Inside the Mechanical Room

Commercial Solar Thermal Storage, Exchangers, Pumps and Controls

By Rich Louis and Chuck Marken

All the components of residential solar thermal systems are present in larger installations. In the latter, however, the parts can increase in scale to the degree that they may be hard to recognize at first glance. Although the tanks, piping and pumps are larger in commercial systems, residential scale controls are often used. Today, while most residential SHW systems are based on preengineered designs and component packages, larger projects require custom engineering. In the October/November 2008 issue of *SolarPro,* we covered the roof work involved in large commercial thermal installations. Here we go inside to the mechanical room to examine the design considerations necessary for large scale systems.

Large solar heating systems incorporated into new buildings are usually included in the overall mechanical plans. The plans drawn up by the mechanical engineer will be detailed enough to allow plumbing contractors with relatively little solar experience to accomplish the installation. However, having an experienced solar technician on-site will keep common mistakes to a minimum and streamline installation.

Retrofit jobs, however, often require solar contractors to design the system in addition to installing it. The system design determines the size of the components and project feasibility. Making room for the storage tank is probably the first consideration in any large retrofit job, because adequate space for the collectors and storage tank(s) is a make or break proposition for any solar heating system.

Courtesy solarassist.net

STORAGE TANKS

Most professionally engineered projects will specify a pressurized storage tank for large solar water heating systems. This is particularly true with installations requiring tanks with capacities greater than about 2,000 gallons. Large pressurized vessels can cost three to 10 times more than unpressurized tanks. They are typically custom built and can have long lead times in procurement. Tanks are often manufactured in a cylindrical shape with a domed top and bottom (or sides in a horizontal tank). Pressure tanks are built from stainless steel or steel with a glass liner to assist in corrosion protection, similar to a typical electric or gas water heater.

The term *atmospheric* is often used to describe open or unpressurized tanks. A tank need not be completely open to be unpressurized, and it might appear to be a pressure tank on quick inspection. Atmospheric tanks can be constructed of any material with a suitable temperature rating. Lined steel, stainless steel, lined fiberglass and polypropylene are all used in atmospheric tank construction. Unpressurized fiberglass tanks resemble a giant egg and are made for vertical and horizontal installations. Steel and stainless tanks are usually cylindrical, and polypropylene tanks can be either cylindrical or rectangular.

Bladder tanks are sometimes used for large SHW system storage because they can be constructed on site. Ethylene Propylene Diene Monomer (EPDM), a rubber roofing material, is used for the bladder. This material has a service temperature of about 300°F (149°C), which is sufficient for an atmospheric tank. A bladder tank starts with a cylindrical or rectangular frame that can withstand the hydrostatic pressure of the water to be contained. At least 2 inches of high-temperature foam insulation line the tank sides, top and bottom, and the bladder is then folded into the cavity. No bottom penetrations are made in a bladder tank; instead, an inverse “U” pipe circulates water from the tank bottom and keeps the pump primed if the tank is used for drainback. The heat exchangers are simple rolls of copper tubing and used with all types of unpressurized tanks. EPDM tanks have a life span of at least 15 to 25 years. Some bladder tanks do start leaking, possibly due to inadequate material thickness or because the EPDM was not folded properly during tank construction.

Storage tanks are usually sized to the building water heating load, with their size proportional to the collector surface area. Others factors that influence sizing include the temperature required, the total load, the local climate and available solar irradiance. Rules of approximation will get you into trouble with large SHW systems, but many throughout the US are designed with ratios of 1 square foot of collector to 1.5 to 2 gallons of storage volume—the same ratio as most residential systems.

In many large systems, the storage tank is designed to be used as the drainback tank. The only difference related to storage in small and large drainback systems is tank size. The same goes for expansion tanks in antifreeze systems. Very large systems with hundreds of collectors can have expansion tanks as large as typical household water heaters.

HEAT EXCHANGERS

Large antifreeze systems use external tube-in-shell and plate heat exchangers. There is nothing unusual about these exchangers other than their size and the sometimes long procurement cycle required. Atmospheric tanks use immersed coils of copper tubing. The coils are simple, efficient and readily available; however, using immersed copper tubing in lined steel tanks could cause premature tank failure in some locations with certain water conditions. This is not a problem with stainless, polypropylene, fiberglass and bladder tanks.

