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Field Study of a ThermoSorber™ System

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TABLE OF CONTENTS

1. EXECUTIVE SUMMARY	3
2. INTRODUCTION	6
2.1 Project Background.....	6
2.2 Project Objective.....	6
2.3 Host Site.....	6
3. THERMOSORBER™ PROCESS.....	8
4. FIELD PERFORMANCE MONITORING DESIGN	11
4.1 Existing Instrumentation.....	11
4.2 Monitoring Equipment.....	13
5. PERFORMANCE EVALUATION METHODOLOGY	16
5.1 System Efficiency	16
5.2 Surface heat loss	17
5.3 System Output Capacity	18
6. RESULTS AND DISCUSSION	20
7. CONCLUSIONS.....	26

TABLE OF FIGURES

Figure 1 Energy flow of the ThermoSorber™ System.....4

Figure 2 Schematics of the host site chilled water and hot water storage system.....7

Figure 3 ThermoSorber™ process and energy flow diagram.....8

Figure 4 ThermoSorber™ system Pictures10

Figure 5 Schematics of the field study Envelope11

Figure 6 Schematics of additional equipment installed on the steam input line14

Figure 7 Monitoring equipment installed on the steam input line.....15

Figure 8 Flow meter installed on the steam condensate return line15

Figure 9 Sample data of chilled water and hot water flow rates – one week.....20

Figure 10 Sample data of hot/chilled water temperature – one week21

Figure 11 Sample data of steam input condition – one week21

Figure 12 Sample host site ThermoSorber™ maintenance log.....22

Figure 13 Long-term ThermoSorber™ operation data.....22

Figure 14 ThermoSorber™ performance curve24

1. EXECUTIVE SUMMARY

The ThermoSorber™ is an ammonia absorption based refrigeration technology. It takes thermal energy, e.g. steam or high-temperature flue gas, as primary energy input and can provide cooling and heating at the same time. For applications in food processing industry and hospitals, where both chilled water and hot water are needed, this technology has large energy savings potential over conventional technologies. Under the support by the PG&E Emerging Technologies Department, Heschong Mahone Group (HMG) conducted a field study to assess the performance of a ThermoSorber™ system installed at a California food processing plant.

The objective of this study was to investigate the performance of a ThermoSorber™ system under field operating conditions. The project team installed monitoring equipment and conducted continuous monitoring for about two months starting from October 10, 2007. The HMG project staff reviewed the host site maintenance logs for long-term performance assessment. Energy flows associated with steam input, chilled water, hot water, and electric power were evaluated to calculate system efficiencies and output capacity. The project team also interviewed the host site maintenance personnel to assess the impact of several operation and maintenance issues to the energy savings potential.

Operation Conditions

The host site ThermoSorber™ used steam as primary energy input and produced chilled and hot water. Figure 1 illustrates the ThermoSorber™ process and energy flows. During the monitoring period of this study, the average chilled water temperature was 54 °F and the average flow rate was about 123 GPM. The average hot water temperature was 121 °F and the average flow rate was about 120 GPM. The city water supply temperature was relatively constant at about 70 °F. The input steam temperature was about 315 °F and the average flow rate was estimated to be 1700 lb/hr. The system consumed a small amount of electric energy, about 1.2% of the net steam energy input, primarily for two ammonia pumps. Total system surface heat loss was assessed with a simplified heat transfer model. It was less than 1% of the net steam energy input.

System Efficiency

The ThermoSorber™ efficiency was demonstrated with two types of coefficient of performance (COP), $COP_{\text{Heat Pump}}$ and COP_{Overall} , which are defined as:

$$COP_{\text{Heat Pump}} = \frac{\text{Total hot water energy output}}{\text{Total steam and electric energy input}}$$
$$COP_{\text{Overall}} = \frac{\text{Total hot and chilled water energy output}}{\text{Total steam and electric energy input}}$$

The $COP_{\text{Heat Pump}}$ was estimated to be 1.48. This result indicates that the ThermoSorber™ was at least 48% more efficient than direct water heating with steam, which has a theoretical COP of 1. It should be noted that the host site did have a parallel process using steam to generate hot water through a heat exchanger. The COP_{Overall} includes the benefits of both the chilled water and hot water and it was estimated to be 1.97. So, in addition to the efficient water heating process, the ThermoSorber™ also produced chilled

water (equivalent to 49% of system energy input), without additional energy input. Therefore, it is clear that ThermoSorber™ is an energy efficient technology for producing chilled and hot water.

