

Condenser Water Pump Calculator Guide

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1.0 INTRODUCTION

The purpose of this guide is to provide the necessary background information on the Condenser Water Pump calculator to be able to use the calculator and to fill out a condenser water pump schedule. This guide covers the overall condenser water system, the calculator and the condenser water pump schedule. The overall condenser water system will help you to visualize how the condenser water pump fits within the overall system and will also help you to determine the hydraulically remote run for pressure drop calculations. Following the overall condenser water system, the inputs, outputs and references used in the calculator will be covered. The primary purpose of the calculator is to find the total dynamic head and net positive suction head available for use in the Condenser Water Pump Schedule. Lastly, each individual item within the Condenser Water Pump Schedule will be discussed in order to give you more knowledge on how to complete the schedule for your specific condenser water pump application.

1.1 UNITS

The primary units that are used in the calculator are United States Customary System Units (USCS). As such, this guide focuses exclusively on the USCS. However, an SI version will also be provided in the future.

2.0 DISCLAIMER

In no event will Engineering Pro Guides be liable for any incidental, indirect, consequential, punitive or special damages of any kind, or any other damages whatsoever, including, without limitation, those resulting from loss of profit, loss of contracts, loss of reputation, goodwill, data, information, income, anticipated savings or business relationships, whether or not Engineering Pro Guides has been advised of the possibility of such damage, arising out of or in connection with the use of this guide/software or any referenced documents and/or websites.

This guide and calculator was created on the basis of helping engineers to increase their efficiency in completing calculations. However, the book and calculator was not intended to replace the engineering judgment necessary to interpret the results of any calculations. The engineer is still responsible for the calculations and results within the calculator.

3.0 OVERALL CONDENSER WATER SYSTEM

This guide covers the design and selection of a condenser water pump. The condenser water pump is a part of an overall condenser water system that often includes a chiller, piping, valves/fittings, water treatment, and a cooling tower. The condenser water pump is used to circulate condenser water either in an open or a closed circuit system. The condenser water pump circulates return condenser water from the chiller back to the cooling tower. The cooling tower then cools the condenser water, and the condenser water is supplied back to the chiller.

The condenser water pump must be sized properly to circulate the correct amount of flow at the correct pressure in order to achieve proper cooling within the building. If there is insufficient flow and pressure, then there will not be enough cooling and the building may get hot during periods of high cooling load. If there is too much pressure and flow, then the electrical system will be unnecessarily burdened and if there is no speed control, then electricity may be wasted due to excess pumping.

In an open circuit system the condenser water sprays into the fill of the cooling tower and comes into direct contact with the atmosphere, as shown below. In a closed circuit condenser water system, the condenser water is isolated by a coil in the cooling tower and never comes into direct contact with the atmosphere. An open circuit system is more commonly used in chiller plant design due to its lower first cost. A closed circuit cooling tower is used when maintaining the quality of the condenser water loop is desired, such as for a water source heat pump loop.

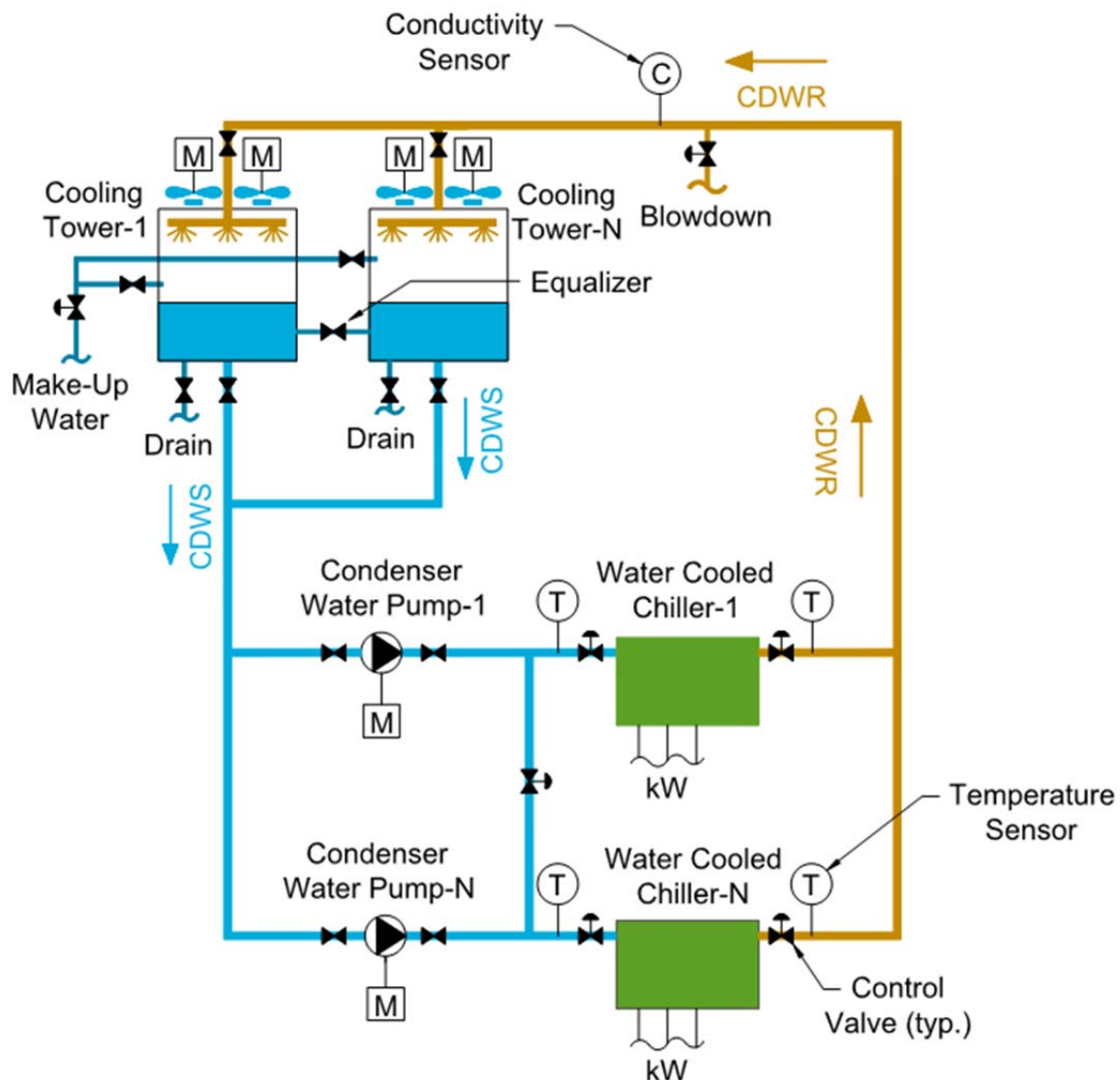


Figure 1: This figure shows an overall open circuit condenser water system. The condenser water pump circulates condenser water through the system. Condenser water removes heat from the chiller, then the

condenser water is sent to the cooling tower where the heat is removed via evaporative cooling. Cool condenser water is then sent back to the chillers. As water is evaporated and solids within the water remain, the concentration of the solids increases, which increases conductivity. Water is removed at the blow-down, when the conductivity measured becomes too high. Make-up water replaces the lost water. An equalizer is provided between multiple cooling towers to stop different water levels from occurring between cooling towers. The cooling tower fans modulate in order to maintain the necessary condenser water supply temperature. The condenser water pumps run at a constant speed/flow.

4.0 CONDENSER WATER PUMP CALCULATOR - INPUTS

In order to best use the condenser water pump calculator you should have an understanding of the inputs and how changes in the inputs will affect the output.

4.1 FLUID INFORMATION

The fluid information required includes the fluid type, temperature, density and kinematic/dynamic viscosity.

Fluid Information

Fluid Type:	Water
Temperature:	68.0 °F
Density:	62.3 lbs/ft ³
Dynamic Viscosity:	0.000673 lbm/ft-s
Kinematic Viscosity:	1.080E-05 ft ² /s
Vapor Pressure:	0.78 ft. head
Absolute Pressure:	33.95 ft. head

Figure 2: The fluid information section is the first set of inputs required for an output from the calculator.

Fluid Type: There are several fluid types available for use in the calculator, including water, propylene glycol mixtures and ethylene glycol mixtures. If you select a fluid type from the drop down menu and a temperature, then the calculator will automatically fill in the properties for density, dynamic viscosity and kinematic viscosity. If your fluid type is not available in the drop down menu, then you must manually input all the values into the calculator, in order for the calculator to work. For condenser water, you will most likely be using “water” as your fluid type.

