MAE 494/598 Applied CFD, Fall 2018, Project 2 - Internal Flow II (10 points)

Hard copy of report is due at 1:30 PM on the due date. Please follow the rules for collaboration as described in the cover page of the document for Project 1. **A statement on collaboration is mandatory for all**. All tasks in this project are for both MAE598 and MAE494.

For all simulations in this project, the mesh should have enhanced resolution along the wall.

Task 1

Background: The water heater we studied in Project 1 is very primitive and inefficient. In practice, the water heaters for household uses have very different designs. One design is to run water through a coiled pipe with heated wall. This allows water to heat up quickly within limited space. This is particularly efficient for "tankless" type of water heaters. We will use Ansys-Fluent to simulate a prototype of the coiled-pipe system filled with ***water***. Unlike Project 1, to keep the physical processes simple we revert the setting to constant density and no gravity. The viscosity and heat conductivity of water are also set to constant, all using the default values in Fluent database.

Consider a helical pipe with its center traced by the equation of a helical curve,

$X(t) = R\cos(t)$ Eq. (1)

$Y(t) = R\sin(t)$ Eq. (2)

$Z(t) = C\,t$, Eq. (3)

where "t" is not time but a dummy parameter to help tracing the curve. For this task, the curve is traced from $t = 0$ to $t = 10\,\pi$ (radian), with $R = 0.3$ m and $C = 0.15/(2\pi)$ m. (The helix is "raised" by 0.15 m every revolution.) The helical curve is shown in Fig. 1. The 3-D helical pipe (with the helical curve as its center) with a circular cross section with radius = 4 cm (diameter = 8 cm) is shown in Fig. 2.

With the above geometric setup, the surfaces of the inlet and outlet of the helical pipe are both perpendicular to the y-direction. The boundary conditions are ***velocity inlet*** for the inlet, and ***outflow*** for the outlet. In addition, set the inlet velocity as 0.05 m/s, in the direction normal to the surface of the inlet (and going *into* the pipe), and inlet temperature as $T = 20$°C. The temperature at the wall of the helical pipe is set to a constant $T = 50$°C.

In addition to the basic setting described in *Background*, we will use *Laminar* model and seek *steady solution*. *Energy equation* is turned on. Although buoyance effect is omitted, heat conduction still takes place in the system, which allows water to warm up as it flows through the pipe.

The deliverables for this task are

(1) A plot of the mesh on the surface of the outlet. This is to confirm that the mesh has enhanced resolution along the wall.

(2) Contour plots of *temperature* and *velocity magnitude* on the surface of outlet. Please indicate the inner and outer edges of the pipe in the contour plots. Adjust the contour interval as needed to clearly show the variation of temperature and velocity across the surface.

(3) The values of the averaged outlet temperature, T_{out}, and the energy flux at outlet, H, calculated using the same definitions as in Homework 1 and Project 1:

$$T_{out} = \frac{1}{A}\iint_A T dA, \qquad \text{Eq. (4)}$$

$$H = \iint_A \rho\, C_p\, v_n T\, dA, \qquad \text{Eq. (5)}$$

where the integral is performed over the surface of the outlet and v_n is the velocity normal to the surface of the outlet. (Please report the value of the energy flux in unit of W.)

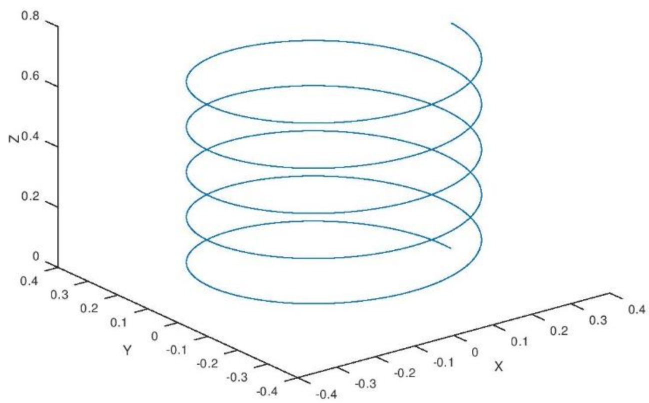

Fig. 1 The helical curve.

