Learning Exercise 3
Course: AAE-E3030 Numerical Modeling of Multiphase Flow

Return exercise by: Thursday April 11th 2019, 23:55

Topics: Simple models on premixed combustion

Problem 1: Writing a code for 1d flame simulation using progress variable approach (c-equation). (10p)
Solve the following equation and demonstrate the behavior for different flame speeds when *u =1m/s*, starting from initial condition *c=1, x<L/2* and *c=0, x>L/2*. (1 → unburnt, 0 → burnt). Physically, this situation corresponds to a case where fresh fuel is supplied from the left end of the domain while the flame either stands still or moves from left to right. You can assume all densities to be 1 kg/m^3.

$$\frac{\partial \rho c}{\partial t} + u\frac{\partial \rho c}{\partial x} = D\frac{\partial^2 c}{\partial x^2} - \rho_u S_L \left|\frac{\partial c}{\partial x}\right|$$

Assume *c=1 at x=0* and *c=0 at x=L* in the 1d domain. For discretization you can assume the basic finite difference formula to calculate the change in progress variable and use the change *dc* to update using explicit Euler formula (*i* refers to space index, *n* to time index).

$$\Delta c_i^n = -u\Delta t\frac{c_{i+1}^n - c_{i-1}^n}{2\Delta x} + D\Delta t\frac{c_{i+1}^n - 2c_i^n + c_{i-1}^n}{\Delta x^2} - S_L \Delta t\left|\frac{c_{i+1}^n - c_{i-1}^n}{2\Delta x}\right|$$

$$c_i^{n+1} = c_i^n + \Delta c_i^n$$

Note CFL and Courant number conditions to make timestep small enough (e.g. Co = $udt/dx << 1$) and CFL = $Ddt/dx^2 << 1$). The purpose of D is only to smoothen out the flame front with a small amount of artificial diffusion (try e.g. D=u*dx/10). You should choose D so that you see no wiggles i.e. the diffusion term acts as a diffusive low-pass filter clipping out the Gibbs waves. **Return:** pictures of flame front propagation in time for three distinct values of laminar flame speed ($S_L<u$, $S_L=u$ and $S_L>u$) and discussion on what you did. Discuss also what physical effects are not accounted for in this simple 1d model. Also attach your code.

Problem 2) Bunsen flame in Matlab (10p)
Use the Matlab code `Fire` to simulate Bunsen flame formation at laminar flame speeds S_L/U_{max} = 0.7, 1.2, 1.7 with Markstein length 2.5dx. Simulate until the flame is fully developed. The simulations should take altogether about 5-10 minutes. The burnt/unburnt temperatures can be here taken as the model values 1000K/500K as they are currently in the code.
a) Explain the density, temperature and pressure variations in the flame using the present computational model. **Discuss your result** from the viewpoint of problem 1. Attach pictures to explain.
b) What happens when the laminar flame speed is very large or very slow ? Attach pictures to explain.
c) Explain, combining information from lectures 5-6, what details of physical premixed flames are ignored in the progress variable approach ?
d) Find information on laminar flame-speeds for common gaseous fuels. What is the order of magnitude of laminar flame speeds and are they smaller or larger than 100m/s ?

Hints: You can create an image of the progress variable (called `C` in the code, e.g. `imagesc([-`

`Lx Lx],[0 Ly],C)` does the job). **Note:** what is important here is the relative velocity. The high velocities here (~100m/s) are chosen to enable running the density-based code fast and efficient.