

FluidFlow

The Flow of Gas via a Compressor

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Problem

Air at 25°C is compressed from a vessel (2 barg) to a storage vessel (5 barg) by means of a compressor. The piping system consists of a 15 m equivalent length of 6" SCH 40 steel pipe from the vessel to the compressor suction; a 4" SCH 40 steel pipe follows the compressor discharge for an equivalent length of 15 m to the storage vessel. The vessel is at an elevation of 2 m. The storage vessel is at an elevation of 10 m. The compressor centerline is 1 m above grade. If it is desired to maintain a flow of air of 3500 kg/h into the storage vessel. Determine the following:

- 1) Velocities in the pipes
- 2) Reynolds number in the pipes
- 3) Darcy friction factors
- 4) Friction loss in the pipes
- 5) Compressor differential pressure

Objective

Compressors are used to transfer gas from the source with lower pressure to the sink with higher pressure. If the compressor is not available, the gas will move in the opposite direction due to pressure differences.

Compressors are also used to transfer gases from the source at a lower elevation to the sink at a higher elevation.

In this example, you will build a model to illustrate the flow of gas via a compressor.

This example includes the following tasks:

- Task 1 – Add the Boundaries, Compressor, and Piping Components
- Task 2 – Define the Boundaries, Fluid, Piping, and Compressor
- Task 3 – Select Results Unit Set
- Task 4 – Calculate and Perform Hydraulic Analysis
- Task 5 – Compare the FluidFlow Results to Hand Calculation

Task 1 – Add the Boundaries, Compressor, and Piping Component

1. Start a new flowsheet by opening the FluidFlow software. The user interface will appear as shown below (Figure 1).

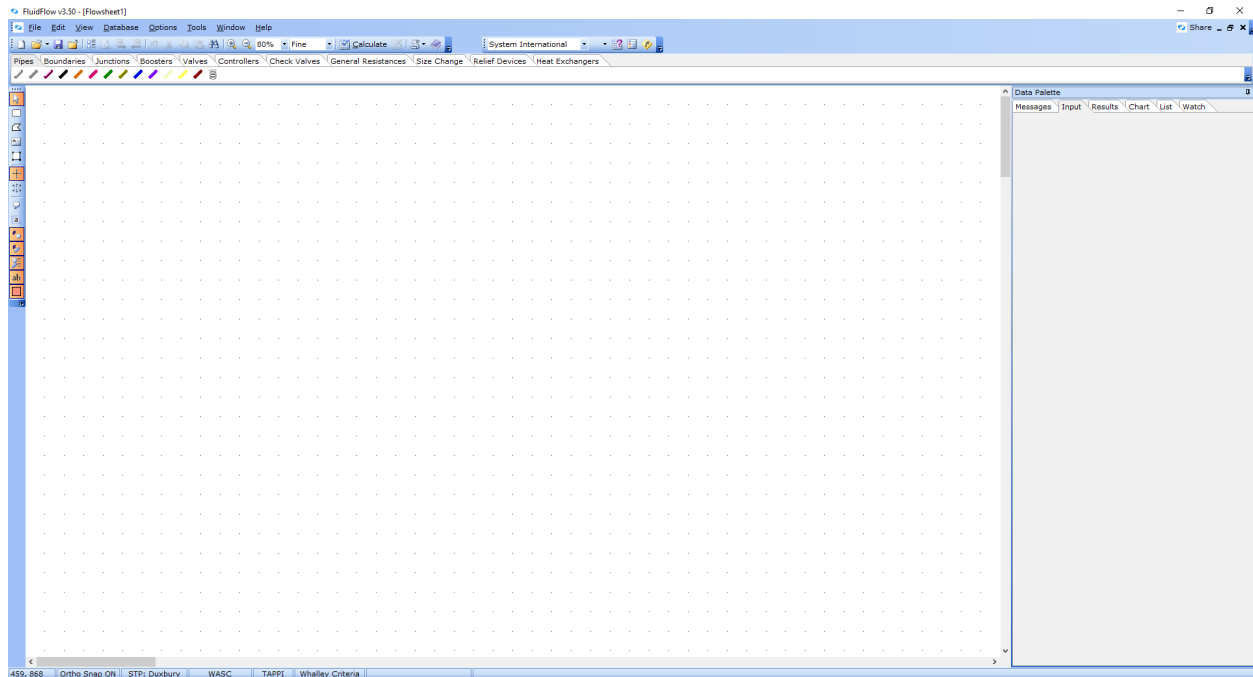


Figure 1: New flowsheet user interface.

2. Consider the boundary nodes to use for the system. Since we know the inlet and outlet pressure, we can use the *Known or Assigned Pressure* node available from the *Boundaries* tab on the *Component Palette* (Figure 2).

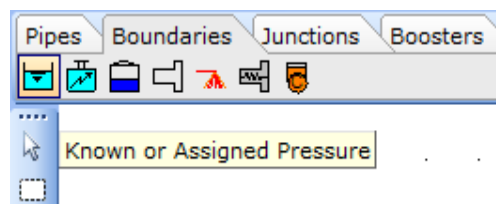


Figure 2: Known or Assigned Pressure Node.

3. Place two of these nodes (inlet & outlet) on the flowsheet by left mouse-clicking on the icon on the *Component Palette*. To place the node on the flowsheet we need to left mouse-click in the desired location (Figure 3).



Figure 3: Known Pressure Nodes.

4. This represents our pipe boundaries. We can now add our fluid motive device by selecting the desired booster from the Component Palette. In this design case, let us select the *Fan or Compressor* from the *Component Palette* (Figure 4).

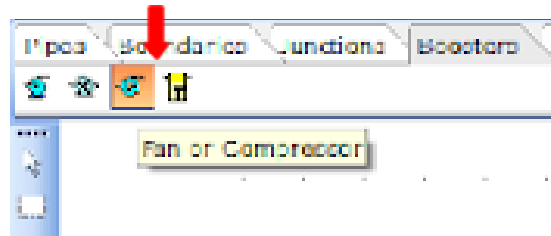


Figure 4: Fan or Compressor Icon.

5. Place the compressor icon on the flowsheet by left mouse-clicking on the icon on the *Component Palette*. To place the node on the flowsheet, we need to left mouse-click in the desired location (Figure 5).

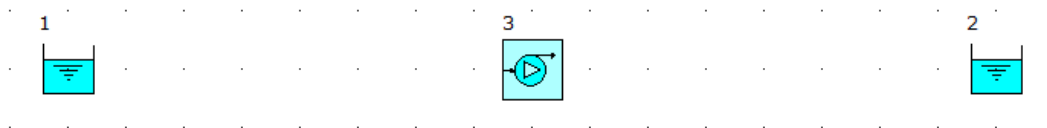


Figure 5: Compressor in the middle of the Known Pressure Nodes.

6. We can now connect the boundaries and compressor by selecting the desired pipe material from the *Component Palette*. In this design case, we know the pipe is a Schedule 40 steel pipe. Therefore, we need to select the Steel Pipe or Duct icon from the Component Palette (Figure 6).

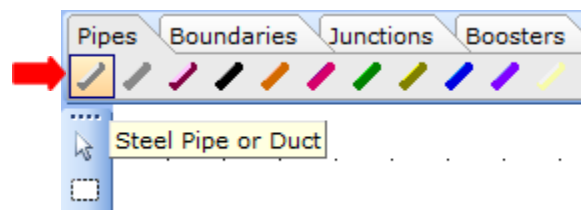


Figure 6: Steel Pipe of Duct Icon.

7. To connect the inlet boundary and compressor, left mouse-click directly over the inlet boundary node (node 1) and again, left mouse-click directly over the compressor suction (node 3). Note, when you position the mouse selector above the boundary node and compressor on the

flowsheet, you will see the selector change to a green “tick” symbol (✔). This indicates that the software is ready to connect our new node. The hydraulic model will appear as shown below (Figure 7):

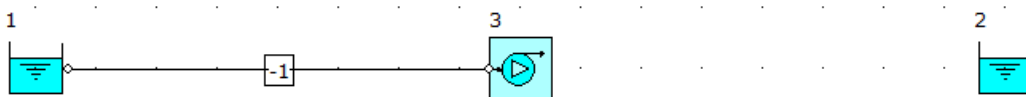


Figure 7: Hydraulic Model.

- To connect the compressor and outlet boundary, left mouse-click directly over the compressor discharge (node 3) and again, left mouse-click directly over the outlet boundary node (node 2).

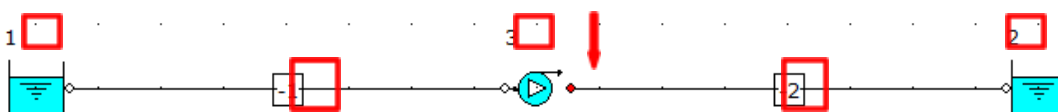


Figure 8: Hydraulic Model.

Note: The **RED** dot on the compressor (Figure 8) indicates the discharge side.

- At this stage, we will notice that the software automatically assigns a unique *User Number* (reference number) to each node placed on the flowsheet. All boundaries and fittings have positive *User Numbers* whereas all pipes have negative *User Numbers*. In Figure 8, we can see that the inlet boundary, outlet boundary, and compressor are assigned with *User Numbers* “1”, “2”, and “3”, respectively. The suction and discharge pipes are assigned with *User Numbers* “-1” & “-2”, respectively. Note, if these reference values have not appeared automatically, they may be toggled off. You can toggle these back on by selecting the buttons to the left of the flowsheet titled “Show or Hide Node Numbers” and “Show or Hide Pipe Numbers”. The buttons appear as follows (Figure 9):

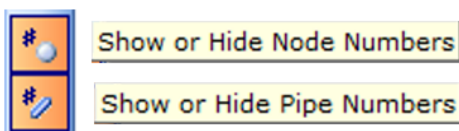


Figure 9: Show or Hide Node/Pipe Numbers buttons.

The automatic assignment of *User Numbers* helps us differentiate each of the nodes when we examine our systems – post calculation. This will become more apparent later.

- Save your flowsheet as **06-FF Gas via Compressor.FF3**

Task 2 – Define the Boundaries, Fluid, Piping, and Compressor

The next step is to edit the default data for each of the nodes placed on the flowsheet (Boundaries, Fluid, Piping, and Compressor). Let us begin with the boundaries. We know the intended pressure units are in **barg** for both the inlet and outlet boundary. We can edit multiple nodes at once which will help speed up model development.

- Left mouse-click on the inlet boundary (node 1) and whilst holding the SHIFT key, left mouse-click on the outlet boundary (node 2). You should now see both nodes highlighted on the flowsheet (Figure 10).

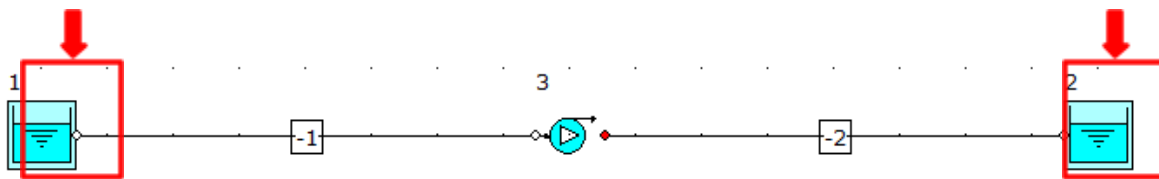


Figure 10: Highlighted Boundary Nodes.

- We can now edit the data entry for both nodes at once from the Input Inspector on the *Data Palette* (Figure 11).