Temperature: The temperature is used by the calculator to automatically find the density, dynamic viscosity, kinematic viscosity and vapor pressure from the fluid properties built-in to the calculator. If you are not using one of the drop down fluid types, then the temperature is not necessary to get an output from the calculator. However, you will need to manually input the previously mentioned values to get an output from the calculator.

The typical condenser water temperatures are shown below as 5 and 15 degrees F higher than the 1% ambient design wet bulb temperatures. (For more information on cooling towers and condenser water temperatures, see the cooling tower white paper on <http://www.engproguides.com/design>.) You should select the average of the supply and return condenser water temperatures as the input temperature for the chilled water pump calculation.

- Supply Condenser Water: Design WB + 5°F
- Return Condenser Water: Design WB + 15°F

Density: The density is used in the calculations to find the Reynolds Number. The Reynolds Number is used to find the friction loss coefficient. The density is automatically found based on the fluid type and the temperature of the fluid.

Dynamic Viscosity: The dynamic viscosity is used in the calculator to find the Kinematic Viscosity. Dynamic viscosity is also known as absolute viscosity. Dynamic viscosity describes a fluid's resistance to flow. The dynamic viscosity is automatically found based on the fluid type and the temperature of the fluid.

Kinematic Viscosity: The kinematic viscosity is used in the calculator to find the Reynolds Number. Kinematic viscosity is found by dividing the dynamic viscosity by the density.

$$v \text{ (kinematic viscosity } \frac{ft^2}{s}) = \frac{\mu \text{ (dynamic viscosity } \frac{lbm}{ft-s})}{\rho \text{ (density } \frac{lbm}{ft^3})}$$

Vapor Pressure: The vapor pressure is used to calculate the net positive suction head available. The vapor pressure is a function of the water temperature. As the temperature increases, the vapor pressure also increases. For example, the vapor pressure of water at 85 F is roughly 1.4 feet of head and the vapor pressure of water at 200 F is roughly 26.6 feet of head. The vapor pressure is the minimum pressure required to keep water in its liquid form. For example, if the pressure of water at 200 F is changed to 20 feet of head, then the water will vaporize. The vapor pressure is automatically found based on the fluid type and fluid temperature.

Fluid Type	Temperature (°F)	Dynamic Viscosity (lbm/ft-s)	Density (lbm/ft ³)	Vapor Pressure (psi)	Vapor Pressure (ft. head)
Water	32	1.20361E-03	62.41	0.0890	0.2056
Water	40	1.03804E-03	62.42	0.1220	0.2818
Water	50	8.77327E-04	62.41	0.1780	0.4112
Water	60	7.53134E-04	62.36	0.2560	0.5914
Water	70	6.54997E-04	62.30	0.3630	0.8385
Water	80	5.75970E-04	62.21	0.5070	1.1712
Water	90	5.11299E-04	62.11	0.6990	1.6147
Water	100	4.57638E-04	61.99	0.9510	2.1968
Water	110	4.12578E-04	61.86	1.2800	2.9568
Water	120	3.74344E-04	61.71	1.7000	3.9270
Water	130	3.41605E-04	61.55	2.2300	5.1513
Water	140	3.13344E-04	61.38	2.8900	6.6759
Water	150	2.88774E-04	61.19	3.7200	8.5932
Water	160	2.67275E-04	61.00	4.7500	10.9725
Water	170	2.48354E-04	60.79	6.0000	13.8600
Water	180	2.31615E-04	60.58	7.5200	17.3712
Water	190	2.16735E-04	60.35	9.3500	21.5985
Water	200	2.03449E-04	60.12	11.5000	26.5650
Water	210	1.91536E-04	59.88	14.1000	32.5710
Water	212	1.89302E-04	59.83	14.7000	33.9570

Figure 3: As temperature increases, the dynamic viscosity decreases and the vapor pressure increases.

Absolute Pressure: The absolute pressure is used to calculate the net positive suction head available. The absolute pressure is the pressure acting upon the fluid at the cooling tower. This is also known as atmospheric pressure. Absolute pressure varies as a function of elevation. At sea level, the absolute pressure is 14.7 PSIA or 34 feet of head.

Elevation (ft.)	Absolute Pressure (psia)	Absolute Pressure (ft. hd.)
0	14.696	33.948
500	14.430	33.333
1000	14.160	32.710
1500	13.910	32.132
2000	13.660	31.555
2500	13.410	30.977
3000	13.170	30.423
3500	12.930	29.868
4000	12.690	29.314
4500	12.460	28.783
5000	12.230	28.251

Figure 4: Absolute pressure is a function of elevation.

4.2 PIPE INFORMATION

The calculator requires you to insert the pipe section information which includes the flow rate, pipe material, pipe type, pipe size and length of pipe. A different pipe section should be used if any of these variables are changed.

Pipe Section	Hydraulically Remote Run?	Suction/Discharge?	Flow Rate (GPM)	Pipe Material	Material Type	Pipe Size	Length (ft)
A-B	Yes	Discharge	100.00	Copper	Type_K	3 in	100.0
B-C	Yes	Discharge	6.00	PP	DR_9	1 in	100.0
C-D	Yes	Discharge	4.00	Steel	Sch_40	1 in	100.0
D-E	Yes	Discharge	4.00	Steel	Sch_40	1 in	100.0
E-F	Yes	Discharge	4.00	Steel	Sch_40	1 in	100.0
F-G	Yes	Discharge	4.00	Steel	Sch_40	1 in	100.0

Figure 5: The pipe information is used to find the inner area and relative roughness of the piping. The pipe information is also used to clarify pipe sections that are on the hydraulically remote run and whether or not the pipe section is on the suction or discharge side of the pump.

There are various pipes available for use in the calculator but you can also add your own pipe information. The pipes built-in to the calculator include, ASTM A53 Steel (Schedule 40 & 80), ASTM B88 Copper (Type K, L & M), ASTM D2241 PVC (SDR 26) and ASTM F2389 Polypropylene (DR 9). These are the most common pipes used in condenser water pipe application. If you have a special case, then please use the references sheet to add in your pipe information or contact Justin via email contact@engproguides.com.

Pipe Material	Standard	Pipe Type	Pipe Size	Item Title	Outer Diameter (in.)	Inner Diameter (in.)	Inner Diameter (ft.)	Inner Area (in ²)	Inner Area (ft ²)
Steel	ASTM A53	Sch_40	1/8 in	SteelSch_401/8 in	0.405	0.269	0.022	0.057	0.000
Steel	ASTM A53	Sch_40	1/4 in	SteelSch_401/4 in	0.540	0.364	0.030	0.104	0.001
Steel	ASTM A53	Sch_40	3/8 in	SteelSch_403/8 in	0.675	0.493	0.041	0.191	0.001
Steel	ASTM A53	Sch_40	1/2 in	SteelSch_401/2 in	0.840	0.622	0.052	0.304	0.002
Steel	ASTM A53	Sch_40	3/4 in	SteelSch_403/4 in	1.050	0.824	0.069	0.533	0.004
Steel	ASTM A53	Sch_40	1 in	SteelSch_401 in	1.315	1.049	0.087	0.864	0.006
Steel	ASTM A53	Sch_40	1-1/4 in	SteelSch_401-1/4 in	1.660	1.380	0.115	1.496	0.010
Steel	ASTM A53	Sch_40	1-1/2 in	SteelSch_401-1/2 in	1.900	1.610	0.134	2.036	0.014
Steel	ASTM A53	Sch_40	2 in	SteelSch_402 in	2.375	2.067	0.172	3.356	0.023

Figure 6: This figure is a sample of the pipe information built-in to the calculator, references tab.

Each pipe material and pipe type within that pipe material have its own standard pipe sizes. For example, Schedule 40 Steel does not have a 5/8 inch pipe size. When you change pipe

materials and pipe types, please also change the pipe size to ensure the pipe size you want is available within the standard. The calculator will give you an error if you select a non-standard pipe size within the pipe material & type.

4.3 VALVE & FITTING INFORMATION

The valves and fittings section requires you to put in the values for each fitting that are on a certain pipe section. A pipe section is defined as having the same flow rate and same pipe information.

Joining Method	Valves						Fittings				
	Gate	Globe	Angle	Swing Check	Butterfly	Ball	90° Long Rad Ell	90° Std Ell	45° Ell	Tee-Standard	Tee-Through
Threaded	1	1	1	1	1	1	1	1	1	1	1
Flanged/Welded/Solder	1	1	1	1	1	1	1	1	1	1	1
Threaded	1	1	1	1	1	1	1	1	1	1	1
Threaded	1	1	1	1	1	1	1	1	1	1	1

Figure 7: Inputting the valves and fittings on a piping section will help to determine the total loss through the piping section.