Large exchangers are commonly used in commercial facilities, so they are available from many suppliers. For instance, Taco, Alfa Laval and Doucette Industries make both plate and tube-in-shell exchangers. These manufacturers can help you with sizing if you provide the data for the desired maximum solar production of your system. You may need to specify flow rates, fluid temperatures and, to a lesser extent, fluid type to size a heat exchanger correctly.

HYDRAULICS—PIPES AND PUMPS

Large SHW projects require skilled mechanical engineers to specify the pumps and piping. Hydraulic calculations for solar thermal projects focus on determining the size of the piping and selecting a pump or pumps. Piping size and design as well as pump selection are interdependent.

When selecting a piping system and pumping equipment, you need to construct a system curve. Calculating the static head and head loss for a range of flow conditions creates this curve. As you might expect, given the same pipe diameter, frictional head increases with higher flow. For simple thermal projects, often this system curve consists of a single point representing the flow and head. *Head* describes the work required by the hydraulic system as measured in feet (or technically foot-pounds per pound), psi or meters (meter-newtons per newton). Total head consists of both static and dynamic components.

Static head is the difference in elevation between the static water surface on the suction side of a pump and the water surface on the discharge side of the same pump. It is the work that a pump needs to perform to lift water from the lower to the higher elevation. The highest water surface elevation in a drainback system is the top header of the collector array. At this elevation, the water begins to return to the pump and free-falls down to the drainback tank. For pressurized glycol systems the static head is zero, because the solution is maintained in a continuous loop—there is no discharge elevation. The weight of the solution getting pushed up the pipe is offset by the equal weight of solution being pulled down on the return.

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Dynamic head is the work required to move water through a pipe or valve. Dynamic head, friction loss and head loss are terms for essentially the same thing: overcoming internal friction in the water and along the pipe walls. Dynamic head is often ignored in residential systems because small pumps and low flow rates create little frictional loss in the piping. In larger systems, dynamic head is dependent on pipe size and flow velocity. It can significantly affect a system's performance if not calculated properly. Dynamic head is independent of static head and must be calculated for both glycol and drainback systems.

Pipe Size Selection

Pipe diameter is selected based on the flow rate, which is determined by the size of the individual collectors and number of collectors in the array. The velocity

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Typical Flow Ranges, Velocities and Head Losses for CU Pipe

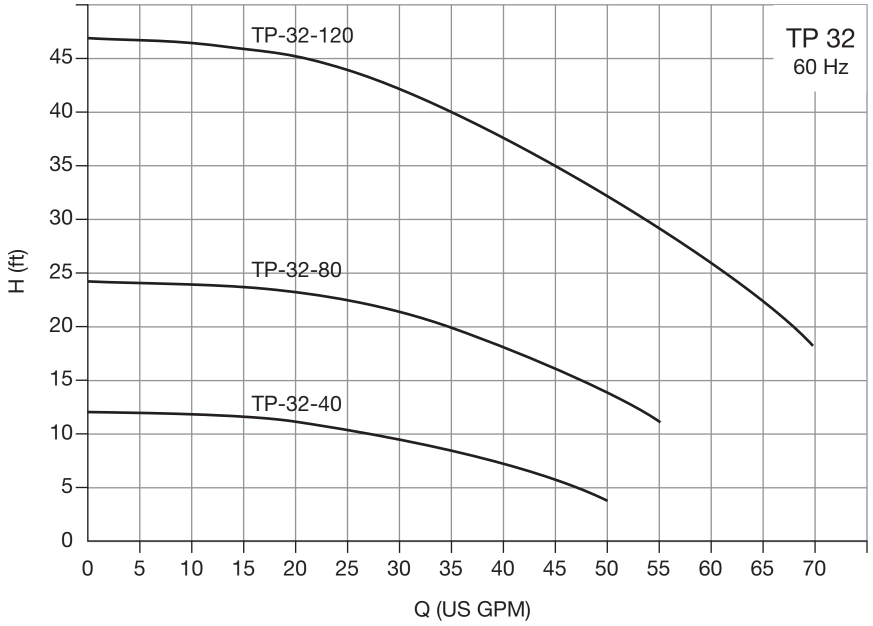
Pipe Diameter (in.)	Flow Range (gpm)		Velocity Range (fps)		Head Loss (C = 130) (ft. per 100-ft. pipe run)	
	Low	High	Low	High	Low	High
0.5	0.5	1.4	0.8	2.3	1.0	6.9
0.75	1	4	0.7	2.9	0.5	6.7
1	2	7	0.8	2.9	0.5	4.7
1.5	6	12	1.1	2.2	0.5	1.8
2	8	20	0.8	2.0	0.2	1.1
2.5	12	40	0.8	2.6	0.1	1.4
3	20	60	0.9	2.7	0.2	1.2