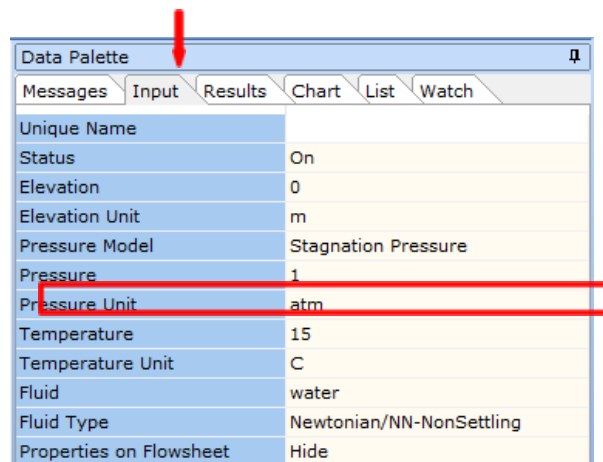


Figure 11: Input Inspector.

- In this case we need to change the *Pressure Unit* from the default **atm** setting to **barg**. Left mouse-click on the *Pressure Unit* field and you will see a drop-down arrow symbol appear on the right-hand side. Click on this symbol and a drop-down menu will appear showing the various units you can choose from. Select **barg** from the list (Figure 12). We have now successfully changed the pressure units for both nodes.

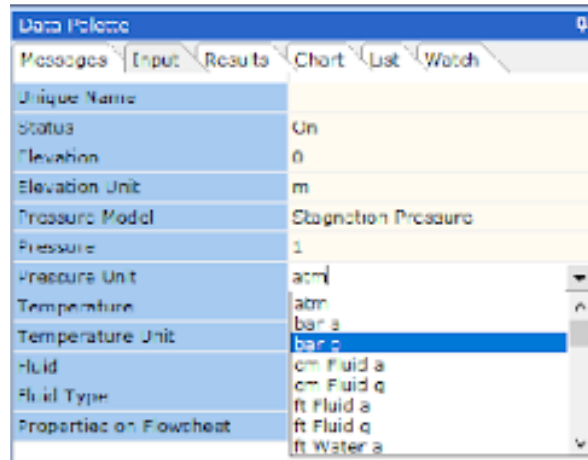


Figure 12: Pressure Units.

14. We can now change the inlet elevation, pressure, temperature, and fluid by selecting node 1. View the *Data Palette* and click the *Input Tab*. Enter the following specifications:

In this cell...	Enter...
Elevation	2
Pressure	2
Temperature	25
Fluid	air

To change the default fluid water, left click on the field titled *Fluid* and a button with 3 dots will appear (Figure 13):

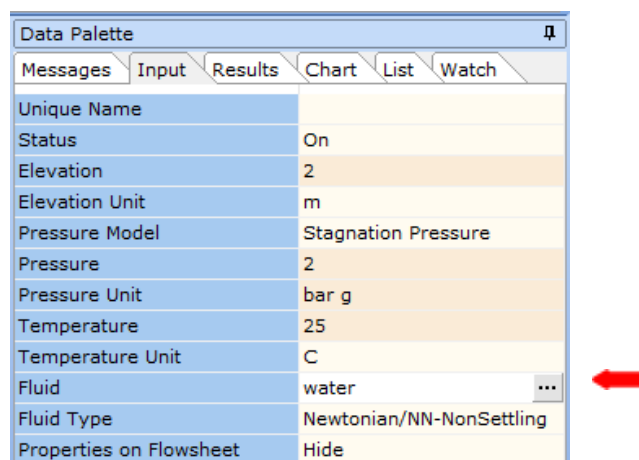


Figure 13: Fluid with 3 dots button.

Click the button and a *Select Fluid* dialog box will appear (Figure 14):

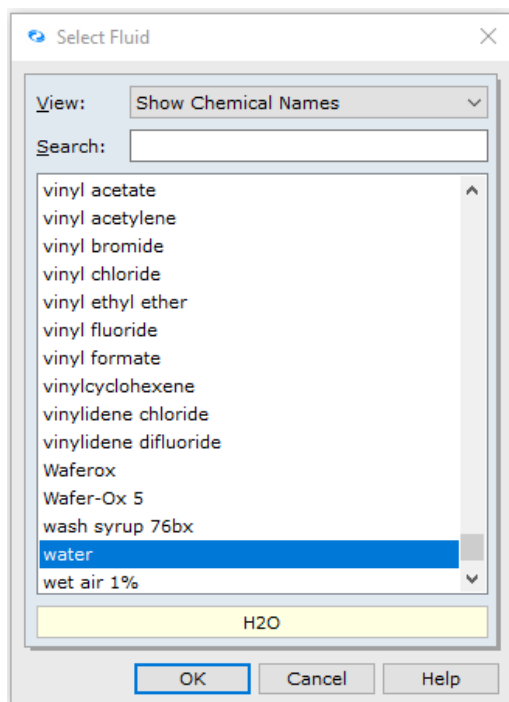


Figure 14: Select Fluid Dialog Box.

This dialog box will allow us to access the fluid database (Figure 14). From the list of the available fluids, you may browse via scroll bar or search for the **air** via the search field. Select **air** and click **OK** to complete this change (Figure 15).

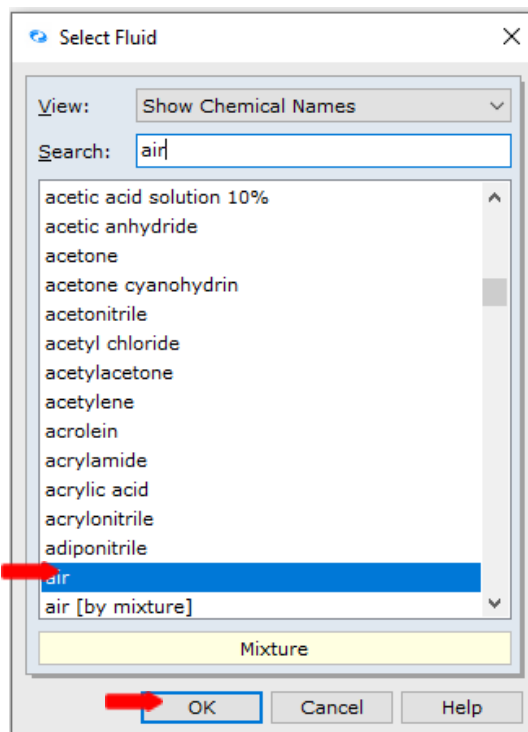
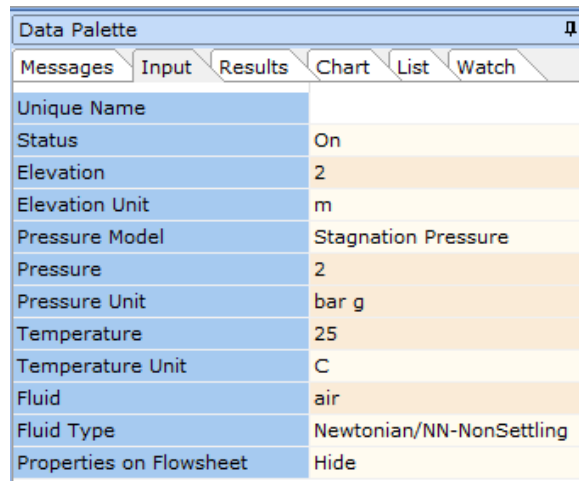


Figure 15: Select Fluid Dialog Box.

The Input Inspector on the *Data Palette* should now look like the screenshot given below (Figure 16).



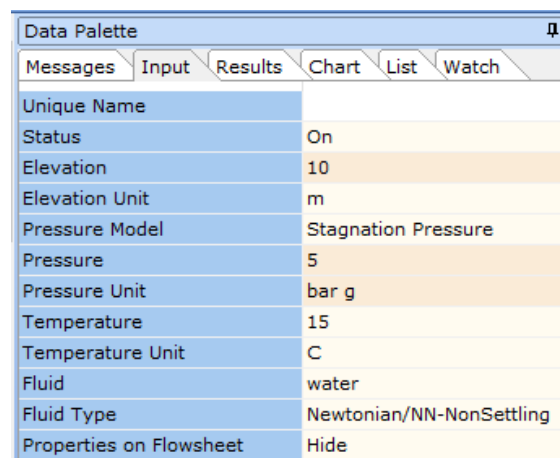
Data Palette	
Messages Input Results Chart List Watch	
Unique Name	
Status	On
Elevation	2
Elevation Unit	m
Pressure Model	Stagnation Pressure
Pressure	2
Pressure Unit	bar g
Temperature	25
Temperature Unit	C
Fluid	air
Fluid Type	Newtonian/NN-NonSettling
Properties on Flowsheet	Hide

Figure 16: Input Inspector at Node 1.

15. We can now change the outlet elevation and pressure by selecting node 2. View the *Data Palette* and click the *Input Tab*. Enter the specification:

In this cell...	Enter...
Elevation	10
Pressure	5

The Input Inspector on the *Data Palette* should now look like the screenshot given below (Figure 17).



Data Palette	
Messages Input Results Chart List Watch	
Unique Name	
Status	On
Elevation	10
Elevation Unit	m
Pressure Model	Stagnation Pressure
Pressure	5
Pressure Unit	bar g
Temperature	15
Temperature Unit	C
Fluid	water
Fluid Type	Newtonian/NN-NonSettling
Properties on Flowsheet	Hide

Figure 17: Input Inspector at Node 2.

For the temperature and fluid inputs, we don't need to change it to 25°C and air, respectively. Note that FluidFlow will use the operating conditions of the source fluid (node 1) in calculating the fluid properties such as density, viscosity, thermal conductivity, etc.

- Let us now edit the default suction pipe data by selecting pipe number -1. You should now see that pipe number -1 is highlighted on the flowsheet (Figure 18).

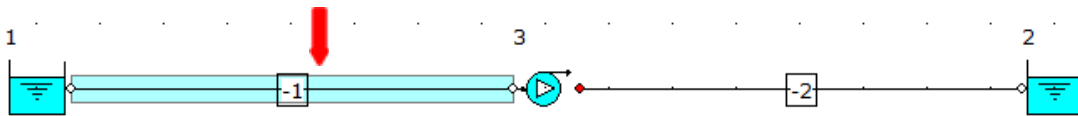


Figure 18: Highlighted Pipe “-1”.

- View the *Data Palette* and click the *Input Tab*. Enter the following specifications:

In this cell...	Enter...
Length	15
Nominal Size	6 inch

To change the default 2-inch size, left click on the field titled *Nominal Size* and a button with 3 dots will appear (Figure 19):

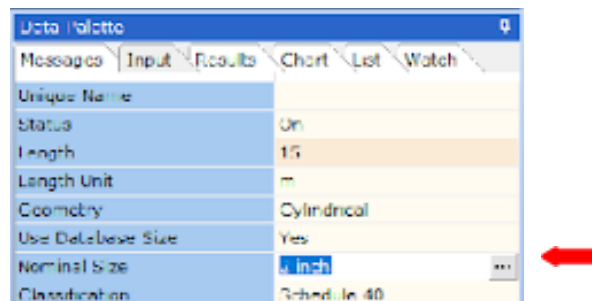


Figure 19: Nominal Size with 3 dots button.