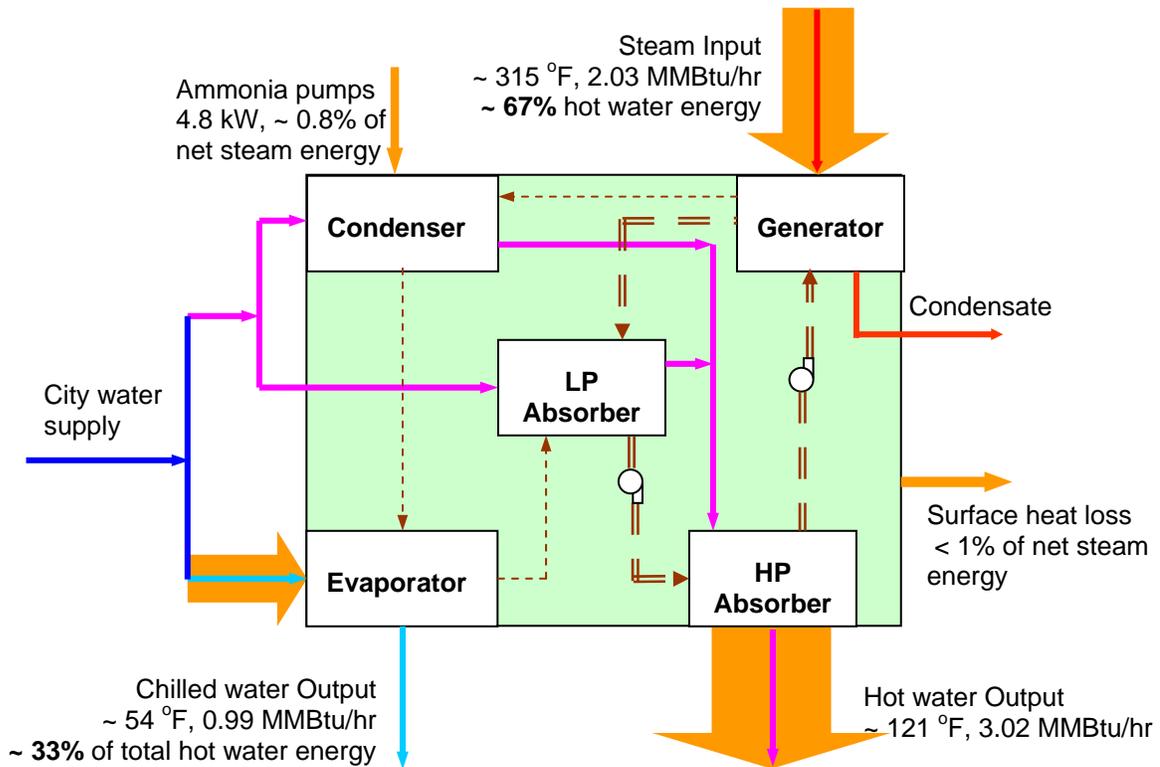


Figure 1 Energy flow of the ThermoSorber™ System

System Output

The rated cooling capacity of the ThermoSorber™ system is 100 Ton. The monitoring results indicated that the average chilled water output during operation was about 82 Ton. This low output was likely due to inadequate steam input. The host site maintenance personnel indicated that higher steam flow settings would lead to steam leak into the condensate system. In an effort to boost system output, the host site decided to build a dedicated condensate tank for handling large steam flow. HMG project staff pointed out to the host site that steam traps on the condensate line were more likely to be undersized and limiting the steam flow. Larger steam traps should be considered as a method to allow higher steam flows. The ThermoSorber™ manufacturer should provide technical assistance to the users to achieve the rated system capacity. This may include system re-commissioning.

Long-term Monitoring

This study also indicated that the system heat loss and electric power input were very small compared to the net steam energy input. When auxiliary pump energy and surface losses are treated as negligible, the hot water energy, chilled water energy and net steam energy form a First Law energy balance in the following way:

$$\dot{E}_{hot\ water} = \dot{E}_{chilled\ water} + \dot{E}_{steam}$$

Net steam energy (entering steam enthalpy minus leaving steam/water enthalpy) can be calculated from the difference of the hot water and chilled water energies. Future performance monitoring can more easily be accomplished by just measuring the city water supply, hot water, and chilled water temperatures and flowrates. Since the onboard sensors are measuring these conditions, HMG project staff suggests that a long-term performance monitoring be carried out to investigate possible performance degradation.

Maintenance Considerations

During the majority of the two-month field monitoring, the ThermoSorber™ was running smoothly. System malfunction occurred once as ammonia level in one of the internal storage tanks was too low and no hot water and chilled water were produced. The ThermoSorber™ manufacturer indicated that ammonia loss was due to the monthly ammonia pump filter change. Occasionally, HMG project staff smelt ammonia, especially when working beneath the system. The host maintenance personnel also reported occasional ammonia leaks on maintenance logs. It was not clear how much the occasional ammonia loss contributed to the total ammonia loss.

According to the host site staff, large scale ammonia leakage is considered a safety hazard by the California Occupational Safety and Health Administration (OSHA). The uncertain level of ammonia leak poses a potential safety concern to the host site. The ThermoSorber™ manufacturer could provide more assistance to adequately address the issue when leakage is ongoing. The project team also noticed that the manufacturer had not provided any system manuals or in-depth training to the host site staff. This study recommends that the manufacturer provide maintenance materials and training for the host site staff.

The host site also raised some concerns on ThermoSorber™ designs, which could impact long-term system maintenance costs. Many of the major heat exchangers were welded to the connecting pipes, making it very difficult and costly for potential parts replacement. Some of the key heat exchangers, e.g. the evaporator, were not standard equipment. The host site staff was concerned about the future part replacement costs.

2. INTRODUCTION

2.1 Project Background

The ThermoSorber™ technology is a promising energy efficient technology for providing chilling and heating. It has high energy savings potential in hospital and food processing application where both chilled water and hot water are required. Heschong Mahone Group (HMG) conducted a field study of a ThermoSorber™ system to assess its energy performance. This study was sponsored by the PG&E Emerging Technologies Department in its continued effort to identify and promote energy efficient technologies.

The ThermoSorber™ is manufactured by Energy Concepts and is based on the ammonia absorption refrigeration cycle. It takes steam or high-temperature flue gas as primary energy source to provide chilling and heating. The chilling process is, in principle, the same as conventional absorption-based refrigeration technologies. The heating is achieved by utilizing the thermal energy released by the working fluids during condensation and ammonia absorption. In conventional technologies, such energy is often released into the atmosphere via a heat rejection device such as a cooling tower. Obviously, this technology is valuable in applications where both heating and cooling are required at the same time.

2.2 Project Objective

The project objective is to assess the energy performance of a ThermoSorber™ system under field operation conditions.

HMG project staff conducted continuous monitoring of conditions for steam input, steam condensate, chilled water, hot water, and supply water. System electric input was also measured several times during the course of the study. HMG project staff also evaluated ThermoSorber™ long-term performance based on the host site maintenance logs and the process data recorded by the on-board data logger. The host site personnel were interviewed to assess system maintenance requirements.

2.3 Host Site

The ThermoSorber™ system in this study was installed at a food processing plant in California. It was rated to have a cooling capacity of 100-Tons. It was used by the host site as a supplementary system to the existing refrigeration and heating capacities, as illustrated by Figure 2. The hot water and the chilled water were taken into corresponding storage tanks before being used. If either storage tank was full, the ThermoSorber™ would be set to standby mode.

The host site staff intended to operate the ThermoSorber™ continuously during weekdays and shut down the unit during the weekend. Occasionally, the chilled water demand was low and the system had to be placed into standby mode for a short period of time. According to maintenance personnel, hot water demand was always more than what could be supplied by the ThermoSorber™ ; therefore, rejecting heat through the hot water supply was never the limiting factor for system operation.

