sentry hand Q at X plus DX distance there is a guy in that heat flux. so the net heat flux which is entering into the control volume will be then Q X - Q X plus DX that is the net conducted terminology which is entering the control volume similarly this was the next direction so we are considering two-dimensional format so similarly we have Qi minus Qi plus die also and our unit distance so it is very DX will come and dy OK so if we are writing it in a in a continuous form so then this becomes just a partial derivative of QX that is the change in the conducted thermal energy and along the X direction and then along the Y direction. Now the main intention here is to convert these equation in terms of temperature and for that purpose we kind of use fourier's law so the word does this horse last ate it basically what it states is that the the thermal I have G flux which happens across the surface is equal to is directly proposed proportional to the gradient of temperature so when the gradient of temperature is high basically a gradient of temperature in simple words we can say if the temperature difference is high between any two points then the heat transfer will also be more in the heat and energy moving from one side to other side will also be more it is very similar to your flow concept wherein you have a potential so if the height difference is very high then you see that kind of potential is very high potential difference is very high so the water can come down with a higher velocity from larger head position to a lower height position so similarly in this also we have two points wherein if the temperature difference is very large then the the heat conducted will be also very large so that is mainly the fourier's law and the - is to say that it happens in the opposite direction so from a higher temperature to the lower temperature the heat flows so that is why the negative sign is usually used. now if we substitute this expression for Q end which is given in equation 3 in our main energy conservation equation in two then we find out that and also one more thing is that the total energy east should be equal to row CP into. assuming that the solid or the fluid which we are dealing with is incompressible nature and we are ignoring the the the changes in the pressure energy and all so ignoring those things only keeping into mind the changing the energy to do to the heat capacity is given by CP here so do to that whatever changes happening in energy can be given by partial derivative of row CPT. OK and it is equal to K in two P square T by TX square plus disquality by DY square so that was the equation which we have to solve OK so just keep that in mind.

now we will see what are the initial conditions for the boundary conditions possible in the solving the energy equation. so initial conditions are the variable values so the temperature values at T is equal to 0 starting of the simulations throughout the domain now if you see boundary conditions these are the conditions of the variables all over the foundries and they are applicable at all the time steps OK so as shown in this figure so at the left boundary we have a constant temperature of the wall OK so that is wherever the eastmont re we have an incoming heat flux constant heat flux which is denoted by QE so this heat flux is given for all the time. And the temperature also is set at all the time instants now. at the bottom we have an insulated so basically which means that there is no heat energy transfer which can happen so basically this Q itself is equal to zero that is the meaning of insulated and then at the top wall of this previous lab we can see that it is exposed to the air environmental air there is a convective heat transfer which is happening so these are all the possible kind of boundary conditions which can be there in a problem so one is the convective boundary condition the other is the specified heat flux which is given by thank you then we have insulated boundary condition which is I feel an approximation of specified heat flux because here the specified heat flux is nothing but zero and then also a specified word temperature. so that is what is given here uniform heat flux you have a say QE it can be zero or some constant value also here it has been written as zero OK and in insulated you have Q is equal to zero that is nothing but this DT by DN will be equal to 0 then the convective boundary condition which you had in the top wall that can be equal to the HT minus capital T Infinity. that is the ambient temperature T Infinity.