Click the button and a *Set Pipe Dimension* dialog box will appear (Figure 20):

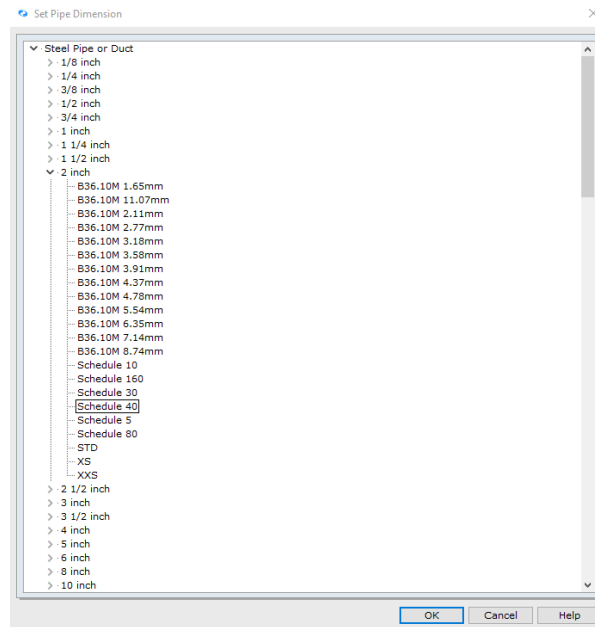


Figure 20: Set Pipe Dimension Dialog Box.

This dialog box will allow us to access the pipe database (Figure 20). From the list of the available pipe sizes, click on the **6 inch** to view the various pipe classifications for this diameter. Select **Schedule 40** and click **OK** to complete this change (Figure 21).

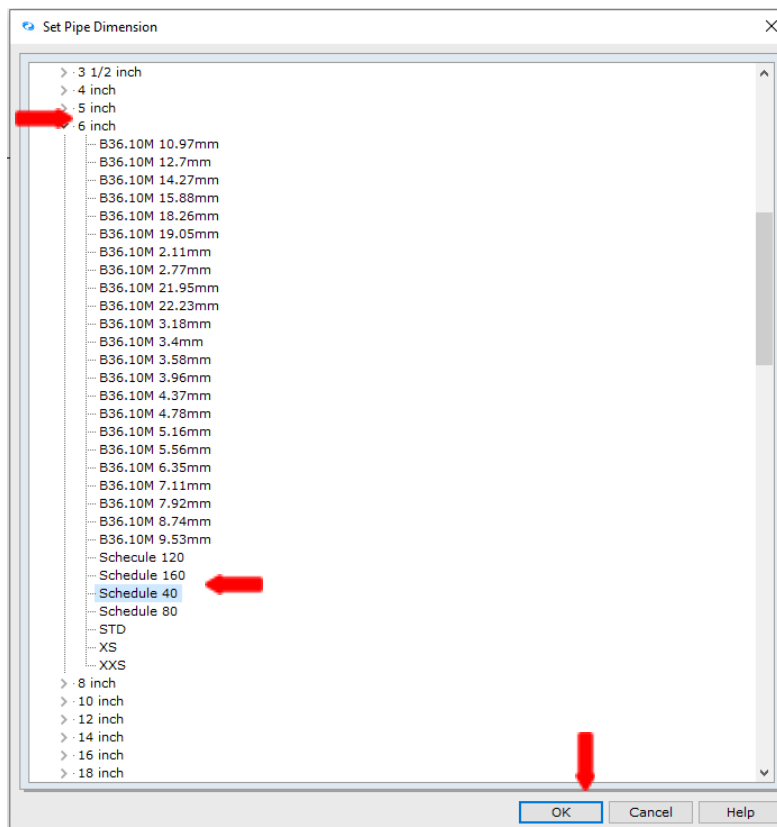


Figure 21: Set Pipe Dimension Dialog Box.

18. The Input Inspector on the *Data Palette* should now look like the screenshot given below (Figure 22).

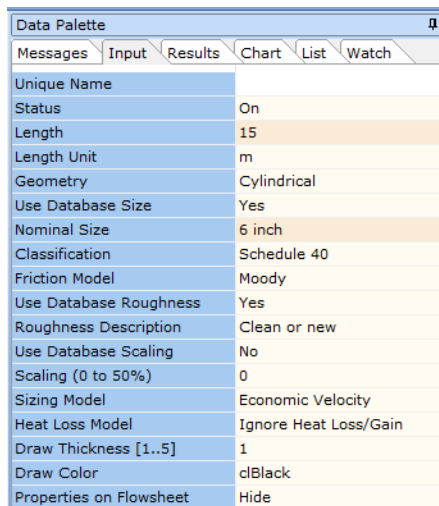


Figure 22: Input Inspector at Pipe Number “-1”.

19. Let us now edit the default discharge pipe data by selecting pipe number -2. You should now see that pipe number -2 is highlighted on the flowsheet (Figure 23).

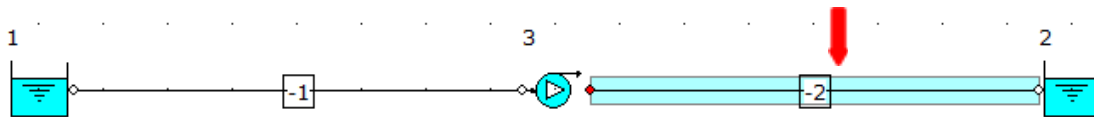


Figure 23: Highlighted Pipe “-2”.

20. View the *Data Palette* and click the *Input Tab*. Enter the following specifications:

In this cell...	Enter...
Length	15
Nominal Size	4 inch

To change the default 2-inch size, left click on the field titled *Nominal Size* and a button with 3 dots will appear (Figure 24):

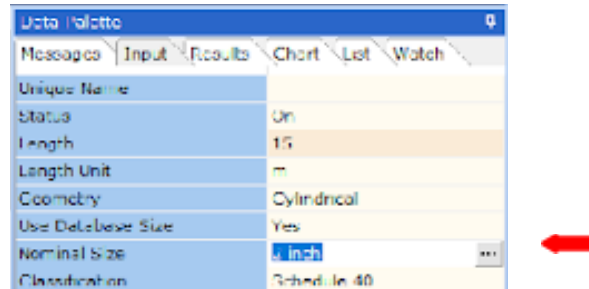


Figure 24: Nominal Size with 3 dots button.

Click the button and a *Set Pipe Dimension* dialog box will appear (Figure 25):

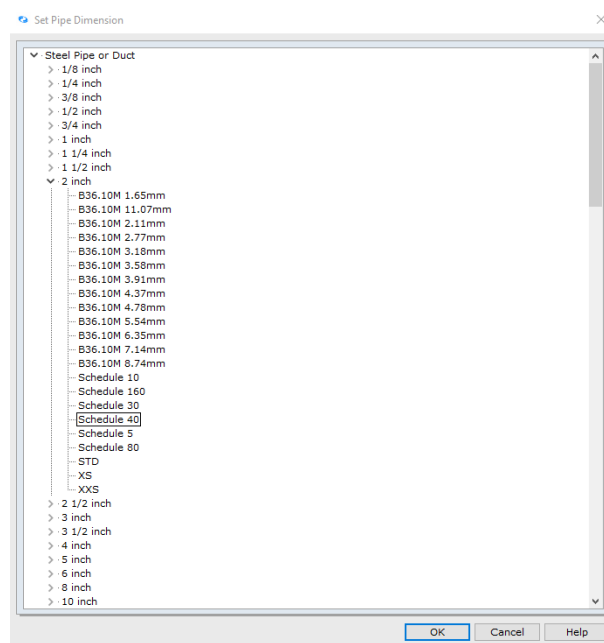


Figure 25: Set Pipe Dimension Dialog Box.

This dialog box will allow us to access the pipe database (Figure 25). From the list of the available pipe sizes, click on the **4 inch** to view the various pipe classifications for this diameter. Select **Schedule 40** and click **OK** to complete this change (Figure 26).

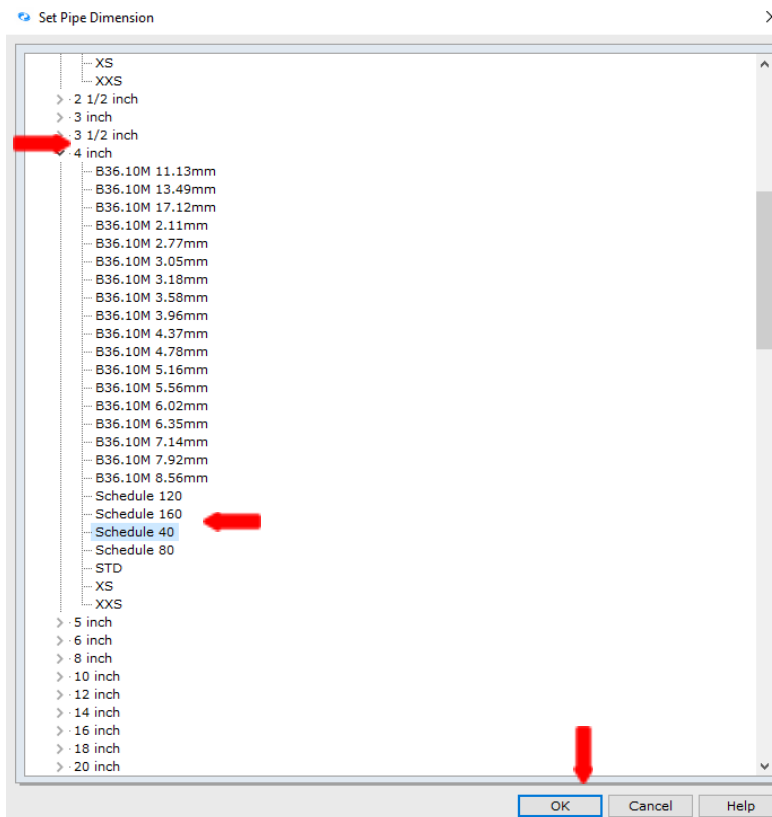


Figure 26: Set Pipe Dimension Dialog Box.

21. The Input Inspector on the *Data Palette* should now look like the screenshot given below (Figure 27).

Data Palette	
Messages Input Results Chart List Watch	
Unique Name	
Status	On
Length	15
Length Unit	m
Geometry	Cylindrical
Use Database Size	Yes
Nominal Size	4 inch
Classification	Schedule 40
Friction Model	Moody
Use Database Roughness	Yes
Roughness Description	Clean or new
Use Database Scaling	No
Scaling (0 to 50%)	0
Sizing Model	Economic Velocity
Heat Loss Model	Ignore Heat Loss/Gain
Draw Thickness [1..5]	1
Draw Color	clBlack
Properties on Flowsheet	Hide

Figure 27: Input Inspector at Pipe Number “-2”.

22. Let us now edit the default compressor data by selecting node 3. You should now see that node 3 is highlighted on the flowsheet (Figure 28).

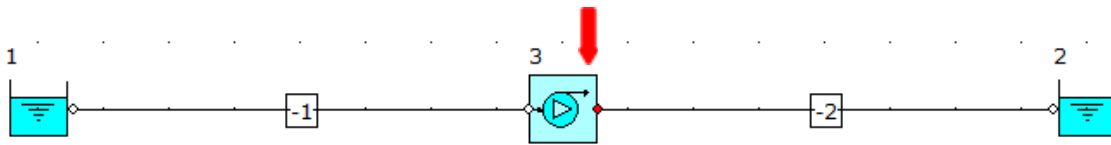


Figure 28: Highlighted Compressor Node.

23. View the *Data Palette* and click the *Input Tab*. Enter the following specifications:

In this cell...	Enter...
Elevation	1
Automatically Size	On
Sizing Model	Size for Flow
Design Flow	3500
Flow Unit	kg/h

24. The Input Inspector on the *Data Palette* should now look like the screenshot given below (Figure 29).

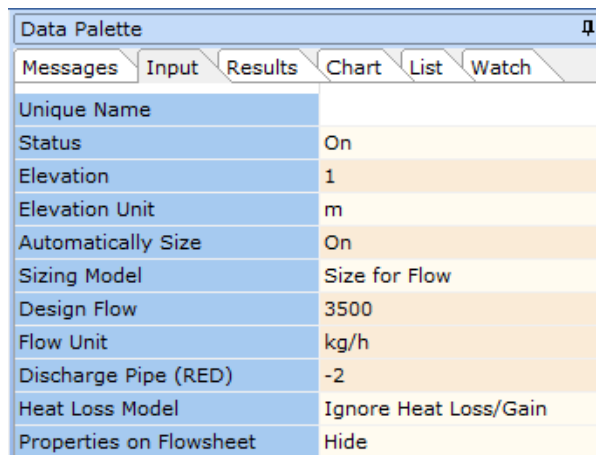


Figure 29: Input Inspector at Compressor.

