ENERGY INNOVATIONS SMALL GRANT (EISG) PROGRAM

EISG FINAL REPORT

Project Title: Solar Thermal Heat Pump/Chiller

EISG AWARDEE:
Energy Concepts Company, LLC
627 Ridgely Avenue
Annapolis, MD 21401
Phone: (410) 266-6521
Email: enerconcep@aol.com

AUTHORS
Dr. G. Anand
Donald C. Erickson, Principal Investigator

Grant #: 55032A/06-01G
Grant Funding: $95,000
Term: 8/15/07 – 10/14/08
PIER Subject Area: Renewable Energy Technologies

Inquires related to this final report should be directed to the Awardee (see contact information on cover page) or the EISG Program Administrator at (619) 594-1049 or email eisgp@energy.state.ca.us.

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Abstract

This project demonstrated a new solar thermal heating and chilling product. The Helisorber™ provides hot water at 60 percent higher efficiency than any existing solar heating product, and it simultaneously produces free chilling. It is believed to be the world's most efficient solar thermal product.

Solar thermal currently produces either chilling or hot water – one or the other. This makes it sufficiently expensive that it requires substantial subsidies. With simultaneous heating and chilling, the Helisorber provides more than twice as much value for the user.

The goal of this project was to demonstrate a Helisorber with a design heating COP (efficiency) of 1.6 and a chilling COP of 0.6. The project involved the design, fabrication, and testing of a Helisorber that produces 800 kBTUH heating and 25 tons chilling from 500 kBTUH thermal input. The test results confirmed that the target performance is achievable with a 240°F solar heat source. That temperature is available from numerous low cost solar collectors. The Helisorber footprint of 30” by 44” is very compact, simplifying shipping and installation.

The Helisorber provides energy savings even when powered by a backup boiler. This eliminates the need for any solar thermal storage. It does not require a cooling tower, as the heat rejection is to the hot water. Both of these features contribute to low system cost. A cost estimate of the complete system including solar collector, backup gas-fired heater, piping, and controls showed a 2 to 4 year payback before subsidies or credits.

Key Words

Helisorber, solar, absorption, chilling, hot water, thermal, cooling, heating

Executive Summary

Introduction

This project demonstrates the feasibility of simultaneously providing chilling and heat pumped hot water with low-cost low-concentration ratio solar collectors and a "Helisorber" absorption heat pump. The Helisorber has about 65 percent higher water heating efficiency than any existing solar heating product and the free chilling is a byproduct of the heating.

Solar thermal is recognized as a potential means of reducing natural gas and electricity used for water heating and cooling. Solar thermal is currently used to produce either chilling or hot water – one or the other. That makes it sufficiently expensive and inefficient that it requires substantial subsidies for widespread use. With the dual output, the Helisorber is a more economical solar thermal technology and provides a competitive alternative to meet customer needs.

The project involved the design, fabrication, and testing of a Helisorber rated at 25 ton chilling. The design showed that the target performance can be achieved with a solar heat source in the 240°F range. This permits the use of low-cost low-concentration ratio collectors. The 25 ton Helisorber was fabricated in a compact skid. Tests confirmed that the Helisorber could simultaneously and efficiently provide both heat pumped hot water and chilling from a heat source in the range of 240°F to 250°F.

The entire system including the hot water and coolant loop load interfaces, solar collector, backup gas-fired heater, and controls was designed and analyzed. Typical average and peak load required were assumed and appropriate storage and backup gas-fired heater capacities were determined. Additional work needs to be done to field demonstrate the entire system and quantify the economical benefits.

Objectives

The goal of this project was to demonstrate the feasibility of converting solar thermal heat to a combination of chilling plus heat pumped hot water with a solar thermal powered absorption heat pump (Helisorber). The project objectives were:

1. Demonstrate thermodynamic feasibility of the desired performance: COP 0.68; 240°F solar heat; 44°F chilling; 130°F hot water.
2. Achieve footprint of 3ft by 3ft for a 25 RT Helisorber.
3. Confirm unit achieves design specifications with variable solar insolation and hot water loads.
4. Confirm fabricability and demonstrate mechanical feasibility
5. Confirm net installed cost of $5,000/RT (or less) and 3 to 5 year payback

Outcomes

1. The thermodynamic design of an ammonia-water single-effect absorption cycle was performed for a Helisorber providing 25 tons of chilling, cooling water/glycol from 55°F to 44°F, and co-producing hot water at 130°F (from 70°F) with solar heat of 240°F. Specifications were developed for all components.
2. A detailed layout of the Helisorber was prepared showing principal dimensions, relative location of components, interconnecting piping, instrumentation, and controls.
3. The hot water and coolant loop load interfaces, solar collector and backup gas-fired heater tie-ins, and controls were designed. Typical average and peak load data from literature were analyzed and appropriate storage and backup gas-fired heater capacities were specified. The control logic for economic Helisorber operation was developed. The startup/shutdown and normal operational controls including the interlock/safety system were specified.
4. Proprietary components were fabricated. Standard heat exchangers; pumps; and instrumentation were specified and procured. The fabricated and procured components and instrumentation were assembled into a skid with easy access to facilitate maintenance.
5. A test program was developed to verify overall system performance at design conditions and corresponding startup and shutdown sequencing. The Helisorber prototype was tested at a variety of conditions. Individual component and overall prototype performance parameters were recorded and analyzed. The Helisorber manufacturing cost was estimated. A preliminary economic analysis was conducted using the cost estimate and performance. The payback was estimated for representative markets.

Conclusions

1. The Helisorber design was optimized at a COP (efficiency) of 0.655. The design indicated that the performance was significantly dependent on one component – the Absorber. Absorber performance data from other absorption units were analyzed to identify optimum absorber configuration for this application. The selected absorber was tested in the test loop and its performance was verified.
2. The 25 ton Helisorber has a footprint of 44” by 30” which is highly compact yet provides good maintenance access.
3. Most places in California have good solar insolation and the Helisorber can provide significant energy savings and economic benefits to the state. The Helisorber is efficient even when operating with a backup boiler. Hence, only a nominal capacity solar storage tank is needed for optimal solar energy utilization and to minimize cycling.
4. Fabrication techniques amenable to low cost mass production were employed in fabrication of proprietary components and an economical compact skid was fabricated.
5. Tests confirmed that the Helisorber could simultaneously provide hot water and chilling from a solar heat source in the range of 240°F to 250°F. Most of the components and controls performed at or above design specification. Two components were performing below design and upgrading these components will help achieve full design performance. Cost estimation of the complete system confirmed a 3 to 5 year payback.

Recommendations

Based upon the conclusion that the Helisorber promises to be the most economical solar thermal technology available, a demonstration program should be initiated to field-demonstrate at least four Helisorbers in a variety of applications in 2009. Plans should be made to rapidly ramp up production to thousands of units per year.

Benefits to California

The Helisorber is targeted towards commercial and industrial users with adequate chilling and hot water loads such as hotels and food processors. A 25-ton Helisorber saves 3.68 billion BTU per year natural gas, and 148,750 kWh per year electricity. With an installed base of 900 Helisorbers, expected to be achieved within ten years, the Helisorber will save 3.3 trillion BTU natural gas per year in California plus eliminate the need for generating 134 million kWh of electricity. The reduction in CO_2 emissions associated with the annual 3.68 billion BTU reduction in energy consumption for each 25 ton Helisorber is estimated at 195 metric tons of carbon per year.

Introduction

This project demonstrates the feasibility of simultaneously providing chilling and heat pumped hot water with low-cost low-concentration ratio solar collectors and a "Helisorber" absorption heat pump.

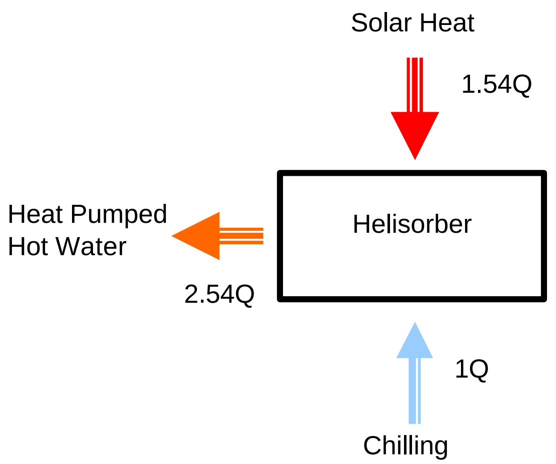
Solar thermal is well recognized as a renewable-energy resource and as a means of reducing natural gas and electricity used for water heating and cooling. However, solar thermal is currently used to produce either chilling or hot water – one or the other. This makes current solar thermal technologies sufficiently expensive and inefficient that they require substantial subsidies for widespread use. For example, for conventional solar water heating a payback period of more than 10 years is estimated (Humboldt 2001). The lower temperature solar lithium bromide/water absorption systems and the solar desiccant systems (Garrabrant et al. 2002; Bergqaum and Brezner 2000; Bergqaum 2001) are dedicated air-conditioning/chilling systems only. In other words, no simultaneous co-production of water heating or space heating is feasible without detracting from the chilling. Also, when these systems are gas-fired (backup power), their operating cost is much higher than electric-chilling, due to the low COP. Therefore the annual utilization and net energy savings with these solar chillers are quite low. Multi-use systems such as the Solar-Combi system (Besana et al. 2006) are a simple integration of conventional solar chilling and heating technologies that can provide hot water, space heating and chilling. However, with a given solar heat input the system provides only one of the three outputs – hot water, space heating, or cooling. If two or three outputs are desired then that much more solar heat is needed. These integrated systems also have very long payback periods (similar to conventional solar chilling and heating technologies), unless high fuel prices and environmental costs are considered (Ataei et al. 2009). Hence, solar thermal needs to be more efficient and economical in order to be competitive and to realize the full benefits of this renewable-energy technology for the California ratepayers.

