CQU-UC Joint Co-op Institute (JCI) Student Project Report

Computational Assignment #1 of Fluid Mechanics

Institution CQU-UC Joint Co-op Institute (JCI)

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流体力学课程报告

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项目名称：Computational Assignment #1

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Abstract

Fully developed flow is when the fluid enters the circular pipe, the thickness of the formed boundary layer is equal to the radius of the pipe, and the flow condition at and after the boundary layer converges on the pipe axis. The velocity of fully developed flow is different at different concentric circles of pipe section, but its distribution remains unchanged.

STAR-CCM+ (Computational Continuum Mechanics) is a new general of CFD software. It uses the most advanced computational continuum mechanics algorithms, combining with the most excellent modern software engineering technology, to achieve an excellent performance and high reliability.

Based on the concept of fully developed flow, this report uses STAR-CCM+ software to simulate velocity vector scene and velocity variation in different situations and makes comparisons of these simulation results.

In question 1, this report attaches the velocity vector scene with a color bar for each Re and the plot of velocity variation along the y-axis for each Re with axisymmetric and periodic boundary conditions.

In question 2, this report attaches the velocity vector scene with a color bar for each Re and the plot of velocity variation along the y-axis with the same length but with a smaller diameter.

In question 3, this report compares the results from problem 1 and 2, plots -dp/dx vs. Re, plots the Darcy friction factor f vs. Re in a log-log plot, and compares the plots from Prob. 1 and 2.

Objective

The purposes of this report are mainly three points in the following contents:

1. Review the knowledge of fully developed flow and related calculation methods.
2. Introduce the method of simulating fully developed flow combining with STAR CCM+ software.
3. Perform the results of the simulations of fully developed flow under different situations combining with STAR CCM+ software.

Key words: Fluid mechanics, STAR CCM+, simulation

Table of Content

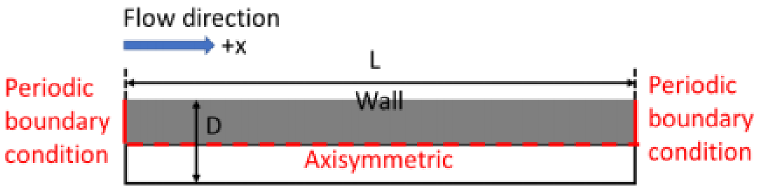
Question 1

For a fully developed flow in a circular pipe with length $L = 3$ m and diameter $D = 0.2$ m, simulate the circular pipe flow with axisymmetric and periodic boundary conditions as shown in the figure below. Run simulations for several Re = 100, 200, 400, and 800 by changing the mean (average) velocity V.

(Use dynamic viscosity $\mu = 2 \times 10^{-3}$ Pa s, density $\rho = 1\text{kg/m}^3$)

(a) Attach the velocity vector scene with a color bar for each Re.

(b) Attach the plot of velocity variation along the y-axis for each Re.



1.1 Problem Analysis

For this problem, we mainly need to use two formulas

$$Re = \frac{\rho \bar{V} D}{\mu} \tag{1}$$

$$\dot{m} = \rho \bar{V} A \tag{2}$$

where Re is the Reynolds number, ρ is the density, $\bar{V}$ is the average velocity, D is the diameter of the circular pipe and μ is the dynamic viscosity. The problem-solving steps are as follows.

1.2 Problem Solving Steps

(i) Use the Reynolds number to calculate the required average speed.

(ii) Use this speed to calculate the required mass flow rate.

(iii)Simulate with this mass flow rate.

(iv) Exhibit result.

(v) Repeat the progress (a)-(d).