Note: The *Size for Flow* sizing model is used to maintain a flow rate of 3500 kg/hr as specified in our problem.

25. **Save** your flowsheet.

Task 3 – Select Results Unit Set

In FluidFlow, it is possible to change the default results unit set used to display variables.

26. View the top portion of the user interface. The Units selector is on the middle portion (Figure 30):

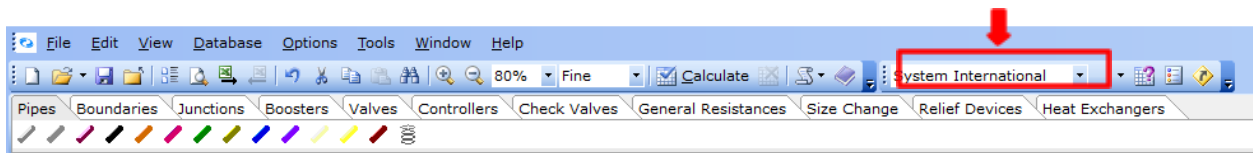


Figure 30: Unit Selector.

27. Click the drop-down menu to select a unit set. There are two default unit sets available: System International and US Basic (Figure 31).

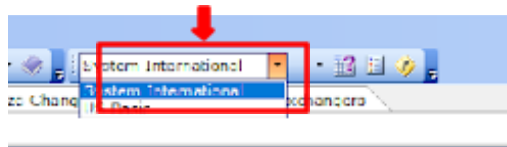


Figure 31: Unit Selector Drop-Down Menu.

28. You can click and select the desired unit set for use, or even create your own custom unit set. In this example, we will use System International and create our own unit set.
29. We can change our units by right mouse-clicking on the *Results* tab followed by selecting *Results Units* from the drop-down menu (Figure 32).



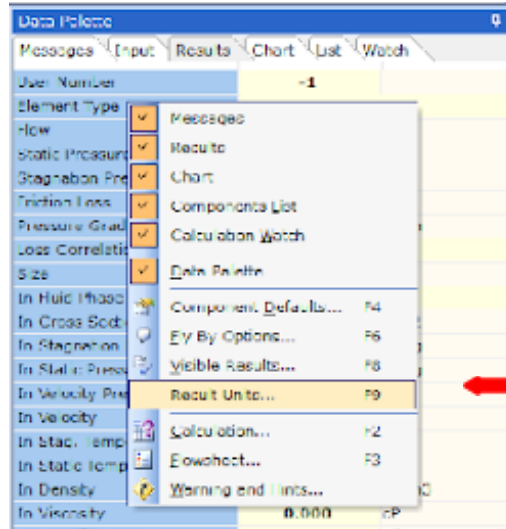


Figure 32: Result Units.

30. Alternatively, you can select F9. This opens a new dialogue box per Figure 33.

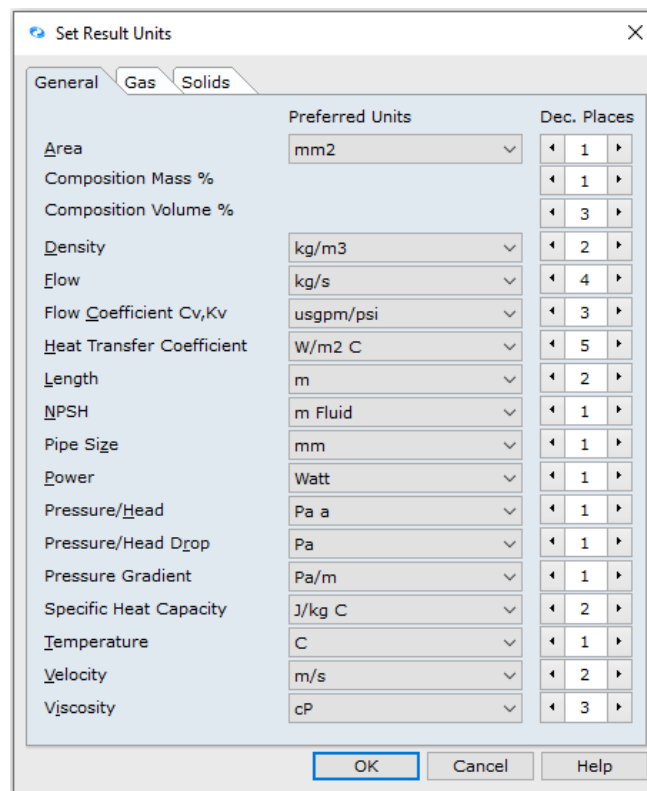


Figure 33: Set Result Units Dialogue Box.

31. Let us select the following units using the drop-down menu:

In this unit...	Select...
Flow	kg/h
Pressure/Head	bar g

Pressure/Head Drop	bar
--------------------	-----

32. The Set Result Units dialogue box should now look like the screenshot given below (Figure 34). Select **OK** to apply the changes.

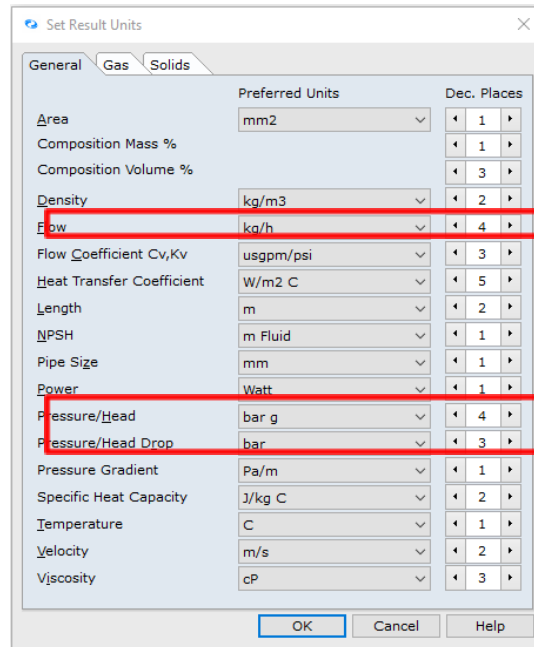


Figure 34: Modified Set Result Units Dialogue Box.

33. Now that we have set the results unit, let us save the custom result unit set. Click the drop-down button at the right of the default unit set and select the Save Environment option (Figure 35).

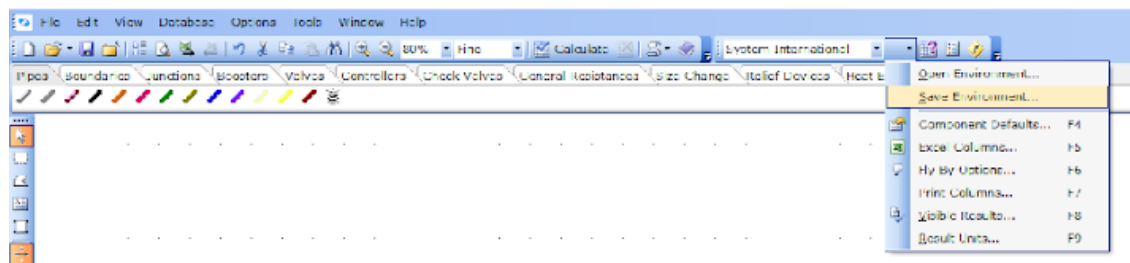


Figure 35: Save Environment Option.

34. The Save Environment dialogue box will appear (Figure 36).

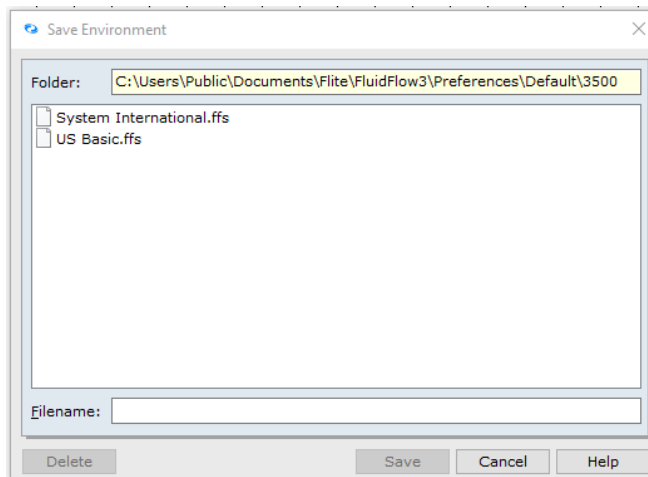


Figure 36: Save Environment Dialogue Box.

35. On the *Filename:* section type **Custom Unit 1** and click Save (Figure 37).

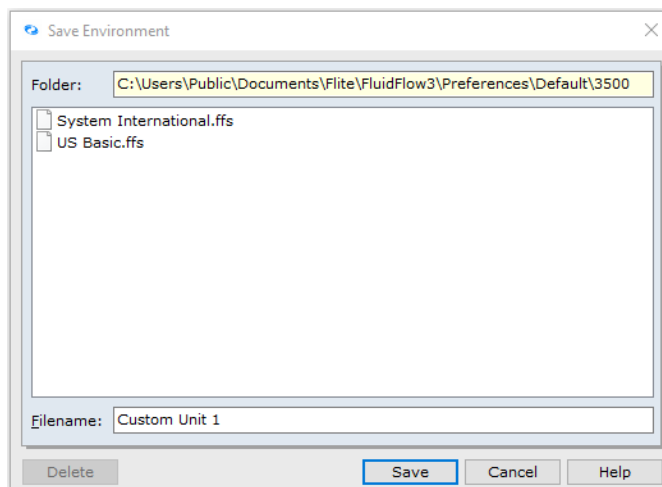


Figure 37: Modified Save Environment Dialogue Box.

36. Now that we have successfully added our custom unit, it is now available in the unit set drop-down menu (Figure 38). Let us now use **Custom Unit 1** as our preferred unit set for this example:

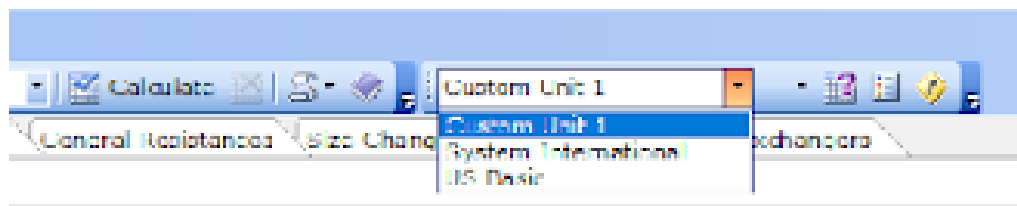


Figure 38: Unit Set Drop-Down Menu.

37. **Save** your flowsheet.

Task 4 – Calculate and Perform Hydraulic Analysis

Now that we have completed all the required inputs and customised the results unit set, we can now calculate the hydraulic model.

38. Calculate the model using the *Calculate* button located at the top of the flowsheet (Figure 39):

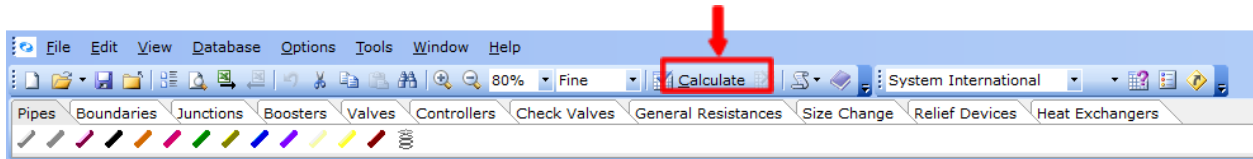


Figure 39: Calculate Button.