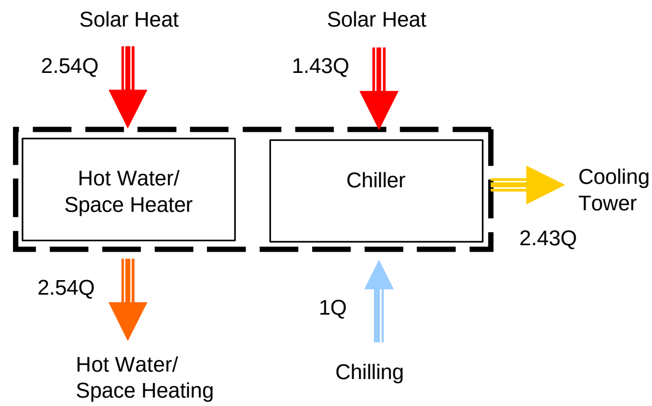
A dual-purpose solar adsorption system is being developed (Alghoul et al. 2009) for domestic refrigeration and hot water. This cycle has a design efficiency of only 82 percent for the dual output. The calculated payback is 5.3 years with credit for displaced electric water heater.

The proposed technology more than doubles the value of solar thermal heat. This enhancement is achieved by inputting the solar heat to a unique heat activated heat pump –"Helisorber". Table 1 compares the relative features of the Helisorber and conventional solar thermal technologies. As shown in the table, the Helisorber has about 65 percent higher water heating efficiency than any existing solar heating product and the free chilling is a byproduct of the heating. With the dual output, the Helisorber is highly efficient even in the backup gas-fired mode.

In order to achieve the dual output, the solar heat temperature must be increased from 200°F up to 240°F. This still falls in the range of low-cost low-concentration ratio collectors. To demonstrate the feasibility of the concept, the project involved the design, fabrication, and testing of a Helisorber rated at 25 tons chilling. The design showed that the target performance can be achieved with a solar heat source in the 240°F range. The 25 ton Helisorber was fabricated in a compact skid. Tests confirmed that the Helisorber could simultaneously and efficiently provide both heat pumped hot water and chilling from a heat source in the range of 240°F to 250°F.

Table 1– Technology Comparison





Helisorber	**Conventional Technology**
Solar – Chilling **and** Heat pumped heating (space/water)	Solar – Chilling **and** Heating (space/water)
Solar Collector Temperature <250°F	Solar Collector Temperature 180°F to 450°F
Backup gas firing Highly economical	Backup gas firing Uneconomical for chilling Neutral for water heating
Market – Commercial/Industrial High utilization Less sensitive to first cost	Market – Residential/Small-Commercial Low utilization Sensitive to first cost

The entire system including the hot water and coolant loop load interfaces, solar collector, backup gas-fired heater, and controls, was designed and analyzed. Typical average and peak load values were assumed and appropriate storage and backup gas-fired heater capacities were determined.

The initial target market includes small-to-medium scale commercial and industrial users. Solar energy could supply as much as 3.8 quads to the manufacturing sector and 3.2 quads to the commercial sector, mostly as process heating with some as air conditioning (Demeter and Carwile 1992). The Helisorber should provide a simple payback of three to five years in these markets.

Project Objectives

Figure 1 is a schematic flow diagram of the Helisorber absorption cycle showing how the utilities interact with the cycle to produce both heat-pumped hot water and chilled water. In a typical application, city water enters at 70°F, is heated to 95°F in the condenser, and further heated to 130°F in the absorber. The driving solar heat is at 240°F. Hot water from the solar collectors powers the absorption cycle.

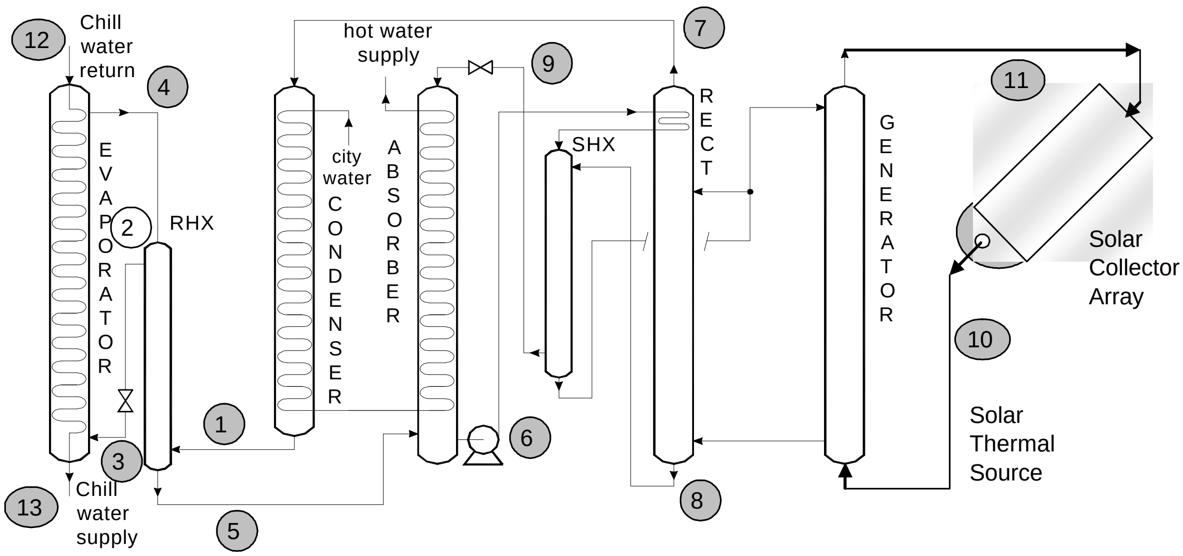


Figure 1– Solar-Powered Helisorber Flowsheet

The absorption cycle is similar to conventional single-effect ammonia-water chillers (Herold et al.1995). The nearly pure ammonia vapor exiting the generator/rectifier is condensed in the condenser. The refrigerant from the condenser is pre-cooled in the Refrigerant Heat eXchanger (RHX) and evaporated in the evaporator. The strong ammonia-water solution (strong in absorbing power) leaves the generator and is subcooled in the Generator Heat eXchanger (GHX) and the Solution Heat eXchanger (SHX). The solution then flows to the absorber and absorbs the vapor from the evaporator. The resulting weak solution exits the absorber and is pumped to the generator/rectifier to complete the cycle.

Figure 2 illustrates the overall operational effect and external heat balance of the 25 RT Helisorber. It is supplied 432,900 Btu/h of heat which is used to heat pump 300,000 Btu/h (25 RT) from the low temperature coolant to the hot water. A net amount of 732,900 Btu/h of heat is thus supplied to the hot water, heating it from 70°F to 130°F. The heating COP of the Helisorber is 1.69. The coolant is chilled from 54°F to 44°F. This cooling is a “free” byproduct of the heat pumping, in the sense that no additional energy is required to produce the cooling.

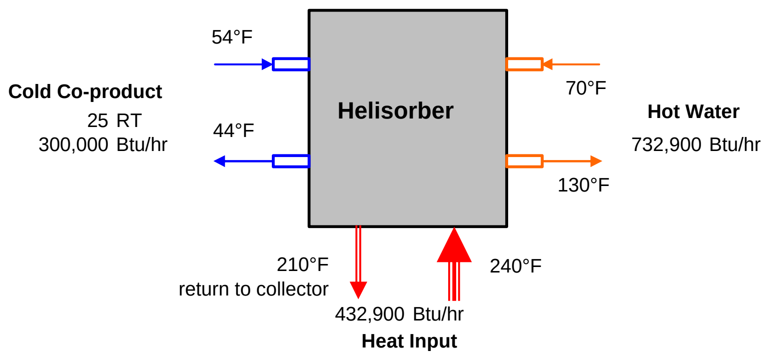


Figure 2- Energy Input/Output Representation of Helisorber

The gas fired precursor to the Helisorber (called "ThermoSorber^{TM}) has been field demonstrated with support from the California Energy Commission. A 15-ton ThermoSorber is installed at a poultry processor in Modesto, California. It has now been operating for four years, and a final report has been published by (California Energy Commission, 2005). A 100-ton ThermoSorber was installed at a poultry processing plant in Livingston, California in January 2006. Its performance was reported by PG&E (Pacific Gas and Electric Company, 2008).

Demonstrate thermodynamic feasibility of the desired performance: COP 0.68; 240°F solar heat; 44°F chilling; 130°F hot water

One key objective of this project was to demonstrate that the dual chilling/hot water output is indeed feasible with lower temperature solar heat (~240°F) powered Helisorber. Solar powering (as opposed to gas-firing) imposes more stringent demands on cycle design and optimization due to the lower temperature of the heat source and the high cost of the collectors. Kim et al. (2005) studied the optimization of a solar ammonia-water absorption chiller. They analyzed the use of stationary CPC, flat-plate, and evacuated tube collectors powering the absorption system at different temperature levels. The flat plate collector operating at about 215°F yielded the lowest investment level. As opposed to the simple absorption chiller studied by Kim et al., the solar heat must be at least about 240°F for the Helisorber in order to achieve the dual chilling/hot water output. This still falls in the range of low-cost low-concentration ratio collectors and avoids the need for the expensive pressure vessels required for a high-temperature high-pressure water system.