1.3 Results

1.3.1 Results of 1-(a)

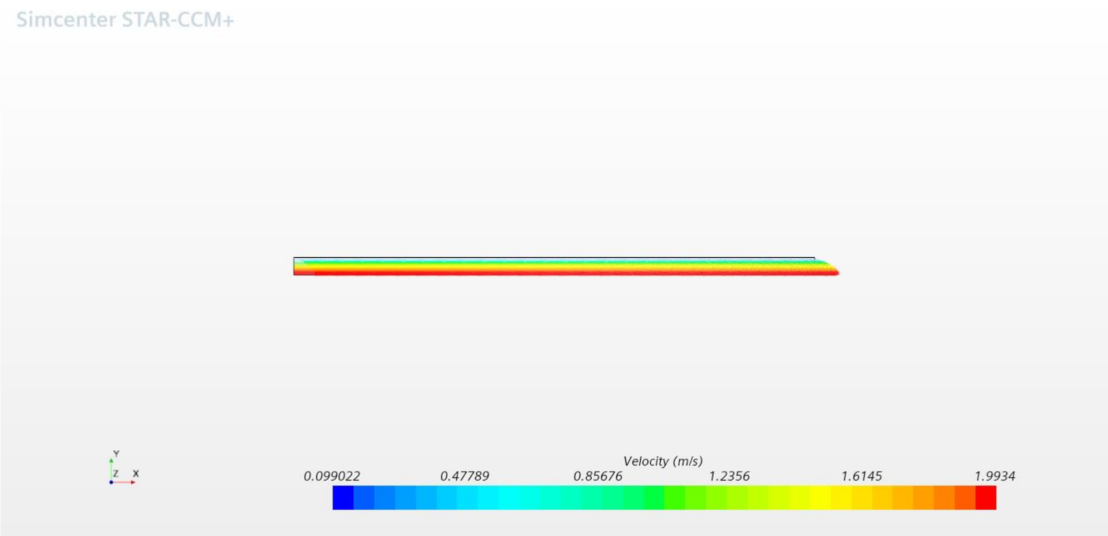


Fig 1. Velocity vector scene changing with average velocity when Re=100

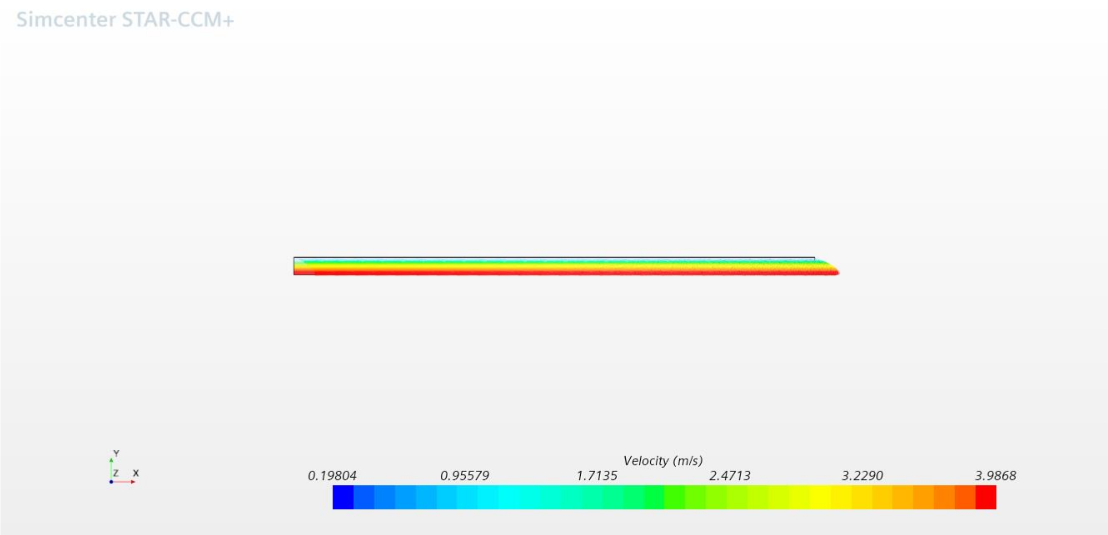


Fig 2. Velocity vector scene changing with average velocity when Re=200

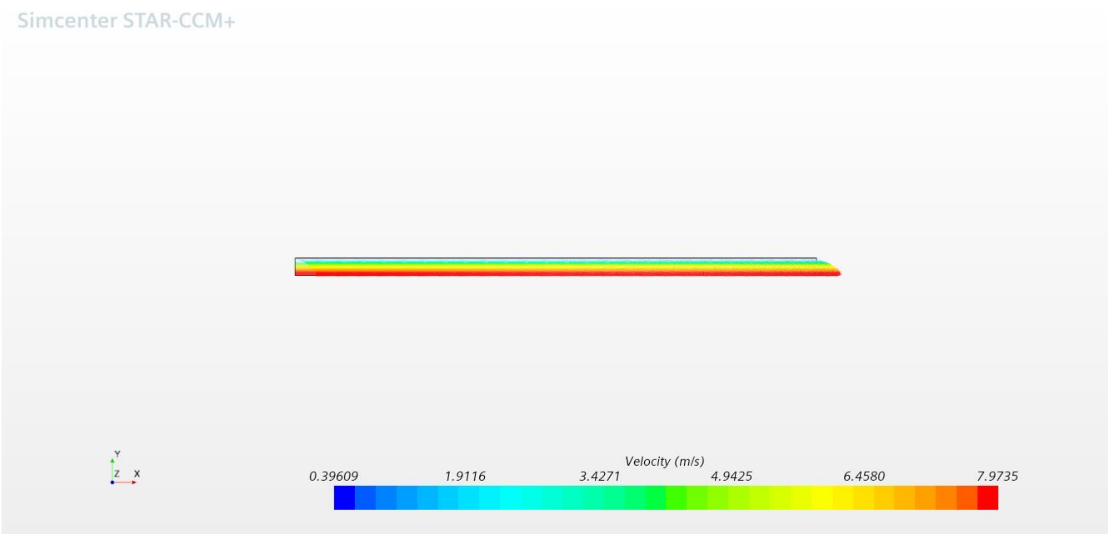


Fig 3. Velocity vector scene changing with average velocity bar when Re=400

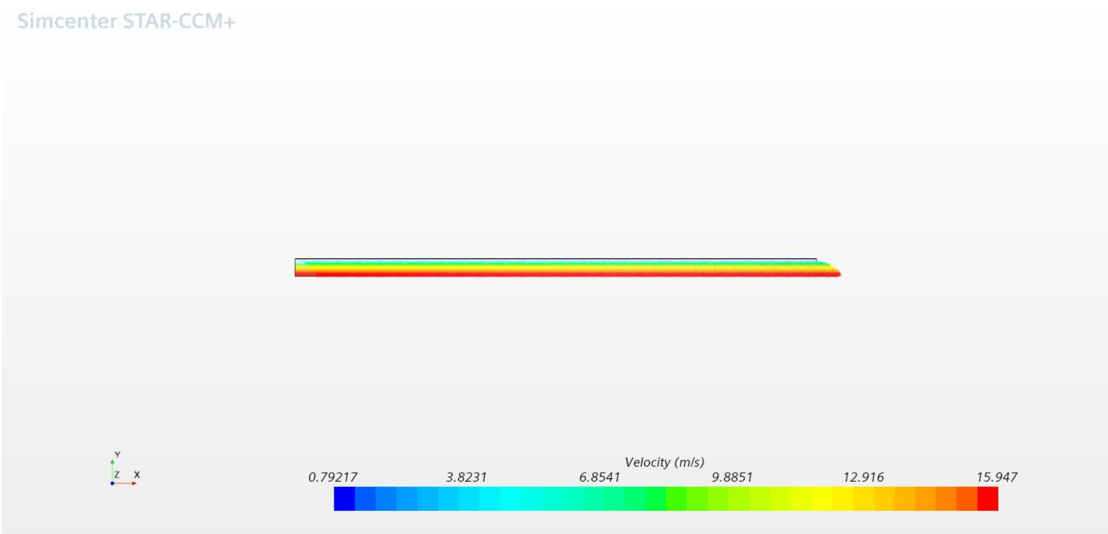


Fig 4. Velocity vector scene changing with average velocity when Re=800

1.3.2 Results of 1-(b)

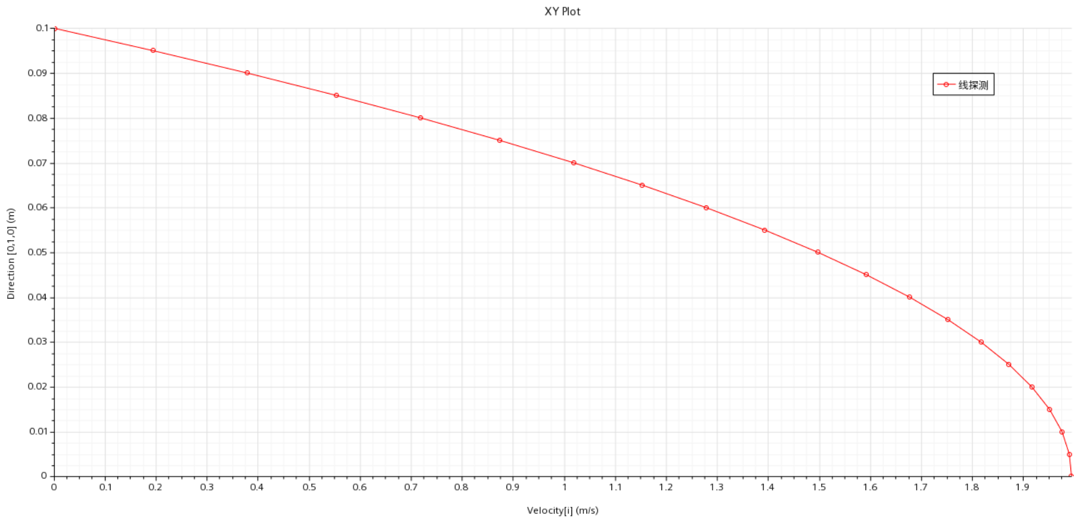


Fig 5. Velocity variation along the *y*-axis changing with average velocity when Re=100

