

# **CFD APPLICATIONS IN CHEMICAL PROCESSES**

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**Lecture 09: Boundary conditions**

Hello everyone, welcome back with another lecture on CFD applications in chemical processes. I am Arnab Atta. We were discussing about the basics of implementing CFD in which we were discussing in the last class about the boundary conditions. what are the most commonly used boundary conditions that we find in the CFD modeling and what are those how those are mathematically implemented or mathematically understood by the CFD code. In that context you have seen we have discussed that in general the inlet boundary conditions in the last class we discussed this inlet boundary condition. this inlet boundary conditions in which if velocity is specified, we call that as the velocity inlet and we have understood what is meant by flat velocity inlet.

if the velocity is not known, if the pressure is specified at the boundary condition, how that can in how that information can be converted to the velocity by the code or by yourself that is specified here or that we discussed here. we do not convert manually we leave it to the solver to convert this information and we specify pressure instead of velocity. So, specifying both velocity and pressure are not necessary and in fact, are not done either one of those are specified at the boundary condition at the inlet, if velocity is specified we call that as the velocity inlet, if pressure is specified we call that as the pressure inlet boundary condition. We also discussed about the outlet boundary condition or specifically say the outflow boundary condition.

We understood why sometimes the extension of computational domain is necessary to find the accurate or more detailed information or more accurate information accurate physics, why it is necessary, when it is necessary. We also discussed about the wall boundary condition. This is the impermeable wall boundary condition when we spoke about regarding the no slip boundary condition and we started discussion on the symmetry. the symmetry boundary condition. Those greatly helps in reducing our computational effort if we find the geometric symmetry and the flow symmetry.

I have emphasized that only geometric symmetry would not be sufficient if several complex phenomena are involved or several complex phenomena are involved. And, in those cases we have to look into the flow symmetry by citing an example or showing you an example. If there is pure hydrodynamics only geometric symmetry suffices. However,

if there is heat transfer, if there is any other thing involved and if we do not expect symmetry of those flow variables, then considering symmetry boundary conditions would lead to erroneous result. and in such cases we have to look for the flow symmetry.

So, in the case of periodic boundary condition. So, again quickly if I just give you an initial that as I told you that most commonly that another boundary conditions that often we used most commonly is the open boundary condition. we say this is the open boundary condition. So, in open boundary condition what happens that this is considered 0. So, this open boundary condition tells that any fluid it is a kind of a fluid interface boundary conditions we will see its application.

that fluid can enter or exit through that boundary condition ok. So, and it can happen freely. So, the example that we can have is that if we have an external also in general what we have seen is that if we consider these are the solid wall. this is our inflow boundary condition or inlet that we say flow happening and this is our outflow or outlet boundary condition, this is the solid wall.

So, this is the classical case of a internal flow, where it is enclosed by the solid boundaries. Now, at the wall what we specify is velocity 0 of this fluid. and we specify temperature or if there is any heat flux. Similarly, the same applies on the other wall. At the inlet we specify the material properties and their density velocity and temperature.

So, velocity is specified throughout the region or throughout the plane. If pressure has to be specified that can be specified for a particular point. that would surface, but here along the along the surface we have to specify this temperature and the velocity profiles. This is the internal flow. In case of the other which is say the external flow say for example, there is a flow happening across a body or

a solid object is there, flow is happening around it. So, in such cases how do we at first zero down to a computational domain? We choose a computational domain far away from the surface of the solid object so that it does not have its influence on this end surfaces we consider that computational domain where these distances are far enough from one end to other the computational surfaces or the planes so that their influences are not failed at this point. But, we try to capture the flow physics around it or say the heat transfer or anything else that is associated with it.

So, in such cases this concept of open boundary comes into play. So, in this case what would be my boundary condition? So, the boundary condition In this case is similar to the

previous one where we specify this density, velocity and temperature. This is the inlet boundary condition.

This is similar to the previous one we have the outlet boundary condition. This is the solid object. here we have to specify the velocities on the surfaces. So, here on the surface because we have to tell that this is a solid object to the CFD code. So, the velocity at this point is 0.

and we have to specify the temperature and or heat flux like we specified in case of the solid wall in the case of internal flow. Now, this is we are giving example for the external flow. Now comes this boundary, which in the case of internal flow we specified as solid wall, but here these are not the solid walls, these are the open boundary. these are the open boundary and what happens here the inflow as the inflow boundary conditions I mean it can be say considered as the inflow boundary conditions or the inlet boundary conditions where flow goes into the solution and the solution domain or the computational domain through this open boundary or it can also be considered as the outflow boundary condition. So, either inflow or outflow based on the flow or how this phenomena is happening.

This acts as both or actually in one of the cases that if say for example, heat is getting dissipated. So, heat transfer will happen it would cross this boundary easily. So, the flow out of the domain or flow into the domain in both the cases. So, this is also is then the open boundary condition. So, in these as I told you for the open boundary cases the consideration is this that we mathematically apply is this.

This is very commonly used It is the simple boundary condition to be implemented here that it acts as a kind of a open boundary case as the name suggests where both or one of these things can easily happen that either something can enter freely or can go out freely. So, the point is in case of like specifically the outflow boundary condition we have seen it has to be far away from its outlet influence the flow physics that can be influenced if there is any constriction or divergence sudden divergence. So, that the there will be some feedback of the flow that is immediately out of the system and we generally cannot place the outflow boundary conditions immediately in such positions we have to extend our domain.