Achieve footprint of 3ft X 3ft for a 25 RT Helisorber

Another objective of this project was to achieve a compact footprint. This requires optimization of all the components of the system and thereby also implies optimization of system cost. Absorption systems were initially developed in the 1950s through the early 1970s. The industrial ammonia absorption units of that era used low-performance shell-and-tube heat exchangers, and were big, heavy, and costly. However, during the past few decades great strides were made in reducing the size, weight, and cost of the absorption units (Erickson 2007). This has resulted in more than 50 percent reduction in system size and weight and a competitive cost of about $1,000 per ton. A compact design enables off-site modular/skid design which simplifies shipping and installation and also minimizes refrigerant inventory.

Confirm unit achieves design specifications with variable solar insolation and hot water loads

A third objective of this development effort was to confirm that the unit achieves design specifications with variable solar insolation and hot water loads. Load matching is a problem always faced by integrated appliances. The various loads, which the appliance would like to supply simultaneously, tend to occur at different times and in different quantities than the outputs delivered by the appliance. With sufficient added storage, virtually any hot water profile and cooling load profile can be accommodated. However, there is economic incentive to minimize the amount of added storage. To optimize storage tank size and to accommodate solar insolation variations a backup gas-fired heater can be used.

Confirm fabricability and Demonstrate mechanical feasibility

A fourth objective of this development effort was to confirm fabricability and demonstrate mechanical feasibility. The first three objectives pertain to the development of a successful prototype. However, for the technology to succeed, the unit design must be amenable to low cost mass production. Standard off-the-shelf components, such as shell and coil heat exchangers; plate heat exchangers; pumps; and instrumentation need to be used. Use of proprietary components should be justified and designed with low cost fabrication techniques. The whole design should be scalable so that units with several standard capacities can be fabricated to match diverse market needs.

Confirm net installed cost of $5,000/RT (or less) and 3 to 5 year payback

The final objective of this development effort was to confirm net installed cost and payback. The goal is to fabricate and test a 25 ton prototype to confirm that the performance and fabrication objectives listed above are in fact practical. The projected performance and cost of the technology should result in a payback periods of under five years in representative markets.

Project Approach

The specific tasks performed in order to accomplish the project objectives listed above are:

Task 1 - Perform Helisorber Cycle Thermodynamic Design

This task generated the detailed designs of the cycle and the components. All of the analysis was performed using software programs written in the EES platform (F-Chart 1996). Sophisticated heat and mass exchange models were used to model proprietary cycle features and components (Anand and Erickson 1999). Realistic temperature driving forces and pressure drops were used to ensure a robust design. An iterative process was performed to achieve optimum design.

The Helisorber design is shown in the Figure 3 PFD and Table 2 summarizes the state point thermodynamic conditions. Figure 4 depicts the same cycle on thermodynamic coordinates of pressure and temperature. This flow sheet at those conditions provides 25 tons of chilling, used for cooling water/glycol from 55°F to 44°F, and co-produces hot water at 130°F (from 70^{o}F) all with with 240°F solar heat.

The design process indicated that producing the 130°F hot water with 240°F solar heat resulted in a small concentration differential in the circulating absorbent solution. This increased circulation loses and lowered cycle efficiency. To minimize circulation loses, a plate heat exchanger was specified for the solution heat exchanger and a multi-pass configuration was selected following several iterations with the vendor. The higher circulation rate also resulted in a larger rectifier. An aggressive absorber design was selected to achieve the optimum concentration differential. Based on the thermodynamic design, individual components were specified. Table 3 summarizes the individual component specifications. The SCR and GHX are part of the rectifier (see Figure 3).

Task 2 - Perform Absorber Tests

The Helisorber design indicated that the absorber performance was very critical to achieving design objectives. Hence a new task of evaluating the absorber performance was added to the project. A shell-and-coil arrangement has been successfully used by Energy Concepts in other applications. The absorber is commercially available in standard sizes. Absorber performance data from those units were analyzed to identify the optimum absorber configuration for this application. However, the standard sizes were not sufficient for the Helisorber application. A custom unit was designed and the vendor agreed to supply it. The absorber was tested in a test-stand shown in Figure 5. The test stand is a complete absorption system (50 tons maximum capacity) and the operator could adjust system parameters to achieve desired absorber conditions. The absorber was tested at the 25 RT Helisorber (Table 2) design conditions to verify performance.

Test results corroborate the design projections of heat transfer rate, pressure drop, and approach temperatures listed in Table 2. Following confirmation of absorber performance, the Helisorber design was finalized.

