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Eutectic cool storage: Current developments

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Eutectic phase change materials provide a versatile cool storage medium that can be applied to a wide variety of building conditions. Like ice and chilled water storage systems, eutectics have been in use for many decades. Such phase change materials (PCMs) have been developed with various phase change points.

To date, the most commonly used eutectic for cool storage applications melts and freezes at 47°F. This material is a mixture of inorganic salts (the primary salt being sodium sulfate), water, and nucleating and stabilizing agents. It has a latent heat of fusion of 41 Btu/lb and a density of 93 lb/cu ft.

The 47°F PCM requires conventional chilled water temperatures (40° - 42°F) to charge the storage system. These temperatures in turn allow any new or existing centrifugal, screw or reciprocating chiller to be used to charge the storage system at refrigeration conditions comparable with standard air conditioning and allow eutectics to be particularly appropriate for retrofit applications.

Like ice storage systems, eutectic systems rely on a phase change. Use of the PCM's latent heat of fusion requires about 6.0 cu ft/ton-hour for the entire tank assembly which includes piping headers and water in the tank. The storage tank is

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usually placed away from the chillers and below a parking lot or service road.

This article describes the world's largest eutectic system: a 10,000 ton-hour retrofit installed at the McDonnell Douglas Helicopter Company in Mesa, Arizona. Construction of the tank began in August, 1989, and the storage system went on-line in December of that year.

The 47°F eutectic storage tank operates as a partial-storage, pre-cooler system shifting 2,200 tons from the 4,200-ton peak summer load. During the winter, the PCMs are frozen at night using indirect evaporative cooling from the cooling towers without mechanical refrigeration. During the day, the PCMs are used as a full storage system to meet a 1,000-ton load. The $1 million installation has a 4.3-year simple payback period.

This article also describes the characteristics and advantages of a 41°F eutectic developed under the sponsorship of the Electric Power Research Institute.

Cooling 1.17 million sq ft

The helicopter company's main manufacturing and administrative facilities are located in a four-building complex comprising 1,170,000 sq ft of air-conditioned space. The buildings are served by a large central plant, as shown in *Figure 1*. This existing plant, which was installed in 1985, includes four 1,260-ton centrifugal chillers.

The central plant has a primary/secondary pumping loop. Each primary chiller pump is rated at 3,015 gpm at 40 ft. Each secondary distribution pump is rated at 3,350 gpm at 55 ft. One of the secondary pumps is operated by a variable speed drive to modulate the chilled water flow rate through the complex.

The combined peak summer load on the central plant is approximately 4,200 tons with supply chilled water temperatures of 45.5°F and return water temperatures of 57.5°F. The nighttime load on the peak summer day is 2,000 tons. Winter peak daytime loads are about 1,000 tons, with a small 200-ton constant nighttime load.

Two heat exchangers between the condenser water loop and chilled water loop are used as water-side economizers for indirect evaporative cooling. These heat exchangers take the place of one 1,260-ton chiller during the winter morning and evening hours when 50°F chilled water is supplied in a "free cooling" mode of operation.

A cool storage feasibility study was commissioned by the owner in 1987. After examining several storage sizing options in the feasibility study, storage was sized to provide 10,000 ton-