39. Check the converged hydraulic model in the flowsheet. The blue arrowhead shows that the flow direction is from the source node 1 to the source node 2. Also, check if the pipes and compressor are highlighted in **RED**, indicating that we have a warning message associated with the pipe elements and compressor (Figure 40).

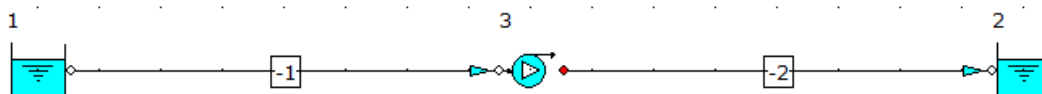


Figure 40: Converged Hydraulic Model

Note: Make sure that the **RED** Show or Hide Warnings Highlight button is selected in the *Flowsheet Toolbar* (Figure 41):

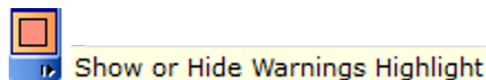


Figure 41: Show or Hide Warnings Highlight Button.

40. Select the *Messages* tab on the *Data Palette*, we can view all warnings for the model including a description of each (Figure 42). The converged hydraulic model has no warnings. Therefore, we can now proceed with the analysis of the results.

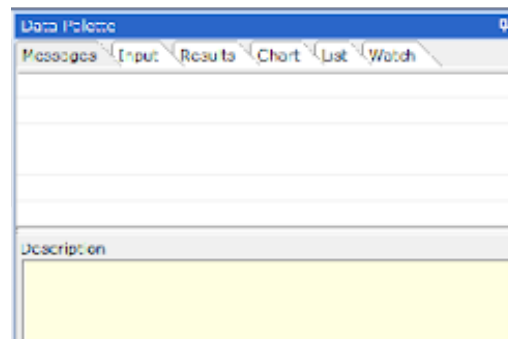
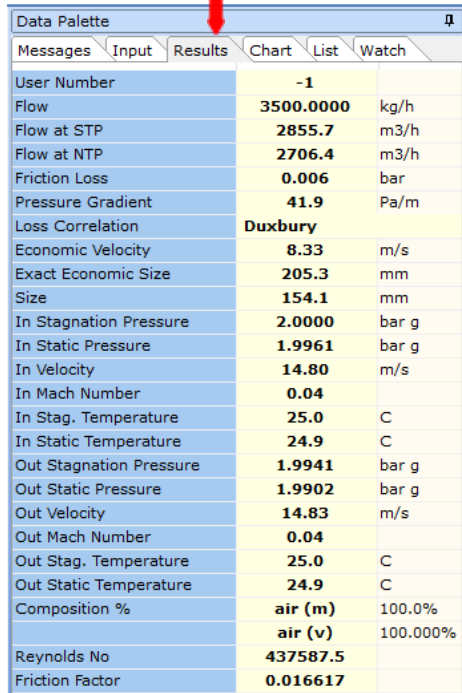


Figure 42: Warning Messages Tab.

Note: Warnings are enunciated by the software automatically to help the user eliminate any unwanted operating conditions and to prompt the user to develop a more efficient system design. Warnings should always be reviewed and considered by the engineer. You can evaluate and choose to ignore warnings if you wish.

41. Left-click the pipe number -1 and select the *Results* tab on the *Data Palette*. We can see all the calculated values for this pipe. Figure 43 provides an overview of these results.



Data Palette		
Messages	Input	Results
User Number	-1	
Flow	3500.0000	kg/h
Flow at STP	2855.7	m3/h
Flow at NTP	2706.4	m3/h
Friction Loss	0.006	bar
Pressure Gradient	41.9	Pa/m
Loss Correlation	Duxbury	
Economic Velocity	8.33	m/s
Exact Economic Size	205.3	mm
Size	154.1	mm
In Stagnation Pressure	2.0000	bar g
In Static Pressure	1.9961	bar g
In Velocity	14.80	m/s
In Mach Number	0.04	
In Stag. Temperature	25.0	C
In Static Temperature	24.9	C
Out Stagnation Pressure	1.9941	bar g
Out Static Pressure	1.9902	bar g
Out Velocity	14.83	m/s
Out Mach Number	0.04	
Out Stag. Temperature	25.0	C
Out Static Temperature	24.9	C
Composition %	air (m)	100.0%
	air (v)	100.000%
Reynolds No	437587.5	
Friction Factor	0.016617	

The "In" values represent the calculated conditions at the pipe Inlet.

The "Out" values represent the calculated conditions at the pipe Outlet.

- Suggested Economic Pipe Ø.
- Actual I.D. of 6" Sch. 40 Pipe.

Figure 43: Calculated Results for Pipe "-1".

42. Left-click the pipe number -2 and select the *Results* tab on the *Data Palette*. We can see all the calculated values for this pipe. Figure 44 provides an overview of these results.

Data Palette					
Messages	Input	Results	Chart	List	Watch
User Number	-2				
Flow	3500.0000	kg/h			
Flow at STP	2855.7	m3/h			
Flow at NTP	2706.4	m3/h			
Friction Loss	0.026	bar			
Pressure Gradient	170.0	Pa/m			
Loss Correlation	Duxbury				
Economic Velocity	6.74	m/s			
Exact Economic Size	161.3	mm			
Size	102.3	mm			
In Stagnation Pressure	5.0317	bar g			
In Static Pressure	5.0218	bar g			
In Velocity	16.78	m/s			
In Mach Number	0.05				
In Stag. Temperature	26.2	C			
In Static Temperature	26.0	C			
Out Stagnation Pressure	5.0000	bar g			
Out Static Pressure	4.9900	bar g			
Out Velocity	16.86	m/s			
Out Mach Number	0.05				
Out Stag. Temperature	26.2	C			
Out Static Temperature	26.0	C			
Composition %	air (m)	100.0%			
	air (v)	100.000%			
Reynolds No	657356.3				
Friction Factor	0.017377				

The "In" values represent the calculated conditions at the pipe Inlet.

The "Out" values represent the calculated conditions at the pipe Outlet.

- Suggested Economic Pipe Ø.
- Actual I.D. of 4" Sch. 40 Pipe.

Figure 44: Calculated Results for Pipe "-2".

43. Warnings are enunciated based on the settings defined in *Warnings & Hints*. You can view these set-points by selecting; Options | Warnings & Hints or alternatively, select the *Warnings & Hints* icon at the top of the flowsheet.

Warning & Hints icon: 

Since we are modeling a gas system, we are only interested in the Gas Limits (Figure 45).

Warnings and Hints	
Messages	Gas Limits
Min. Pipe Velocity	0.5
Max. Pipe Velocity	200
Velocity	m/s
Min. Opening Control Valve (%)	30
Max. Opening Control Valve (%)	85

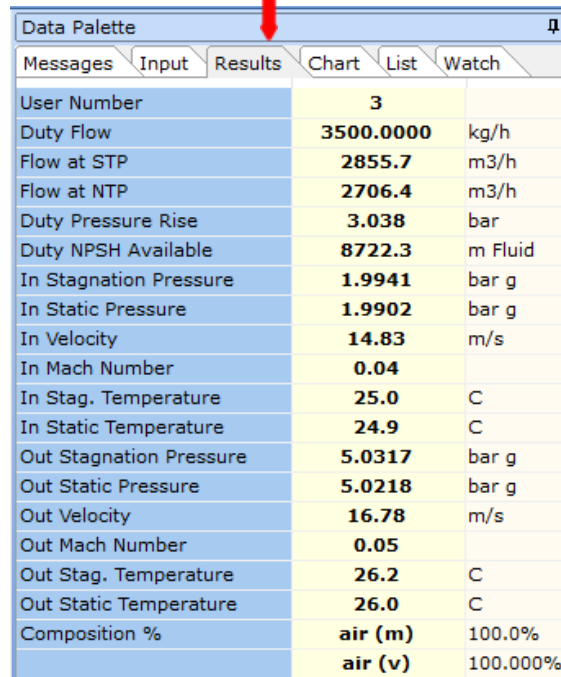
OK Cancel Help

Figure 45: Warning and Hints: Gas Limits.

44. As we can see in Figures 43 and 44, the actual flowing velocity of the gas in pipes "-1" and "-2" are **14.80 m/s (inlet)/14.83 m/s (outlet)** and **16.78 m/s (inlet)/16.86 m/s (outlet)**, respectively. The velocities are within the **0.5 – 200 m/s** range for the minimum and maximum pipe velocity

(Figure 45). The high-velocity warning is enunciated once the actual flowing velocity is higher than the maximum velocity level set in our warnings (**200 m/s** – See Figure 45).

45. FluidFlow automatically calculates an *Economic Velocity* and associated *Exact Economic Size* for each pipe in the model. These results can be viewed on the *Results* tab (Figure 43 and 44) and are provided as a suggestion in order to help develop an efficient system design. Note, it is down to the engineer’s discretion as to whether or not the actual pipe size needs to be changed to be more in line with that suggested by the software. Therefore, the results for *Economic Velocity* and associated *Exact Economic Size* are suggested values only and do not have any effect on the overall operating conditions for the system.
46. Left-click the compressor (node 3) and select the *Results* tab on the *Data Palette*. We can see the calculated values for this compressor. Figure 46 provides an overview of these results.



Data Palette		
Messages	Input	Results
User Number	3	
Duty Flow	3500.0000	kg/h
Flow at STP	2855.7	m3/h
Flow at NTP	2706.4	m3/h
Duty Pressure Rise	3.038	bar
Duty NPSH Available	8722.3	m Fluid
In Stagnation Pressure	1.9941	bar g
In Static Pressure	1.9902	bar g
In Velocity	14.83	m/s
In Mach Number	0.04	
In Stag. Temperature	25.0	C
In Static Temperature	24.9	C
Out Stagnation Pressure	5.0317	bar g
Out Static Pressure	5.0218	bar g
Out Velocity	16.78	m/s
Out Mach Number	0.05	
Out Stag. Temperature	26.2	C
Out Static Temperature	26.0	C
Composition %	air (m)	100.0%
	air (v)	100.000%

Figure 46: Calculated Results for Compressor.

Based on our design flow rate and system configuration, the compressor will have a duty pressure rise (differential pressure) of **3.038 bar**.

47. To answer the problem in this example, the following required parameters are also calculated by the FluidFlow:

Parameter	Pipe “-1”	Pipe “-2”
Friction Loss	0.006 bar	0.026 bar
Reynolds Number	437588	657356
Darcy Friction Factor	0.0166	0.0174

48. Note that we can improve the presentation of our model by selecting the pipes “-1” and “-2” and changing the *Draw Thickness* and *Draw Color* from the *Input Inspector*. We have set the *Draw Thickness* to **3** and *Draw Color* to **clRed** (Figure 47).

Data Palette					
Messages	Input	Results	Chart	List	Watch
Unique Name					
Status	On				
Length	15				
Length Unit	m				
Geometry	Cylindrical				
Use Database Size	Yes				
Nominal Size	6 inch				
Classification	Schedule 40				
Friction Model	Moody				
Use Database Roughness	Yes				
Roughness Description	Clean or new				
Use Database Scaling	No				
Scaling (0 to 50%)	0				
Sizing Model	Economic Velocity				
Heat Loss Model	Ignore Heat Loss/Gain				
Draw Thickness [1..5]	3				
Draw Color	clRed				
Properties on Flowsheet	Hide				

Figure 47: Modified Draw Thickness and Draw Color.