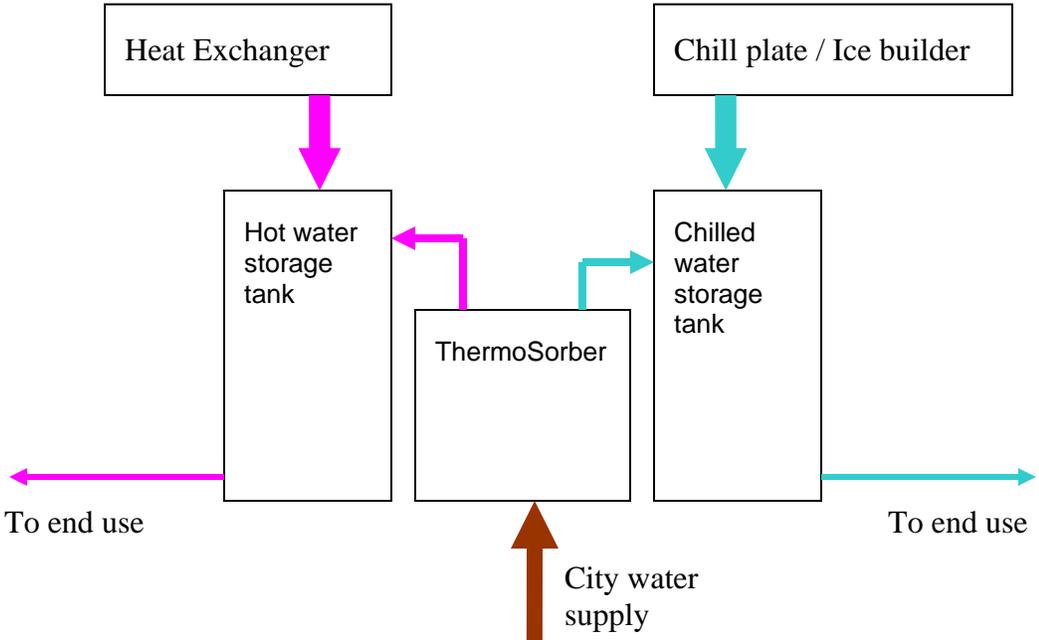
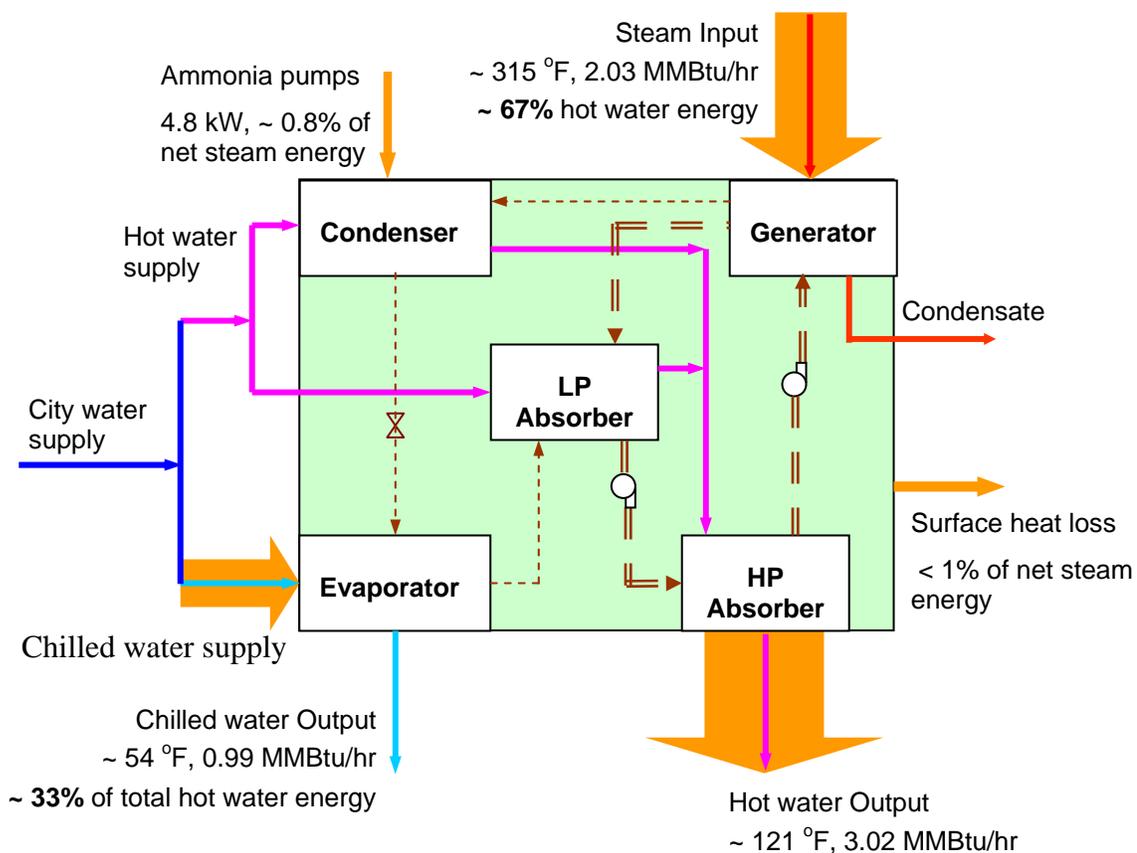


Figure 2 Schematics of the host site chilled water and hot water storage system

3. THERMOSORBER™ PROCESS

Figure 3 illustrates the ammonia absorption cycle inside the ThermoSorber™ system. The diagram also shows the energy balance between different inputs and outputs. At the condenser, high-pressure ammonia vapor is cooled and condensed into liquid phase by part of the hot water supply. After passing through an expansion valve, ammonia pressure is suddenly reduced, flashing some of the ammonia into vapor phase at the evaporator. The city water supply entering the other side of the evaporator is cooled to the desired low temperatures, by giving up thermal energy to evaporate the liquid ammonia. After leaving the evaporator, ammonia vapor is absorbed by the ammonia-water solution at two pressure levels. The absorption processes are exothermic and heat the supply water at two stages. The high concentration ammonia solution was pumped into the generator at a higher pressure. When heated by the steam, ammonia was desorbed from the solution to form high-pressure ammonia vapor, which was taken into the condenser to continue the cycle. At the same time, low concentration ammonia solution flowed back to the low-pressure absorber to sustain the ammonia absorption cycle.



*Figure 3 ThermoSorber™ process and energy flow diagram
 Solid lines: water/steam; Dashed lines: ammonia; Double dashed line: ammonia/water solution*

Chilled water is produced at the evaporator. Hot water is generated in two stages. The first stage is at the condenser plus the low-pressure absorber. The second stage is at the high-pressure absorber.

The diagram in Figure 3 also illustrates the system energy flow. Both steam input and chilled water supply release thermal energy to system working fluids, ammonia and ammonia solution, which, in turn, transfers the thermal energy to the hot water. The ammonia pump power also adds a small amount of energy into the system. System surface heat dissipation was the only route of energy loss and it is also small.

Pictures in the Figure 4 show the ThermoSorber™ system installed at the host site. City water supply was pumped into the system by a booster pump. The steam supply was from the host site boiler. Both water flow and steam were regulated by manual controlled valves. The ThermoSorber™ did not have any internal flow control mechanisms. Any flow variation would come from variation in supply pressures. For the water supply, the pressure variation was relatively small; therefore the flow rates were relatively constant. Steam input pressure had relatively large and frequent fluctuation; therefore the flow variation was large. The chilled water and hot water output temperatures were determined mainly by steam supply and the cycle efficiency.