Table 1 Proper design minimizes head loss in supply and return piping. Note that the head loss values listed here were calculated using a Hazen-Williams coefficient of 130, which represents the roughness of the internal pipe surface.

in the pipe is usually designed to be approximately 2 feet per second (fps). At this velocity, the frictional head loss is often kept low enough that it does not increase the energy required for pumping. When pumping clean fluids such as water and glycol mixtures, a very low velocity of 0.5 fps is acceptable. Using the ballpark rate of 2 fps, a collector array requiring a flow rate of 9 gpm would require a 1.5-inch pipe and have a corresponding velocity of 1.6 fps and a head loss of 1 foot per 100 feet of pipe run. See Table 1 (p. 78) for a summary of typical velocities and head loss values for copper pipe.

Pump Selection

A pump's capabilities for a range of flow and head conditions are represented in a *pump curve,* which the manufacturer can provide. A comprehensive pump curve includes a performance (capacity-head) curve, a net positive suction head required (NPSHR) curve, a power curve and an efficiency curve.



Data courtesy grundfos.com

Graph 1 A performance curve enables designers to specify the optimal pump model to maximize heat transfer from the collectors to the storage tank.

The performance curve. Graph 1 shows a performance curve representing the flow that a pump will produce for a given head condition. A constant-speed pump, typically used in solar water heating, will operate at a flow that depends on the head. When you select a pump, be sure to match its required output (the flow rate to the collectors) with the system curve (the head needed to produce the flow). The pump head is the sum of the static head and the dynamic head at the desired flow rate. For a flow of 45 gpm and a head of 35 feet, for example, Grundfos pump TP-32-120 would perform as needed (see Graph 1). The deadhead condition is the pump head at zero flow. While this value is not used to select a pump, knowing it can be useful in troubleshooting.

The NPSHR curve. When selecting a pump, it is critical to avoid cavitation, which is the implosion of air bubbles on the impeller. Pump cavitation occurs as air bubbles pass from the low pressure of the inlet to the high pressure at the edge of the impeller blade. These air bubbles form as the pump sucks a fluid to a pressure that is equal to or below its vapor pressure. Essentially the water boils, even at room temperature. A pump experiencing severe cavitation may sound like it is pumping marbles or making popcorn. Cavitation will wear away the pump's impeller, reducing the flow, decreasing system performance and eventually leading to pump failure. The problem arises when a pump is installed in an improper location, or when the wrong pump is selected for a specific application.

Fortunately, during the system design phase you can avoid the conditions that cause cavitation. Calculating the required net positive suction head available (NPSHA) and comparing that value with the NPSHR makes it possible to choose a suitable pump. NPSHA is the physical measure of a fluid's ability to resist cavitation and can be calculated as:

$$NPSHA = APH +/- SPH - VPH - FHL$$

where APH is atmospheric pressure head, SPH is suction pressure head, VPH is vapor pressure head and FHL is friction head loss in the suction piping.