49. The hydraulic model should now look like the screenshot given below (Figure 48).

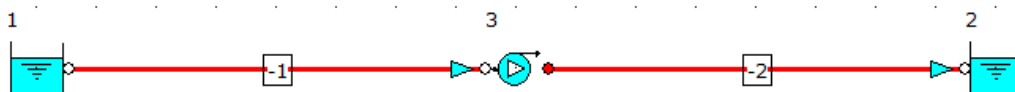


Figure 48: Hydraulic Model with Modified Draw Thickness and Draw Color.

50. Now let us show the properties of the boundaries. Left mouse-click on the inlet boundary (node 1) and whilst holding the SHIFT key, left mouse-click on the outlet boundary (node 2), and from the *Input Inspector*, change the field titled *Properties on Flowsheet* from *Hide* to *Show* (Figure 49).

Data Palette					
Messages	Input	Results	Chart	List	Watch
Unique Name					
Status	On				
Elevation	10				
Elevation Unit	m				
Pressure Model	Stagnation Pressure				
Pressure	5				
Pressure Unit	bar g				
Temperature	15				
Temperature Unit	C				
Fluid	water				
Fluid Type	Newtonian/NN-NonSettling				
Properties on Flowsheet	Show				
Alignment	Bottom				
Font	Verdana,9,clWindowText,[
Properties					

Figure 49: Show Properties on Flowsheet.

51. Now we will select the field titled *Properties* from the Input list. An *Element Properties* dialogue box will appear (Figure 50):

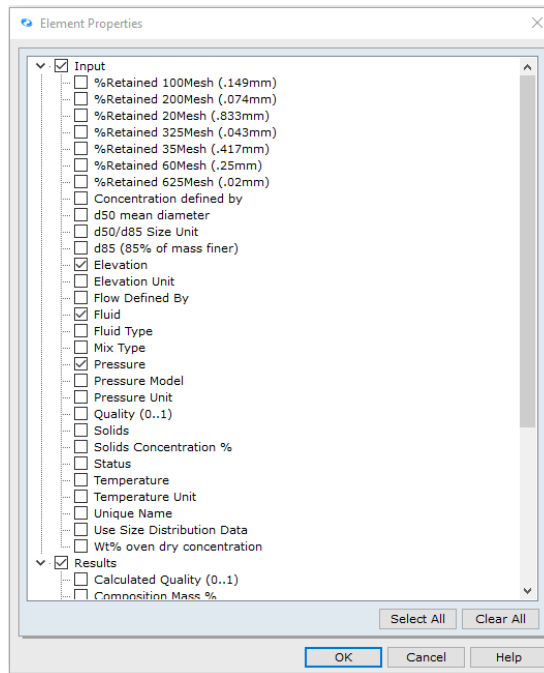


Figure 50: Element Properties Dialogue Box.

52. Place a checkmark in the box for the following parameters and click **OK**:

Element Properties	
Input	Results
Elevation	Composition %
Pressure	Density
	Temperature
	Viscosity

53. The hydraulic model should now look like the screenshot given below (Figure 51).

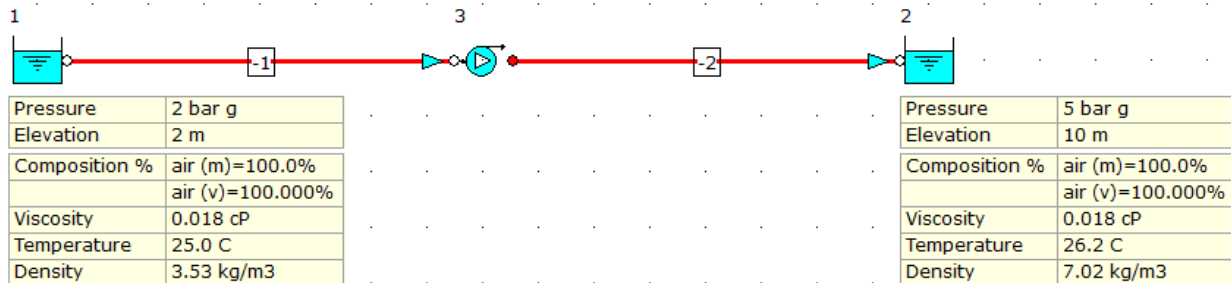


Figure 51: Hydraulic Model with Inlet and Outlet Boundary Properties.

54. Now let us show the properties of the pipes. Left mouse-click on the pipe number “-1” and whilst holding the SHIFT key, left mouse-click on the pipe number “-2” and from the *Input Inspector*, change the field titled *Properties on Flowsheet* from *Hide* to *Show* and *Alignment* from *Bottom* to *Top* (Figure 52).

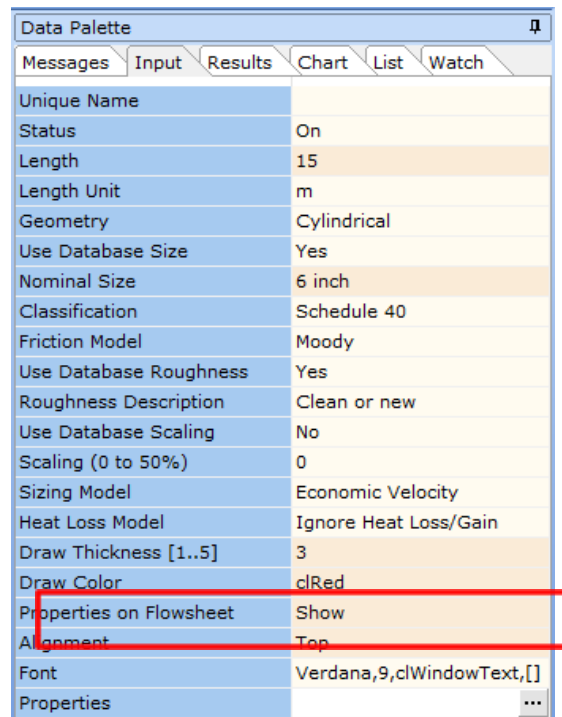


Figure 52: Show Properties on Flowsheet.

55. Now we will select the field titled *Properties* from the Input list. An *Element Properties* dialogue box will appear (Figure 53):

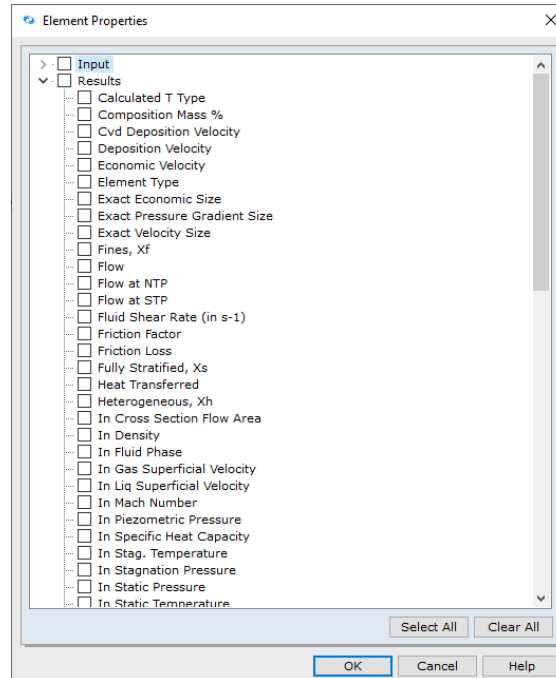


Figure 53: Element Properties Dialogue Box.

56. Place a checkmark in the box for the following parameters and click **OK**:

Element Properties	
Input	Results
Length	Flow
Nominal Size	Friction Factor
	Friction Loss
	In Density
	In Velocity
	In Viscosity
	Out Density
	Out Velocity
	Out Viscosity
	Reynolds No
	Size
	Stagnation Pressure Loss
	Static Pressure Loss

57. The hydraulic model should now look like the screenshot given below (Figure 54).

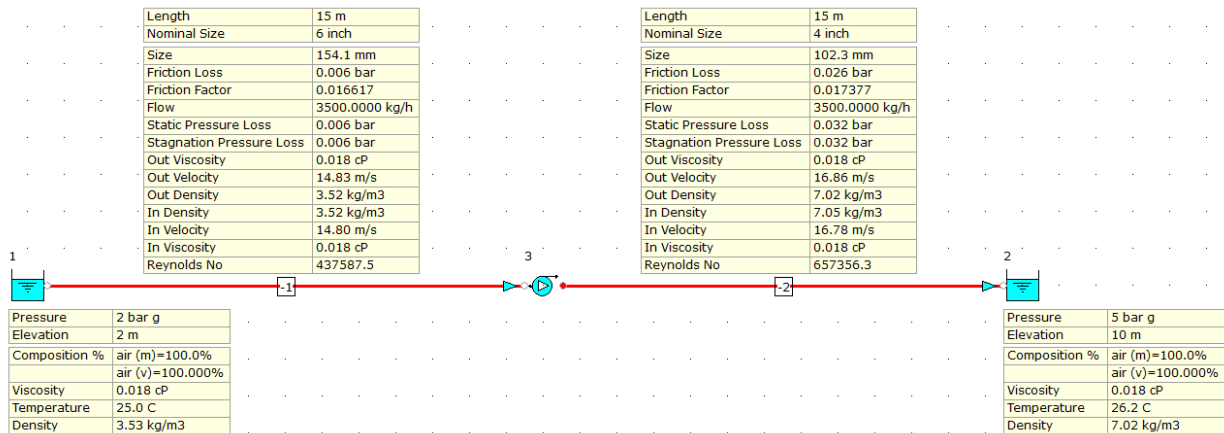


Figure 54: Hydraulic Model with Pipe Properties.

58. Now let us show the properties of the compressor. Left mouse-click on the compressor (node 3) and from the *Input Inspector*, change the field titled *Properties on Flowsheet* from *Hide* to *Show* (Figure 55).

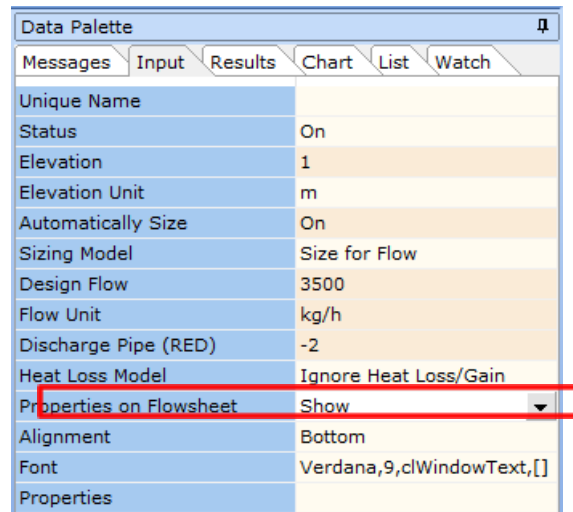


Figure 55: Show Properties on Flowsheet.