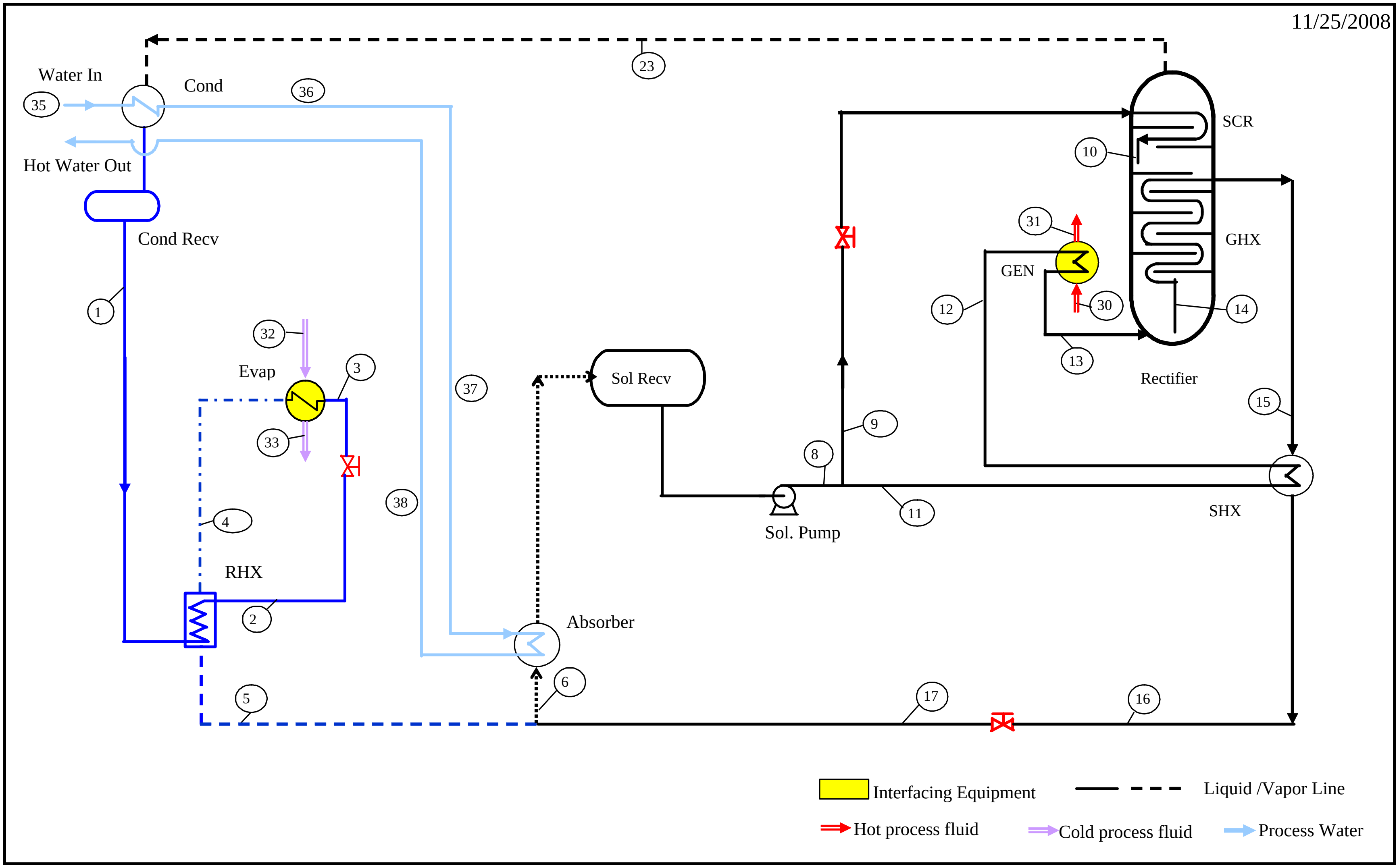


Figure 3– 25 RT Helisorber Process Flow Diagram

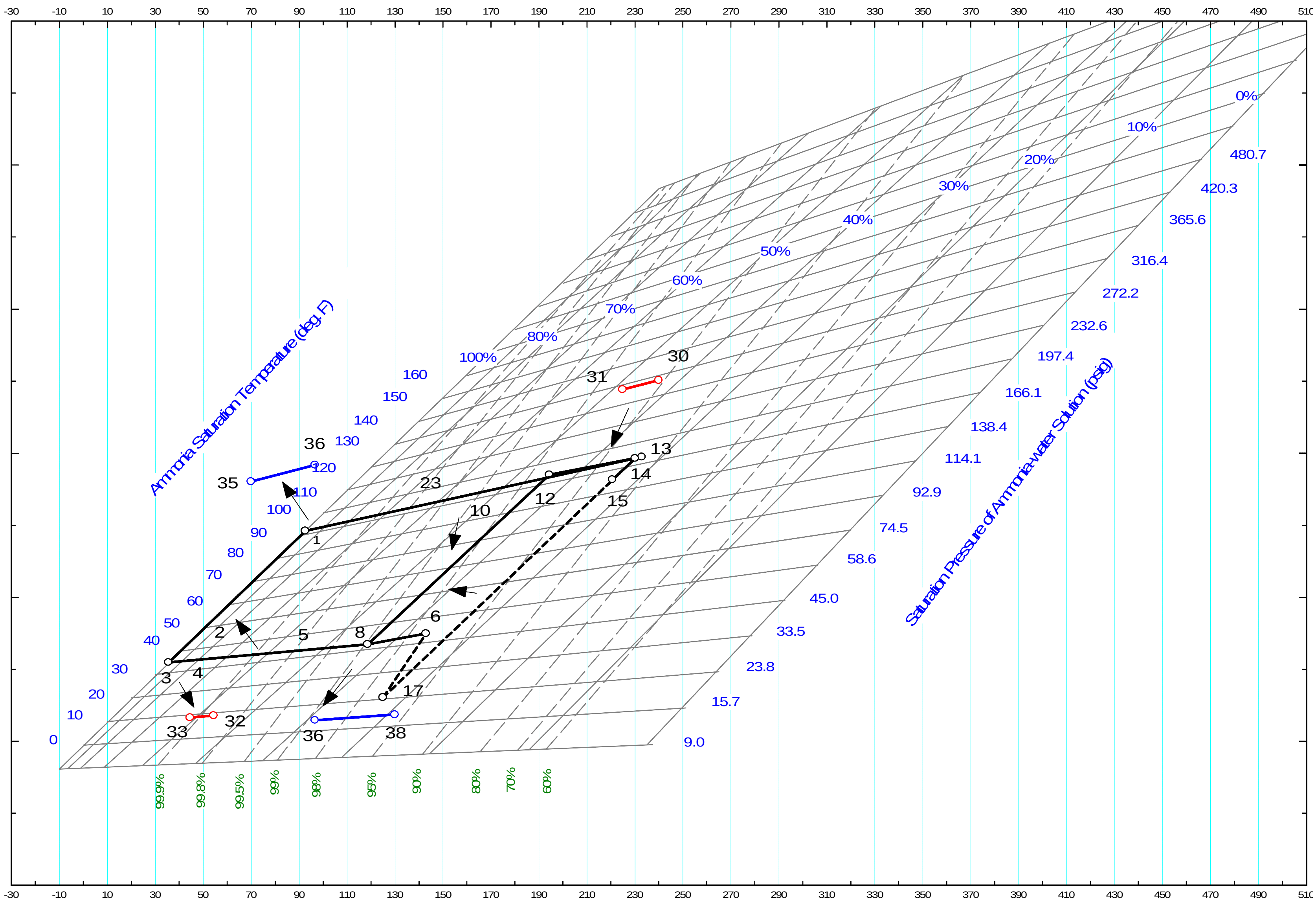


Figure 4 - Helisorber Cycle on Pressure, Temperature Coordinates

Table 2– 25 RT Helisorber Sate-Point Specifications

Flow	Temperature	Pressure	Mass flow	Vapor Quality	Concentration
Stream	F	psig	lb/h		
1	90.43	163.95	617.5	0	0.9830
2	51.10	148.95	617.5	0	0.9830
3	33.64	48.56	617.5	0.0360	0.9830
4	44.15	47.56	617.5	0.9183	0.9830
5	74.23	46.56	617.5	0.9631	0.9830
6	143.01	46.56	4692.9	0.0950	0.3968
7	124.86	45.56	4692.9	0.0184	0.3968
8	120.24	173.95	4692.9	0	0.3968
9	120.24	173.95	757.1	0	0.3968
10	151.79	169.95	757.1	0	0.3968
11	120.24	173.95	3935.7	0	0.3968
12	202.26	169.95	3935.7	0.02797	0.3968
13	233.01	166.95	3935.7	0.15899	0.3968
14	229.62	166.95	4075.4	0	0.3080
15	222.03	151.95	4075.4	0	0.3080
16	126.54	147.95	4075.4	0	0.3080
17	126.54	46.56	4075.4	0	0.3080
18	120.24	45.56	8804.8	0	0.3968
19	120.24	60.56	4111.9	0	0.3968
20	102.31	55.56	4111.9	0	0.3968
23	174.11	165.95	617.5	1	0.9830
24	90.43	163.95	617.5	0	0.9830
30	240.01		30203		
31	225.00		30203		
32	54.50		30290		
33	44.60		30290		
35	70.00		12656		
36	97.30		12656		
37	103.68		12656		
38	129.99		12656		

Table 3– 25 RT Helisorber Component Specifications

	Q	A	LMTD
	kW	m2	K
Generator	134.3	6.68	8.0
Condenser	101.1	5.05	6.7
Absorber	121.1	7.50	9.5
Evaporator	87.9	6.00	5.9
RHX	8.1	1.78	6.1
SHX	125.5	15.00	3.6
SCR	7.8	0.37	27.8
GHX	10.3	0.21	19.3

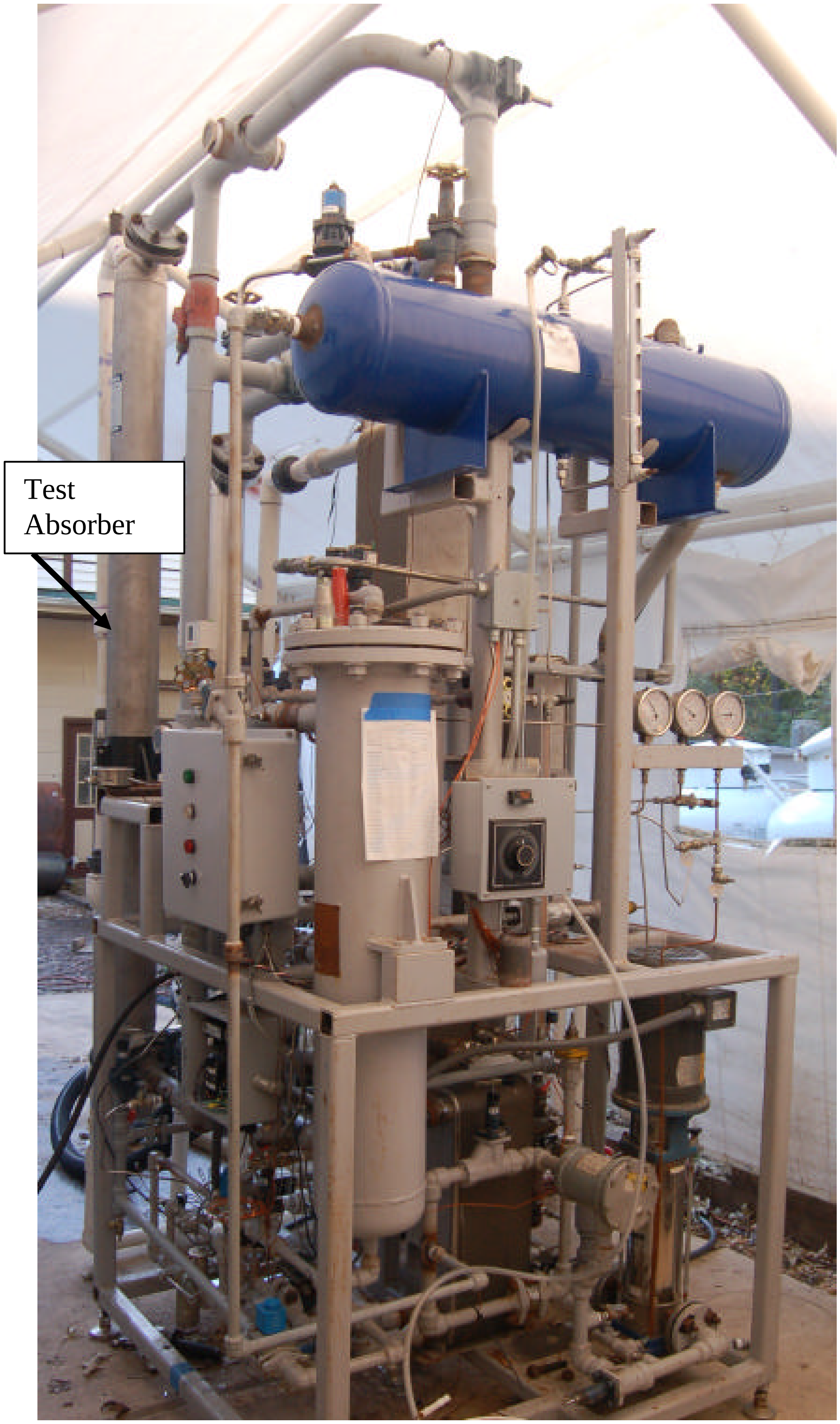


Figure 5 -Absorber Test Stand

Task 3 - Perform Helisorber Mechanical Design

Specification sheets were developed for all components including overall dimensions. The rectifier and RHX components are designed and fabricated by Energy Concepts. For these components sufficient details were show to meet the fabrication shop requirement including identification of any special manufacturing techniques and tooling. All the other components were procured from vendors.