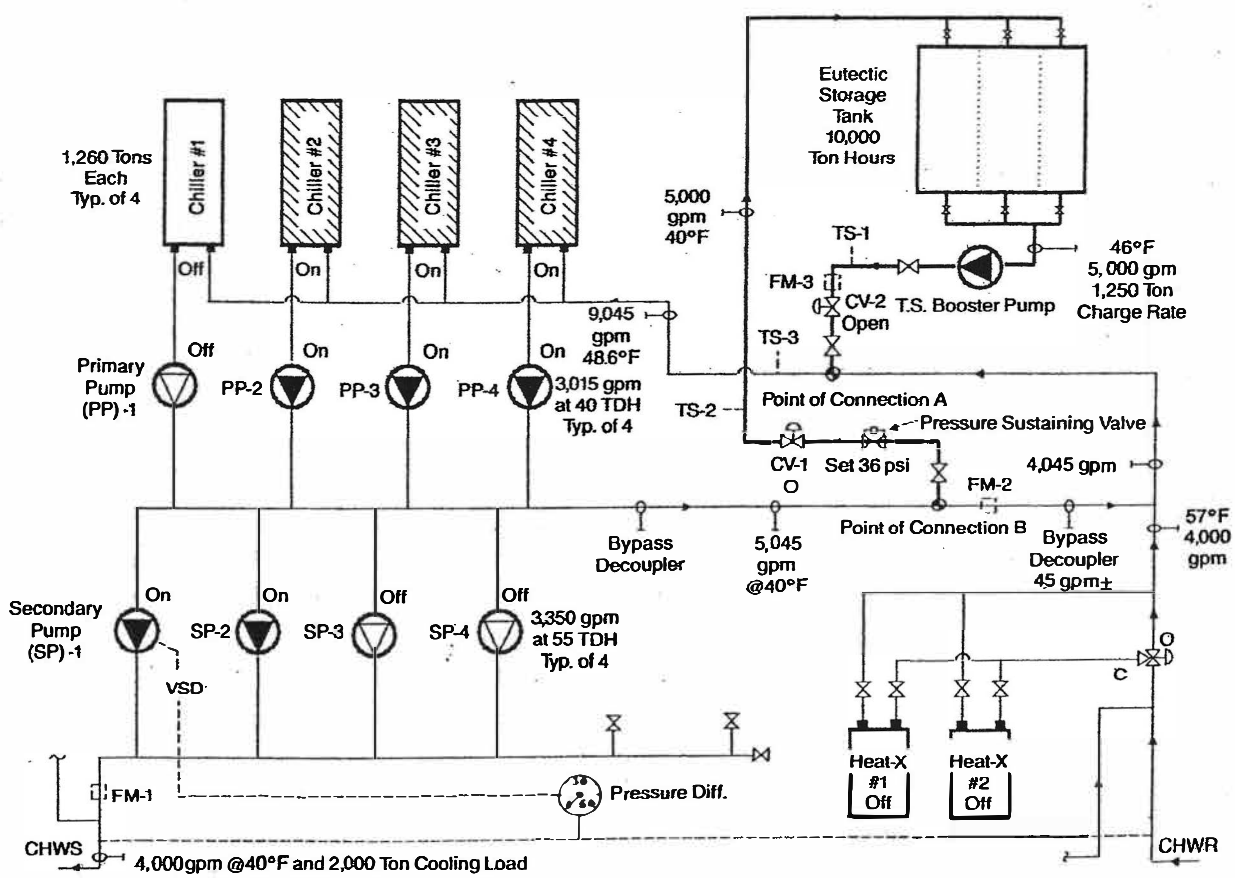

Figure 1. Eutectic cool storage system at helicopter company; charging the tank and cooling the buildings; 2,000-ton night-time building load.

hours and a 2,200-ton peak load; which is 52 percent of the 4,200-ton facility peak load. Salt River Project (SRP), the electric utility, has a five-hour afternoon summer on-peak time period.

The storage medium chosen for the project is a eutectic salt that melts and freezes at 47°F. The PCM is sealed inside high density polyethylene containers that stack on top of each other with space for water to flow between the containers. Because the PCM is 1.5 times the weight of water and does not expand or contract when it freezes and melts, there is no movement inside the tank.

The storage tank for the project measures 103 ft long by 53 ft wide by 10.5 ft deep. The tank was built with a poured concrete floor, "shotcrete" walls, and a pre-cast concrete top. It is located beneath a service road within the facility and approximately 50 ft from the central plant.

Charging and cooling operations

During the charging mode, the storage tank is in parallel with the buiding load as shown in *Figure 1*. Chilled water (40° - 42°F) from the chillers is used to freeze the PCM and charge the tank. The number of chillers and primary pumps operated for charging is controlled to equal the number of secondary pumps on to meet the load plus one. For example, when there is a 2,000-ton nighttime load during a warm summer night, two secondary pumps will be on and 4,000 gpm will circulate through the facility. At the same time, three chillers and three primary pumps will operate with a primary loop flow rate of 9,045 gpm.