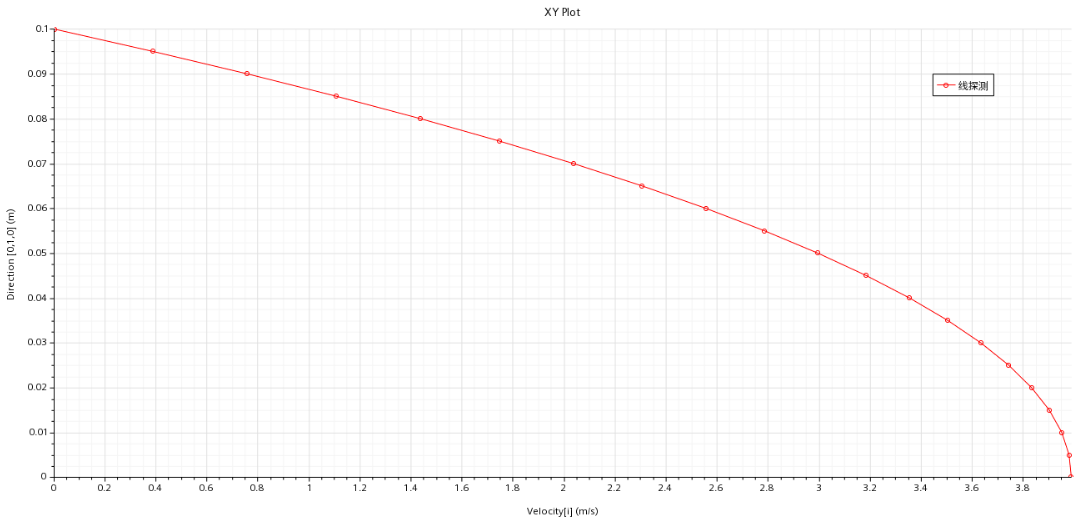


Fig 6. Velocity variation along the *y*-axis changing with average velocity when Re=200

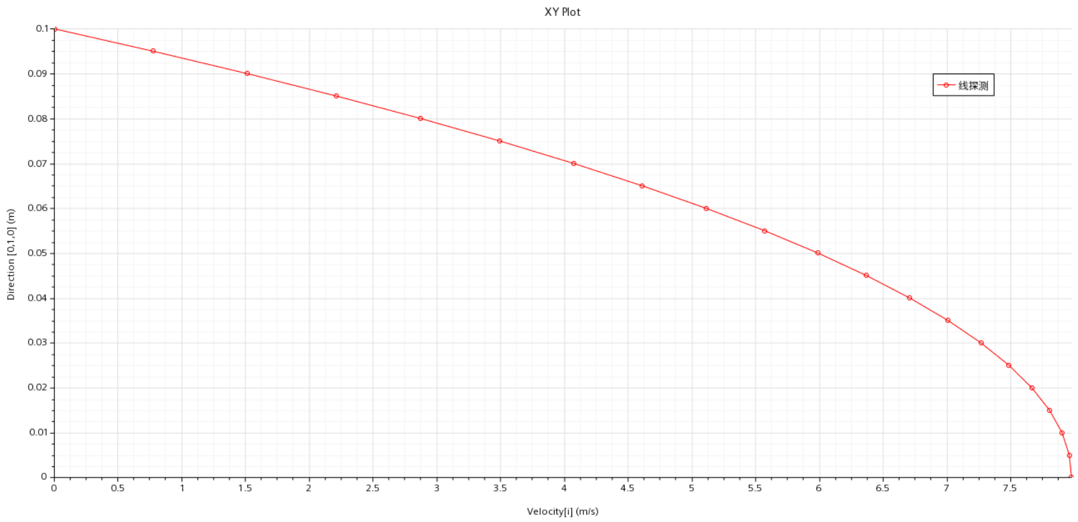


Fig 7. Velocity variation along the *y*-axis changing with average velocity when Re=400

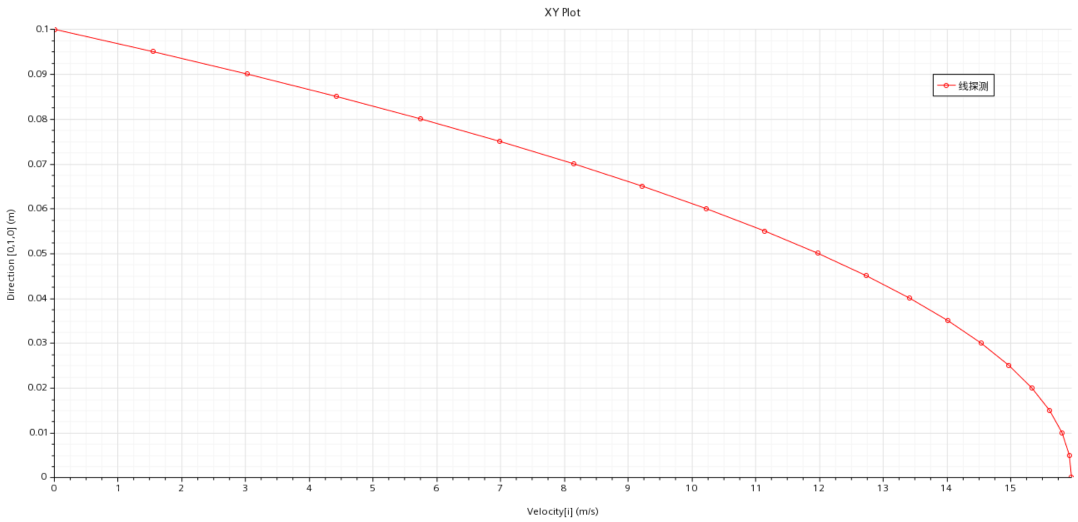


Fig 8. Velocity variation along the *y*-axis changing with average velocity when Re=800

Question 2

Run simulation again with the same length but with a smaller diameter, $D = 0.1$ m. Run the simulation for Re = 100, 200, 400, and 800 by changing the dynamic viscosity this time.

(Use the density ρ = 1kg/m^3, the mean velocity V = 1m/s, mesh base size = D, relative size = 0.05)

(a) Attach the velocity vector scene with a color bar for each Re.

(b) Attach the plot of velocity variation along the y-axis for each Re.

2.1 Problem Analysis

For this problem, we also need to use equation (1) and (2) to solve the problems.

2.2 Problem Solving Steps

The solving steps are similar as 1.2.