59. Now we will select the field titled *Properties* from the Input list. An *Element Properties* dialogue box will appear (Figure 56):

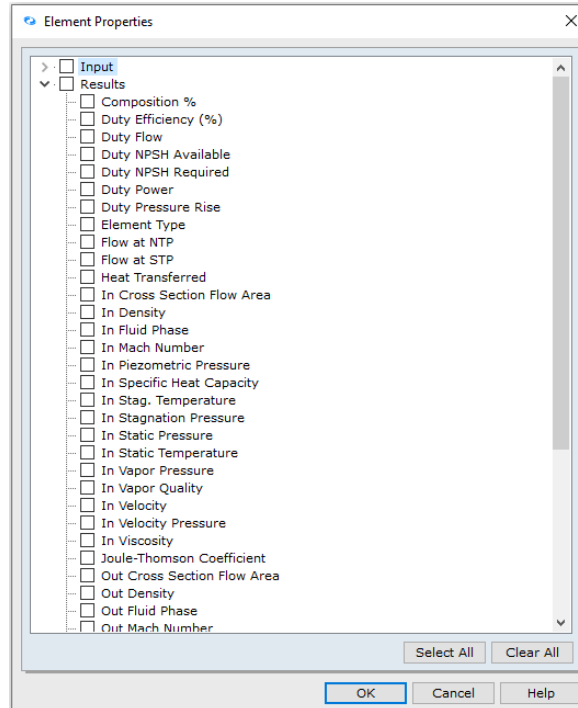


Figure 56: Element Properties Dialogue Box.

60. Place a checkmark in the box for the following parameters and click **OK**:

Element Properties	
Input	Results
Design Flow	Duty Flow
Elevation	Duty Pressure Rise
	In Density
	In Fluid Phase
	In Stagnation Pressure
	In Velocity
	In Viscosity
	Out Density
	Out Fluid Phase
	Out Stagnation Pressure
	Out Velocity
	Out Viscosity

61. The hydraulic model should now look like the screenshot given below (Figure 57).

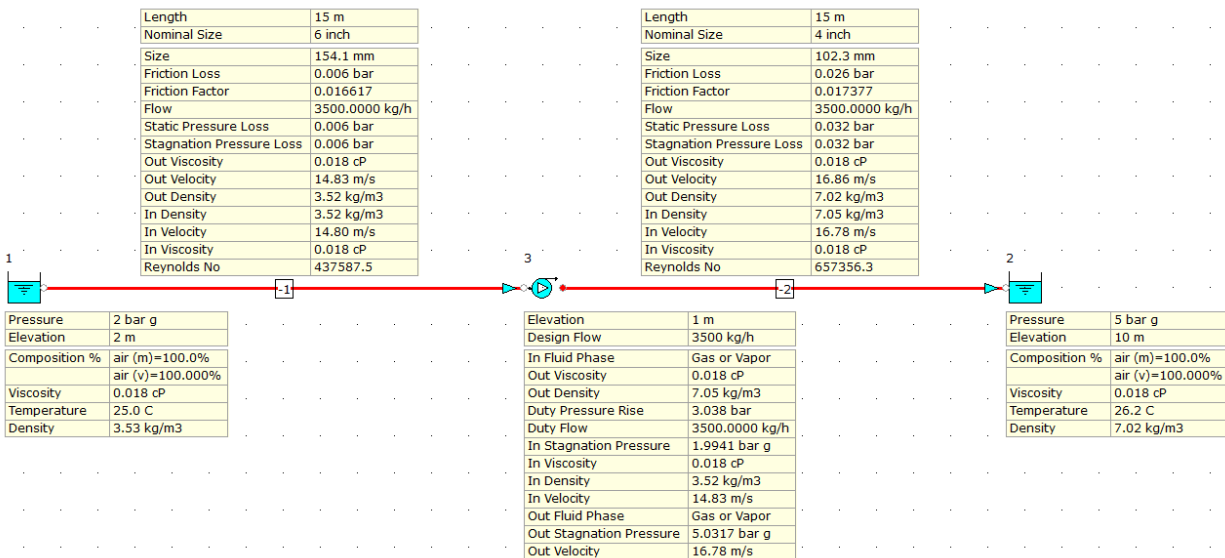


Figure 57: Hydraulic Model with Compressor Properties.

62. **Save** your flowsheet.

Task 5 – Compare the FluidFlow Results to Hand Calculation

FluidFlow software is designed to allow the modeling of fluid behaviour within complex piping systems, and accurately predict how the system will work for a given set of design conditions.

In this task, we will verify the accuracy of FluidFlow against our hand calculation.

Given:

$$P_1 = P_{-1,in} = 2 \text{ barg} = 301325 \text{ Pa}$$

$$P_2 = P_{-2,out} = 5 \text{ barg} = 601325 \text{ Pa}$$

$$z_1 = 2 \text{ m}$$

$$z_2 = 10 \text{ m}$$

Suction line size = 6" SCH 40

Discharge line size = 4" SCH 40

$$L_{-1} = 15.0 \text{ m}$$

$$L_{-2} = 15.0 \text{ m}$$

$$\text{Mass Flow Rate, } \dot{m} = 3500 \frac{\text{kg}}{\text{h}}$$

Air at 25°C

Required:

$$\text{Inlet Velocity at Pipe (- 1), } V_{-1, \text{in}} = ?$$

$$\text{Outlet Velocity at Pipe (- 1), } V_{-1, \text{out}} = ?$$

$$\text{Inlet Velocity at Pipe (- 2), } V_{-2, \text{in}} = ?$$

$$\text{Outlet Velocity at Pipe (- 2), } V_{-2, \text{out}} = ?$$

$$\text{Reynolds Number, } Re_{-1} = ?$$

$$\text{Reynolds Number, } Re_{-2} = ?$$

$$\text{Darcy Friction Factor, } f_{D_{-1}} = ?$$

$$\text{Darcy Friction Factor, } f_{D_{-2}} = ?$$

$$\text{Compressor Differential Pressure, } \Delta P_{\text{Compressor}} = ?$$

$$\text{Friction loss}_{-1} = -\Delta P_{-1} = ?$$

$$\text{Friction loss}_{-2} = -\Delta P_{-2} = ?$$

Solution:

$$6" \text{ SCH 40, I.D.} = D_{-1} = 154.1 \text{ mm} = 0.1541 \text{ m}$$

$$4" \text{ SCH 40, I.D.} = D_{-2} = 102.3 \text{ mm} = 0.1023 \text{ m}$$

Inlet and Outlet Temperature of Pipe " - 1" from FluidFlow results

$$T_{-1,in} = T_{-1,out} = 25^{\circ}\text{C} = 298.15 \text{ K}$$

Inlet and Outlet Temperature of Pipe " – 1" from FluidFlow results

$$T_{-2,in} = T_{-2,out} = 26.2^{\circ}\text{C} = 299.35 \text{ K}$$

Molecular Weight of Air from FluidFlow Properties Database

$$M_w = 28.9505 \frac{\text{g}}{\text{gmol}} = 29.59505 \times 10^{-3} \frac{\text{kg}}{\text{gmol}}$$

Density of Air at 25.0°C and 2 barg from FluidFlow Calculated Properties Database

$$\rho_{Air_{-1,in}} = 3.53 \frac{\text{kg}}{\text{m}^3}$$

Density of Air at 26.2°C and 5.0 barg from FluidFlow Calculated Properties Database

$$\rho_{Air_{-2,out}} = 7.02 \frac{\text{kg}}{\text{m}^3}$$

Viscosity of Air at 25°C & 2 barg and 26.2°C & 5 barg from FluidFlow Calculated Properties Database

$$\mu_{Air_{in}} = \mu_{Air_{out}} = 0.018 \text{ cP}$$

Let us assume the following for this calculation:

- 1) *The flow is steady and one – dimensional.*
- 2) *Negligible gravitational effects and potential energy term.*
- 3) *Assume skin frictional losses only.*
- 4) *The fluid is an ideal gas of constant specific heat.*
- 5) *The flow of fluid in a conduit of constant cross – section is kept isothermal.*

Let us solve the Mass Velocities, G_{-1} and G_{-2}

$$G_{-1} = \frac{\dot{m}}{S_1} = \frac{\dot{m}}{\frac{\pi}{4} D_{-1}^2} = \frac{3500 \frac{\text{kg}}{\text{h}} \left(\frac{1 \text{ h}}{3600 \text{ s}} \right)}{\frac{\pi}{4} (0.1541 \text{ m})^2} = 52.1279 \frac{\text{kg}}{\text{m}^2 \cdot \text{s}}$$

$$G_{-2} = \frac{\dot{m}}{S_2} = \frac{\dot{m}}{\frac{\pi}{4} D_{-2}^2} = \frac{3500 \frac{\text{kg}}{\text{h}} \left(\frac{1 \text{ h}}{3600 \text{ s}} \right)}{\frac{\pi}{4} (0.1023 \text{ m})^2} = 118.2836 \frac{\text{kg}}{\text{m}^2 \cdot \text{s}}$$

Let us solve the Reynolds Numbers, Re_{-1} and Re_{-2}

$$Re_{-1} = \frac{D_{-1} G_{-1}}{\mu} = \frac{(0.1541 \text{ m}) \left(52.1279 \frac{\text{kg}}{\text{m}^2 \cdot \text{s}} \right)}{0.018 \text{ cP} \times \frac{\text{Pa} \cdot \text{s}}{1000 \text{ cP}}} = 446272.7439$$

$$Re_{-2} = \frac{D_{-2} G_{-2}}{\mu} = \frac{(0.1023 \text{ m}) \left(118.2836 \frac{\text{kg}}{\text{m}^2 \cdot \text{s}} \right)}{0.018 \text{ cP} \times \frac{\text{Pa} \cdot \text{s}}{1000 \text{ cP}}} = 672245.1267$$

Let us solve the Fanning Friction Factors, $f_{F_{-1}}$ and $f_{F_{-2}}$

Perry's Chemical Engineer's Handbook – 8th ed.

The Colebrook formula Equation (6 – 38)

$$\frac{1}{\sqrt{f_F}} = -4 \log \log \left[\frac{\epsilon}{3.7D} + \frac{1.256}{Re \sqrt{f_F}} \right] \quad Re > 4,000$$

$$\frac{1}{\sqrt{f_{F_{-1}}}} = -4 \log \log \left[\frac{\epsilon}{3.7D_{-1}} + \frac{1.256}{Re_{-1} \sqrt{f_{F_{-1}}}} \right]$$

$$\frac{1}{\sqrt{f_{F_{-2}}}} = -4 \log \log \left[\frac{\epsilon}{3.7D_{-2}} + \frac{1.256}{Re_{-2} \sqrt{f_{F_{-2}}}} \right]$$

Perry's Chemical Engineer's Handbook – 8th ed.

Table 6 – 1 Value of Surface Roughness for Various Materials

Commercial steel or wrought iron, $\epsilon = 0.0457 \text{ mm}$

Substitute the values of D , ϵ , and Re .

$$\frac{1}{\sqrt{f_{F_{-1}}}} = -4 \log \log \left[\frac{0.0457 \text{ mm}}{3.7(154.1 \text{ mm})} + \frac{1.256}{446272.7439 \sqrt{f_{F_{-1}}}} \right]$$

$$f_{F_{-1}} = 4.0962 \times 10^{-3}$$

$$\frac{1}{\sqrt{f_{F_{-2}}}} = -4 \log \log \left[\frac{0.0457 \text{ mm}}{3.7(102.3 \text{ mm})} + \frac{1.256}{672245.1267 \sqrt{f_{F_{-2}}}} \right]$$

$$f_{F_{-2}} = 4.2700 \times 10^{-3}$$

Let us calculate for the value of Darcy friction factors

$$f_{D_{-1}} = 4f_{F_{-1}} = 4(4.0962 \times 10^{-3})$$

$$f_{D_{-1}} = 0.0164$$

$$f_{D_{-2}} = 4f_{F_{-2}} = 4(4.2700 \times 10^{-3})$$

$$f_{D_{-2}} = 0.0171$$

Let us calculate the outlet pressure of Pipe " - 1".

Perry's Chemical Engineer's Handbook – 8th ed.