(a) ThermoSorber™ system front view



(b) ThermoSorber™ system side view with the piping system



Figure 4 ThermoSorber™ system Pictures

4. FIELD PERFORMANCE MONITORING DESIGN

Figure 5 shows the schematics of the host site ThermoSorber™ system, with the dash-line box shows the physical scope of this study. The city water booster pump was considered to be the unique requirement by the host site configuration and was not included in the study. Figure 5 also shows the required process parameters for performance monitoring. These parameters were measured with a combination of existing on-board sensors and additional sensors installed by HMG project staff.

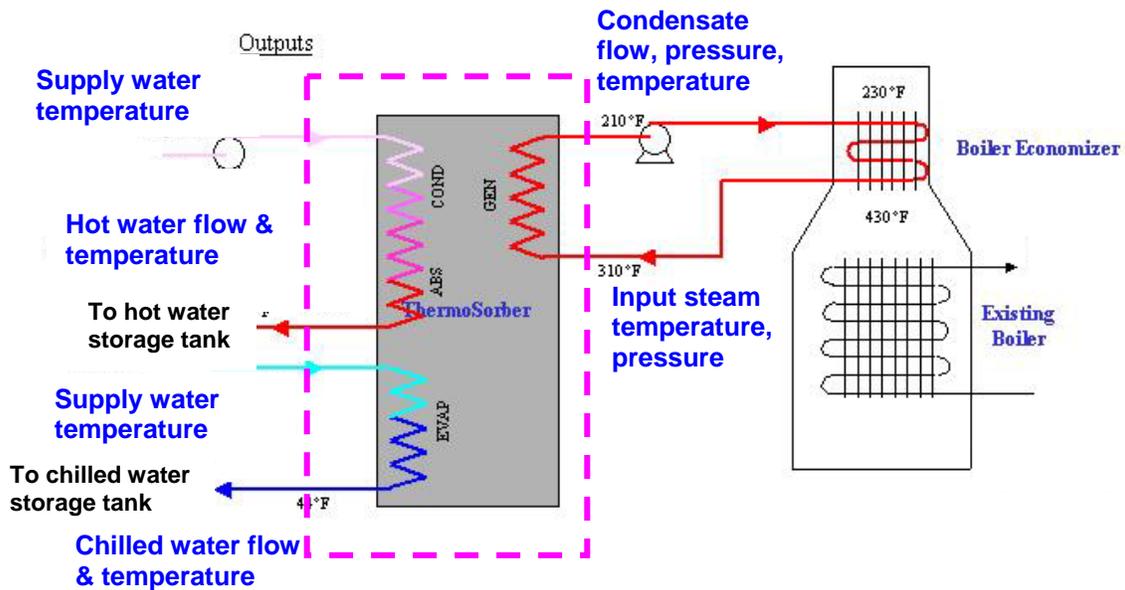


Figure 5 Schematics of the field study Envelope

4.1 Existing Instrumentation

Table 1 lists the process parameters and sample data measured by existing on-board sensors. The system had an on-board HOBOTM data logger, which was configured to record temperatures of city water supply, hot water output, chilled water output, and condenser water output.

Table 1 Existing Measurement Point and Sample Values

Foster Farms 100-ton ThermoSorber (Date: 5/24/07 Time: 9:00 am)			
Measurement Point	Average	Measurement Point	Average
Temperature (°F)		Temperature (°F)	
1 COND-vap-in	198.9	19 COND-cw-out	107.2
2 RHX-liquid-out	65.7	20 LT-ABS-cw-out	97.8
3 EVAP-2p-out	65.5	21 HT-ABS-cw-in	106.9
4 RHX-2p-out	85.5	22 HT-ABS-hw-out	127.6
5 LT-ABS-sol-in	131.6	23 BR-pump inlet	131.1
6 LT-ABS-sol-out	90.6	Flow (GPM)	
7 SCR-sol-in	95.0	BR-pump	17.88
8 SHX-sol-in	136.5	LT-pump	8.96
9 SHX-sol-out	221.8	Chill water	117 ~ 121
10 GEN-sol-out	297~309	Hot water	-
11 GHX-letdown-in	268~280	COND-cw	56
12 GHX-letdown-out	222.4	LT-ABS-cw	50
13 SHX-Letdown-out	164.3	Pressure (PSIG)	
14 GEN-steam-in	319.4	LT-pump-out	231.3
15 GEN-condensate-out	299~309	LP (BR-rcvr)	50.7
16 EVAP-cw-in	70.6	HP (NH3-Rcvr)	201.0
17 EVAP-cw-out	51.5	BR-pump-out	249.7
18 EVAP-cw-out	50.6	Condensate-out	63.7

4.2 Monitoring Equipment

Table 2 provides a summary of the required process parameters for performance evaluation, along with their monitoring status in the study.

Table 2 Monitoring Equipment Summary

Process Parameter	Symbol	Monitoring Status
For determined steam energy input, \dot{E}_{steam}		
Steam flow rate	\dot{m}_{steam}	Not directly measured; use the condensate flow $\dot{m}_{steam} = \dot{m}_{condensate}$
Steam pressure	P_{steam}	Measured by a pressure sensor and recorded by a HOBO data logger; installed at the ThermoSorber™ steam input entrance after the steam separator
Steam temperature	T_{steam}	Measured by a J-type thermocouple and recorded by a HOBO data logger; installed at the ThermoSorber™ steam input entrance after the steam separator
Steam quality		Installed a Clark-Reliant 2" steam separator to ensure the input steam quality was more than 99%
Condensate flow rate	$\dot{m}_{condensate}$	Measured by a turbine flowmeter and recorded by a HOBO data logger
Condensate pressure	$P_{condensate}$	Measured by an on-board pressure indicator
Condensate temperature	$T_{condensate}$	Measured by an on-board temperature sensor; Recorded by the on-board HOBO data logger
For determined chilled water energy output, $\dot{E}_{chilled\ water}$		
Chilled water flow rate	$\dot{m}_{chilled\ water}$	Measured with the on-board flow sensor; Recorded by a HOBO data logger
Supply water temperature	$T_{supply\ water}$	Measured by an on-board temperature sensor; Recorded by the on-board HOBO data logger
Chilled water temperature	$T_{chilled\ water}$	Measured by an on-board temperature sensor; Recorded by the on-board HOBO data logger
For determined hot water energy output, $\dot{E}_{hot\ water}$		
Hot water flow rate	$\dot{m}_{hot\ water}$	Measured with the on-board flow sensor; Recorded with a HOBO data logger
Hot water output temperature	$T_{hot\ water}$	Measured by an on-board temperature sensor; Recorded by the on-board HOBO data logger
For determined electric power input, $P_{electric}$		
ThermoSorber™ Power input	$P_{electric}$	Measured with a Fluke power meter