A detailed layout of the Helisorber was prepared showing principal dimensions. The relative location of the components, interconnecting piping, and instrumentation and controls were illustrated along with the utility connections. The detailed design also included structural design for mounting the components, specification of insulation, and design for maintenance access.

Task 4- Perform System Design Calculations

This task focused on the analysis and design of the hot water and coolant loop load interfaces, solar collector and backup gas-fired heater tie-ins, and controls. Appropriate storage and backup gas-fired heater capacities were specified. The control logic for economic Helisorber operation was developed. The startup/shutdown and normal operational controls including the interlock/safety system were specified.

Solar Collector

Table 4 below shows daily solar insolation for flat plate collectors for some major cities in California. The table shows that most places in California have good solar insolation (NREL 2003) with a maximum daily insolation of about 7 kWh/m^2. The average annual insolation is a little less than 5.5 kWh/m^2 per day. The peak solar flux is about 1 kW/m^2. A 25 ton Helisorber with an efficiency (COP) of 0.655 requires 134 kW heat input. This heat input requirement translates to 268 m^2 of collector area with a collector efficiency of 50%.

Analysis of different solar collector performance and cost data indicated that the parabolic troughs were “overkill” – they go to much higher temperatures, and deliver around 60% efficiency. Moreover, they cost about \$30/ft^2 installed. Evacuated tube collectors have an installed cost below \$15/ft^2 (purchased cost below \$10/ft^2). However most are designed for heating, at temperatures below 180°F. At the 250°F temperature their efficiency decreases to below 30%, and hence the overall cost is essentially the same as for parabolic collectors. Also, they do not yet have the required safety features for 250°F operation (tube explosion is a real hazard). Cheaper parabolic collectors (e.g. Heliodynamics) or upgraded evacuated tubes were judged to be the optimum collectors for the project.

System Operation

Figure 6 shows the overall system configuration including the Helisorber, solar array, pumps, controls, appropriate storage, and backup gas-fired heater. Availability of solar energy is sensed by an increase in temperature of sensor T1. When this temperature is higher than a preset value (230°F) the Solar Pump is turned ON. The Solar Pump draws water (glycol) from the Solar Tank

Table 4– Solar Radiation for Flat-Plate Collectors Facing South at a Fixed-Tilt (kWh/m2/day)

	Tilt(deg)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
BAKERSFIELD	Lat + 15	Average	3.5	4.7	5.5	6	6.1	6.1	6.2	6.6	6.7	6.1	4.5	3.4	5.4
		Minimum	2.1	3.1	3.9	4.6	5.5	5.8	5.9	5.8	5.6	5	3.2	2.3	4.8
		Maximum	5.2	5.9	6.8	6.7	6.5	6.3	6.4	6.9	7.2	6.8	5.5	5.2	5.8
FRESNO	Lat + 15	Average	3.2	4.5	5.6	6.2	6.3	6.1	6.3	6.6	6.7	6.1	4.2	3	5.4
		Minimum	2	3.3	4.1	4.8	5.4	5.7	6	5.8	5.8	5.1	2.6	1.7	4.7
		Maximum	4.8	6.1	6.9	6.9	6.7	6.4	6.5	6.9	7.2	6.6	5.4	5	5.8
LONG BEACH	Lat + 15	Average	4.6	5.1	5.5	5.8	5.4	5.2	5.8	6.1	5.8	5.5	5	4.5	5.4
		Minimum	3.5	3.8	4.7	5.1	4.5	4.1	5.3	5.5	4.4	4.4	4	3.2	4.9
		Maximum	5.9	6.5	6.7	6.7	6	5.8	6.2	6.5	6.6	6.2	5.7	5.4	5.6
SACRAMENTO	Lat + 15	Average	3.1	4.3	5.2	5.9	6	6	6.3	6.5	6.6	5.8	3.9	2.9	5.2
		Minimum	2	2.9	3.8	4.4	5.2	5.4	5.8	5.8	5.7	4.8	2.5	1.8	4.7
		Maximum	4.3	6.2	6.8	6.6	6.5	6.3	6.4	6.9	7.1	6.4	5.4	4.7	5.6
SAN DIEGO	Lat + 15	Average	5.1	5.5	5.7	5.9	5.2	5.1	5.6	5.9	5.8	5.8	5.4	5	5.5
		Minimum	4	4.3	5	5.3	4.5	4	4.6	5.4	4.2	4.8	4.3	3.8	5.1
		Maximum	6.1	6.5	6.8	6.7	6	5.8	5.9	6.4	6.6	6.7	6.2	5.9	5.7
SAN FRANCISCO	Lat + 15	Average	3.7	4.4	5.1	5.6	5.7	5.6	5.9	6.1	6.1	5.5	4.1	3.6	5.1
		Minimum	2.8	3.1	3.8	4.2	4.8	4.7	5.6	5.3	5.2	4.3	3.2	2.1	4.6
		Maximum	4.7	6.4	6.8	6.4	6.3	6.1	6.3	6.7	7	6.5	5.2	5	5.5

and/or the Helisorber loop. The Solar Pump flow is modulated to maintain a temperature of about 240°F at T1. The high temperature water flows to the Solar Tank and/or the Helisorber as needed. If T1 falls below a preset minimum value (220°F) due to loss of solar power then the pump is turned OFF. Similarly, if T3 is higher than a preset value (250°F) due the Helisorber being OFF and the Solar Tank being fully charged, then the Solar Pump is again turned OFF. The various temperature limits, idle/stand-by operation, and extreme weather operation will be finalized with input from the solar array supplier.

Hot water draw from the hot water tank is sensed by a drop in temperature of sensor T5 which turns the Helisorber ON. If the Solar Tank sensor T2 temperature is greater than 240°F, valve V1 is opened and valve V2 and the Boiler are kept OFF. The Loop Pump turns ON, circulating the high temperature water (glycol) to power the Helisorber. Colder return water from the Helisorber loop enters the Solar Tank and/or the Solar Pump.

If sufficient solar heat is available then the solar array powers the Helisorber. However, if the solar power drops, water is drawn from the Solar Tank to power the Helisorber. If the temperature at T2 falls below 230°F valve V2 is opened and the boiler turned ON and valve V1 is shut. The Helisorber is now powered by the boiler. The Solar Pump continues to operate and recharges the Solar Tank if solar energy is available. Once the Solar Tank is recharged and T3 reaches 240°F, V1 is opened and V2 and the Boiler are turned OFF. When the hot water demand falls, the Helisorber continues operating till the hot water tank is recharged and T5 reaches a present temperature limit (130°F).

System Sizing

The air conditioning/chilling load of most commercial and industrial establishments requiring hot water is typically substantially larger than the hot water load. Hence, the Helisorber will be sized appropriately for the hot water load. A normal air conditioning plant will usually be required, although it can be downsized to account for the contribution from the Helisorber.

The Helisorber supplies both chilling and hot water and thereby provides energy savings and economic benefits even when operating with the boiler (prime fuel). A full backup boiler can be specified to allow cloudy day or night-time operation. With full backup boiler it is not necessary to have significant solar energy storage. A nominal 1000 gal capacity Solar Tank is provided to optimize solar energy utilization and to minimize boiler cycling.

On the supply side, the hot water tank will be sized based on site hot water demand profile. A minimum capacity of 500 gal is envisioned to minimize Helisorber ON/OFF cycling to 20 minute.