2.3 Results

2.3.1 Results of 2-(a)

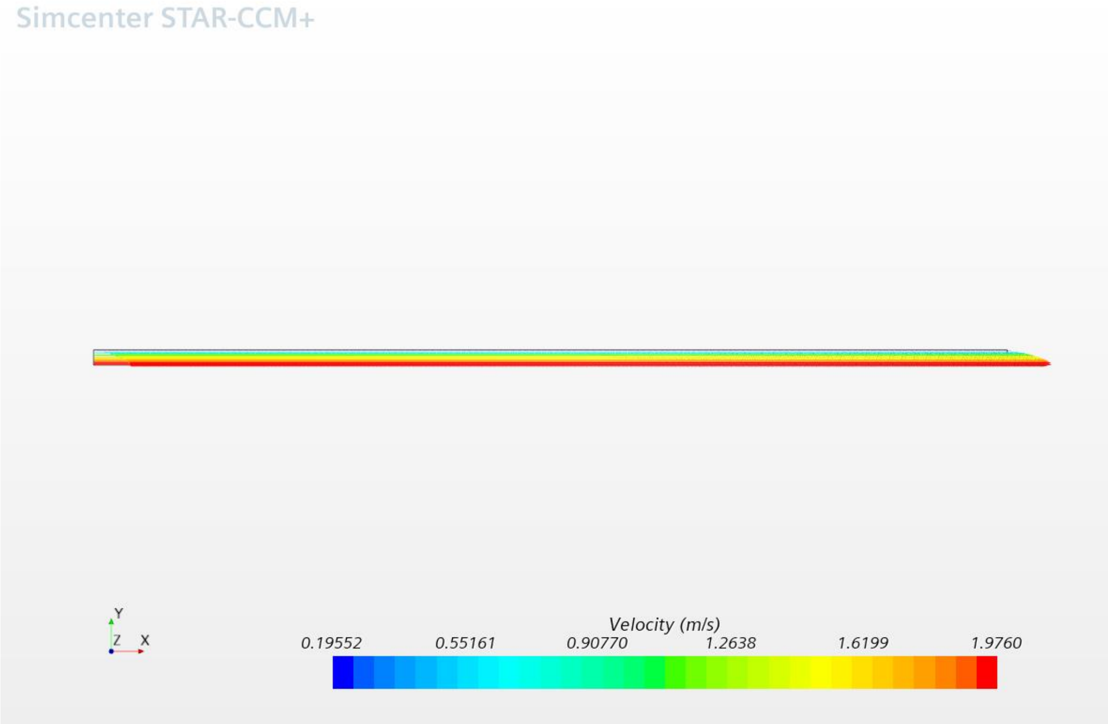


Fig 9. Velocity vector scene changing with dynamic viscosity when Re=100

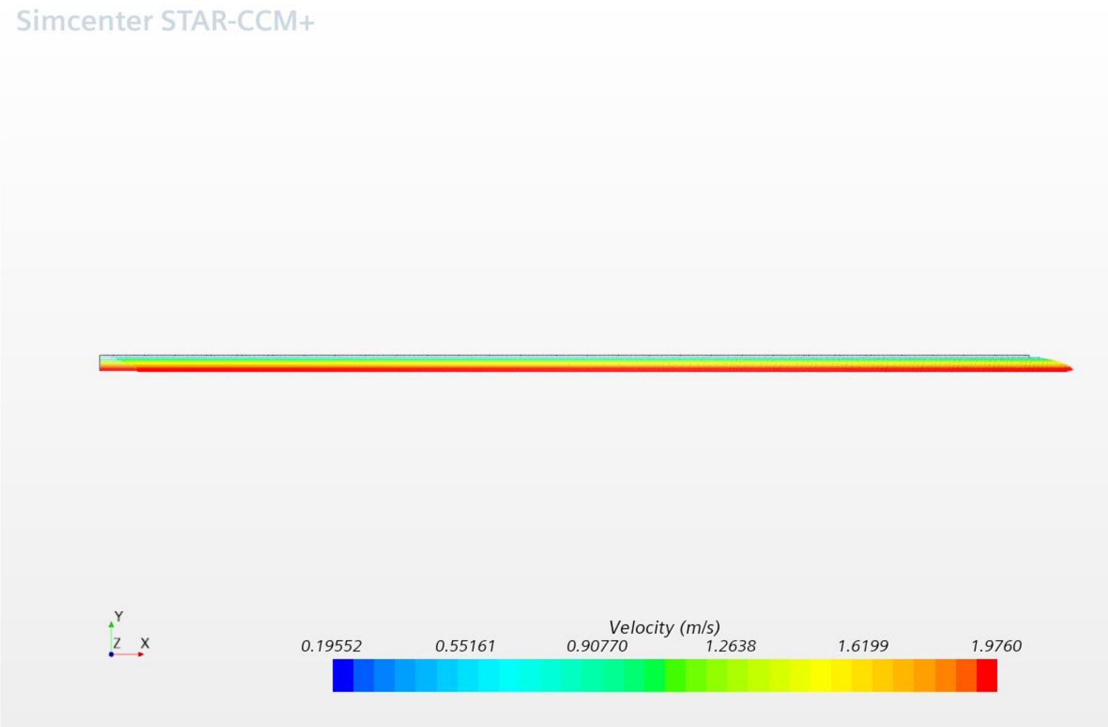


Fig 10. Velocity vector scene changing with dynamic viscosity when Re=200

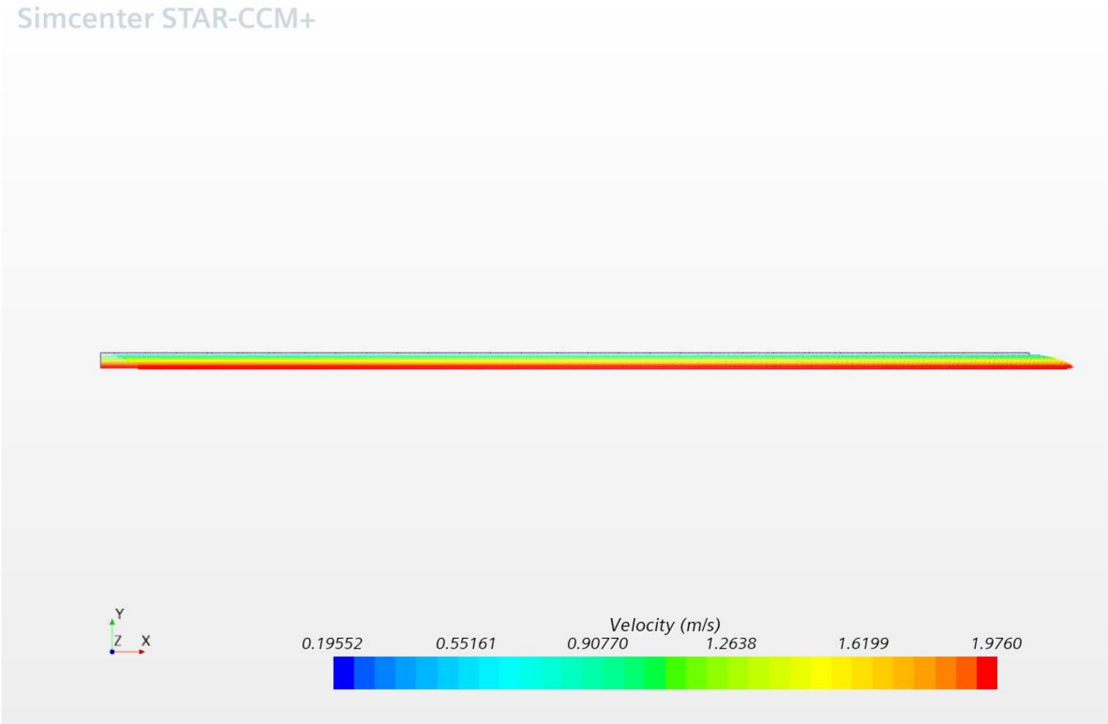


Fig 11. Velocity vector scene changing with dynamic viscosity when Re=400