Isothermal Gas Flow in Pipes and Channels Equation (6 – 114)

$$P_1^2 - P_2^2 = G^2 \frac{RT}{M_w} \left[\frac{4fL}{D_H} + 2 \ln \ln \left(\frac{P_1}{P_2} \right) \right]$$

$$P_{-1,in}^2 - P_{-1,out}^2 = G_{-1}^2 \frac{RT_{-1}}{M_w} \left[\frac{4f_{F_{-1}} L_{-1}}{D_{-1}} + 2 \ln \ln \left(\frac{P_{-1,in}}{P_{-1,out}} \right) \right]$$

Left – Hand Side Equation:

$$P_{-1,in}^2 - P_{-1,out}^2 = (301325 \text{ Pa a})^2 - P_{-1,out}^2$$

Right – Hand Side Equation:

$$\begin{aligned} G_{-1}^2 \frac{RT_{-1}}{M_w} \left[\frac{4f_{F_{-1}} L_{-1}}{D_{-1}} + 2 \ln \ln \left(\frac{P_{-1,in}}{P_{-1,out}} \right) \right] \\ = \left(52.1279 \frac{\text{kg}}{\text{m}^2 \cdot \text{s}} \right)^2 \frac{\left(8.314 \frac{\text{m}^3 \cdot \text{Pa}}{\text{gmol} \cdot \text{K}} \right) (298.15 \text{ K})}{28.9505 \times 10^{-3} \frac{\text{kg}}{\text{gmol}}} \left[\frac{4(4.0962 \times 10^{-3})(15 \text{ m})}{0.1541 \text{ m}} + 2 \ln \ln \left(\frac{301325 \text{ Pa a}}{P_{-1,out}} \right) \right] \\ G_{-1}^2 \frac{RT_{-1}}{M_w} \left[\frac{4f_{F_{-1}} L_{-1}}{D_{-1}} + 2 \ln \ln \left(\frac{P_{-1,in}}{P_{-1,out}} \right) \right] = 232664018.1 \left[1.5949 + 2 \ln \ln \left(\frac{301325 \text{ Pa a}}{P_{-1,out}} \right) \right] \end{aligned}$$

Combine Left – Hand Side and Right – Hand Side Equations:

$$(301325 \text{ Pa a})^2 - P_{-1,out}^2 = 232664018.1 \left[1.5949 + 2 \ln \ln \left(\frac{301325 \text{ Pa a}}{P_{-1,out}} \right) \right]$$

$$P_{-1,out} = 300707.041 \text{ Pa a} = 1.9938 \text{ barg}$$

Let us calculate the inlet pressure of Pipe " - 2".

Perry's Chemical Engineer's Handbook – 8th ed.

Isothermal Gas Flow in Pipes and Channels Equation (6 – 114)

$$P_1^2 - P_2^2 = G^2 \frac{RT}{M_w} \left[\frac{4fL}{D_H} + 2 \ln \ln \left(\frac{P_1}{P_2} \right) \right]$$

$$P_{-2,in}^2 - P_{-2,out}^2 = G_{-2}^2 \frac{RT_{-2}}{M_w} \left[\frac{4f_{F-2} L_{-2}}{D_{-2}} + 2 \ln \ln \left(\frac{P_{-2,in}}{P_{-2,out}} \right) \right]$$

Left – Hand Side Equation:

$$P_{-2,in}^2 - P_{-2,out}^2 = P_{-2,in}^2 - (601325 \text{ Pa a})^2$$

Right – Hand Side Equation:

$$\begin{aligned} G_{-2}^2 \frac{RT_{-2}}{M_w} \left[\frac{4f_{F-2} L_{-2}}{D_{-2}} + 2 \ln \ln \left(\frac{P_{-2,in}}{P_{-2,out}} \right) \right] \\ = \left(118.2836 \frac{\text{kg}}{\text{m}^2 \cdot \text{s}} \right)^2 \frac{\left(8.314 \frac{\text{m}^3 \cdot \text{Pa}}{\text{gmol} \cdot \text{K}} \right) (299.35 \text{ K})}{28.9505 \times 10^{-3} \frac{\text{kg}}{\text{gmol}}} \left[\frac{4(4.2700 \times 10^{-3})(15 \text{ m})}{0.1023 \text{ m}} + 2 \ln \ln \left(\frac{P_{-2,in}}{601325 \text{ Pa a}} \right) \right] \end{aligned}$$

Combine Left – Hand Side and Right – Hand Side Equations:

$$G_{-1}^2 \frac{RT_{-1}}{M_w} \left[\frac{4f_{F-1} L_{-1}}{D_{-1}} + 2 \ln \ln \left(\frac{P_{-1,in}}{P_{-1,out}} \right) \right] = 1202769154 \left[\frac{854}{341} + 2 \ln \ln \left(\frac{P_{-2,in}}{601325 \text{ Pa a}} \right) \right]$$

$$P_{-2,in}^2 - (601325 \text{ Pa a})^2 = 1202769154 \left[\frac{854}{341} + 2 \ln \ln \left(\frac{P_{-2,in}}{601325 \text{ Pa a}} \right) \right]$$

$$P_{-2,in} = 603832.7421 \text{ Pa a} = 5.0251 \text{ barg}$$

Let us calculate the

$$\Delta P_{\text{Compressor}} = P_{-2,in} - P_{-1,out} = 5.0251 \text{ barg} - 1.9938 \text{ barg}$$

$$\Delta P_{\text{Compressor}} = 3.0313 \text{ bar}$$

Let us calculate the Pipe (– 1) and Pipe (– 2) inlet velocities ($V_{-1,in}$, $V_{-2,in}$)

We will use the calculated density ($\rho_{-1,in}$) of FluidFlow based on $P_{-1,in}$ & $T_{-1,in}$ value to solve for $V_{-1,in}$.

$$V_{-1,in} = \frac{\dot{m}}{\rho_{-1,in} S_{-1}} = \frac{\dot{m}}{\rho_{-1,in} \left(\frac{\pi}{4} D_{-1}^2 \right)} = \frac{3500 \frac{\text{kg}}{\text{h}} \left(\frac{1 \text{ h}}{3600 \text{ s}} \right)}{\left(3.53 \frac{\text{kg}}{\text{m}^3} \right) \left[\frac{\pi}{4} (0.1541 \text{ m})^2 \right]} = 14.77 \frac{\text{m}}{\text{s}}$$

Since the calculated value $P_{-2,in}$ is close to FluidFlow results, we will use the calculated density ($\rho_{-2,in}$)

of FluidFlow based on $P_{-2,in}$ & $T_{-2,in}$ to solve for $V_{-2,in}$.

$$V_{-2,in} = \frac{\dot{m}}{\rho_{-2,in} S_{-2}} = \frac{\dot{m}}{\rho_{-2,in} \left(\frac{\pi}{4} D_{-2}^2\right)} = \frac{3500 \frac{kg}{h} \left(\frac{1 h}{3600 s}\right)}{\left(7.05 \frac{kg}{m^3}\right) \left[\frac{\pi}{4} (0.1023 m)^2\right]} = 16.78 \frac{m}{s}$$

Let us calculate the Pipe (- 1) and Pipe (- 2) outlet velocities ($V_{-1,out}, V_{-2,out}$)

Since the calculated value $P_{-1,out}$ is similar to FluidFlow results, we will use the calculated density ($\rho_{-1,out}$) of FluidFlow to solve for $V_{-1,out}$.

$$V_{-1,out} = \frac{\dot{m}}{\rho_{-1,out} S_{-1}} = \frac{\dot{m}}{\rho_{-1,out} \left(\frac{\pi}{4} D_{-1}^2\right)} = \frac{3500 \frac{kg}{h} \left(\frac{1 h}{3600 s}\right)}{\left(3.52 \frac{kg}{m^3}\right) \left[\frac{\pi}{4} (0.1541 m)^2\right]} = 14.81 \frac{m}{s}$$

We will use the calculated density ($\rho_{-2,out}$) of FluidFlow based on $P_{-2,out}$ value to solve for $V_{-2,out}$.

$$V_{-2,out} = \frac{\dot{m}}{\rho_{-2,out} S_{-2}} = \frac{\dot{m}}{\rho_{-2,out} \left(\frac{\pi}{4} D_{-2}^2\right)} = \frac{3500 \frac{kg}{h} \left(\frac{1 h}{3600 s}\right)}{\left(7.02 \frac{kg}{m^3}\right) \left[\frac{\pi}{4} (0.1023 m)^2\right]} = 16.85 \frac{m}{s}$$

Let us calculate for the value of frictional losses based on the outlet velocities of Pipe(- 1) & (- 2)

$$Friction\ loss_{-1} = F_{Line_{-1}} = h_{Line_{-1}} = \frac{-\Delta P_{-1}}{\rho_{-1,out}} = \frac{4f_{F_{-1}} L_{-1} V_{-1,out}^2}{2D_{-1} g_c}$$

$$Friction\ loss_{-1} = -\Delta P_{-1} = \frac{2f_{F_{-1}} L_{-1} V_{-1,out}^2 \rho_{-1,out}}{D_{-1} g_c}$$

$$Friction\ loss_{-1} = -\Delta P_{-1} = \frac{2(4.0962 \times 10^{-3})(15 m) \left(14.81 \frac{m}{s}\right)^2 \left(3.52 \frac{kg}{m^3}\right)}{(0.1541 m) \left(1 \frac{kg-m}{N-s^2}\right)} = 616 Pa$$

$$Friction\ loss_{-1} = -\Delta P_{-1} = 616 Pa \times \frac{1.01325 bar}{101325 Pa}$$

$$Friction\ loss_{-1} = -\Delta P_{-1} = 0.006 bar$$

$$Friction\ loss_{-2} = F_{Line_{-2}} = h_{Line_{-2}} = \frac{-\Delta P_{-2}}{\rho_{-2,out}} = \frac{4f_{F_{-2}} L_{-2} V_{-2,out}^2}{2D_{-2} g_c}$$

$$Friction\ loss_{-2} = -\Delta P_{-2} = \frac{2f_{F_{-2}} L_{-2} V_{-2,out}^2 \rho_{-2,out}}{D_{-2} g_c}$$

$$Friction\ loss_{-2} = -\Delta P_{-2} = \frac{2(4.2700 \times 10^{-3})(15 m) \left(16.85 \frac{m}{s}\right)^2 \left(7.02 \frac{kg}{m^3}\right)}{(0.1023 m) \left(1 \frac{kg-m}{N-s^2}\right)} = 2496 Pa$$

$$Friction\ loss_{-2} = -\Delta P_{-2} = 2496 Pa \times \frac{1.01325 bar}{101325 Pa}$$

$$\text{Friction loss}_{-2} = -\Delta P_{-2} = 0.025 \text{ bar}$$

Results Comparison:

Description	Unit	FluidFlow Results	Hand Calculation	% Difference
	m/s	14.80	14.77	0.2029%
Outlet Velocity @ Pipe " - 1", V_{-}	m/s	14.83	14.81	0.1350%
Inlet Velocity @ Pipe " - 2", $V_{-2,i}$	m/s	16.78	16.78	0%
Outlet Velocity @ Pipe " - 2", V_{-}	m/s	16.86	16.74	0.7143%
Reynolds Number, Re_{-1}	-	437588	446273	1.9652%
Reynolds Number, Re_{-2}	-	657356	672245	2.2396%
Darcy Friction Factor, $f_{D_{-1}}$	-	0.0166	0.0164	1.2121%
Darcy Friction Factor, $f_{D_{-2}}$	-	0.0174	0.0171	1.7391%
Compressor dP, $\Delta P_{Compressor}$	bar	3.038	3.031	0.2307%
Friction loss ₋₁ , $-\Delta P_{-1}$	bar	0.006	0.006	0%
Friction loss ₋₂ , $-\Delta P_{-2}$	bar	0.026	0.025	3.9216%

Commentary:

The results compare very well with the hand calculation.