During charging, the storage tank booster pump is set for 5,000 gpm. Hydraulically, the tank acts as an injection pumping loop and is decoupled from both the primary and the secondary loops. With a 6°F temperature difference across the tank and 5,000 gpm, the tank charges at a rate of 1,250 tons, and is designed to be fully charged in 8 to 10 hours.

Towards the end of the charging period, as the leaving tank temperature returning to the chillers drops, the DDC system is set to shut off a chiller and primary pump. In this way, the tank will continue to be charged, but the chillers will be kept more fully loaded. Also, the end of the charging coincides with the increased morning cooling load, again to keep the chillers more fully loaded.

Part-storage, pre-cooler discharge mode

The design allows the storage discharge rate to vary as the load varies, with the chillers meeting a constant base load. In this way, storage can provide a greater kW shift than if storage was discharged at a constant rate.

To accomplish this goal, storage is piped as a pre-cooler in series between the load and the chiller, with the same tie-in points used during the charging mode. Storage discharges at whatever rate is required to provide a constant return temperature to the chillers with a constant flow rate in the primary loop.

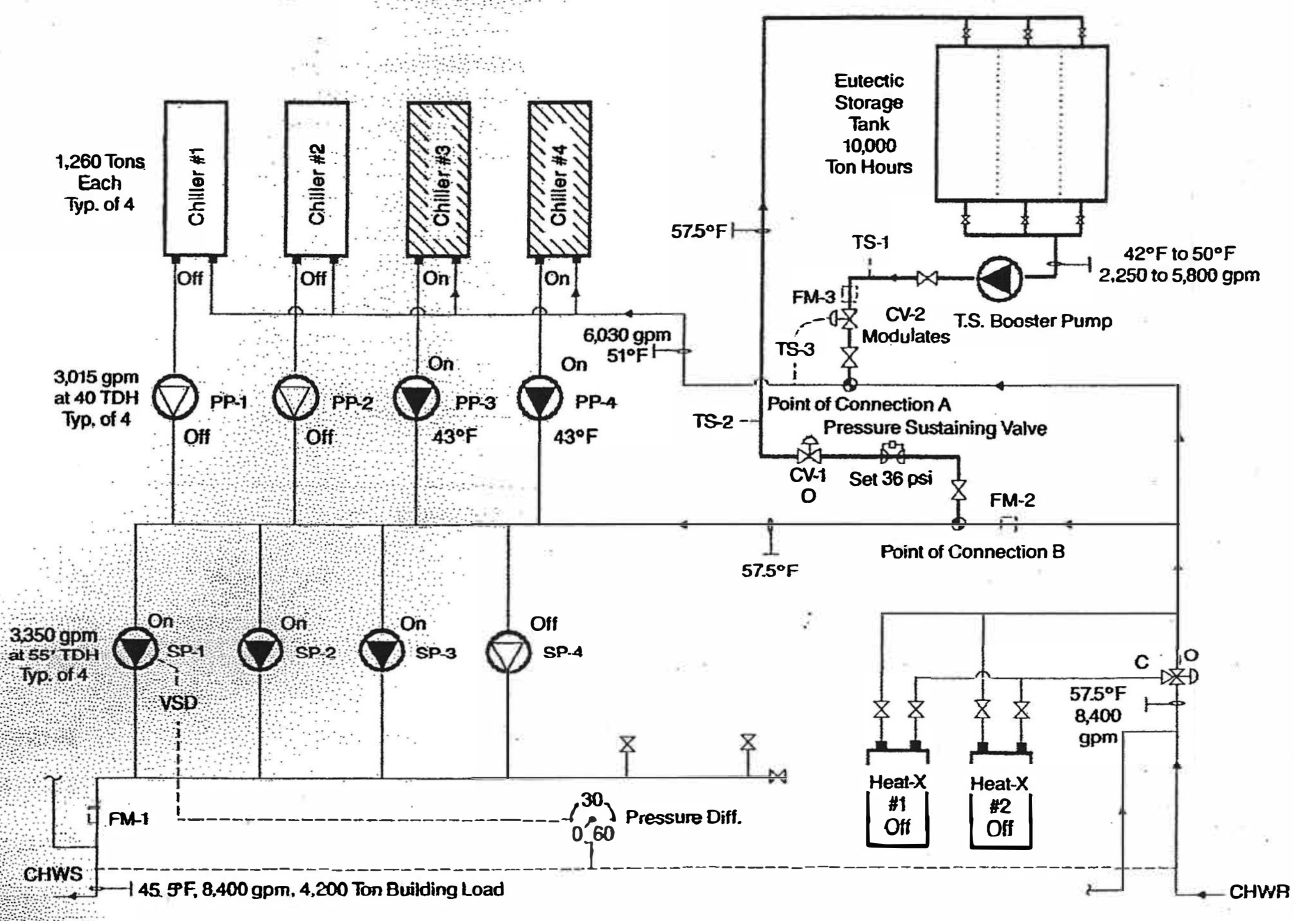

Figure 2. Eutectic cool storage system at helicopter company; part-storage, pre-cooler discharge mode, 4,200 tons.

The flow rate through the storage tank will vary depending on the required rate of discharge and the leaving tank temperature. At the beginning of the discharge period, water leaves the tank at 40° to 42°F (the water charging temperature). The leaving tank temperature will gradually rise to and remain at 47° to 48°F, until the end of the discharge period, when the leaving tank temperature rises to 50°F. Water temperatures leaving the tank are within 1°F of the phase change point due to the very large 71 sq ft/ton-hour heat transfer surface area provided by the 24 in. by 8 in. by 1-3/4 in. PCM-filled containers.

A modulating valve (CV-2) just downstream of the storage booster pump varies the flow rate through the storage tank so that water from the tank mixes with water returning from the building to meet the 51°F blended water temperature set point (TS-3). In practice, the tank modulating valve (CV-2) will slowly open during the discharge period. The pressure sustaining valve maintains a constant backpressure equal to the static head of the facility (36 psi) so the amount of water entering the unpressurized tank always equals the amount of water that exits the tank and is injected back into the chiller return piping.