The valve and fitting quantities are matched to 3-K values within the references tab. If you have a special valve and fitting, you can add in the 3-K values to the references tab. If you don't have the 3-K values you can either choose a similar valve/fitting or you can estimate the pressure drop and add this to the equipment information section.

4.4 EQUIPMENT INFORMATION

The equipment section requires you to insert the flow rate and pressure drop for each piece of equipment. You should also indicate if the equipment is on the hydraulically remote run. Remember, only items listed as hydraulically remote will be used to calculate the pressure drop for the condenser water pump.

Equipment	Hydraulically Remote Run?	Suction/Discharge?	Flow Rate (GPM)	Pressure Drop (ft. head)
CH-1	Yes	Discharge	200	10
CT-1	Yes	Discharge	200	10
	Yes	Discharge	200	

Figure 8: The pressure loss due to equipment is specific to the manufacturer of the equipment. You should check the manufacturer product data for this information, but you should also remember that the pressure loss is specific to a certain flow rate. If your flow rate is different, then you will need to adjust the pressure drop to match your application.

4.5 PIPE EXPANSIONS & REDUCTIONS INFORMATION

Pipe expansions and reductions use different equations to calculate pressure drops than those used for pressure loss through straight length of piping and through valves & fittings. Pipe expansion and reductions are dependent on the ratio between the two different pipe diameters. For example, the pressure drop through a 4" - 6" pipe expansion is less than the pressure drop through a 2" – 6" pipe expansion.

Pipe Expansions & Reductions

Pipe Section	Hydraulically Remote Run?	Suction/Discharge?	Flow Rate (GPM)	Pipe Material	Material Type	D1	D2	D1 Inner Area (ft ²)	D1 Inner Diameter (ft)	Velocity (fps)	Reynolds Number	Expansion/Reduction Type	Quantity	Theta (θ°)	K-Value
A-B	Yes	Suction	6.00	Steel	Sch_80	1 in	1-1/2 in	0.0050	0.080	2.66	2.0E+04	Tapered Expansion	2	30	0.24
B-C	Yes	Discharge	6.00	Steel	Sch_80	1 in	1-1/2 in	0.0050	0.080	2.66	2.0E+04	Tapered Expansion	2	30	0.24
C-D	Yes	Suction	6.00	Steel	Sch_80	1 in	1-1/2 in	0.0050	0.080	2.66	2.0E+04	Rounded Expansion	2	30	0.36

Figure 9: Pipe expansion and reductions are different from valves and fittings.

4.6 ELEVATION DIFFERENCE

The elevation difference is used to determine the net positive suction head available. This requires you to input the pump discharge elevation head and pump suction elevation head.

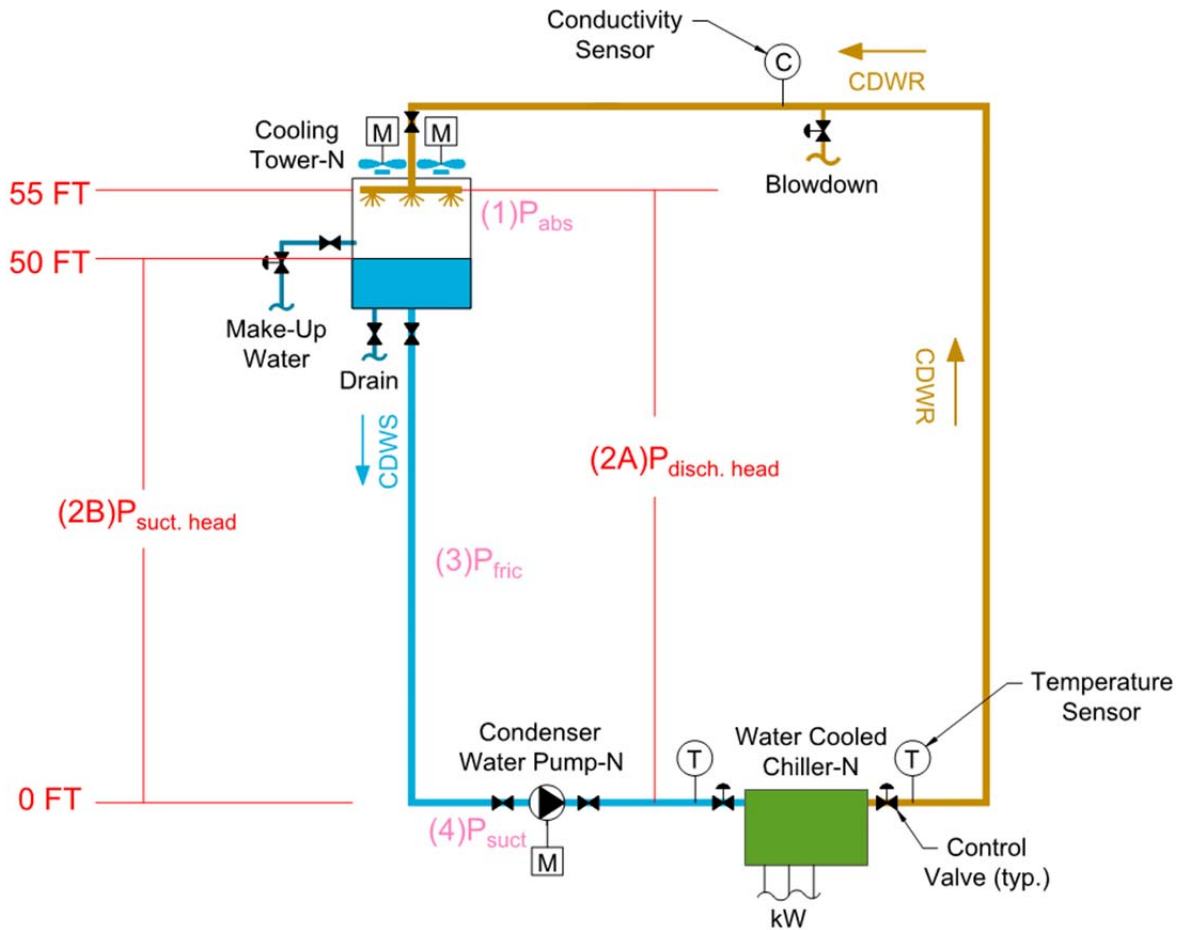


Figure 10: In this figure, the pump discharge head is 55 feet. This is the elevation difference between the pump suction and the discharge point at the cooling tower. The pump suction head is 50 feet. This is the elevation difference between the pump suction and the water level in the cooling tower. Positive elevation values are used when the cooling tower is above the condenser water pump.

Pump Suction Elevation Head: This is the difference in elevation between the pump suction and the cooling tower basin. The zero elevation point is taken as the pump suction. If the cooling tower basin is above the pump suction, then the elevation head will be positive.

Pump Discharge Elevation Head: This is the difference in elevation between the pump discharge and the piping discharge at the top of the cooling tower. The zero elevation point is taken as the pump discharge. If the condenser water piping discharge at the top of the cooling tower is above the pump discharge, then the elevation head will be positive.