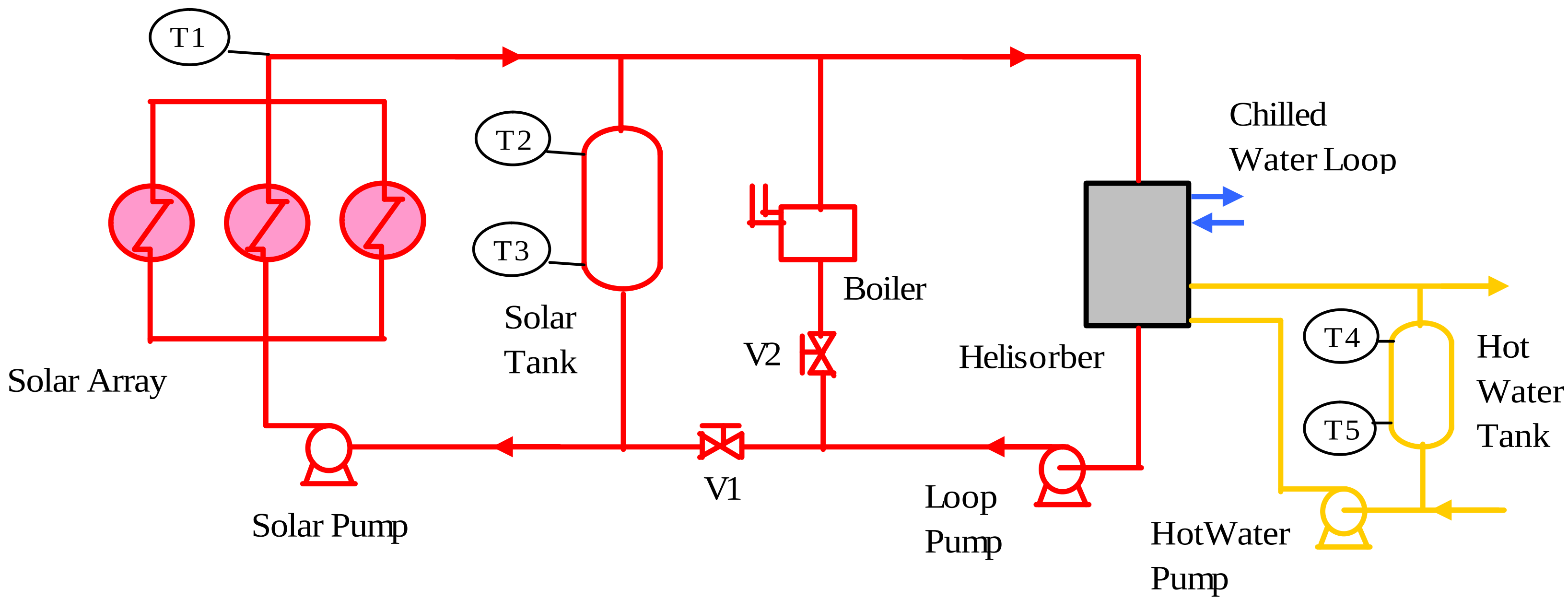


Figure 6 – Helisorber System Configuration

Task 5- Fabricate 25-Ton Helisorber

Energy Concepts fabricated the receivers and the proprietary components (rectifier and RHX). A simpler rectifier fabrication technique was developed to enable lower cost mass production. Standard components, such as shell and coil heat exchangers; plate heat exchangers; pumps; and instrumentation were specified and procured.

The fabricated and procured components and instrumentation were assembled. Easy access to instrumentation and controls, filters, and pumps were provided to facilitate maintenance. The skid frame was fabricated and the components, instrumentation, and controls were assembled. The assembled skid is shown in Figure 7.

Task 6- Plan a System Test of the Helisorber

A test program was developed to verify overall system performance at design conditions and corresponding startup and shutdown sequencing. Table 5 is the test data sheet Run 91208 showing various steady-state parameters that were recorded. Similar data was recorded for several runs with variations in solar hot water temperature and load variations. Individual component and overall prototype performance parameters were recorded and analyzed. Table 6 summarizes the overall system parameters for these test runs.

Testing confirmed that the Helisorber can simultaneously provide 130°F hot water and 44°F chilling from a heat source in the range of 240°F to 250°F. Unit capacity ranged from 23 to 32 tons with chilling COP ranging from 0.6 to 0.63. Most of the components and controls performed at or above design specification. Two components performed slightly below design. These components will be upgraded on future units to achieve the design COP of 0.655.

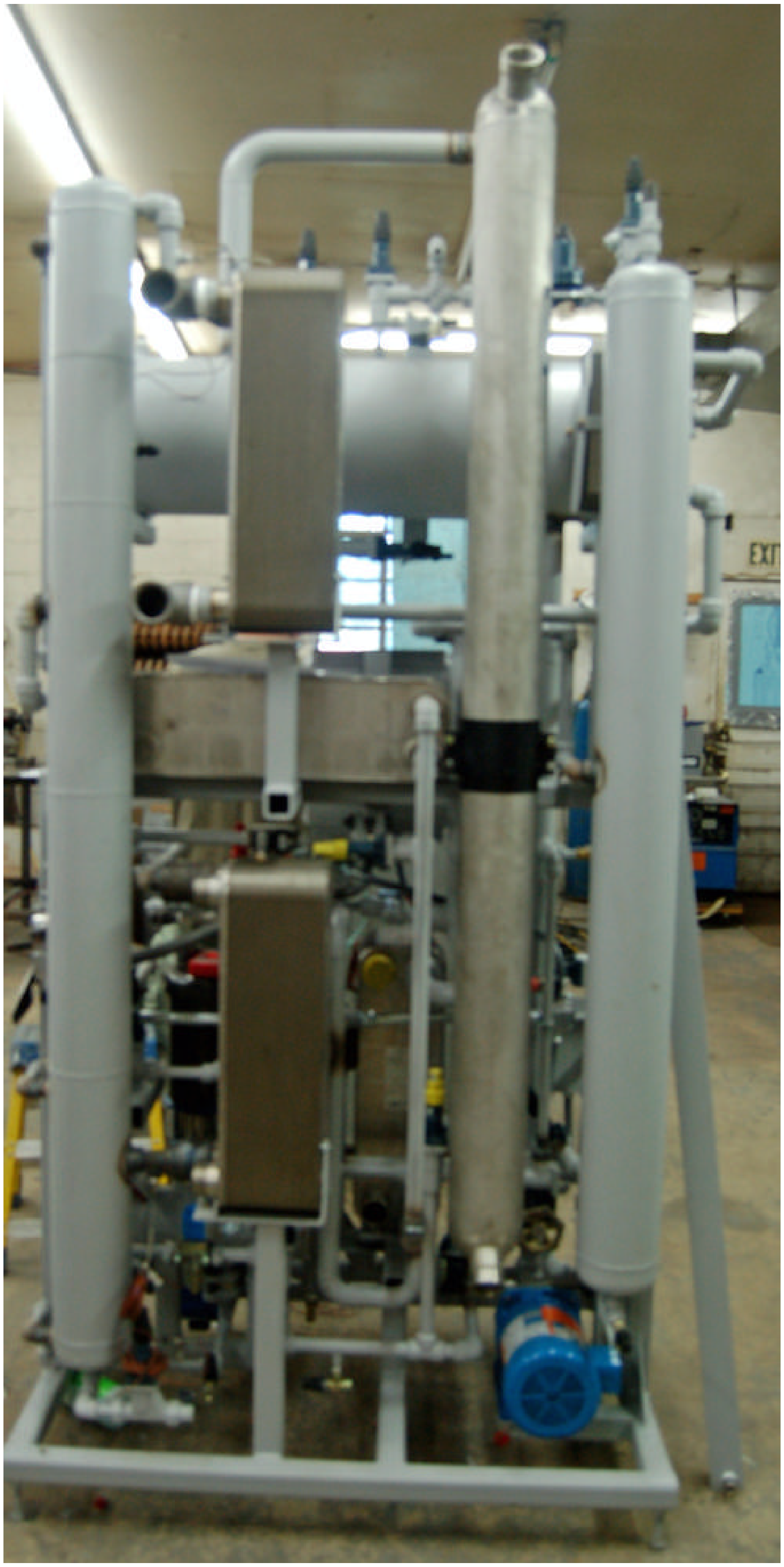


Figure 7 - 25 RT Helisorber

Table 5- Helisorber Test Data- Run 91208

Run 91208				
Temperature (°F)				
1 COND-vap-in (23)	85.3	84.8	84.8	85.7
2 RHX-liquid-out (2)	18.8	19.1	19.1	19.4
3 EVAP-2p-out (4)	16.6	16.7	16.3	16.7
4 RHX-2p-out (5)	29.3	29.4	30.2	29.8
5 ABS -2p-out (7)	49.2	48.9	49.6	49.9
6 SPX-sol-out (20)	46.6	46.6	46.5	46.6
7 SPX-sol-in (19)	48.6	48.7	48.6	48.8
8 SHX sol-in (11)	48.9	48.9	48.9	49.2
9 SHX-sol-out (12)	94.7	94.3	94.1	95.1
10 GEN-sol-out (13)	116.2	115.6	116.1	117.2
11 GHX-letdown-in (14)	114.6	114	114.4	115.2
12 SHX-letdown-in (15)	105.2	104.7	104.9	106.1
14 GEN-EG-in (30)	116.1	115.3	116.1	117.1
15 GEN-EG-out (31)	109.1	109.1	109.8	110.9
16 Cond-cw-in (35)	21.6	21.5	21.7	21.8
17 Cond -cw-out (36)	36.9	36.7	37.4	37.4
18 ABS -cw-in (37)	37.6	37.5	38.2	38.2
19 ABS -cw -out (38)	56.5	56.6	56.9	57.3
20 Evap-cw-in (32)	15.6	15.6	16.2	16.2
21 Evap -cw-out (33)	9	9.5	9.8	10.1
22 Spray-pump-sol-in (18)	47.8	47.7	47.9	48.2
23 SHX-letdown-out (23)	55.3	55.5	55.7	56.6
24 SPX-cw-out	47.1	47.1	47.1	47.5
Flows (gpm)				
Column	1.76	1.76	1.76	1.75
SHX sol	7.44	7.4	7.31	7.2
EVAP- water	50.15	50.15	50.15	50.15
COND-water	23.78	23.78	23.81	23.8
Pressure (psig)				
1 NH3-Rcvr	175	174	175	174
2 Sol-Rcvr	44	44	45	44

