The Heart of The Pump's Performance

What is Total Head?

Understanding Total Head (formerly Total Dynamic Head) is vital for efficient pumping systems. It represents the energy required to overcome resistance in a piping system and deliver water from one point to another. Total head (TH) is crucial for pump selection, system design, and energy efficiency. Engineers use TH to choose the right pump, size pipes, and optimize operations. Understanding TH helps detect maintenance needs and troubleshoot issues. By grasping TH, water systems can operate effectively and save on energy costs.

Accurately calculating TH ensures your pump can handle the job. Selecting a pump with insufficient TH can lead to:

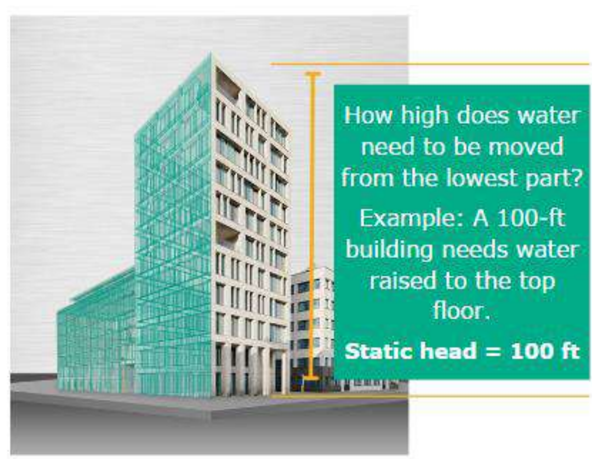
- **Reduced flow rates:** The pump struggles to push the liquid, slowing the process.
- **Overheating and damage:** The pump strains, potentially leading to breakdowns.
- **Inefficient operation:** Higher energy consumption due to the pump working harder.
- **Cavitation:** The formation of water vapor bubbles that damage metal components when they collapse back to the liquid phase. This occurs due to insufficient pressure at the pump's suction end (insufficient Net Positive Suction Head available NPSHa).

The Components of Total Head

Total head is a formal term, meaning we are using two components to determine the "total head", or pressure, needed to move water:

- Static head (elevation loss)
- Friction head (friction loss)

Static head is the vertical distance water needs to be pumped. As the height increases, more energy is required to overcome gravity. The higher the water needs to go, as in a tall office building or a submersible ground water pump, more energy is required to overcome gravity. Even when water is not flowing, it still has pressure that can be measured with a pressure gauge. The pressure increases as the height of water increases.



Imagine pumping water across a flat surface, it is easy. But pumping water straight up requires more pressure (energy) because of gravity. The higher the water needs to go, the more pressure required to pump the water.

Pressure is measured in pounds per square inch (psi), generally with a pressure gauge. However, in the pump world, we express pressure as "feet of head". The relationship between psi and feet of head is 1 psi = 2.31 feet of head. Thus, a column of water that is 1-inch square and 2.31 feet tall, weighs 1 pound.

Friction head (or friction loss) refers to the energy lost in a piping system due to resistance. As water flows through the system, resistance slows the flow and causes energy loss, affecting flow rate and pressure. Friction losses must be considered in system design and pump selection. Factors such as pipe diameter, length, materials, fittings, joints, valves, and filters, impact friction losses.

<u>Pipe Diameter and Friction Loss:</u> Smaller pipe diameters result in greater friction loss. For example, a 2" diameter pipe has a friction loss of 0.009 pounds per square inch (psi)/foot at 30 gallons per minute (gpm), whereas a 3" diameter pipe at the same flow rate has a friction loss of only 0.001 psi/foot (see **Table 1**). Larger diameters reduce friction loss, allowing for less restricted water flow.

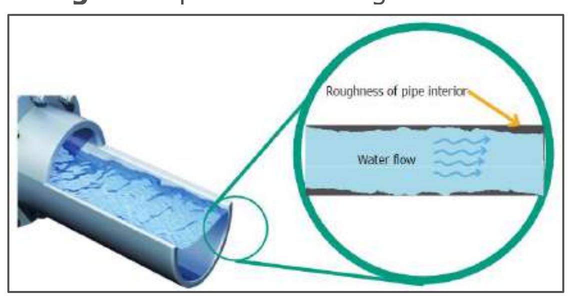
Table 1: Friction loss based on pipe diameter and water flow

Pipe diameter	Water Flow (gpm)										
	10	20	30	40	50	60	70	80	90	100	110
	Friction loss (psi/foot)										
1.5"	0.005	0.017	0.036	0.062	0.093	0.131					
2"	0.001	0.004	**0.009**	0.016	0.024	0.034	0.045				
2.5"	0.000	0.002	0.003	0.005	0.008	0.012	0.015	0.020	0.025	0.030	0.036
3"	0.000		**0.001**		0.004		0.007		0.010		0.015
4"			0.000			0.001			0.003		

Source: The Engineering Toolbox

<u>Surface roughness:</u> All surfaces exhibit some degree of roughness, affecting friction loss (**Image 1**). For instance, copper pipes and PVC may appear to be smooth, however, they have roughness depths of 0.00006-0.001 inches (0.00015-0.0025 mm). Concrete pipes range from 0.012-0.12 inches (0.3-3.0 mm), (see **Table 2**). To put these values in perspective, human hair and aluminum foil are approximately 0.001 inches thick.