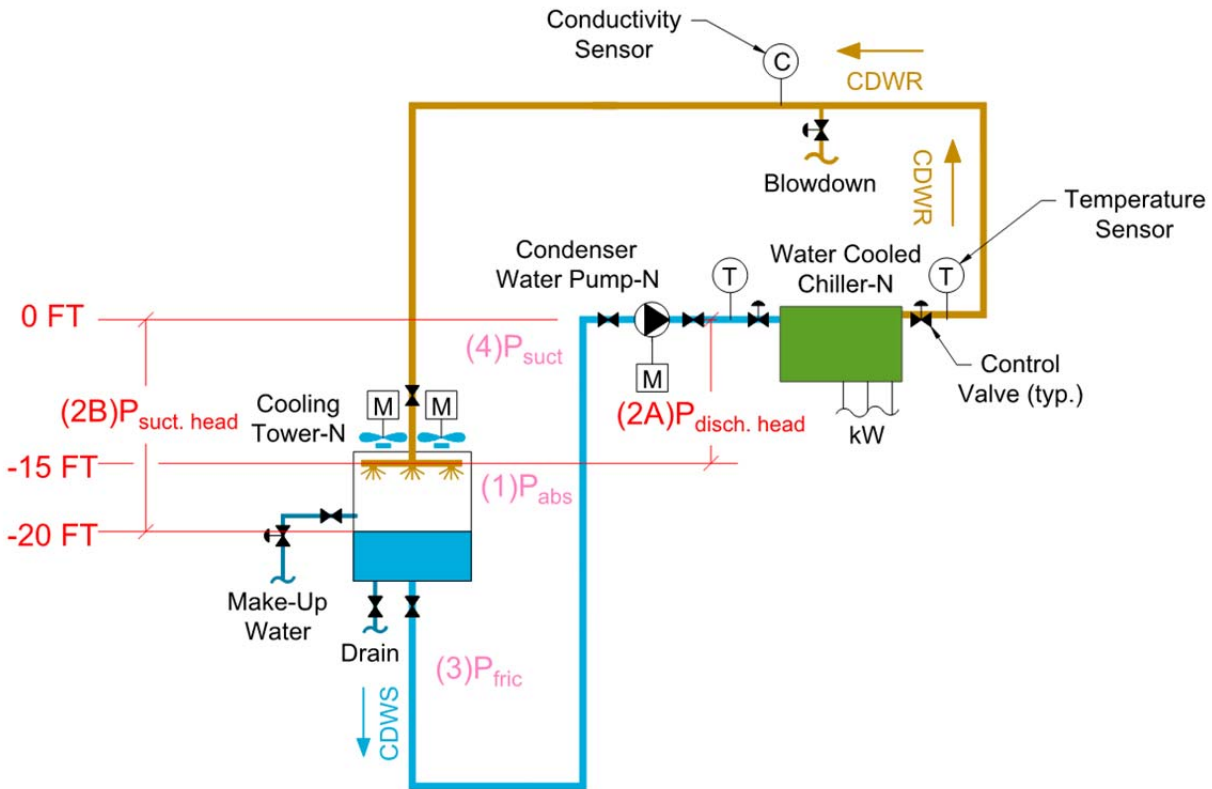


Figure 11: This is not a practical example of the relative heights between a condenser water pump and a cooling tower. This is only shown to reiterate how elevations are used in the calculator. In this figure, the discharge head is -15 feet and the suction head is -20 feet.

5.0 CONDENSER WATER PUMP CALCULATOR - OUTPUTS

This section covers the equations that use the inputs and references to create the outputs in the calculator.

5.1 FLUID VELOCITY

The first equation uses the inputs from the pipe information section and the user input flow rate to find the fluid velocity in the pipe. When you choose the pipe material, pipe type and pipe size, the calculator will automatically determine the inner area from the table within the references. If the combination of pipe material, pipe type and pipe size are not in the calculator then a "N/A" will appear in the velocity column. You should double check to make sure the combination exists before proceeding.

$$V \left(\frac{ft}{sec} \right) = \frac{Flow Rate \left(\frac{gallons}{minute} \right) * \left(\frac{7.48 ft^3}{1 gallon} \right) * \left(\frac{1 min}{60 sec} \right)}{Inner Area (ft^2)}$$

5.2 REYNOLDS NUMBER

The first equation uses the inputs from the pipe information section and the user input flow rate to find the fluid velocity in the pipe. When you choose the pipe material, pipe type and pipe size, the calculator

The next equation calculates the Reynolds Number. This equation uses the velocity from the previous equation along with the pipe inner diameter and the fluid properties (density & viscosity).

$$Re = \frac{\rho \left(\frac{lbm}{ft^3} \right) * V \left(\frac{ft}{sec} \right) * Inner\ Diameter(ft)}{\mu \left(\frac{lbm}{ft - sec} \right)}$$

The Reynolds Number classifies the fluid flow into either (1) Laminar, (2) Transition or (3) Turbulent. The breakdown between these three classifications is defined below. The friction calculations are most accurate with fluid flow in the turbulent region. For this reason, the calculator will highlight in red any Reynolds Number that is below the turbulent region.

$$Laminar \rightarrow Re < 2,000$$

$$Transition \rightarrow 2,000 < Re < 10,000$$

$$Laminar \rightarrow Re > 10,000$$

5.3 FRICTION FACTOR

The friction factor is found through the Colebrook Equation. The Colebrook Equation relates the friction factor to the Reynolds Number and the relative roughness.

$$\frac{1}{\sqrt{f}} = -2 * \log\left(\frac{e/D}{3.72} + \frac{2.51}{Re * \sqrt{f}}\right)$$

$$f = \text{friction coefficient}; e/D = \text{relative roughness (unitless)}$$

Iterative Process: Since the friction coefficient is on both sides of the equation, you must use an iterative process to find the friction coefficient. You must first choose a value for the friction coefficient on the right side of the equation and then solve for the friction coefficient on the left side. Then use the friction coefficient that you just computed and plug-in this value to the right side of the equation and repeat the process. The process ends when the right and left side friction coefficients converge to nearly the same number. The calculator completes this process by running nine iterations.

Turbulent Flow: This equation only works for turbulent flow. A different equation is used for laminar flow. Luckily in practical condenser water applications, flow is nearly always turbulent. However, the calculator does incorporate conditional formatting to visually tell you if the flow is not turbulent. You should use your knowledge of the turbulent range from the previous section to ensure that your flow calculations are in the turbulent range.

5.4 PRESSURE DROP

The next step in the calculator is to calculate the pressure drop for the four different categories, (1) Piping, (2) Valves & Fittings, (3) Equipment and (4) Expansions/Reducers. Each of the four categories has their own specific equations, but (1) and (2) are included in the same line item on the calculator. The next paragraphs will go through the calculations for each of the four categories.

Outputs

CDWP-___:	Pump Suction	Pump Discharge
Piping Pressure Drop:	-3.8 ft. head	41.99 ft. head
Equipment Pressure Drop:	-10.0 ft. head	10.00 ft. head
Pipe Expansion/Reduction Pressure Drop:	-0.3 ft. head	0.14 ft. head
Elevation Head:	25.0 ft. head	20.0 ft. head
<i>Total:</i>	<i>10.9 ft. head</i>	<i>72.1 ft. head</i>
Total CDWP Dynamic Head:	61.2 ft. head	<i>(pump discharge - pump suction head)</i>
Total NPSHA:	44.1 ft. head	<i>(pump suction head (water) + absolute pressure - vapor pressure)</i>

Figure 12: The top of the calculator summarizes the pressure drop of the hydraulically remote run. This includes the pressure drop due to piping, valves & fittings, equipment and expansions/reducers.

5.4.1 PRESSURE DROP – PIPING & VALVES/FITTINGS

The pressure drop for a straight length of piping is found through the friction factor and the Darcy Weisbach equation. This equation uses the velocity, friction factor, pipe inner diameter and the length of piping to calculate the pressure drop. For more details, see the equation below. The output for this equation is the pressure drop in units of feet head.

$$\Delta h_{piping} = f * \frac{L}{D} * \frac{V^2}{2 * g}$$

Δh = pressure drop (ft head); f = coefficient of friction (unitless)

L = length (ft); D = inner pipe diameter (ft); V = fluid velocity ($\frac{ft}{s}$)

$$gravity (g) = 32.2 \frac{ft}{s^2}$$

The pressure drop through valves and fittings is found through the 3-K method. The 3-K method uses three K-values to characterize each type of valve and fitting. These three K-

values are K_1 , K_{inf} and K_d . These K-values are used with the Reynolds Number and nominal pipe diameter to find the final K-value.

$$K = \frac{K_1}{Re} + K * (1 + \frac{K_d}{(D_n)^3})$$

Since, the calculated K-value is a function of Reynolds Number and nominal pipe diameter, the K-value is applicable for various pipe sizes, pipe materials, fluids and fluid velocities. Once you have the K-value, the K-value is used to calculate the pressure drop through the valves and fittings.

$$\Delta h_{valves \& fittings} = K * \frac{V^2}{2 * g}$$

5.4.2 PRESSURE DROP – EQUIPMENT

There are no equations governing the pressure drop in equipment section. In this section of the calculator you can input the values for pressure drop at equipment. Typical equipment includes chillers, strainers, fan coils, flow meters, control valves and air handling unit coils. The pressure drop through this equipment at a specified flow rate must be provided by the manufacturer of the equipment. Typically, the manufacturer will provide a single value that indicates the pressure drop at a specified flow rate (GPM). This is typical of chillers, fan coils and air handling units. Other times, a manufacturer will provide a graph that shows the pressure drop at various flow rates. This is typical of flow meters, control valves and strainers.