The host site informed HMG project staff that the input steam was not saturated. In order to accurately assess steam input energy, it was important to know the steam quality, however, which was not easy to be directly measured. During the site survey, HMG project staff noticed that the input steam line was aligned horizontally and was connected to the middle of a vertical main steam line. With such a configuration, the moisture was likely to flow along the vertical main steam line and the extracted steam was likely to be relatively dry. HMG project staff decided to install a steam separator at the entrance of the steam input to further remove the carried moisture. According to the steam separator specifications, the conditioned steam should have a quality of at least 99%. In the data analysis, we assumed the input steam quality to be 99.5%. The error associated with this assumption was about 0.5%. In order to evaluate the system performance under different load conditions, HMG project staff installed a globe valve to regulate the steam input flow.

Figure 6 and Figure 7 show the configurations of additional monitoring equipment on the steam input line. Figure 8 shows the installed steam condensate flow meter. Bypass line was installed on both the steam input line and the condensate line. In events of equipment malfunction, the steam separator and the condensate flow meter could be bypassed to prevent possible disruption to ThermoSorber™ operation.

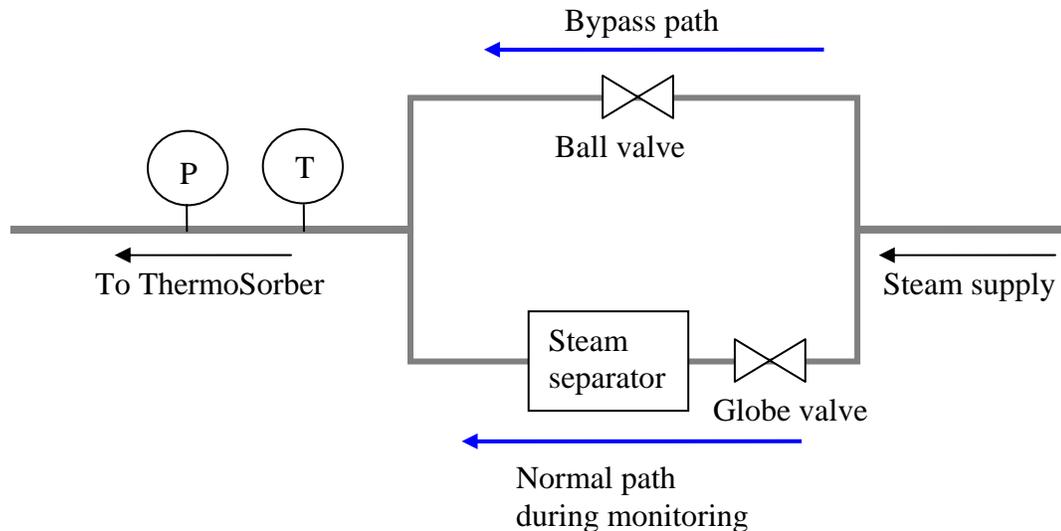


Figure 6 Schematics of additional equipment installed on the steam input line



Figure 7 Monitoring equipment installed on the steam input line



Figure 8 Flow meter installed on the steam condensate return line

5. PERFORMANCE EVALUATION METHODOLOGY

This study evaluated the ThermoSorber™ efficiency as well as the field output capacity. The combination of these measures enables the estimation of totally energy savings potential.

5.1 System Efficiency

Two types of coefficient of performance (COP) are used to demonstrate ThermoSorber™ efficiency, $COP_{Heat\ Pump}$ and $COP_{Overall}$, which are defined as:

$$COP_{Heat\ Pump} = \frac{\text{Total hot water energy output}}{\text{Total steam and electric energy input}}$$

$$= \frac{\sum \dot{E}_{hot\ water}}{\sum (\dot{E}_{steam} + P_{electric})} \quad (5-1)$$

and

$$COP_{Overall} = \frac{\text{Total hot and chilled water energy output}}{\text{Total steam and electric energy input}}$$

$$= \frac{\sum (\dot{E}_{chilled\ water} + \dot{E}_{hot\ water})}{\sum (\dot{E}_{steam} + P_{electric})} \quad (5-2)$$

The former only considered the heat pump aspect of the ThermoSorber™, while the latter consider the benefits of both the hot water and chilled water. The evaluation was over a period of time to eliminate short term process variations and average out random measurement errors. Each term in the above equations can be calculated as:

Chilled water energy:

$$\dot{E}_{chilled\ water} = \dot{m}_{chilled\ water} \cdot (h_{supply\ water} - h_{chilled\ water})$$

$$= C_p \cdot \rho \cdot \dot{V}_{chilled\ water} \cdot (T_{supply\ water} - T_{chilled\ water}) \quad (\text{Btu/hr}) \quad (5-3)$$

Hot water energy:

$$\dot{E}_{hot\ water} = \dot{m}_{hot\ water} \cdot (h_{hot\ water} - h_{supply\ water})$$

$$= C_p \cdot \rho \cdot \dot{V}_{hot\ water} \cdot (T_{hot\ water} - T_{supply\ water}) \quad (\text{Btu/hr}) \quad (5-4)$$

Net steam energy:

$$\dot{E}_{steam} = \dot{m}_{Condensate} \cdot (h_{steam} - h_{condensate})$$

$$= \rho_{condensate} \cdot \dot{V}_{condensate} \cdot (h_{steam} - h_{condensate}) \quad (\text{Btu/hr}) \quad (5-5)$$

where $\dot{V}_{chilled\ water}$: measured chilled water volumetric flow rate

$\dot{V}_{hot\ water}$: measured hot water volumetric flow rate

$\dot{V}_{condensate}$: measured condensate volumetric flow rate

C_p : heat capacity of water

ρ : density of water

h_{steam} : Input steam enthalpy,

$h_{condensate}$: Steam condensate enthalpy.

Steam enthalpy was calculated based on measured steam temperature, assuming the steam quality is 99.5%, since the installed steam separator guaranteed to yield a minimum 99% steam dryness (quality) for the output steam. The average pressure and temperature measurement indicated that the condensate was about 10 °F sub-cooled and this was used in the calculation for condensate enthalpy. Net steam energy was not very sensitive to degree of sub-cooling. An error of 10 °F in sub-cooling temperature would lead to less than 1% error in \dot{E}_{csteam} .