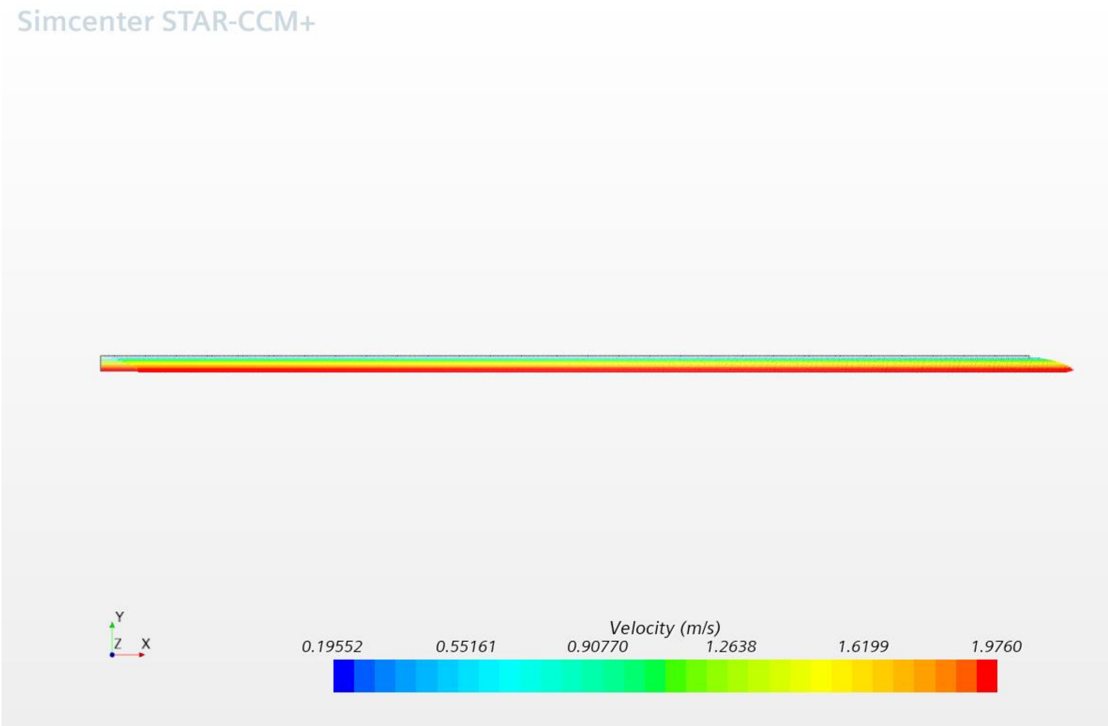


Fig 12. Velocity vector scene changing with dynamic viscosity when Re=800

2.3.2 **Results of 2-(b)**

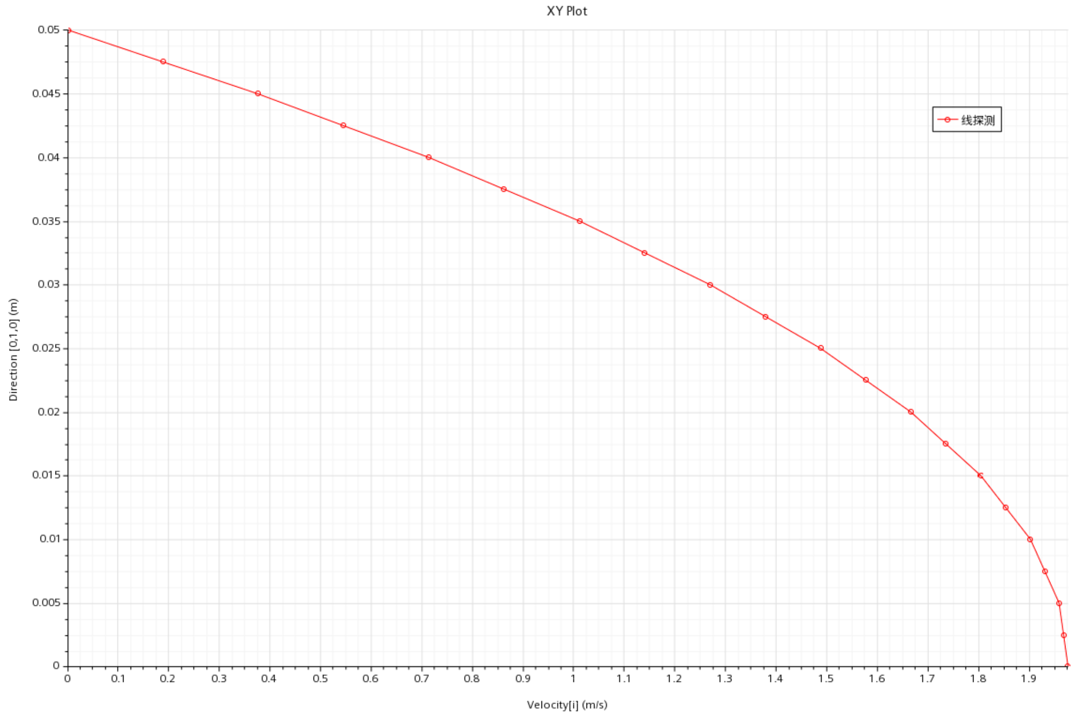


Fig 13. Velocity variation along the *y*-axis changing with dynamic viscosity when Re=100

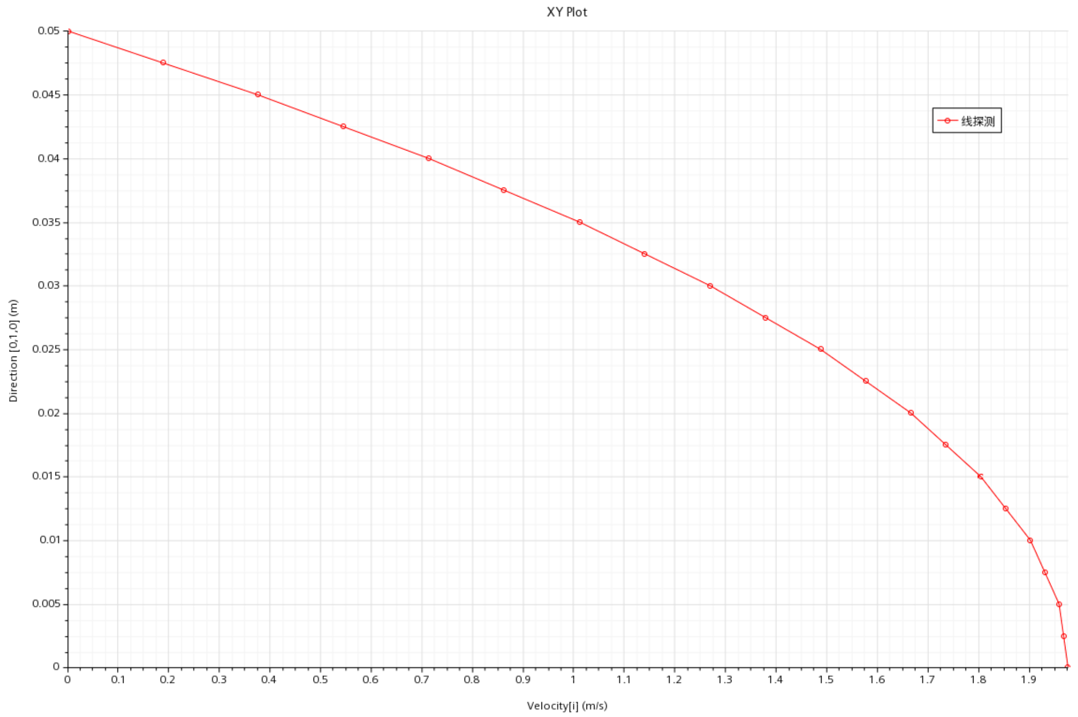


Fig 14. Velocity variation along the *y*-axis changing with dynamic viscosity when Re=200