5.4.3 PRESSURE DROP – EXPANSIONS/REDUCERS

The last pressure drop calculation is the pressure drop due to pipe expansion and reductions. These pipe expansions and reductions occur when there is a change in pipe size. This calculation is dependent on the shape of the pipe size change. For example, the shape could be square, rounded, tapered and the pipe size change could be sharp or gradual. Each type of pipe size change has its own equation

An example of the equations used in the calculator include the square reduction equation. First, you must solve for the K-value.

$$K = \sqrt{\sin(\frac{\theta}{2})} * (0.6 + 0.48 * f) * (\frac{D_1}{D_2})^2 * [(\frac{D_1}{D_2})^2 - 1]$$

applicable for $45^\circ < \theta < 180^\circ$ & $Re > 2,500$

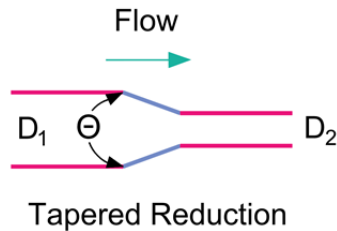
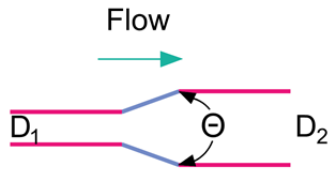
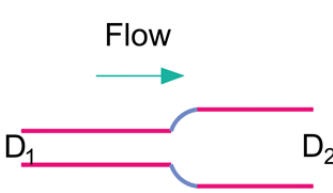


Figure 13: The tapered reduction type requires you to input the first and second diameters with respect to the flow direction. This is similar for all pipe expansion/reduction types.

The calculator automatically ensures that you are meeting the requirements of the equation. There are other equations for each pipe expansion/reduction and each set of requirements as shown in the table below.

Name	Figure	Equation
Square Reduction	<p style="text-align: center;">Square Reduction</p>	$Re < 2,500$ $K = \left(1.2 + \frac{160}{Re}\right) * \left[\left(\frac{D_1}{D_2}\right)^4 - 1\right]$ $Re > 2,500$ $K = (0.6 + 0.48 * f) * \left(\frac{D_1}{D_2}\right)^2 * \left[\left(\frac{D_1}{D_2}\right)^2 - 1\right]$
Tapered Reduction	<p style="text-align: center;">Tapered Reduction</p>	$45^\circ < \theta < 180^\circ$ $K = \sqrt{\sin\left(\frac{\theta}{2}\right) * K_{square\ red.}}$ $45^\circ < \theta < 180^\circ$ $K = 1.6 * \sin\left(\frac{\theta}{2}\right) * K_{square\ red.}$
Rounded Reduction	<p style="text-align: center;">Rounded Reduction</p>	$K = \left(0.1 + \frac{50}{Re}\right) * \left[\left(\frac{D_1}{D_2}\right)^4 - 1\right]$
Square Expansion	<p style="text-align: center;">Square Expansion</p>	$Re < 4,000$ $K = 2 * \left[1 - \left(\frac{D_1}{D_2}\right)\right]$ $Re > 4,000$ $K = (1 + 0.8 * f) * \left(\frac{D_1}{D_2}\right)^2 * \left[1 - \left(\frac{D_1}{D_2}\right)\right]^2$

Tapered Expansion	 <p style="text-align: center;">Tapered Expansion</p>	$\theta > 45^\circ$ $K = K_{square\ exp.}$ $\theta < 45^\circ$ $K = 2.6 * \sin\left(\frac{\theta}{2}\right) * K_{square\ exp.}$
Rounded Expansion	 <p style="text-align: center;">Rounded Expansion</p>	$K_{square\ exp.}$

Once, the K-value is calculated, then the calculator calculates the pressure drop with the below equation.

$$\Delta h_{tapered\ pipe\ reduction} = K * \frac{V^2}{2 * g}$$

5.4.4 TOTAL HYDRAULICALLY REMOTE PRESSURE DROP – SUCTION & DISCHARGE

Two of the last columns on the right side of all the pressure drop categories is the total pressure drop on the hydraulically remote run of the suction or discharge piping. If you select “Yes” under hydraulically remote run and “Suction” or “Discharge”, then this column will show the pressure drop in the section of pipe, pipe reducer/expansion section or equipment under “Suction Hydraulically Remote Run” or “Discharge Hydraulically Remote Run”. This value is used to calculate the total net positive suction head available and also the total dynamic head of the condenser water pump.

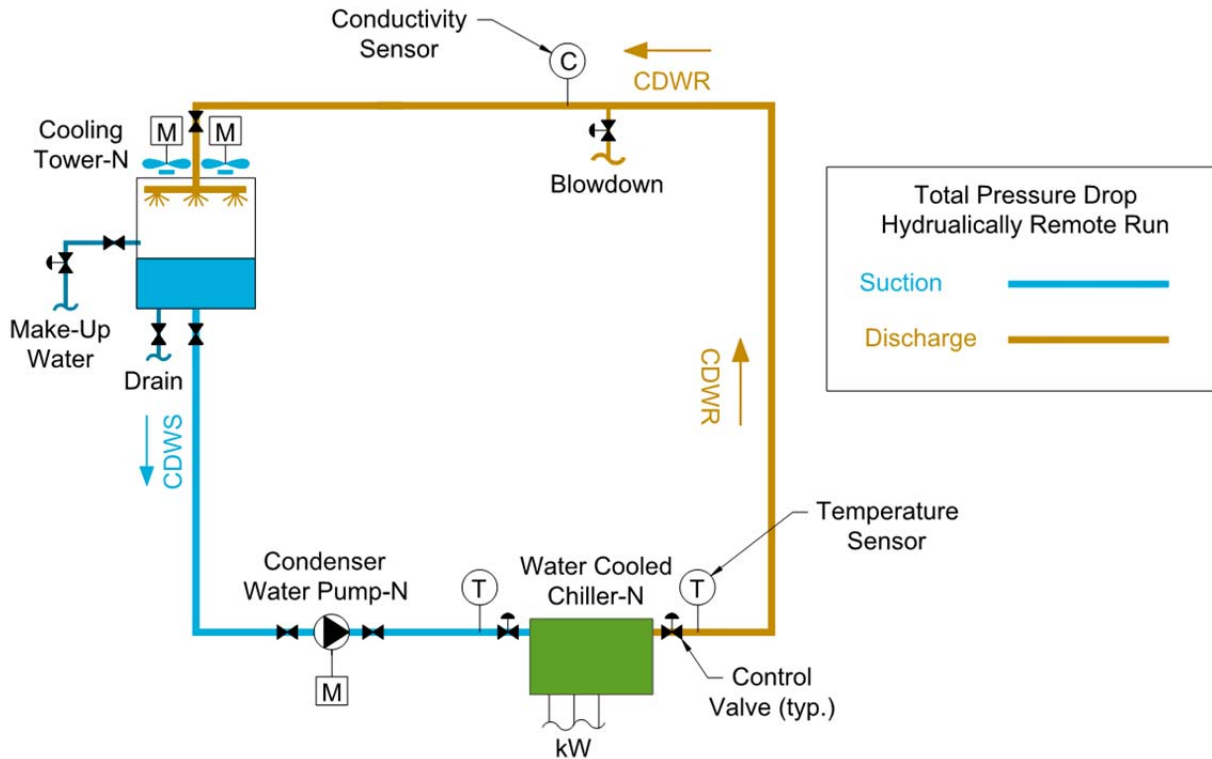


Figure 14: The pressure drop in the hydraulically remote run is summed up and assigned to either the suction or discharge side of the piping. The calculation for the suction side is used for the net positive suction head available calculation. The calculation for the discharge and suction side are both used for the total dynamic head calculation.

Total Hydraulically Remote (ft. hd.)	Total Hydraulically Remote Suction (ft. hd.)	Total Hydraulically Remote Discharge (ft. hd.)	Total Pressure Drop (ft. hd.)
7.39	0.00	7.39	7.39
6.71	0.00	6.71	6.71
2.00	0.00	2.00	2.00

Figure 15: On the right side of the calculator, under each section (piping/valves/fittings, equipment and reducers/expansions), there are columns that identify whether or not the line item is on the suction or discharge and whether or not the line item is on the hydraulically remote run.