Both steam pressure and temperature had large fluctuations, possibly due to upstream steam draw variations. These fluctuations did not cause significant error in the steam latent heat calculation, because latent heat is not very sensitive to steam pressure. However, the pressure fluctuation did cause large variation in the condensate flow, which was measured.

The electric power input, $P_{electric}$, was directly measured with a Fluke power meter. This power input was primarily for running two ammonia pumps, each of which had a rated power of 7.5 HP (5.5 kW). The measured total electric power input was about 4.8 kW, with small variation during the study. On average, the electric power only represented about 0.8% of the net steam energy input.

5.2 Surface heat loss

The surface heat loss accounts for heat dissipation through equipment surfaces. It was not directly measured. The magnitude of the heat loss was assessed with a simplified heat transfer model.

HMG project staff measured the sizes of major ThermoSorber™ components, with the results shown in Table 3. The surface temperatures were estimated based on the status of working fluid inside and the insulation condition. Heat loss for a particular component, $\dot{E}_{heat\ loss, i}$, was estimated as:

$$\dot{E}_{heat\ loss, i} = h \cdot A_{surface} \cdot (T_{surface, i} - T_{ambient}) \quad (5-6)$$

where

h : Heat transfer coefficient, estimated based on heat transfer formulas for free convection over a horizontal cylinder or vertical surface

$A_{surface}$: Surface area a component

$T_{surface,i}$: Surface temperature of a component

$T_{ambient}$: Ambient temperature

The total heat loss for all major components was estimated to be 8100 Btu/hr, with a low ambient temperature of 50 °F. Total system heat loss, which also includes heat loss from connecting pipes and other small components, was assumed to be 50% more than the above results, or 12200 Btu/hr. The monitoring results showed that this heat loss was very small compared to net steam energy.

Table 3 Surface area and temperature of major ThermoSorber™ component

Component	Estimated Surface Area (sq. ft.)	Estimated Surface Temperature (°F)
Condenser	7.9	< 190 °F
Evaporator	7.9	~ 70 °F
HT absorber	17.8	~ 180 °F
LT absorber	10.3	~ 130 °F
LT ammonia pump	2.5	~ 140 °F
BR ammonia pump	2.5	~ 190 °F
Generator	20.5	~ 100 °F
RHX	4.5	~ 120 °F
LT ammonia receiver	9.1	~ 130 °F
BR ammonia receiver	9.1	~ 190 °F
Aux ammonia receiver	9.1	~ 150 °F

This small surface heat loss was further validated by a First Law analysis of the ThermoSorber™ system. All energy entering the system has to be equal to all energy leaving the system. The net energy entering the system (steam, chilled water, pump power) closely matched (within 8%) the heat leaving the system via water heating and heat losses. The 8% difference is related to measurement error.

5.3 System Output Capacity

The ThermoSorber™ system was rated to have 100 ton cooling capacity. The field chilled water output, $\dot{E}_{chilled\ water}$, was assessed based on the measured chilled water flow and temperature, and the city water supply temperature.

For evaluating system long-term output variation, HMG project staff also used data manually recorded by the host site personnel and data recorded by an on-board HOBO data logger. The former carried 2-hour interval records of chilled water flow rate, city supply water temperature, chilled water temperature, hot water temperature, and other process parameters. The latter had 1-minute temperature data for city water supply, hot water output, chilled water output, and condenser water output.

6. RESULTS AND DISCUSSION

The project team started the monitoring equipment installation and testing on September 7, 2007 and started to successfully record required processing parameters on October 10, 2007. The HOBO data loggers were set to have 20 seconds sampling and recording intervals. HMG project staff visited the host site almost every week to retrieve the recorded data and to observe ThermoSorber™ operation. Whenever possible, HMG project staff discussed operation and maintenance issues with the host site personnel.

Operation Overview

Figure 10 through Figure 11 present the measured results during one week period from October 19, 2007 to October 26, 2007, which reflect a typical week cycle of ThermoSorber™ operation. The unit was turned off during the weekend and was also briefly turned off or set into standby mode during some of the weekdays. The recorded data indicated that the system was operated for 85% of the weekday time. When operated, it was most under steady conditions with stable chilled water and hot water output.

Both the chilled water and the hot water flows stay at about 120 GPM. The flow variations were caused by the system pressure fluctuations and sensor errors. The sensor error was particularly large for the hot water. According to the host site maintenance personnel, hot water and chilled water flows were seldom adjusted. During the study, HMG project staff noticed only one instance of water flow adjustment. It was when the ThermoSorber™ was not working properly. The host site personnel tried to manual control the chilled water output temperature by adjusting the chilled water flow. Later on, the system malfunction was found out to be due to ammonia level running low. Chilled water flow was restored to the normal level after the problem was fixed.