Table 6 – 25 RT Helisorber Test Result Summary

Run	COP	RT	thw_in	thw_out	tw_in	tw_out	tevap_in	tevap_out	gpm_solar	gpm_evap	gpm_cond
			[F]	[F]	[F]	[F]	[F]	[F]			
Design	0.655	25	240	225	70	130	54.5	44.6	63.8	60.6	25.3
826083	0.633	32.14	240.5	219.7	68.2	118.9	60.9	48.6	61	57.7	39.4
826082	0.62	25.47	241.3	224.4	66.7	128.8	61.6	51.2	61	58.7	25.7
826081	0.611	25.18	241.5	224.6	67.9	129.9	62.5	52	61	58.8	25.7
902081	0.591	22.48	247.9	232.3	72.4	134.1	65.8	57.5	61	60.5	23.0
902082	0.592	19.41	246.2	232.7	74.8	129.5	59.9	49	61	39.7	22.5
903081	0.581	23.79	246.5	229.7	69.7	135	55.4	46.0	61	61.0	23.7
903082	0.616	25.47	246.6	229.6	68.8	136.3	53.6	44.9	61	61.0	23.6
910081	0.603	24.72	248.8	231.9	69.6	136.4	56.4	46.5	61	61.0	23.5
912081	0.607	23.78	245.7	229.6	71	134.3	60.6	49.3	61	50.2	23.8

Project Outcomes

Demonstrate thermodynamic feasibility of the desired performance: COP 0.68; 240°F solar heat; 44°F chilling; 130°F hot water

The thermodynamic design conformed the feasibility of the Helisorber providing 25 tons of chilling, cooling water/glycol from 55°F to 44°F, and co-producing hot water at 130°F (from 70^{o}F) with solar heat of 240°F. With optimization of various components the target cycle efficiency was lowered slightly resulting in a final design COP of 0.655. The design indicated that the performance was significantly dependent on two components – the solution heat exchanger and the absorber. A multi-pass solution heat exchanger and a custom shell-and-coil absorber meet design performance.

Achieve footprint of 3ft X 3ft for a 25 RT Helisorber

The fabricated 25 RT Helisorber, shown in Figure 7, had a footprint of 44” by 30”. The footprint is of similar area as the original target of 3ft by 3ft. However, the aspect ratio was modified to accommodate a longer receiver and also to provide easy access to instrumentation and controls.

Confirm unit achieves design specifications with variable solar insolation and hot water loads

The integrated system design showed that most places in California have good solar insolation and the 25 RT Helisorber will require 260 m^2 of collector area. Because the Helisorber is efficient even when operating with a backup boiler, only a nominal 1000 gal solar storage tank and a 500 gal hot water tank is needed to optimize solar energy utilization and to minimize cycling to 20 minute.

Confirm fabricability and Demonstrate mechanical feasibility

Fabrication techniques amenable to low cost mass production were employed in fabrication of proprietary components (rectifier and RHX). All other components, instrumentations, and controls are available from vendors. The whole design is amenable to scale up and mass production.

Confirm net installed cost of $5,000/RT (or less) and 3 to 5 year payback

Based on the 25 ton Helisorber design and fabrication a manufacturing cost of $44,000 was estimated. The associated 260 m^2 of collector area cost was estimated as $ 61,000 from vendor data and the installed cost of the combined was estimated as $125,000. These costs are comparable to other absorption system and solar collector costs noted in literature (Garrabrant et al. 2003, NREL 2000).

Table 7 presents energy usage and savings data for delivering hot water and chilling via either conventional technology (gas fired hot water heater plus mechanical vapor compression chilling) or the Helisorber, for 25-ton capacity. Case 1 is for Helisorber operation with solar heat input

Table 7 - 25-Ton Helisorber Energy Savings

	Case 1 Helisorber (Solar only)	Case 2 Helisorber (Full backup)	Conventional Technology ? 25-Ton Chiller ? 0.73 MMBH Water Heater
Hot Water Out	0.76 MMBH	0.76 MMBH	0.76 MMBH
Solar Heat In	0.46 MMBH	-	-
Gas In	-	4.14 therms/h (average)	8.46 therms/h
Chilling Out	25 Ton	25 Ton	25 Ton
Electricity In	1.25 kW	1.25 kW	18.75 kW
Operating Hours/yr	2100	8500	Case 1 – 2100 Case 2 – 8500
HeliSorber Savings ? **Gas** ? **Electricity**	 8.46 therms/h 17.5 kW	 4.32 therms/h 17.5 kW	
Annual Savings ? **Gas** ? **Electricity** ? **Total**	 $22,389 $4,778 **$27,167**	 $46,315 $19,338 **$65,653**	
Installed Cost	$125,000	$135,000	$35,000
Payback	**3.3 yr**	**1.5 yr**	

- Helisorber chilling COP 0.65
- Conventional hot water heating operates at 90% efficiency (HHV); $10,000 installed
- Conventional chilling produced by mechanical vapor compression, operating at 0.75 kW per ton (including air cooling); $25,000 installed
- Energy rates = $1.25/therm (natural gas); $0.13/kWh (electric)
- Annual usage = Case 1- 2,100 hours/year (7 hr/day solar heat, 300 days per year)
  Case 2- 2,100 hours/year solar and 6,400 hours/year backup heater

only for 2,100 hours per year. Case 2 is for Helisorber operation for 2,100 hours per year with solar heat and 6,400 hours per year with backup heat (8,500 hours per year total).

The projected savings for Case 1 is 1.78 billion BTU per year natural gas, plus 36,750 kWh per year electricity. The projected energy savings for Case 2 is 3.68 billion BTU per year natural gas, plus 148,750 kWh per year electricity. This results in 2 to 4 year payback before subsidies or credits. This is at least 50% shorter payback than conventional solar thermal technologies.

Table 7 represents typical applications of the Helisorber in commercial (hotels, laundries, hospitals etc) and light industrial (food processing, drying) applications where 44°F chilling and 130°F hot water is needed. However, the design can be adapted to varying site demands as shown in Figure 8. The figure shows the standard cycle (ABCD) for the 44°F chilling and 130°F hot water. If higher temperature hot water (140°F e.g.) is needed then the Helisorber condenser and absorber have to operate at higher temperature as shown by cycle (1234). The solar heat input temperature is correspondingly higher (~260°F) and parabolic-collectors may be needed. However, if chilling is at a higher temperature, then the higher temperature hot water can be supplied with the 240°F solar heat (cycle abcd). If the site has no chilling requirement then the Helisorber can use the ambient air or a waste heat source to provide the evaporator heat. In some cases only the absorber heat is useful and the condenser heat has to be rejected (higher inlet water temperature, higher chilling-to-heating ratio). Applications without useful chilling will have about 20% longer payback and applications with only absorber heat recovery will have proportionately longer payback periods. If chilling alone is required a more efficient cycle should be used (Erickson 2007). Chilling efficiency COP) of 0.75 can be achieved with a single effect cycle and much higher efficiency with double-effect and other advanced cycles.

Conclusions

This project demonstrated the feasibility of simultaneously providing chilling and heat pumped hot water with low-cost low-concentration ratio solar collectors. The Helisorber has about 65 percent higher water heating efficiency than any existing solar heating product and the free chilling is a byproduct of the heating.

The prototype Helisorber performed essentially as designed. With 240°F solar heat, the Helisorber delivered 130°F hot water at a COP of 1.6, and 44°F chill water at a COP of 0.6. The very compact footprint simplifies shipping and installation, and makes this the world’s most compact solar thermal chiller.

The Helisorber does not require a cooling tower, as the heat rejection is to the hot water. With a natural gas fired boiler no solar storage is required. Both of these features contribute to low system cost. The net installed cost of the complete system was estimated as $5,000/RT. Cost estimation with representative utility costs confirmed a 3 to 5 year payback. The Helisorber promises to be the most economical solar thermal technology available.