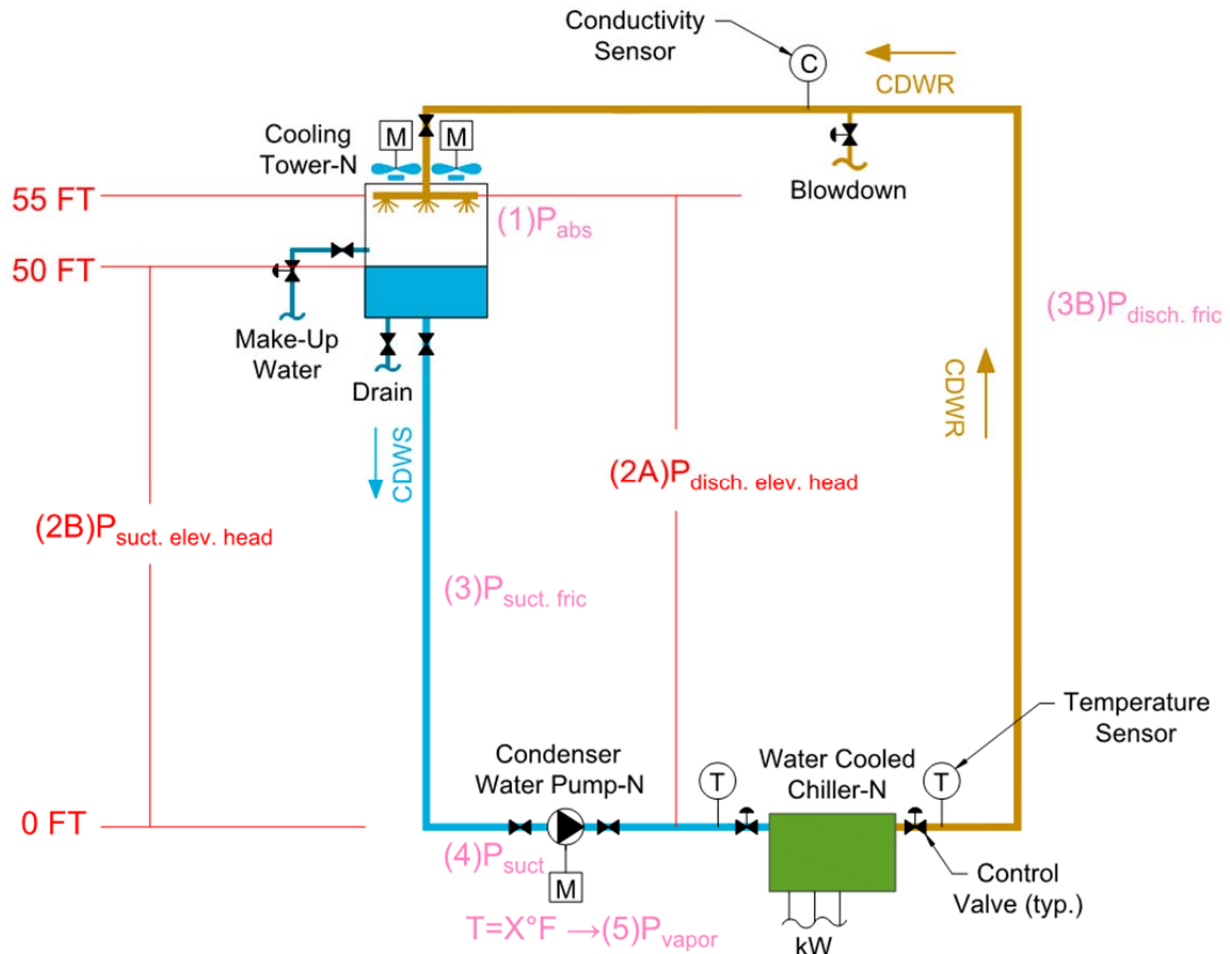
5.5 NET POSITIVE SUCTION HEAD AVAILABLE

The calculator also calculates the net positive suction head available, which is used to choose a pump that can operate at the design conditions without reaching cavitation. Cavitation occurs when the suction pressure (head) at the pump is less than the vapor pressure of the water. If the suction pressure is lower than the vapor pressure, then small vapor bubbles form. When these bubbles reach the pump, the pressure of the fluid increases and the bubbles implode causing damage to the impellers and other parts of the pump. This is what is known as cavitation.

Suction head is defined as the pressure at the inlet of the pump and net positive suction head is the difference between the suction head at the inlet and the vapor pressure of the fluid at the inlet of the pump.

$$\text{Net Positive Suction Head}_{available} (NPSHA) = \text{Suction Head}_{inlet\ of\ pump} - \text{Vapor Pressure}_{fluid}$$

Suction head is found by determining all the pressures acting upon the fluid whether positive or negative in the suction piping. The following figure best describes all the pressures that can be acting upon a pump.



(1) P_{abs} : This pressure refers to the absolute pressure acting on the fluid. If the tank is pressurized, then the value is pre-determined. If the tank is open to the atmosphere, then the pressure is equal to 1 atmosphere [atm] or 14.7 psia or 33.9 ft. of water.

(2) P_{elev} : This pressure identifies the elevation difference between the top surface of the liquid and the pump centerline on the suction side of the piping. This value can be positive or negative and is measured in “feet of head”. In order to calculate this value, you only need to find the P_{elev} for the suction piping.

$$P_{elev} = P_{suction,elev}$$

(3) $P_{suct. fric}$: The suction friction pressure or head is the amount of pressure lost due to friction in the piping, fittings, equipment, valves, etc. leading from the fluid source to the pump.

(4) $P_{suction}$: Finally, all of the pressures leading to the pump are summed and the resulting value is the suction pressure at the pump due to both the water and absolute pressure.

$$P_{suction} = P_{abs} \pm P_{elev} - P_{fric}$$

(5) P_{vapor} The vapor pressure of the water is found by simply looking up fluid property tables and finding the vapor pressure at the operating temperature. Water is the most common fluid used in

condenser water pumping systems and a table of corresponding vapor pressure and temperatures are shown below. Use the ASHRAE Fundamentals book to find similar tables.

Water Temperature (°F)	Water Vapor Pressure (feet head)
32	0.206
40	0.2822
50	0.411
60	0.591
70	0.839
80	1.171
90	1.615
100	2.197
110	2.957

From the table above, it can be seen that as the temperature of the water increases, the pressure at which vaporization will occur also increases. The issue of cavitation becomes even more critical at higher temperatures.

Finally, the equation for NPSHA, found at the beginning of this section can be summarized as:

$$NPSHA = P_{abs} \pm P_{elev} - P_{fric} - P_{vapor}$$

Total Hydraulically Remote (ft. hd.)	Total Hydraulically Remote Suction (ft. hd.)	Total Hydraulically Remote Discharge (ft. hd.)	Total Pressure Drop (ft. hd.)
7.39	0.00	7.39	7.39
6.71	0.00	6.71	6.71
2.00	0.00	2.00	2.00

The net positive suction head required (NPSHR) is an important criteria when selecting the condenser water pump.

NPSHR is provided by the pump manufacturer and it is the minimum required pressure at the suction of the pump. The NPSHA must be higher than the NPSHR to prevent cavitation.

$$NPSHA > NPSHR$$

The calculator also shows the net positive suction head available at the top of the calculator as a final sum of all friction loss values, suction elevation head, vapor pressure and absolute pressure.

Outputs

CDWP-___:	Pump Suction	Pump Discharge
Piping Pressure Drop:	-3.8 ft. head	41.99 ft. head
Equipment Pressure Drop:	-10.0 ft. head	10.00 ft. head
Pipe Expansion/Reduction Pressure Drop:	-0.3 ft. head	0.14 ft. head
Elevation Head:	25.0 ft. head	20.0 ft. head
<i>Total:</i>	<i>10.9 ft. head</i>	<i>72.1 ft. head</i>
Total CDWP Dynamic Head:	61.2 ft. head	<i>(pump discharge - pump suction head)</i>
Total NPSHA:	44.1 ft. head	<i>(pump suction head (water) + absolute pressure - vapor pressure)</i>

Figure 16: The pump suction column sums up all the friction losses in the piping/fitting/valves, equipment and pipe expansions/reductions. These pressure drop values are shown as negative because these values reduce the pressure available at the suction of the pump. The elevation head is shown as a positive value because the cooling tower basin is located above the pump suction. This provides positive pressure to the pump suction. The pressure available at the pump suction due to the water is equal to 10.9 feet, but there is also the 34 feet available from the absolute pressure. Finally, the vapor pressure of 0.8 feet must be subtracted to give the result of 44.1 feet of head.

5.6 TOTAL DYNAMIC HEAD

The total dynamic head sums up all the friction losses in both the discharge and suction piping for all three categories (piping/fitting/valves, equipment/misc. & reducers/expansions). Total dynamic head also includes the discharge elevation head minus the suction elevation head. The final equation is shown below.

$$TDH = (P_{disch.elev.head} - P_{suct.elev.head}) + P_{disch. fric.} + P_{suct. fric.}$$

If you use the example below, you can see an example as to how the above equation is used.

Outputs

CDWP-___:	Pump Suction	Pump Discharge
Piping Pressure Drop:	-3.8 ft. head	41.99 ft. head
Equipment Pressure Drop:	-10.0 ft. head	10.00 ft. head
Pipe Expansion/Reduction Pressure Drop:	-0.3 ft. head	0.14 ft. head
Elevation Head:	25.0 ft. head	20.0 ft. head
<i>Total:</i>	<i>10.9 ft. head</i>	<i>72.1 ft. head</i>
Total CDWP Dynamic Head:	61.2 ft. head	<i>(pump discharge - pump suction head)</i>
Total NPSHA:	44.1 ft. head	<i>(pump suction head (water) + absolute pressure - vapor pressure)</i>

Figure 17: The total dynamic head is found by adding up all the pressure drops in both the discharge and suction piping. Since the system is open, you must also find the net elevation change. This is found by subtracting the suction elevation head from the discharge elevation head. A negative value indicates that the discharge pipe opens at an elevation above the suction pipe. The total dynamic head can also be found by subtracting the pump suction value from the pump discharge value.