Figure 2 shows the various flow rates and temperatures with a 4,200-ton daytime peak load. The building is supplied with 45.5°F water and returns at 57.5°F. To supply 8,400 gpm, three secondary pumps are on, with one pump operated by a variable speed drive.

Two chillers are on and provide a constant 1,000 tons each, with 51°F entering/43°F leaving and 3,015 gpm. Therefore, TS-3 is at 51°F. During the discharge mode, the control logic sets the number of chillers and primary pumps so there is always excess flow in the secondary loop relative to the primary loop.

At 3 pm when the projected peak load occurs, the temperature leaving the tank will be 47°F, CV-2 will modulate to maintain TS-3 set-point at 51°F, and the flow rate through the tank will be at 5,280 gpm.

During the discharge period, the flow rates through the tank will vary between 2,250 and 5,800 gpm. The storage discharge rate will vary between 1,500 tons and 2,200 tons, while the chiller loads remain constant at 2,000 tons.

Through control of the TS-3 set-point and the number of operating chillers/primary pumps, the discharging strategy can accommodate any type of chiller/storage priority strategy or alternative time periods.

Charging with the cooling towers

During winter months, there is approximately an 800- to 1,400-ton daytime cooling load and a 200- to 400-ton nighttime load. With the heat exchangers and low nighttime wet bulb temperatures in the Phoenix area, 3,000 gpm of 39° to 43°F water is available on the chilled water side of the heat exchangers using indirect evaporative cooling from the cooling towers. With no mechanical refrigeration, the 47° PCM is frozen at night.

During the day, with 60° to 75°F dry bulb ambients, storage is discharged and the system operates in a full storage mode. Without storage, a chiller would need to be operated to meet the daytime peaks. By using the cooling towers to charge storage during the winter months, significant electric energy conservation is achieved in addition to shifting the peak demand.

System provides four-year payback

Salt River Project's rate structure includes a $4.53 summer on-peak demand charge with $0.0608 per kWh on-peak and $0.0199 per kWh off-peak. Winter demand charges are based on an 80 percent ratchet of summer demand. Total annual savings are estimated at $171,000 per year based on a computer analysis of the loads and costs. A summary of the cost savings is shown in *Table 1*. Installation costs for the 10,000 ton-hour system are shown in *Table 2*.