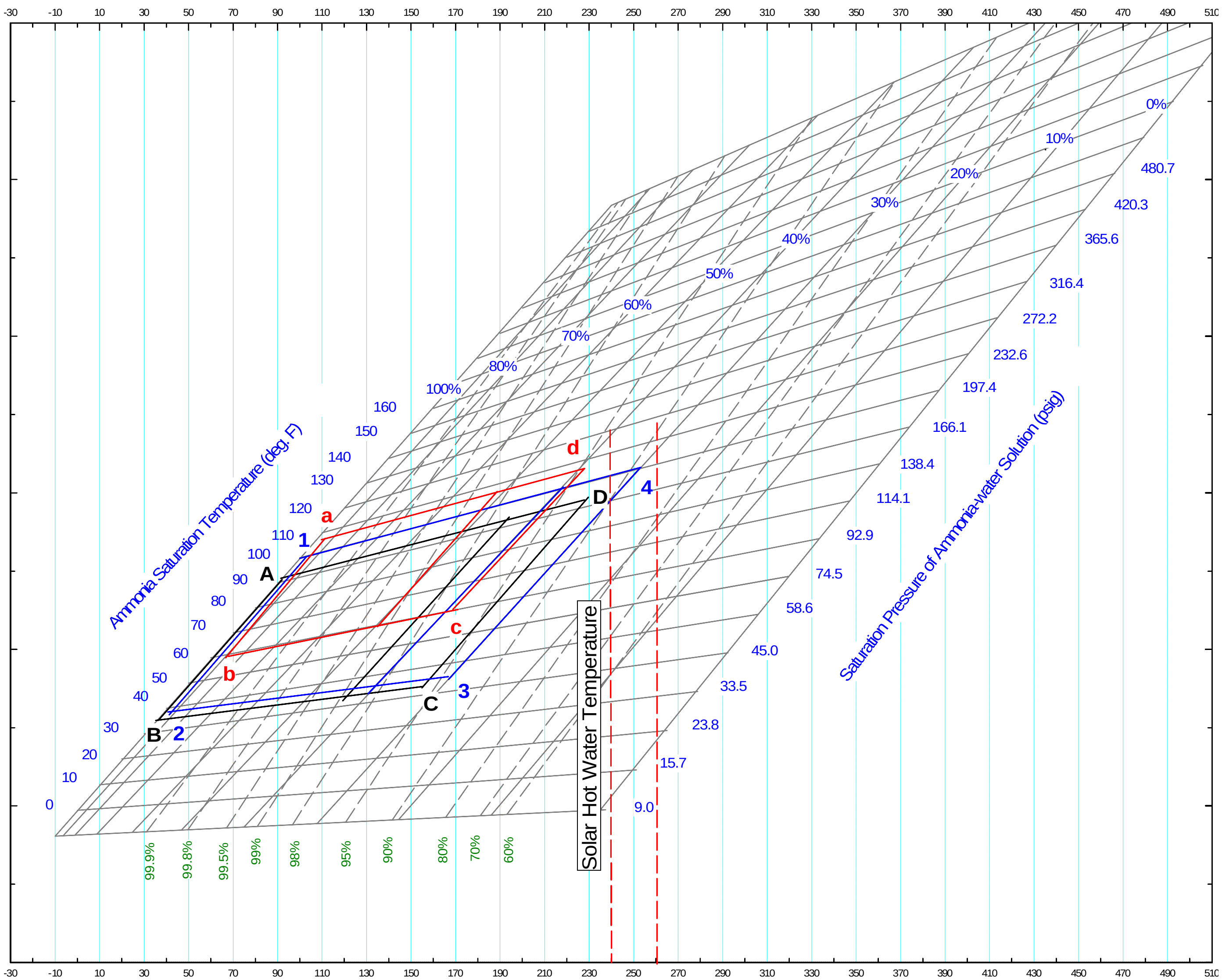


Figure 8 - Helisorber Options

The 25-ton Helisorber is targeted towards commercial and industrial users such as hotels, hospitals, and food processors. Such markets are less sensitive to initial cost. They also have adequate year round chilling and hot water loads thereby realizing the most energy cost savings.

Recommendations

Based upon the conclusion that the Helisorber promises to be the most economical solar thermal technology available, a demonstration program should be initiated to field-demonstrate at least four Helisorbers in a variety of applications in 2009 to validate the economic benefits. Plans should be made to rapidly ramp up production to thousands of units per year. The next steps are:

1. Locate field demonstration sites.
2. Update system design to match host site requirements.
3. Manufacture four field test prototypes.
4. Qualify various solar collectors (at least 2)
5. Field-test the Helisorbers to validate energy savings and economics.
6. Perform a market assessment to estimate the market penetration and economic/energy impact in California.
7. Publicize and advertise Helisorber performance and economics.
8. Develop residential scale units.

Public Benefits to California

Lodging, food service, and health care use 169 trillion BTU of total fuel per year in California. 79 trillion BTUs are consumed as natural gas. Of this, 53.5 trillion BTU are used for space and water heating. The largest gas customers in these 3 industries use 25% of the total energy consumed (US Energy Information Agency, 1998).

Energy Concepts Company expects to achieve at least 25% market penetration at this size range. In terms of the 25-ton Helisorber, which saves 3.68 billion BTU per year of natural gas and 148,750 kWh per year (Table 7), this represents an installed base of over 900 Helisorbers expected to be achieved within ten years. At that level of penetration the Helisorber will save 3.3 trillion BTU (900*3.68 billion BTU) of natural gas per year in California plus eliminate the need for 134 million kWh (900*148,750 kWh) of electricity. The reduction in CO_2 emissions associated with the 3.68 billion BTU savings in gas consumption per 25 RT Helisorber is estimated at 195 metric tons of carbon per year (3.68 billion BTU *53.05 ton CO_2 per billion BTU, California Energy Commission 2002b).

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California Energy Commission Energy Innovations Small Grant (EISG) Program **PROJECT DEVELOPMENT STATUS**	**Questionnaire**

Answer each question below and provide brief comments where appropriate to clarify status. If you are filling out this form in MS Word the comment block will expand to accommodate inserted text.

Please Identify yourself, and your project: **PI Name** Don Erickson ___**Grant** # _55032A/06-01G

Overall Status	
Questions	**Comments:**
1) Do you consider that this research project proved the feasibility of your concept?	*Yes. Both the performance and economic benefits of the Helisorber were successfully demonstrated.*
2) Do you intend to continue this development effort towards commercialization?	*Yes. We are contacting several collector manufacturers and potential host sites for field demonstrations.*
Engineering/Technical	
3) What are the key remaining technical or engineering obstacles that prevent product demonstration?	*None.*
4) Have you defined a development path from where you are to product demonstration?	*A plan to field four prototypes and to qualify various collectors has been developed.*
5) How many years are required to complete product development and demonstration?	*Two years.*
6) How much money is required to complete engineering development and demonstration?	*About $500,000 to demonstrate four units.*
7) Do you have an engineering requirements specification for your potential product?	*Capacity – 25 tons* *Solar heat – 240°F* *Efficiency (COP) – 0.65 (chilling)* *Chilling – 44°F* *Hot Water – 130°F* *Cost - $125,000 installed*
Marketing	
8) What market does your concept serve?	*Commercial and industrial users with adequate chilling and hot water loads, such as hotels, hospitals, and food processors.*
9) What is the market need?	*The market need is the reduction of high energy consumption by these users for this purpose (hot water and chilling)*
10) Have you surveyed potential customers for interest in your product?	*No.*
11) Have you performed a market analysis that takes external factors into consideration?	*No.*
12) Have you identified any regulatory, institutional or legal barriers to product acceptance?	*No.*

13) What is the size of the potential market in California for your proposed technology?	*Lodging, food service, and health care use 53.5 trillion BTU of gas for space and water heating. The largest gas customers in these 3 industries use 25% of the total energy consumed. Energy Concepts Company expects to achieve at least 25% market penetration at this size range.*
14) Have you clearly identified the technology that can be patented?	*Energy Concepts holds patents to key components required to achieve performance and cost targets.*
15) Have you performed a patent search?	*YES. This product does not infringe or appear to infringe on any other active or expired patent.*
16) Have you applied for patents?	*None on this project.*
17) Have you secured any patents?	*Energy Concepts holds numerous background patents*
18) Have you published any paper or publicly disclosed your concept in any way that would limit your ability to seek patent protection?	*Yes.*
Commercialization Path	
19) Can your organization commercialize your product without partnering with another organization?	*Energy Concepts has established a limited manufacturing capability able to manufacture approximately one hundred of the 25-ton Helisorbers per year, which should cover the anticipated demand for the first two or three years.* *Energy Concepts is already working with gas utilities(PG&E, SoCal) and Desert Power in California to commercialize the related Thermosorber product in California. We are also talking to collector manufacturers for potential partnership(s).*
20) Has an industrial or commercial company expressed interest in helping you take your technology to the market?	*No.*
21) Have you developed a commercialization plan?	*No.*
22) What are the commercialization risks?	*A return of low energy prices; high subsidies to competing solar technologies.*
Financial Plan	
23) If you plan to continue development of your concept, do you have a plan for the required funding?	*Yes.*
24) Have you identified funding requirements for each of the development and commercialization phases?	*No.*
25) Have you received any follow-on funding or commitments to fund the follow-on work to this grant?	*No.*
26) What are the go/no-go milestones in your commercialization plan?	*NA*
27) How would you assess the financial risk of bringing this product/service to the market?	*Medium risk, but lower than other solar technologies.*

28) Have you developed a comprehensive business plan that incorporates the information requested in this questionnaire?	*No.*
Public Benefits	
29) What sectors will receive the greatest benefits as a result of your concept?	*Commercial, industrial, and the environment.*
30) Identify the relevant savings to California in terms of kWh, cost, reliability, safety, environment etc.	*Each 25-ton Helisorber saves 3.3 billion BTU per year natural gas, and 148,750 kWh per year. With an installed base of 1,270 Helisorbers, expected to be achieved within ten years, the Helisorber will save 4.2 trillion BTU natural gas per year in California plus 90 million kWh of electricity.*
31) Does the proposed technology reduce emissions from power generation?	*The reduction in CO_2 emissions associated with the 3.3 billion BTU reduction in energy consumption is estimated at 16 metric tons of carbon per year (per 25 RT Helisorber).*
32) Are there any potential negative effects from the application of this technology with regard to public safety, environment etc.?	*The technology uses ammonia as refrigerant and applicable codes and standards must be followed.*
Competitive Analysis	
33) What are the comparative advantages of your product (compared to your competition) and how relevant are they to your customers?	*Simultaneous heating and chilling* *Twice as much value for the user* *Minimized auxiliary components* *Results in 2 to 4 year payback before subsidies or credits*
34) What are the comparative disadvantages of your product (compared to your competition) and how relevant are they to your customers?	*Uses ammonia and nominal capacity of 25 tons.* *These are not show stoppers for most commercial and industrial users.*
Development Assistance	
The EISG Program may in the future provide follow-on services to selected Awardees that would assist them in obtaining follow-on funding from the full range of funding sources (i.e. Partners, PIER, NSF, SBIR, DOE etc.). The types of services offered could include: (1) intellectual property assessment; (2) market assessment; (3) business plan development etc.	
35) If selected, would you be interested in receiving development assistance?	*Yes – cost share support for demonstration projects, plus publicity.*