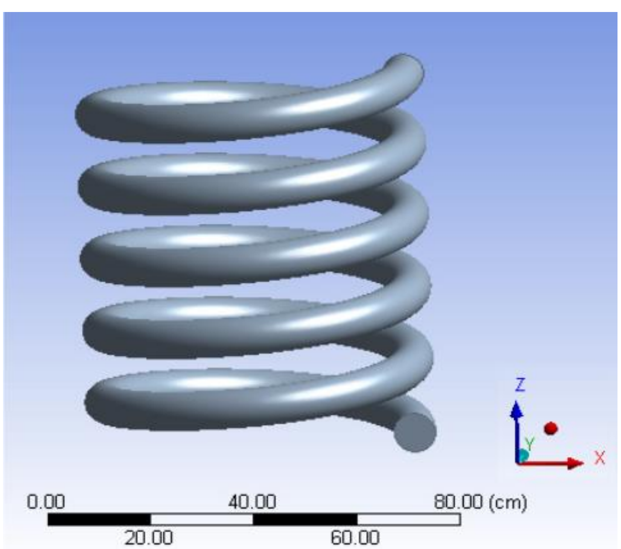

Fig. 2 The 3-D helical pipe.

Task 2

We now modify the design of the helical pipe in Task 1 but with the constraint that the diameter and the total length of the pipe remain the same. Perform two more simulations: The first uses a *straight pipe* of the same diameter and total length as the helical pipe in Task 1. The second simulation uses a "stretched" version of the helical pipe in Task 1, by tripling the value of C in the helical equation but decreasing R accordingly to maintain the same total length of the pipe as that in Task 1. For the "stretched" helical curve, the parameter "t" should still run from 0 to 10 π. All boundary conditions and setup of physical parameters for the 2 runs in this task are the same as their counterparts in Task 1. The deliverables are

(1) A figure that shows the geometry of the stretched helical pipe (no need to show the geometry of the "straight pipe" as it is obvious), in the fashion of Fig. 2.

(2) For both runs, contour plots of *temperature* and *velocity magnitude* on the surface of outlet, similar to deliverable #2 for Task 1.

(3) For both runs, the values of the averaged outlet temperature, T_{out}, and the energy flux at outlet, H. Are those values the same across the three cases in Task 1 and 2?

[Note: The arc length of a helical curve, as defined by Eqs. (1)-(3), is $L = \sqrt{R^2 + C^2}\, t$.]

Task 3

The behavior of a flow in a curved pipe can be examined more closely using a simpler system of a classic U-shaped pipe with a circular cross section, as shown in Fig. 3. The system is filled with water. Here, we turn Energy equation off and ignore temperature variation in the system. The setting of the simulation is otherwise the same as that in Task 1 and 2, except that the outlet is set as ***pressure outlet*** with zero gauge pressure. The inlet velocity (normal to the surface of the inlet and going into the pipe) is set to 0.01 m/s.

The geometry of the system along the plane of symmetry is shown in Fig. 4. The radius of the pipe is 5 cm (diameter is 10 cm). The U-shaped pipe can be constructed by merging 3 segments together. Two are straight pipes, each with length of 1 m. The third, the "curved section", traces a half annulus (spanning 180° angle) with inner radius = 45 cm and outer radius = 55 cm in the plane of symmetry. The simulation for this task can be run using either the full pipe, or the half pipe by invoking symmetry. Please indicate your choice.

The deliverables are:

(1) Line plots ("*XY plot*" in ANSYS) of *velocity magnitude* along four line segments in the plane of symmetry, as indicated in Fig. 5. The four lines mark (1) The "entry" of the curved section of pipe, (2) The middle point of the curved section, (3) The "exit" of the curved section, and (4) The outlet of the whole system. It is recommended (although not strictly required) that all four curves be collected in one plot to facilitate a clearer comparison among them.

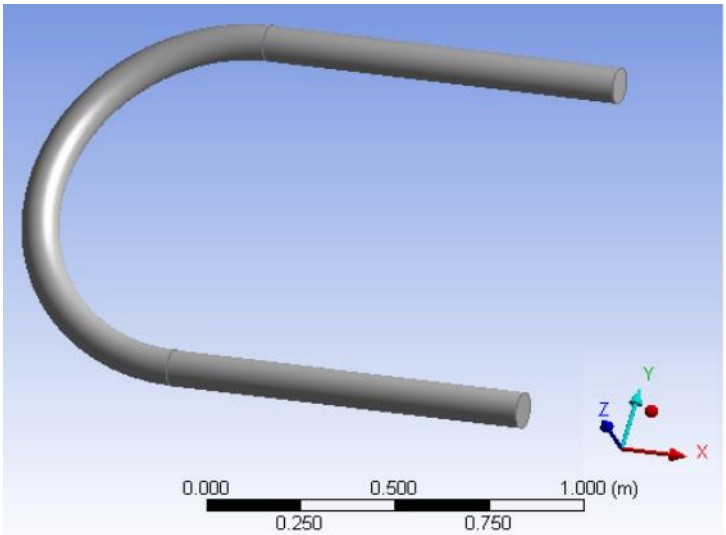

Fig. 3 The U-shaped pipe.