The full turn-key installed cost for the 10,000 ton-hour system, including structural, mechanical and electrical engineering, eutectic containers, traffic-loaded tank, piping and controls, was $1 million. With a rebate of $258,000 from Salt River Project, the estimated simple payback period for the

Table 2. Installation Costs 10,000 Ton-Hour System

Traffic-loaded tank	$250,000
Eutectic and containers	$600,000
Piping, valves, insulation, booster pump & electrical	$105,000
Controls	$20,000
Engineering & commissioning	$25,000
	$1,000,000
Electric utility rebate	– $258,000
	$742,000
Annual electrical cost savings	$171,000
Simple payback period	4.3 years

Table 1. Electric Cost Reductions Summary

Demand charges:	
Summer—	
2,220 tons × 0.95 kW/ton × $4.53/kW × 6 mos.	$56,806
Winter—	
2,200 tons × 0.8 ratchet × 0.95 kW/ton × $3.25/kW × 6 mos.	$32,604
Energy charges:	
Summer—	
10,000 ton-hr/day × 0.95 kW/ton × 22 days/mos. × 6 mos./year × ($0.0608/kWh – $0.0199/kWh)	$51,288
Winter—	
10,000 ton-hr/day × 0.95 kW/ton × 22 days/mos. × 6 mos./year × ($0.0310/kWh – $0.0199/kWh)	$13,919
Charging with cooling towers (Replace chiller operation):	
10,000 ton-hr/day × 0.75 kW/ton × 100 days/year × $0.0199/kWh	$14,925
Added pumping horsepower during charging:	
125 kW × 10 hr/day × 270 days/year × $0.0199/kWh	($6,716)
	$162,826
Taxes, 5 percent	$8,141
	$170,967

project is 4.3 years. This payback is achieved without any credit due to displacing the need for a future 1,000-ton chiller.

41°F eutectic PCM

Under the sponsorship of the Electric Power Research Institute (EPRI), a eutectic that melts and freezes at 41° to 42°F has been developed. A nucleating agent has also been developed to be used with the new PCM. The nucleating agent acts as an insoluble seed crystal to prevent supercooling or supersaturation, so that the PCM will not remain in the liquid state as it is cooled below its freezing point. Because the 41°F PCM is a true eutectic, gelling agents are not required. A comparison of the thermophysical properties of the 41° and 47°F eutectic is shown in *Table 3.*

Table 3. Comparison of Eutectics' Thermophysical Properties

	41 Eutectic	47 Eutectic
Phase change point	41-42	47-48
Latent heat of fusion	53 Btu/lb	41 Btu/lb
Density	92 lb/cu ft	92 lb/cu ft
Storage density	4.0 cu ft/ton-hr	6.0 cu ft/ton-hr
Required charging temp.	35°F	41°F
Leaving tank temp.	41-41°F	47-50°F

The 41° eutectic has a 29 percent higher heat of fusion than the 47° material. With its equivalent density, this translates into a 29 percent decrease in storage tank size. The overall costs of the storage tank and contents will be considerably reduced with the 41°F eutectic.

The 41°F PCM requires 35°F water for charging purposes. In new building applications, "low-approach" chillers may be available to produce these temperatures without glycol. Whether an existing chiller originally specified for 44°F water can provide 35°F temperatures with lower nighttime condensing temperatures will depend on the specific chiller. However, in many cases using existing chillers will be practical along with adding a 5 percent glycol solution where environmentally allowable.

With the 41°F material, there will be about a 10 percent chiller derating and efficiency loss when compared to the 47° PCM, but the chiller will still be more efficient than refrigeration systems for ice storage.

Conclusion

Eutectics for cool storage have now been operating in the field for eight years and have been subjected to 12 years of accelerated life cycling tests without any degradation in storage capacity. As a reliable, versatile cool storage medium, eutectics will significantly increase the efficiency of electric power generation, thereby contributing to the reduction of the greenhouse gas emissions.

When capacity additions are required, eutectic cool storage may be used to reduce the need for new CFC-based chillers. For retrofits or new building applications, eutectic cool storage systems are becoming an economically and environmentally important resource for the future.

Acknowledgments

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