The following equation shows total dynamic head solved with the previous equation.

$$TDH = (20 - 25) + 52.1 + 14.1 \text{ ft head}$$

$$TDH = 61.2 \text{ ft. head}$$

The following equation shows total dynamic head solved by taking the difference between the pump discharge pressure and the pump suction pressure.

$$TDH = 72.1 (\text{Pump Discharge Head}) - 10.9 (\text{Pump Suction Head})$$

$$TDH = 61.2 \text{ ft. head}$$

6.0 CONDENSER WATER PUMP SCHEDULE

The design and selection of a condenser water pump typically results in the completion of the condenser water pump schedule. A sample schedule is provided in the calculator as a separate sheet. The condenser water pump schedule provides all the necessary design requirements to purchase the condenser water pump. This includes, pump type, flow rate, total dynamic head, pump speed, efficiency, net positive suction head available and motor information. There are a few other non-pump design requirements like the location and unit number and a section called remarks for pump design requirements that do not fit under the previously mentioned categories.

CONDENSER WATER PUMP SCHEDULE		
UNIT NO.	LOCATION	SERVICE
CDWP-1	MECHANICAL ROOM	CONDENSER WATER
CDWP-2	MECHANICAL ROOM	CONDENSER WATER
<u>REMARKS AND NOTES:</u>		
(1) PROVIDE WITH TEFC VFD COMPATIBLE MOTOR		
(2) PROVIDE VFD WITH BYPASS		
(3) PROVIDE PREMIUM EFFICIENCY MOTOR		
(4) PROVIDE BRONZE HOUSING & IMPELLER		

Figure 18: Once you have found the pressure drop and net positive suction head available, then you can begin to fill in the condenser water pump schedule. This figure shows the first half of the schedule.

TYPE	GPM	TOTAL DYNAMIC HEAD (FT. HEAD)	NPSHA (FT. HEAD)	RPM
END SUCTION				
END SUCTION				

Figure 19: The second part of the schedule is mainly from the calculations completed in the schedule and the pumps available from the manufacturer. The Total Dynamic Head and NPSHA is found through the calculator. The flow rate is found based on the chiller. These previous three values will be used to search through available pumps provided by various manufacturers. The various manufacturers will provide the qualities like pump type, efficiency and pump speed to match the values found in the calculator and to best suit the needs of the pump. For example, a slower speed pump will most likely have a longer lifetime than a faster speed pump. However, the slower speed pump may be larger and a

higher first cost. The pros and cons for the various types, speeds and efficiencies will be discussed in the following sections.

MIN. PUMP EFF.	ELECTRICAL				REMARKS
	V	PH	HZ	MOTOR (HP)	
60	208	3	60	3	(1) (2) (3)
60	208	3	60	3	(1) (2) (3)

Figure 20: The final part of the schedule shows the electrical information, which is heavily dependent on the minimum pump efficiency. The voltage must be coordinated with the electrical engineer to match the available voltage. Additional remarks can be provided for specific qualities that are required for the pump.

6.1 FLOW RATE (GPM)

The flow rate for the condenser water pump is typically determined by the maximum condenser water flow of the chiller(s).

6.2 TOTAL DYNAMIC HEAD (FEET HEAD)

The total dynamic head is found through the excel calculator. This total dynamic head is the total pressure drop in the most hydraulically remote run from the condenser water pump supply from the pump to the condenser water return of the pump.

6.3 NET POSITIVE SUCTION HEAD AVAILABLE

The net positive suction head available will be an output of the calculator. The net positive suction head available is equal to the suction head pressure at the pump less the vapor pressure of the fluid at the pump suction. The condenser water pump must have a net positive suction head required that is less than the net positive suction head available.

6.4 SERVICE

This column is used to clarify the fluid of the pump, since these schedules may often be used as a general pump schedule. A general pump schedule could include condenser water pumps, condenser water pumps, hot water pumps, etc. In this case, the service column could be removed since the entire schedule is dedicated to condenser water pumps.

6.5 LOCATION

Condenser water pumps are typically located in a mechanical room with or near the water cooled chiller(s). The condenser water pump should be located with sufficient net positive suction head to ensure proper operation of the pump.

6.6 PUMP TYPES

There are three main types of pumps, centrifugal, rotary and reciprocating pumps. Rotary and reciprocating pumps are positive displacement pumps. This guide will not cover positive displacement and reciprocating pumps in detail because they are not typically used for condenser water pumps.

Centrifugal pumps are the most common type of pumps used for condenser water applications. The following information is tailored to centrifugal pumps and should not be applied freely to positive displacement pumps.

Centrifugal pumps operate on the principle of "centrifugal force", which is the conversion of rotational kinetic energy imparted by rotating impellers onto the liquid to produce a flow rate (kinetic energy) at a certain pressure (pressure energy). Fluid enters the pump at the center or eye of the impeller. The rotating impellers then push the fluid to the outer edges, imparting a flow rate and pressure.

There are two main types of centrifugal pumps, in-line and end-suction. These two types are discussed below.

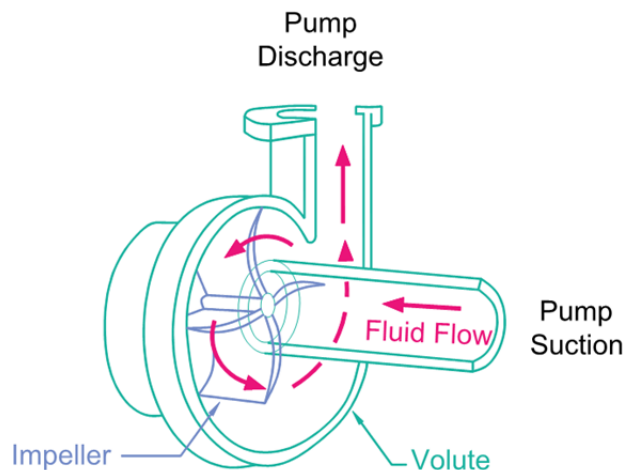


Figure 21: This figure shows a cut-away of an end-suction centrifugal pump. In a centrifugal pump, the impeller rotates, which pushes the fluid to the outer edges of the volute. The volute directs the fluid to the discharge. This centrifugal pump is an end suction type, because the suction and discharge are at 90 degrees to each other. (1) Fluid flows into the center of the impeller, (2) as the impeller rotates, (3) the centrifugal force pushes fluid to the edges (4) until the fluid travels out the pump discharge.

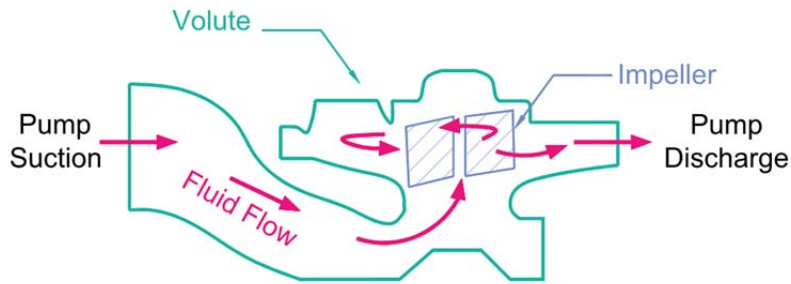


Figure 22: (1) Fluid flows into the center of the impeller, (2) as the impeller rotates, (3) the centrifugal force pushes the fluid to the edges (4) until the fluid travels out the pump discharge.

Within each centrifugal pump type (end suction & in-line) are horizontal and vertical type pumps, which are characterized by the orientation of the pump shaft as either horizontal or vertical. In addition, pumps can be further classified by the number of stages that the fluid proceeds through. Finally the last classification is how the pump is connected to the motor. Pumps can be long-coupled where the pump is connected to the motor by a flexible coupling or they can be close-coupled where the connection between the pump and motor is through a rigid coupling. The table below is a summary of the most common condenser water pump types.

Centrifugal Pump Type	Description
Horizontal, End Suction, Split Coupled:	A split coupled pump has two shafts (motor and pump shafts) connected by a coupler. Sometimes the coupler can be flexible.
Horizontal, End Suction, Close Coupled	There is a single shaft between the motor and pump.
Horizontal, In-Line, Split Coupled:	Similar to the end-suction, split coupled, except the suction and discharge are arranged in-line to one another.
Horizontal, In-Line, Close Coupled:	Similar to the end-suction, close coupled, except the suction and discharge are arranged in-line to one another.