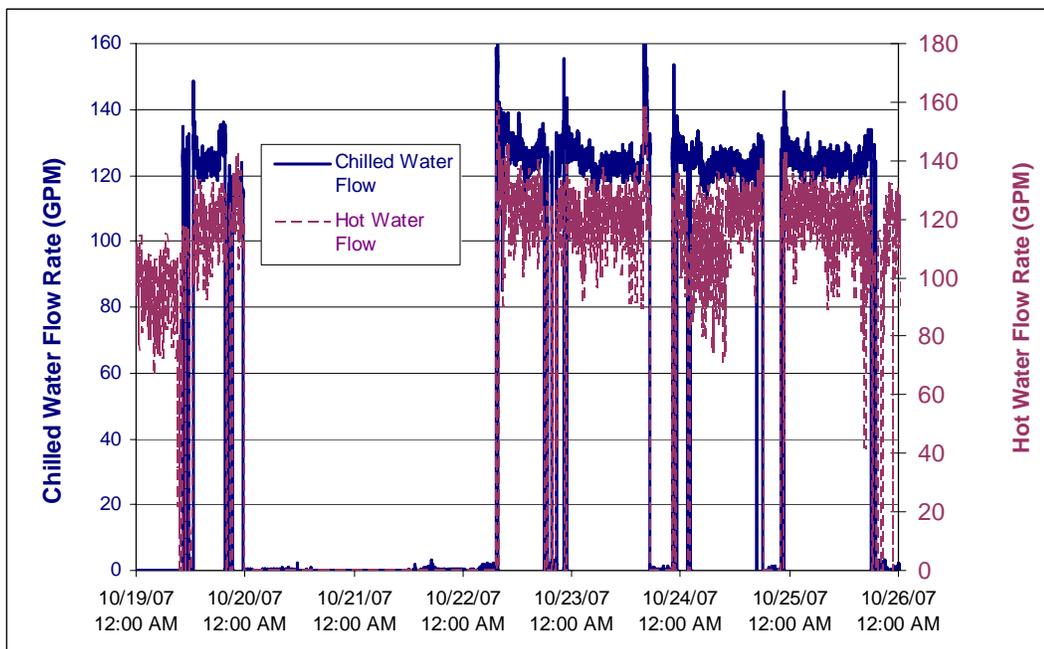


Figure 9 Sample data of chilled water and hot water flow rates – one week

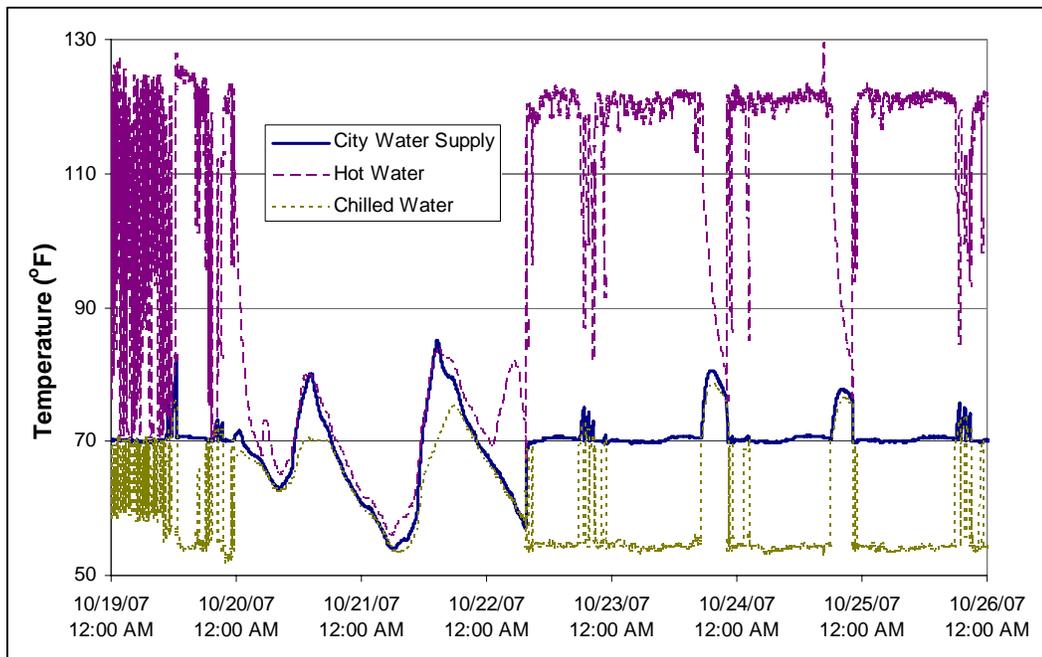


Figure 10 Sample data of hot/chilled water temperature – one week

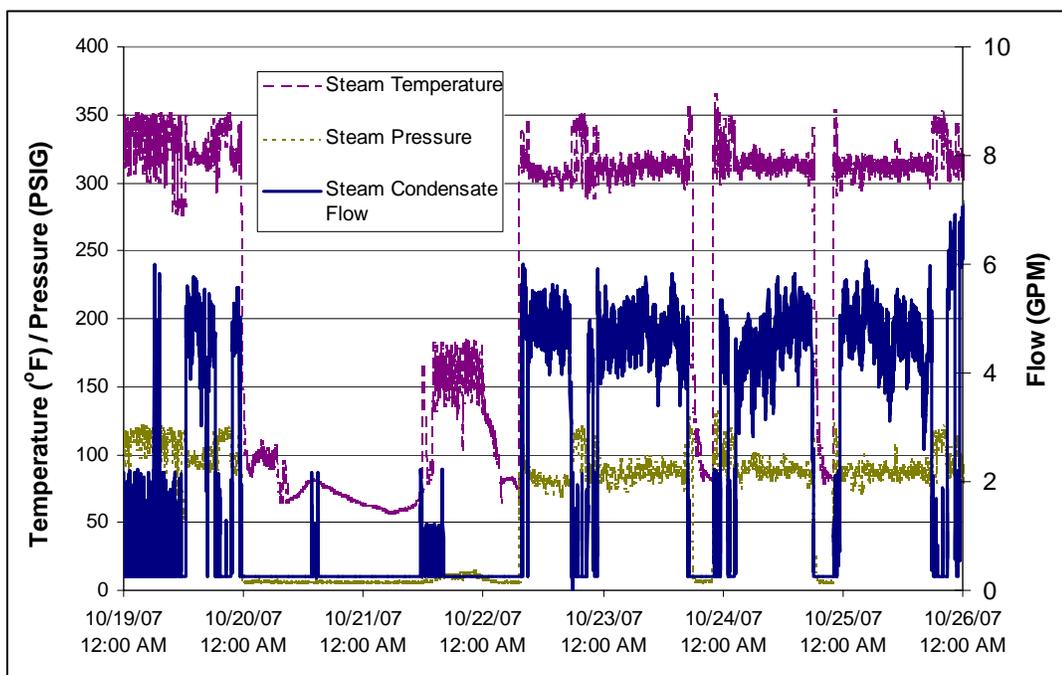


Figure 11 Sample data of steam input condition – one week

The hot water and chilled water output temperatures were relatively stable. The chilled water output was about 54 °F and the hot water output was about 121 °F.

The host site had manually recorded key processing parameter and important system observation since the system was commissioned in May 2007. Figure 12 shows a sample of recorded data. The hot water flow data was missing because the flow sensor transducer was broken. Data from the host site maintenance logs is plotted in Figure 13 to

demonstrate long-term system operation. There was little operation variation since the system was commissioned.