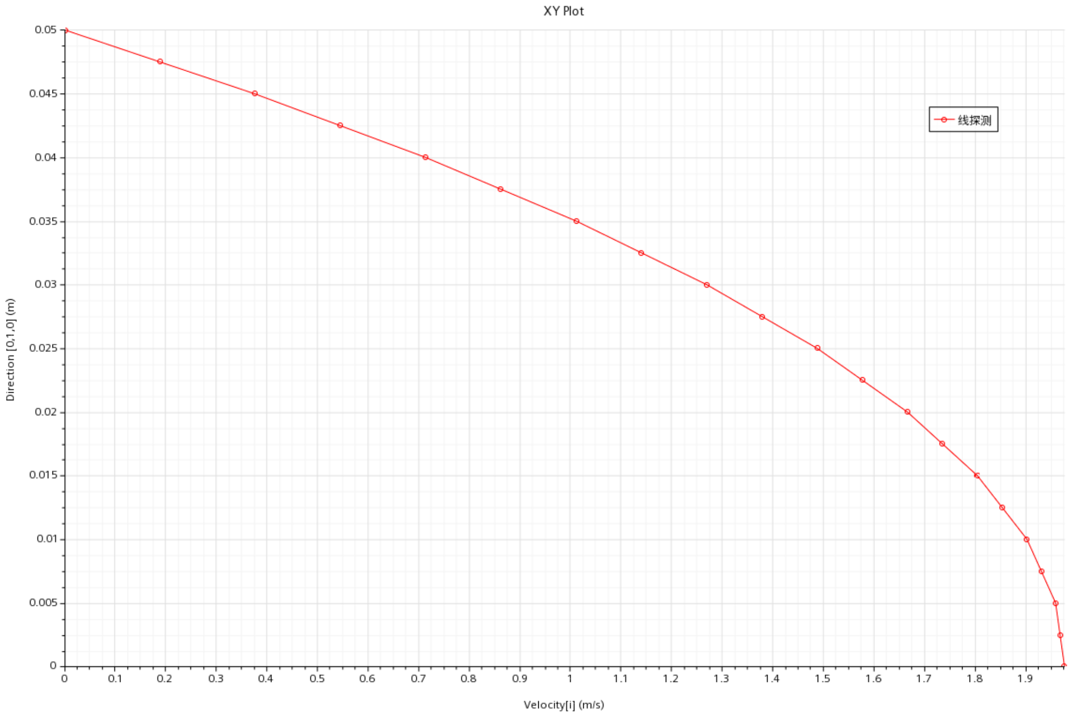


Fig 15. Velocity variation along the *y*-axis changing with dynamic viscosity when Re=400

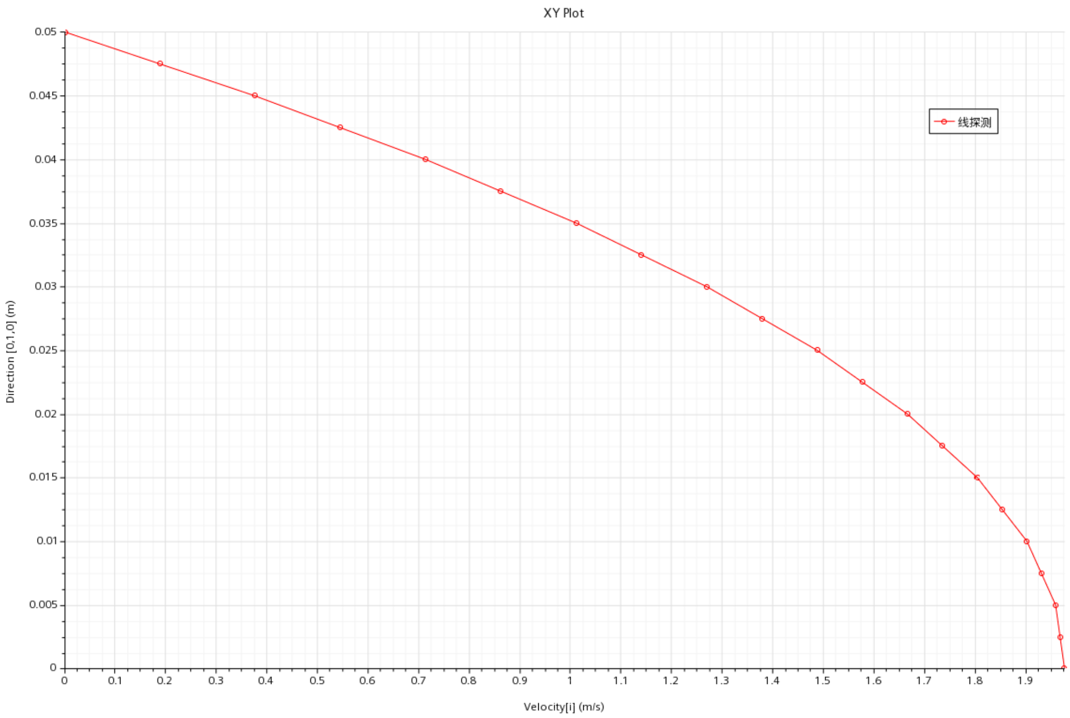


Fig 16. Velocity variation along the *y*-axis changing with dynamic viscosity when Re=800

Question 3

Compare the results from Problem 1 and 2.

(a) Plot -d*p*/d*x* vs. Re, and compare the plots from Prob. 1 and 2. Add your comments and analysis.

(b) Plot the Darcy friction factor *f* vs. Re in a log-log plot, and compare the plots from Prob. 1 and 2. Add your comments and analysis

3.1 Problem Analysis

For this problem, we mainly need to use two formulas

$$h_l = f\frac{L}{D}\frac{\bar{V}^2}{2} \tag{3}$$

$$\left(\frac{p_1}{\rho} + \alpha_1\frac{\bar{V}_1^2}{2} + z_1\right) - \left(\frac{p_2}{\rho} + \alpha_2\frac{\bar{V}_2^2}{2} + z_2\right) = h_l \tag{4}$$

where h_l is the head loss, f is the Darcy friction coefficient, L is the length of the pipe, D is the diameter of the pipe, $\bar{V}$ is the average velocity. Equation (2) is called Bernoulli equation, where $p_{1,2}$ is the pressure of state 1 and 2, ρ is the density, $\alpha_{1,2}$ is the kinetic energy coefficient, $z_{1,2}$ is the height.