So, that those influences are filtered or are becomes smooth or not felt in this cases. So, this outflow inflow open boundary conditions, walls these are most commonly used in this CFD modeling and specifically in the technique that we will learn in next classes or next couple of classes after next couple of classes are this finite volume method. there these

boundary conditions inflow or inlet outflow or outlet this open boundary conditions while these are frequently used. Now, regarding this symmetry boundary conditions we have understood this.

There are situations also where we see the periodicity nature or say the periodic nature where a geometry can be repeated if we go in a particular direction or in all the directions. Say for example, we have say shell and tube heat exchanger kind of a situation. where we have say from here we have a baffle where flow is happening from this side it is going outside. So, what we see here that we have if we extend this further then it would be more clear. So, what we see from here is that we have a certain periodicity that if we repeat this in this direction, we find its similar periodic behavior of the geometry and also the flow. So, in such cases we see we call these are the periodic boundary conditions along these lines or along these surfaces or along this plane which means if we simulate only this green part by defining these as the periodic boundary conditions our requirement would surface. So the computational domain would eventually look like that I have So, basically I have this part I have to. So, flow is happening going out from this side and if we make this periodic or say translationally

So, it is basically a transitional periodic boundary condition. So, this dotted surfaces or this part essentially are the transitionally periodic boundary condition and if we consider that our computational domain significantly reduces in size and accordingly we can find the or we can achieve the less computationally intensive scenario and we can quickly solve the parameter. The other scenario that can happen is that say we have and in this cases we have say four tangentially and equispaced inlet.

So, these are four tangential inlet this is say 1 2 3 and 4 in a say top surface say consider this is kind of a cyclone separated top view where you have 4 such tangential inlet and in those cases then we can find or we can see that if we consider one quarter of say if this is my centre. So, one quarter would be sufficient to represent the whole geometry and in these cases we will call this boundary condition as the rotationally we call that as

rotationally periodic boundary condition. So, in this one as well as this one these two surfaces. So, eventually the geometry looks like the computational domain looks like with one inlet here. So, this becomes the computational domain where this and this.

So, these two boundaries are the rotationally periodic boundary conditions. So, in those cases in the case of rotationally periodic periodicity what we have all the values are equal.

In the case of transitional periodicity all the flow variables or the scalar quantities that we consider that  $\varphi_1 = \varphi_2$  except pressure. So, like symmetry periodic boundary condition can also in fact also helps us in achieving a reduced domain. or a shorter domain, shorter computational domain where the number of equations the same number of equations we solve, but for a smaller domain and that would give us a quicker result to gain insights on the physics what is happening.

But the boundary conditions in the case of periodic boundary conditions there can be two scenarios one is the transitional periodicity that you go in transitional steps or it can happen in a periodic manner that is shown here. So, in both the cases what we see is that we can reduce the computational domain to a smaller size and that has a greater importance. Similar to that also what if I ask you now that if I have this kind of a simpler geometry or the geometry that looks like this is the solid surface and at the bottom I have this group kind of a structure.

So, now, you think and suggest that whether I need to solve see the flow is happening like this. that whole domain is to be considered or has to be considered for the solution or if we can apply our previous understanding that whether some sort of special boundary condition we can apply in such scenario, so that our computational effort becomes lesser. or computational effort is put into the solution in a lesser way. In this case what you can identify that still here we can have a periodic boundary condition ok. Now, that periodic boundary because these are clearly the wall boundary condition and if you consider

this part you can see that if you repeat that you can have your whole domain represented and that you can consider as the periodic boundary condition ok. here you will have the inflow boundary condition, here you will have your outflow boundary condition or inlet or outlet boundary condition. So, these are now become that what you have is the if you consider until unless if you consider that these are your periodic boundary conditions this faces or this plane and this plane this becomes your inlet and outlet but in this case it becomes only this is the computational domain and this is your periodic boundary condition where you have the  $\varphi_1 = \varphi_2$  in other cases say you have solving a series of this scenario. When the flow is happening around this, here you may consider

this as your cyclic boundary condition. So, these are your cyclic boundary condition, this is your outflow boundary condition and this is your inflow boundary condition instead of solving the whole set. So, the point is what we have seen here in the boundary condition. If I have to specify a categorically inlet a complete specification you have to if you have to

do that then for all inlet we have to provide distribution of all variables at the inlet if I say those are  $\varphi$  except pressure in our computational domain.

specification of pressure if you want to specify a pressure in just one location would be sufficient and that would be comprehensive. At the outlets we have to set gradients of all variables  $\varphi$  and this gradients to  $\varphi$  should be 0 in the flow directions in the direction of the flow where we set the outlet boundary conditions. this gradient of all variables  $\varphi$  we have to set to 0 in the direction of flow ok. And at the solid walls we have to set all gradients of variables I mean variables I would say the gradients of all variable

except pressure and density. We have to specify these gradients of all variables except pressure and density or their normal gradients. at the solid walls we have to specify those gradients whether it is moving or stationary accordingly that would be judged or that would be applied. So for the no slip boundary condition as we generally speak at the wall we set the velocity the transverse velocity that is there to the 0. for the moving case it is moving with the same velocity as that of the object.

So, with this I stop here with the basic or the common set of boundary conditions that are applied in the case of CFD modeling and specifically those are popular or most commonly used in the finite volume method that is one of the techniques that we will learn in the next class for the solving this partial differential equations. So thank you for your patience and thank you for listening.