so let us try to see how we can kind of discretize the governing equation we will look at only a one-dimensional case for simplicity now the main reason behind teaching this is that you should know what happens in open form how it kind of solves the equation because you are going to ultimately right the main equation itself in the continuous form but you should be knowing how it solves through so that you kind of can modify it as according to the situations OK. so if you just consider A1 dimensional domain as shown in this figure now it is required to obtain the algebraic equation father steady state conservation. and then she conservation at a control volume P as shown in this figure so for this particular P you control volume you need to train the a discretized form of energy conservation. so first you start with the governing equation you also have a Q generation here OK so you can just add the generated energy within the control volume. and assuming that it is a steady state so the partial derivative of temperature with respect to time it will be equal to 0 so if you kind of integrate situation with respect to control volume DB and then if you use a gauss divergent theorem that is the integral over volume can be equal to the integral over a surface if there is a gradient which is involved we can remove the gradient of the variable we can just put the variable and then the normal direction to the surface and the surface area. so that is the cost so here you have. partial derivative of DT by DX so basically that variable 5 will be nothing but DT by DX OK uh then you have the surface area that is divided into dies at since it is 1D we all have died easy as one note so that is what is shown here delta X is there a participant volume delta Y 1D is also one OK. now this is applicable from east to West so that is what is given here so then you just expand this you find out that the equation turns out like DT by DX on the east side east face partial derivative of temperature on the West surface plus cube generation into delta X will be equal to 0. now the partial derivative of temperature at the east face you can use the second order central difference scheme as it was taught in the second lecture so you can approximately 80 by DX at this phase to be at east control volume minus TP the temperature at the fifth control volume divided by the distance between eith control volume and Pete it is text similarly in the West so the IT through this you can come up with a linear algebraic equation that it is left as an exercise for you to find out what are these API you can just expand this keep TP at one point bring TW at the other point and T here the other point and see what are the coefficients coming so that you will get a PAW. and then using this Q generation you can get B also. so this is the equation which needs to be solved now this can be solved either through direct scheme or an indirect scheme which we haven't discussed in the last class OK. so we will see now how in open form these equations are written and then how they can be modified how they can be used. so for this we have to check the laplacian solution implementation in open form. uh that is all application solver so for that you need to go to this particular folder opt openfoam version number applications solvers basic so this is the basic solver laplacian form so this is a solver OK it comes in the basic solver package OK so when you open this solver you get many uh files again there you have to open this laplacian phone dot C file once you open this and mainly look into this while loop you see that the implementation of the error equation happens like this so if we are deep DT of T that is the partial derivative of temperature with respect to time minus F move laplacian DTD that is minus half K DT is nothing but your K here the thermal conductivity OK yeah K2 that is given by laplace India operator you know that it is dose square tibideaux X square plus row square T by two Y squared that is the laplacian operator now end this here it is nothing but zero in our case so this you can anyway mention it to be 0. direct now the only thing which is remaining so basically if we scalar matrix what it does is it kind of forms the matrix from this particular equation and then basically it is solved so mainly only thing is what is this FMLA is remaining so option is used to create the matrix of coefficients AP and AE through finite volume discretization technique which was discussed earlier so that is why I have discussed that particular 1D discretisation below it might be not very much necessary for you but so as to understand that particular topic that was necessary two when they like this it is implemented then the openfoam itself kind of takes the integral and then it kind of gets into these values of A PAW and a that is the crux which is happening inside the OpenFoam.

so let us about how it discretize in-openfoam . now let us see how it solves the solution methodology so the solution methodology you can always find it in an example case so previously we went into a solver which was there in the open form OK that is the solver which we saw now whenever we want to see solution we have to see a particular example which uses that particular solver which uses laplace inform solver OK we have to see the example so that is why now we go into the group torreilles section so once we go into opt openfoam tutorials basic laplacian foam and there is only one example flange example is that if you go into system folder you will see solvers so in the solver this return PCG now we discussed in the last week that we have mainly direct and indirect solvers for linear algebraic equations the direct solvers word elude composition direct inverse or say Thomas algorithm which is mainly used for tridiagonal matrix systems OK and we have indirect methods like gauss Jacobi conjugate gradient so the solver which opened from here it is using is a conjugate gradient PCG means preconditioned conjugate gradient so as to get faster solution preconditioning is done and so as we avoid instability also preconditioning is usually done if you're interested you can check these things online but as of now just keep in mind that it is solving conjugate gradient scheme it is using conjugate gradient scheme so that is how you check the solution methodology and also the time stepping schemes also which is given by DDT schemes now let us try to get an appreciation using illustrative example of 2D unsteady state heat conduction OK so this is mainly the problem statement which is given here you have a 2D slab and wherein you have at the West Palm tree you have a constant temperature at the north palm tree you have a constant temperature S boundary is insulated east Darwin tree as a constant heat flux of 30 vacuum meters square.

now, this is an exercise for all of you so with this particular video the zip file which will be attached so you can download the zip file which is given with the video and extract the files end of table to extract the files OK we will try to solve this particular example so you have zero folder wherein you can modify the boundary conditions then we have constant and then we have the Poly mesh wherein there is a file called block mesh wherein you can modify the geometry but all these are already kept in the standard condition to suit the problem OK so you need not modify anything just extract the files and just go to the terminal OK and just type this block mesh once you type this block mesh you will be able to generate the mesh file OK so that is the first step once you are able to generate the mesh file then the next step is to solve the equation I'll text you can just type laplacian from on the terminal OK then it kind of solves the equations at every time step using the particular conjugate gradient solver it gets the solution at every time step and once third time steps get over whatever is being specified. then you can go and see the results using the para foam command so it opens the para foam window wherein you can just check that our temperature contours and they should look something she's shown in this particular figure so you can see that at the bottom we have very straight lines which indicates that DT by DX is zero because the slope is coming out to be 0 here and that is why I said that it is an insulated whereas at the left wall you can see that there is a constant temperature that the north also is a constant temperature whereas if you see on the right side you will find that the slopes are not zero they're constant because there are straight line with same in nature so DT by DX is constant DT by DX is constant OK so. I hope that kind of news the appreciation for the boundary conditions and how to solve such heat conduction problems in open also if you can as a part of exercise check the 0T file to see the implementation of various doctor conditions in open form. so these are the references which were I used for today's presentation mainly the contents are taken from the introduction to computational fluid dynamics development application analysis book by professor Atul sharma . alright thank you for listening.