3.2 Problem Solving Steps

For question 3-(1), In the report module of the simulation software, the pressures of inlets and outlets are obtained respectively, and then the pressure difference is calculated and divided by the total length *L* to obtain the pressure gradient.

For question 3-(2), since this is a horizontal pipe and the pipe area remains unchanged, *z* and *V* remain unchanged, and the formula (3) is rewriting as

$$\left(\frac{p_1}{\rho}\right) - \left(\frac{p_2}{\rho}\right) = h_l \tag{5}$$

Then, *f* can be calculated by equation (3).

In the report module of the simulation software, the pressure of inlet and outlet are obtained respectively, and then the pressure difference is calculated

The head loss is obtained according to equation (5), and then the coefficient Darcy friction factor is obtained.

3.3 Results

3.3.1 Results of 3-(a)

Table 1. Pressure gradient changing with Reynolds number from problem 1 (changing average velocity)

p_inlet	p_outlet	-dp/dx	Re
0.0039945	-4.790022	1.598005	100
0.00799073	-9.580055	3.196015	200
0.01598118	-19.16011	6.39203	400
0.0319544	-38.32018	12.78404	800

Table 2. Pressure gradient changing with Reynolds number from problem 2 (changing dynamic viscosity)

p_inlet	p_outlet	-dp/dx	Re
0.00796074	-9.544617	3.184193	100
0.00397971	-4.772307	1.592096	200
0.00199022	-2.386292	0.796094	400
0.00103259	-1.193976	0.398336	800

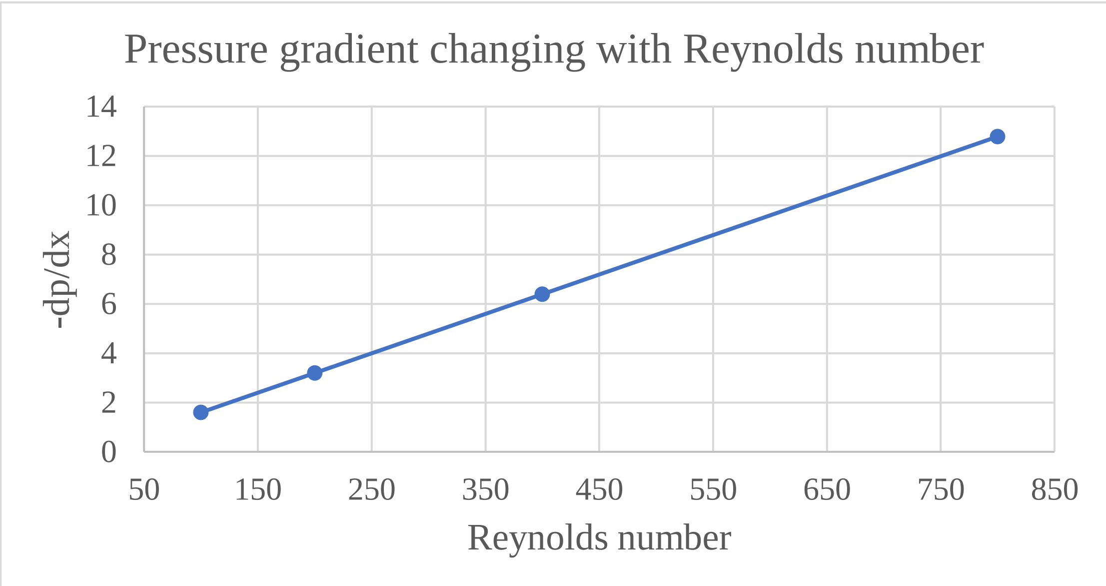


Fig 17. Pressure gradient changing with Reynolds number from problem 1 (changing average velocity)

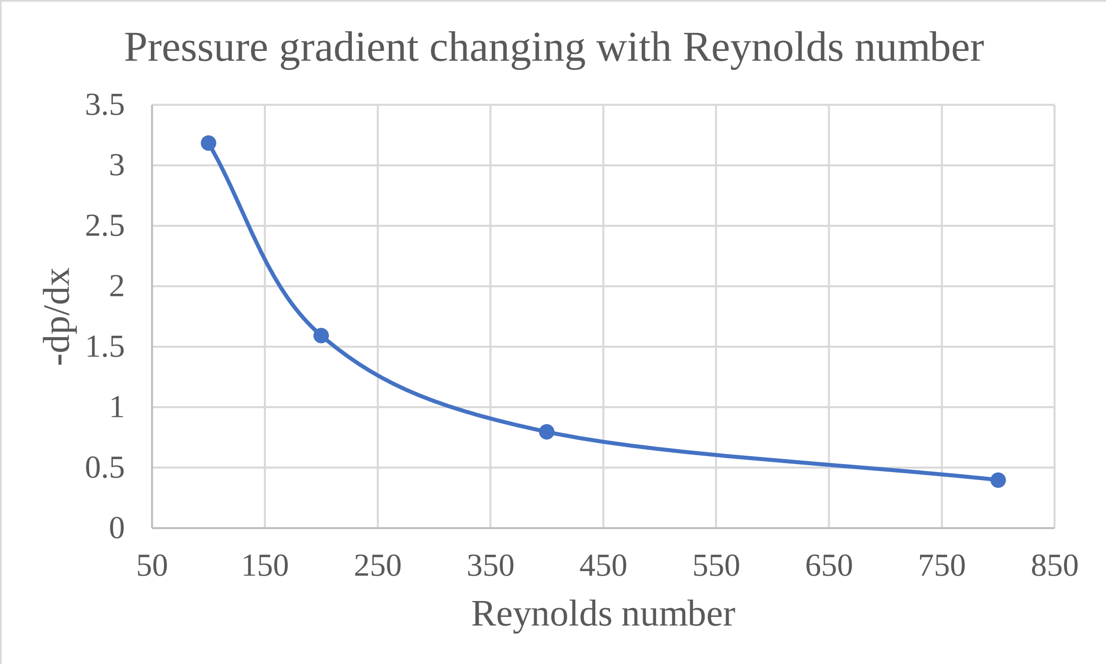


Fig 18. Pressure gradient changing with Reynolds number from problem 2 (changing dynamic viscosity)

Comparison:

In Fig 17, the curve is almost a straight line, implying that the pressure gradient is directly proportional to Reynolds number when changing the average velocity. In comparison, in Fig 18, the curve is like an inverse scale function, implying that the pressure gradient is inversely proportional to Reynolds number when changing the dynamic viscosity.

Comments and analysis:

Form equation (1) and equation as follows

$$u = -\frac{R^2}{4\mu}\left(\frac{\partial p}{\partial x}\right)\left[1-\left(\frac{r}{R}\right)^2\right] \tag{6}$$

when the dynamic viscosity is constant, the speed in the pipe is directly proportional to the negative pressure gradient, and the speed in the pipe is directly proportional to Re, so as the average velocity. Then, Re is also directly proportional to the negative pressure gradient, which conforms to the image relationship of Fig. 17.