Keep in mind that atmospheric pressure depends on elevation, which is why water boils at a lower temperature at higher elevations. To understand the impact of elevation on atmospheric pressure consider the following. At sea level, the atmospheric pressure head is 33.9 feet. In Denver, Colorado, where the elevation is approximately 5,000 feet, the atmospheric pressure head is approximately 28.6 feet. The highest city on the planet, Lhasa, Tibet,

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Vapor Head Variation with Temperature

Temperature	Vapor Pressure Head (ft.)
60°F	0.59
100°F	2.19
140°F	6.67
180°F	17.33

Table 2 Vapor pressure head values increase dramatically as transfer fluid increases in temperature. Installing pumps on the cooler supply side piping will reduce issues related to cavitation.

is located at 12,000 feet and has an atmospheric pressure head of approximately 21.6 feet. To find the atmospheric pressure head at your project location visit turblex.com/altitude/index.cfm.

The second factor in the formula, vapor pressure head, varies with temperature. Table 2 (p. 80) illustrates this variation.

The NPSHA for pumping 140°F water in Denver, Colorado, is calculated as:

28.6 ft. (APH) + 5 ft. (SPH) - 6.67 ft. (VPH) - 0.5 ft. (FHL)
= 26.4 ft.

The SPH and FHL were arbitrary values chosen to illustrate the formula.

The higher the fluid temperature and the higher the elevation, the greater the potential for cavitation. The pump should therefore be placed at the lowest-temperature point in the system—on the supply piping for the collectors, not the return piping.

NPSHR is the physical characteristic provided with each pump curve. In order to prevent cavitation, the NPSHR must always be less than the NPSHA, with a safety margin of 2 feet or more. In Graph 2, note how rapidly the NPSHR increases as the flow reaches the upper range. You can avoid this by choosing a pump that will meet the head and flow requirements in the *middle* of the curve. For the TP-32-120 pump referenced in Graph 2, the NPSHR is approximately 6 feet, which is well below the NPSHA calculated earlier. Note that glycol solutions have different properties, which change the vapor pressure head. These factors must be considered when pumping glycol solutions.

You can avoid cavitation by selecting a pump that operates at a low NPSHR. It is also possible to place the pump far enough below the drainback tank to increase the NPSHA, or to pressurize the system and thus increase the NPSHA. For some closed loop drainback systems, you can use a compressor to input air into the drainback tank and pressurize the system that way. For a glycol system using an expansion tank, you would use an external pump to pressurize the fluid at startup.

The power curve. The power curve indicates the load conditions under which the pump can operate. A pump might be designed to operate under varying conditions. For example, multiple radiant floor circulation loops or alternating radiator heating circulation loops can create different head or flow conditions. If each of those conditions remains within the power curve, a single pump may be used. See Graph 3 for a typical power curve.

The efficiency curve. Although efficiency can often be overlooked when choosing small pumps, it becomes important when selecting larger pumps. Choosing an efficient pump minimizes overall energy consumption and results in a more efficient solar thermal system. For example, the pump referenced in Graph 4 (p. 84) has a peak efficiency of 65% at the design flow.

■ Valve Selection

Choosing the right valves is critical to system performance and service. Two primary types of valves are used in solar thermal piping systems of all sizes: gate valves and ball valves.

Gate valves are designed specifically for equipment isolation and have two proper positions: fully open or fully closed. These valves are not appropriate for flow restriction or balancing. If such a valve is left partially open, fluids at high velocity will wear away the gate.

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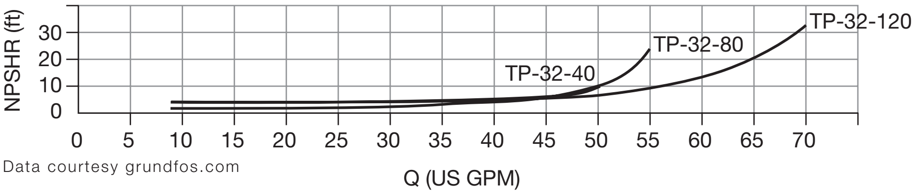
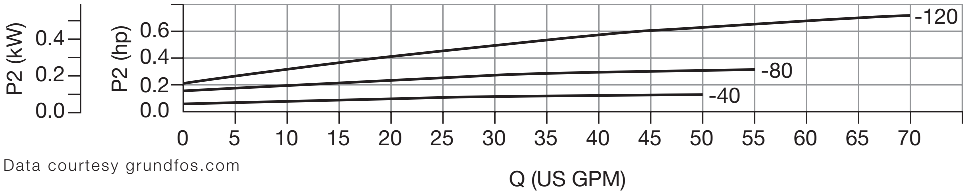
Pump NPSHR Curve



Data courtesy grundfos.com

Graph 2 Detailed system design calculations made during the pump specification phase will minimize the possibility of pump cavitation, related pump failures and service calls.