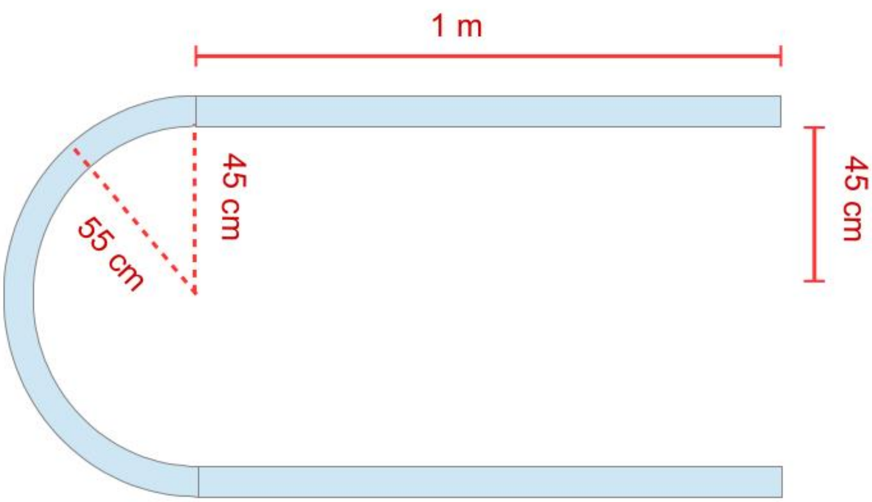

Fig. 4 Geometry of the pipe along the plane of symmetry. The inner and outer edges of the curved section traces two semicircles with radius = 45 cm and 55 cm, respectively.

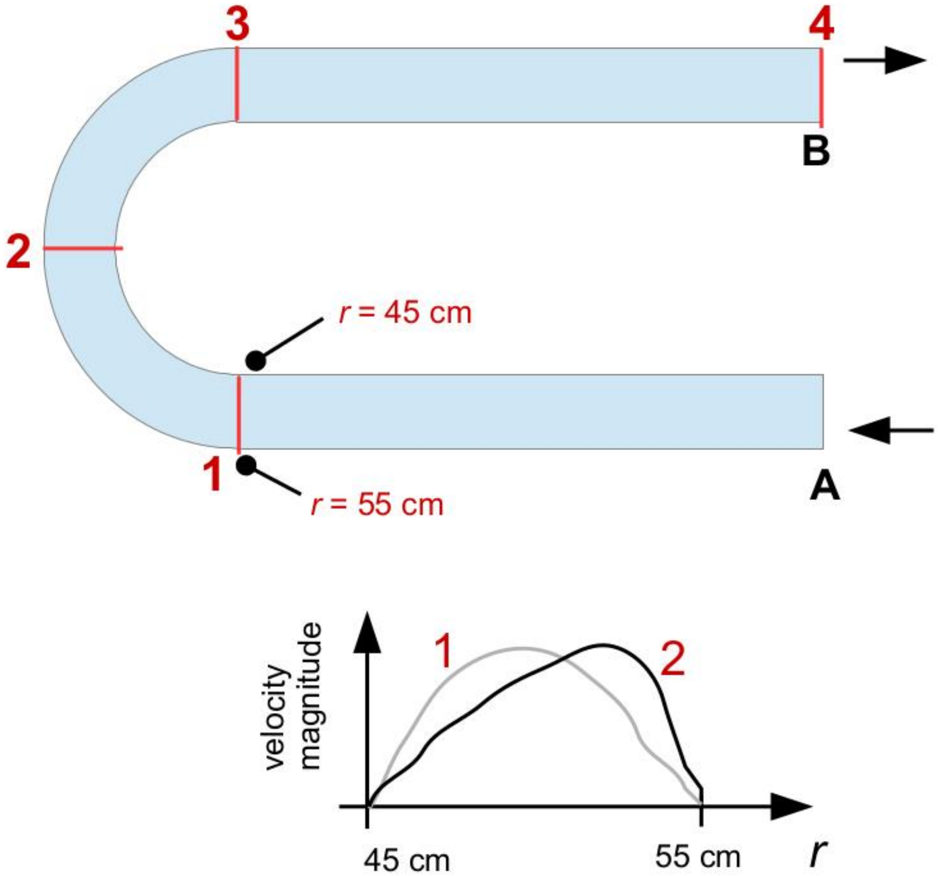

Fig. 5 *Top*: The four segments in the plane of symmetry along which line plots should be drawn for velocity magnitude for Task 3. Inlet and outlet are marked by "A" and "B". *Bottom*: A schematic of how the curves should be presented. For a clear comparison, all curves should be consistently drawn from the inner edge to the outer edge of the pipe.