Image 1: Pipe interior roughness



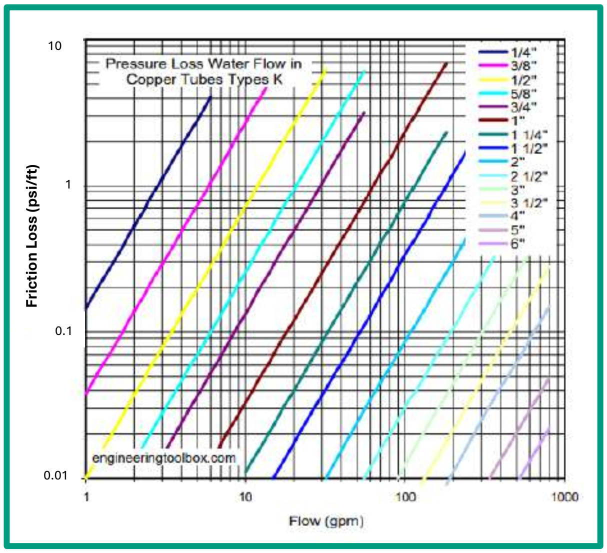
Source: T. Kohlman via Canva.com

Table 2: Interior pipe nominal roughness based on material

Material	Depth of nominal roughness	
	inches	mm
Concrete	0.012 – 0.12	0.3 – 3.0
Cast iron	0.006 – 0.010	0.15 – 0.26
Concrete (new, fairly smooth)	0.004	0.1
Steel Pipes	0.001 – 0.0018	0.025 – 0.045
PVC, Cooper	0.00006 – 0.001	0.0015 – 0.0025

Minimal roughness can still impact water flow, with increased flow rates leading to higher friction losses (see **Graph 1**).

Graph 1: Pressure loss water flow in Type K copper piping



Source: The Engineering Toolbox

For example, friction loss in a 2” pipe at 20 gpm water flow is 0.004 psi/foot. When water flow is increased to 50 gpm, friction losses increase to 0.024 psi/foot (see **Table 3**).

Table 3. Friction losses based on pipe diameter and water flow

Pipe diameter	Various Water Flow (gpm)										
	10	20	30	40	50	60	70	80	90	100	110
	Friction loss (psi/foot)										
1.5”	0.005	0.017	0.036	0.062	0.093	0.131					
2”	0.001	**0.004**	0.009	0.016	**0.024**	0.034	0.045				
2.5”	0.000	0.002	0.003	0.005	0.008	0.012	0.015	0.020	0.025	0.030	0.036
3”	0.000		0.001		0.004		0.007		0.010		0.015
4”			0.000			0.001			0.003		

Source: The Engineering Toolbox

Length of Pipe: Friction loss increases with pipe length. For example, a 110-foot length of 2” straight copper pipe with a 70-gpm flow has a friction loss of 4.95 feet. When we shorten the length to 50-foot of the same diameter pipe with the same flow, the friction loss is less with 2.25 feet **(Table 4).**

Example:

110-foot pipe x 0.045psi/foot (at 70 gpm flow) x 2.31 feet/1 psi water = **4.95 feet friction loss**

versus

50-foot pipe x 0.045 psi/foot (at 70 gpm flow) x 2.31 feet/1 psi water = **2.25 feet friction loss**

Table 4: Friction losses based on pipe diameter and water flow

Pipe diameter	Various Water Flow (gpm)										
	10	20	30	40	50	60	70	80	90	100	110
	Friction loss (psi/foot)										
1.5”	0.005	0.017	0.036	0.062	0.093	0.131					
2”	0.001	0.004	0.009	0.016	0.024	0.034	**0.045**				
2.5”	0.000	0.002	0.003	0.005	0.008	0.012	0.015	0.020	0.025	0.030	0.036
3”	0.000		0.001		0.004		0.007		0.010		0.015
4”			0.000			0.001			0.003		

Source: The Engineering Toolbox

Fittings & Valves: Objects within the piping system, like fittings, some sensors, valves, and filters, contribute to friction loss. Changes in direction, such as with tee- or elbow-joints, also cause friction loss. This loss can be estimated based on the equivalent length of straight pipe.