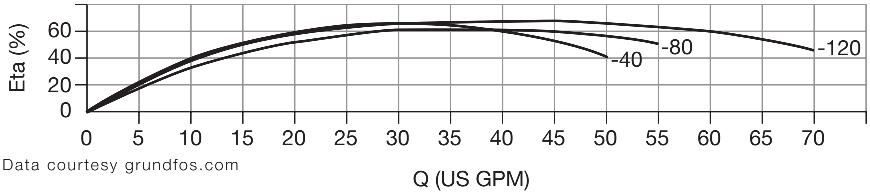
Pump Power Curve



Data courtesy grundfos.com

Graph 3 A system's head and flow requirements dictate the range of conditions within which a specific pump can operate. Load conditions may vary and must be considered during pump selection.

Pump Efficiency Curve



Data courtesy grundfos.com

Graph 4 Large solar water heating systems require larger, higher power pumps than do residential systems. Pump efficiency is often not a priority in smaller systems, but it is crucial in large systems to minimize energy use over the life of the system.

Once this gate begins to wear, the valve can no longer fully close. Sometimes a gate valve is installed and used for both system throttling and its intended purpose of equipment isolation. Then in 4–5 years, when a piece of equipment may need to be serviced, the maintenance staff must isolate it to perform the repair; they rely on that gate valve to isolate the equipment. If that valve cannot stop the water in the lines from leaking out, their repair can become a messy, time consuming effort instead of a routine project.

Ball valves can be used for flow balancing and for equipment isolation. This type of valve, which uses a sealing mechanism composed of a ball and a seat, can handle a partially closed position without experiencing wear.

Diagnosing pump problems

The proper instrumentation is valuable for system troubleshooting and performance verification. Two critical instruments are pressure gauges and flow meters.

Pressure gauges. Every pump needs a pressure gauge, located on the discharge side. If you cannot easily observe the level of the suction side water reservoir, a pressure gauge on the suction of the pump can also be helpful to diagnose problems. Do not cut corners here: a high quality, liquid filled gauge is always worth its price. Finally, your pressure gauges should always be properly calibrated.

Flow meters. Although every installation should have a flow meter, these instruments are critical in larger commercial systems. Comparing the design flow rate to the observed flow rate will help determine the system's performance or identify when a valve is in the wrong position. For example, if a ball valve used for balancing is closed too much, it reduces flow to the collectors. If this valve is open too much, flow may be too high and the collector array may function poorly in peak heat gain conditions. If all valve positions check out properly, this may indicate that a pump is malfunctioning and requires service.

If you know the pump curve, you can diagnose a pump condition with a few easy tests, such as the following. With the pump running, observe and record the flow rate and pressure gauge reading. Next, keep the pump running and close the pump discharge valve so that the flow is zero. This is the deadhead condition. Record the pressure gauge reading. Compare these readings to those shown on the pump curve. If they match, this is a good indicator of pump health. If they do not, the pump impeller may have deteriorated.

CONTROLS

The complexity of the controls is proportional to the applications that the solar thermal system will serve. The interface with the backup SHW, building or process heat system, or swimming pool will also influence the control strategy. Some of the very largest SHW systems built are now controlled with simple, off the shelf differential controls. These older systems were designed with more sophisticated controls, but the lack of repair parts led to retrofits that were simple and more reliable. Multihorsepower 3-phase pumps can easily be controlled with a 120 V/10 A differential control using relays and motor controls of adequate size. Small controls are the brains of many large systems today.

A good system design will ensure decades of efficient energy production and also facilitate a quick, smooth installation. "Anything is possible, as long as you don't have to install it," is a complaint too often heard from installers who are frustrated with design flaws in the plan sets. Good designs make everybody happy, even the inspector.

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