The same four types of pumps also can be found with a vertical arrangement.

Another type of pump that is used for larger flow rates is the split case type. This centrifugal pump type has two chambers (split case) as opposed to the single chamber for end suction and in-line pumps.

6.7 PUMP EFFICIENCY

The typical pump efficiencies are within the range of 60% to 80%. You should select a pump that has its best efficiency point near your design operating point (typically around 10%). For example, if the best efficiency point of a pump is 72%, then you should choose this pump if your operating point is greater than 62% efficiency.

6.8 PUMP SPEED

The pump speeds available for condenser water pumps include 1,200, 1,800 and 3,600 RPM. When you choose the pump speed, you must first ensure that the pump manufacturer has that speed available. Lower pump speeds are preferred because the increased number of rotations will cause increased wear and tear. Bearings lifetimes are rated based on number of rotations, so if the rotations are reduced, then the bearings should have a longer life. This is true of all rotating objects. The most common pump speed is 1,760 RPM and then 3,500 RPM. The 1,160 RPM is sometimes used for smaller pumps with motors less than 5 HP.

Sometimes the pump manufacturer will indicate a speed slightly below 1,200, 1,800 or 3,600. This is because the motor is an induction motor as opposed to a synchronous motor. This means that electrically the rotation will be 1,200, 1,800 or 3,600 RPM, but the shaft will lag slightly behind this rotation.

6.9 MOTOR

The motor provides the necessary mechanical power to rotate the impeller within the pump. A motor takes in electrical power and converts the power to rotation. The motor must be able to meet the brake horsepower requirements of the pump. This is based on the pump flow rate, pump pressure and the efficiency of the pump.

With these inputs, the brake horsepower of the condenser water pump is calculated with the following equation.

$$\text{Pump Power (BHP)} = \frac{\text{GPM} * \text{FT HEAD}}{3,956 * \text{Pump Efficiency}}$$

The pump needs a motor to provide the power to spin the pump. The motor will need to provide more than the pump power because there will be losses due to motor inefficiencies. Typically motor efficiencies range from 90% – 95%.

$$\text{Motor Power (HP)} = \frac{\text{Pump BHP}}{\text{Motor Efficiency}}$$

The calculated motor horsepower must be less than the available motor horsepower ratings. The available horsepower motor ratings are shown in the table below.

Table 1: This table shows the available NEMA motor sizes that is used to size the motors for pumps and fans. Although the actual energy usage will be equal to the BHP, electrical engineers must size their equipment and wiring based on the HP value provided by the mechanical engineer.

NEMA Motor Sizes (HP)				
1/6	2	25	125	400
1/4	3	30	150	450
1/3	5	40	175	500
1/2	7-1/2	50	200	
3/4	10	60	250	
1	15	75	300	
1-1/2	20	100	350	

Pump manufacturers have online software that automatically shows the available pumps for a given flow rate and pressure drop. The software will show the speed (RPM), efficiency, brake-horsepower (BHP) and horsepower (HP) for the various pump types that can meet the required flow rate and pressure drop.

Sample Online Pump Selector: <http://www.pacopumps.com/PumpSelect.aspx>

Although the pump selection tool makes it very easy to select pumps, you should also know how to select pumps via the pump curves. A pump curve shows the pressure and flow rate operating points for a pump operating at various speeds or impeller diameters. If a pump speed is selected (1,200, 1,800 or 3,600) for a pump, then the pump curve graph will show multiple pump curves at various impeller diameters. If an impeller diameter is selected, then the pump curve graph will show multiple pump curves at various speeds. The following figure shows a specific pump speed, with multiple pump curves at various impeller diameters.

The graph also shows curves of pump horsepower in blue. These curves are created by calculating the horsepower based on the pressure, flow rate and pump/motor efficiency at a point. The efficiency curves shown on the figure are found based on a series of tests of the actual pump.

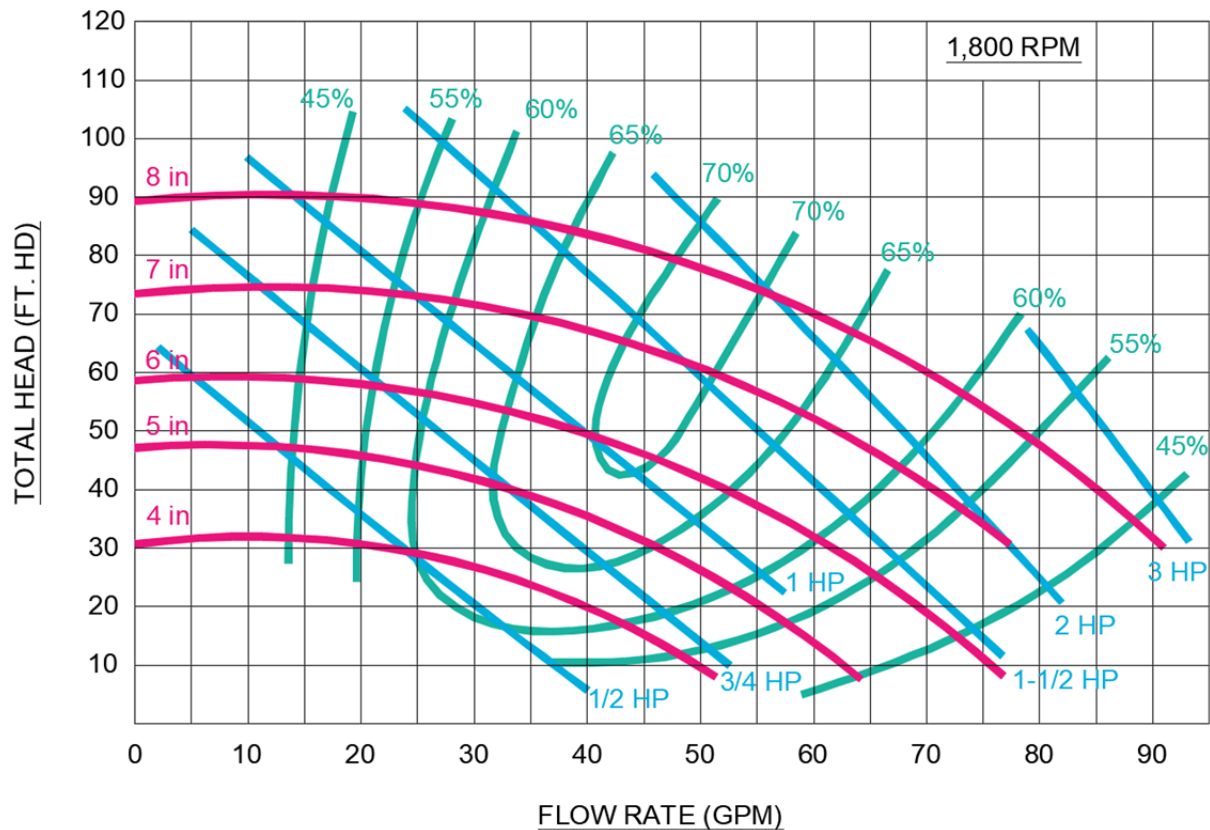


Figure 23: This sample pump curve shows the operating conditions for a pump at a specific pump speed. The red curves show the operating points for this pump at various impeller diameters. The red curves show the pressure that can be provided at various flow rates. The intersection of the red curve and the blue horsepower curve shows the horsepower required at a certain operating point. The intersection of the red curve and the green efficiency curves show the efficiency at a certain operating point

6.10 REMARKS, ADDITIONAL FEATURES

A condenser water pump will often require additional features besides the basic requirements that were discussed in the

Non-Overloading Pump: A non-overloading pump is a pump with a sufficiently sized motor that can provide enough power at all operating points along a pump curve. For example, in the previous figure a non-overloading pump with 6" impeller diameter will have a 1-1/2 HP motor. At every point on the red curve, the horsepower required is less than the 1-1/2 blue HP curve.

Premium Efficiency Motor: A premium efficiency motor describes a motor that has a minimum efficiency specific to each motor horsepower in compliance with NEMA Premium Efficiency Motor Standards. The motor standards can be found in the below links. As an example, an energy efficient 5 HP/1,800 RPM motor will have an efficiency of 87.5% and a premium efficient motor will have an efficiency of 89.5%.

<https://www.nema.org/Policy/Energy/Efficiency/Pages/NEMA-Premium-Motors.aspx>

https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_handbook_web.pdf

Variable Frequency Drive: A variable frequency drive is used to increase the speed of the pump rotation, which causes the pump curve to shift up and down. This causes the pump to provide more flow/pressure as the speed is increased and less flow/pressure as the speed is decreased.