However, when the average velocity is constant, the negative pressure gradient is inversely proportional the dynamic viscosity and the Reynolds number, which conforms to the image relationship of Fig. 18.

3.3.2 Results of 3-(b)

Table 3. Log (f) changing with log (Re) changing from problem 1 (changing average velocity)

Log (Re)	Log (f)
2	-0.19436174
2.30103	-0.49539116
2.60206	-0.79642116
2.90309	-1.0974517

Table 4. Log (f) changing with log (Re) changing from problem 2 (changing dynamic viscosity)

Log (Re)	Log (f)
2	-0.19597
2.30103	-0.497
2.60206	-0.79801
2.90309	-1.09872

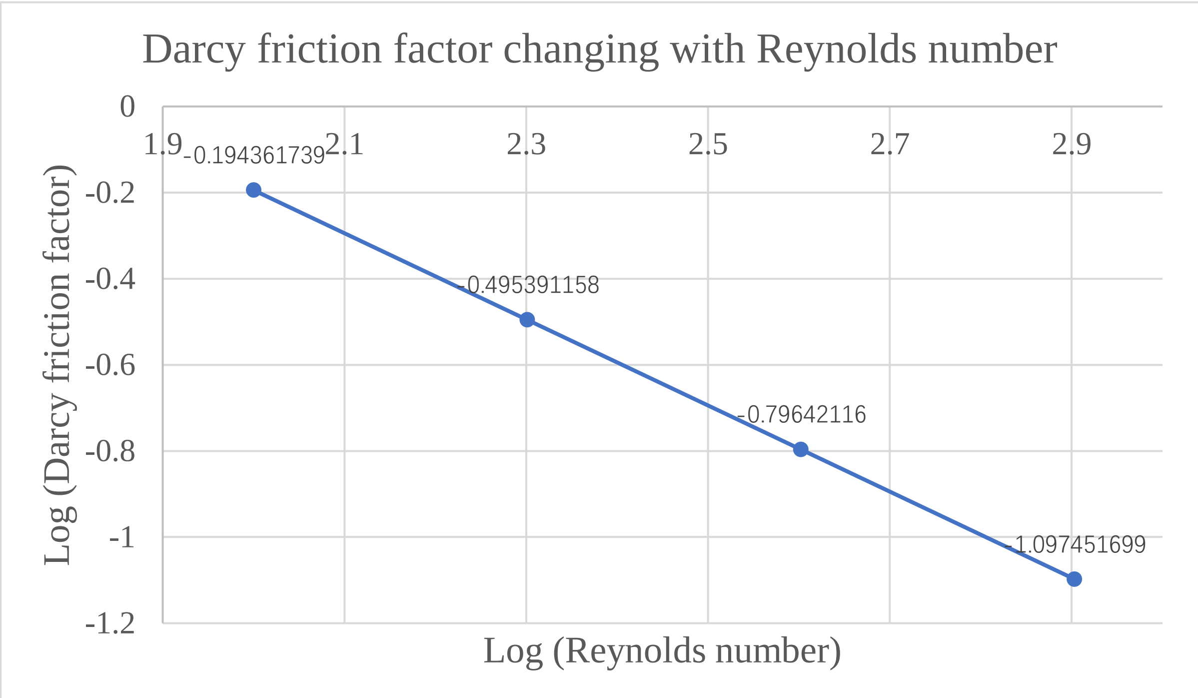


Fig 19. Log (f) changing with log (Re) changing from problem 1 (changing average velocity)

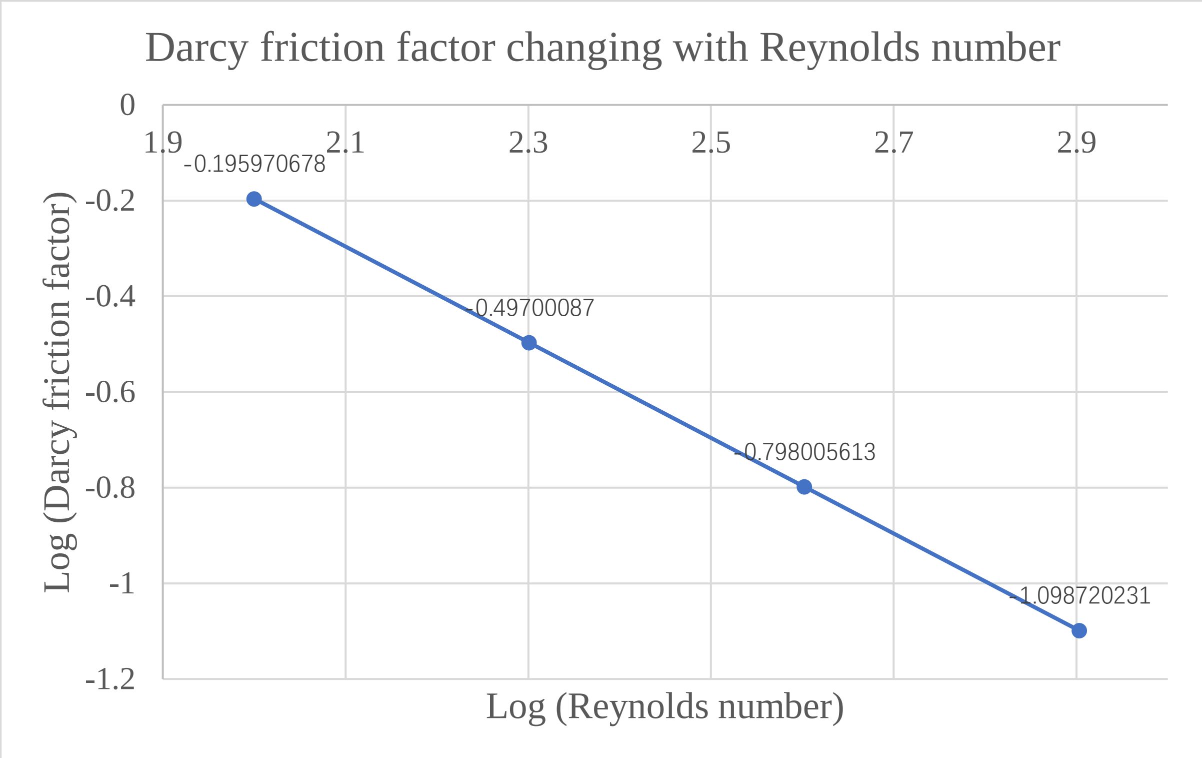


Fig 20. Log (f) changing with log (Re) changing from problem 2 (changing dynamic viscosity)

Comparison:

Figure 19 and 20 are almost the same, and they both represents that log (f) is proportional to the negative log (Re).

Comments and analysis:

Due to the research object is laminar flow, the Darcy friction factor f and the Reynolds number Re has a relationship as follows

$$f = \frac{64}{Re} \tag{7}$$

When we take logarithm on both sides of equation (7), we can get the formula

$$\log(f) = -64\log(Re) \tag{8}$$

which demonstrates the accuracy of fig 19 and 20.