For example, the friction loss through a 2” 90^0 elbow is equivalent to friction loss from a 5.5 feet length of straight 2” pipe, while a 2” ball valve has an equivalent friction loss of 0.5 feet equivalent length of straight 2” pipe (see **Table 5**). All components’ friction losses must be considered and added based on manufacturers’ specifications.

Table 5: Equivalent length friction loss in selected copper fittings and values

Size fitting (in)	90^0 Elbow	45^0 Elbow	Line 90^0 Tee Joint	Branch 90^0 Tee Joint	Ball Valve	Gate Valve	Butterfly Valve	Check Valve
	Equivalent Length (feet)							
³/₈	0.5		1.5					1.5
½	1	0.5	2					2
⁵/₈	1.5	0.5	2					2.5
¾	2	0.5	3					3
1	2.5	1	4.5		0.5			4.5
1 ¼	3	1	5.5	0.5	0.5			5.5
1 ½	4	1.5	7	0.5	0.5			6.5
2	**5.5**	2	9	0.5	0.5	0.5	7.5	9
2 ½	7	2.5	12	0.5		1	10	11.5
3	9	3.5	16	1		1.5	15.5	14.5
3 ½	9	3.5	14	1		2		12.5
4	12.5	5	21	1		2	16	18.5

Source: The Engineering ToolBox

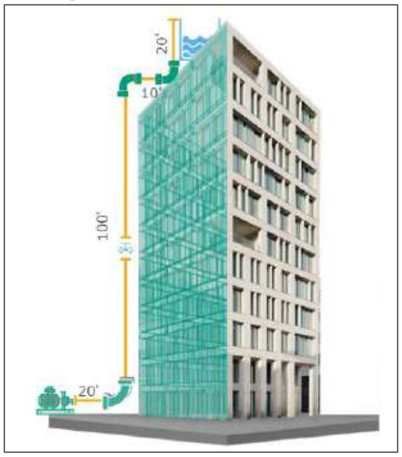
By considering all these factors and consulting manufacturer charts and online resources, you can accurately estimate friction loss and ensure efficient system design and pump selection.

Adding it Together

To determine the TH needed to size a pump, the elevation and friction losses the pump needs to overcome must be added together to determine the total head (energy) needed to overcome height and friction:

Total Head (TH) (ft) = Static Head (ft) + Friction Head (ft)

Image 2.



Source: T. Kohlman via Canva.com

In this simplified example, what is the TH needed to deliver water into a storage tank on the roof in **Image 2.**

- Building height: 100 feet
- Storage tank height: 20 feet
- Total piping length: 150 feet of 3" copper piping
- Components: One ball valve, one 90^0 long elbow, two 90^0 short elbows
- Flow rate: 210 gpm

Static Head (ft) = Building height + Tank height
Static Head (ft) = 100 feet + 20 feet
Static Head (ft) = 120 feet

Friction Head:

Total 3"pipe length	150 feet x 0.05 psi/ft (at 210 gpm) x 2.31 ft/psi	=	17.3 feet
Ball valve	1 x 0.5 feet equivalent	=	0.5 feet
90^0 short elbows	2 x 5.5 feet equivalent	=	11.0 feet
90^0 long elbow	1 x 4.3 feet equivalent	=	4.3 feet
	Total Friction Head	**=**	**33.1 feet**

*Note "head" is expressed in units of feet. To convert psi to feet, multiply by 2.31 ft/psi

Systems should be designed to keep the friction loss and installation and operational costs to a minimum. Remember, friction loss depends on several factors like pipe diameter, length of pipe, fittings, and other obstructions in the piping system. Consult manufacturer charts or online resources to find the appropriate friction loss value for your specific application.

Now add the total static head and friction head to determine the Total Head (energy) needed to overcome height and friction:

Total Head (ft) = Elevation Head (ft) + Friction Head (ft)

Total Head (ft) = 120 ft + 33.1 ft

Total Head (ft) = 124.3 ft

Thus, in our simplified example, a pump delivering 125 (rounded up) feet of Total Head is needed to supply water to a 100-foot-tall building with at 210 gpm through 3" copper piping and components.

Wilo is Your Solution Provider

Total head (TH) is crucial for pump selection, system design, and energy efficiency. Engineers and contractors use TH to choose the right pump, size pipes, and optimize operations. Wilo's Intelliquip Pump Selection Online Software can assist you in finding the right pump for your application. By inputting the total head and flow the pump needs to perform, Intelliquip narrows down the pumps suitable for your needs.

Wilo USA headquartered in Cedarburg, WI, is a multi-national pump manufacturer and one of the world's leading premium suppliers of pumps and pumps systems for building services, water management, and the industrial sector. With innovative solutions, smart products, and individual services, Wilo is your solution provider in making water move using intelligent, efficient, and eco-friendly techniques.

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