Date		7-05-07											
Time		0:00	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Flow [gpm]	BR-pump	1757	1849	1801	1798	1801	1799	1855	1881	1865	1764	2011	
	LT-pump	912	913	913	899	888	939	953	914	955	906	1023	
	Chill water	1267	1217	1221	1198	1237	1197	1225	1184	1257	130	120	
	Hot water	80	NA										
Pressure [psig]	LP	57	54	58	55	56	56	56	56	55	55	55	
	HP	205	205	210	208	207	204	207	206	205	200	190	
	Condensate out	80	67	67	70	65	64	63	64	70	70	70	
Temp. [F]	T1(COND-vap-in)	201	223	202	202	199.2	198.7	199.8	201.6	199.6	199	165.6	
	T14 (steam-in)	327	322	322	323	320.4	318.9	319.9	320.8	321	305.5	318	
	T15 (condensate-out)	298	310	305	305	305.7	305.9	308.1	310.7	307	305.6	255.2	
	T16 (EVAP-ow-in)	70	68	68	68	70.3	70.5	70.8	70.6	70	71.7	69.2	
	T18 (EVAP-ow-out)	52	50	51	50	52.7	52.7	52.9	52.7	54.5	54.3	54	
	T22 (Hot-water-out)	129	127	128	127	128.9	129.1	127.0	128.1	127.3	127.7	116.7	

0400 - SLIGHT ODOR OF NH₃ NOTICED

Figure 12 Sample host site ThermoSorber™ maintenance log

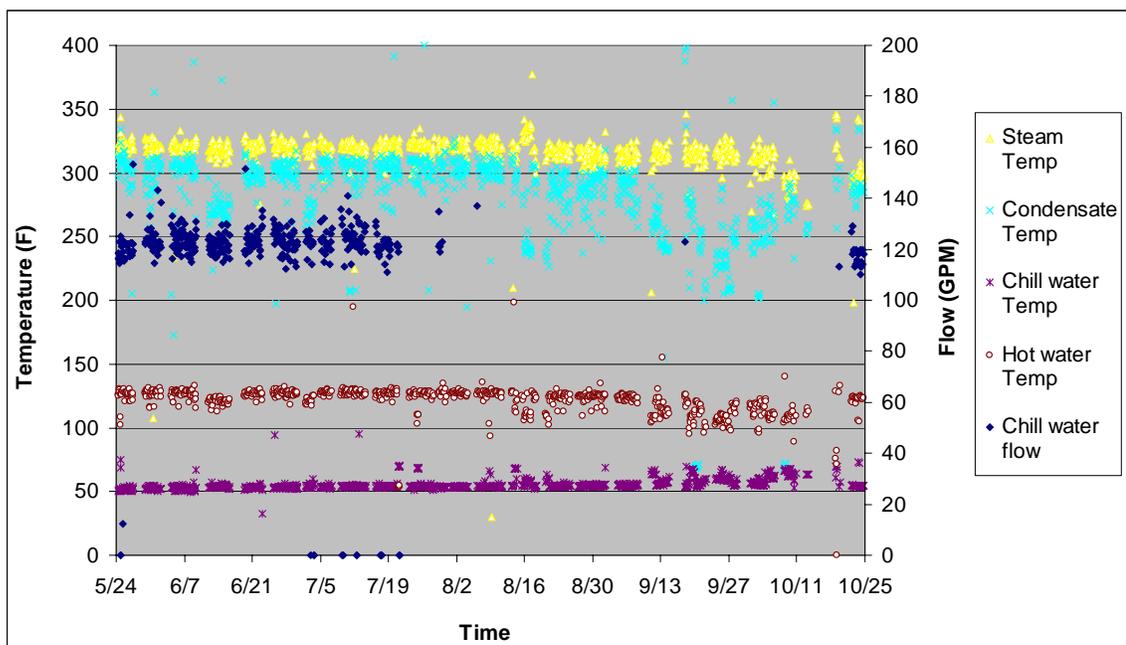


Figure 13 Long-term ThermoSorber™ operation data

Energy Flows

Steam input conditions were consistent, however, with large variations. There were several steam draw upstream the ThermoSorber™ with much higher steam demand. The host site informed HMG project staff that the steam supply was barely adequate for the overall demand. Any change in steam usage by upstream equipment would likely to cause steam pressure change. The pressure measurement indicated that steam pressure

had large and frequent fluctuations. This affected the accuracy of steam flow measurements.

The average energy inputs and outputs during stable ThermoSorber™ operation were calculated and listed in Table 4. It is very clear that the hot water energy, chilled water energy, and net steam energy were much larger than the surface heat loss and the electric power input. Also, from a heat balance point of view, system energy inputs should be balanced with the outputs in following way:

$$\Sigma(\dot{E}_{hot\ water} + \dot{E}_{heat\ loss}) = \Sigma(\dot{E}_{chilled\ water} + \dot{E}_{steam} + P_{electric}) \quad (6-1)$$

The results in Table 4 indicated that the total input, right side of the equation, is 8% more than the total output, left side of the equation. It is believed that the error was mainly due to error in net steam energy estimation as the measured steam flow had large variations. A calculated net steam energy based the heat balance equation is also shown in Table 4. It is 12% smaller than the measured value. For data consistency, this calculated net steam energy was used for further performance evaluation.

If the surface heat loss and the electric power input were ignored as they were relatively small, it is more obvious that the hot water energy was from the steam energy and the energy released by the chilled water supply. It is also clear that for future performance monitoring, measurements of water flow conditions will be sufficient. Steam energy can be derived from the difference between the hot water energy and the chilled water energy.

Table 4 Average energy input/output during normal ThermoSorber™ operation (Btu/hr)

Hot water energy	3.02 X 10 ⁶
Chilled water energy	0.99 X 10 ⁶
Electric Energy	1.64 X 10 ⁴
Estimated heat loss	1.22 X 10 ⁴
Net steam energy (measured)	2.27 X 10 ⁶
Net steam energy (Heat balance)	2.03 X 10 ⁶

System Efficiency

Based on the energy flow results in Table 4 and equations 5-1 and 5-2, the ThermoSorber™ efficiencies were calculated to be:

$$COP_{Heat\ Pump} = 1.48$$

and $COP_{Overall} = 1.97$.

From a heat pump point of view, the ThermoSorber™ took one Btu of energy to produce 1.48 Btu of hot water. Compared to direct water heating with steam, it is at least 48%

more efficient. It should be noted that the host site did have a parallel process using steam to generating hot water through a heat exchanger.

When including the benefits of both the chilled water and hot water, the result of COP_{Overall} implied that the ThermoSorber™ took one Btu of energy to produce 1.48 Btu of hot water and 0.49 Btu of chilled water, or total 1.97 Btu of combined energy benefits. The chilled water could almost be deemed to be produced without any energy cost and all energy inputs were used to efficiently produce hot water. Therefore, it is clear that ThermoSorber™ is an energy efficient technology for producing chilled and hot water.

Output Capacity

The ThermoSorber™ had a rated cooling capacity of 100 Tons. In Table 4, the chilled water energy implied that the average chilled water output was about 82 Tons. HMG project staff also tested system performance with lower steam flows. The results are shown in Figure 14. The host site maintenance personnel indicated that higher steam flow settings would lead to steam leaking into the condensate system. Therefore, higher steam flow tests were not allowed.

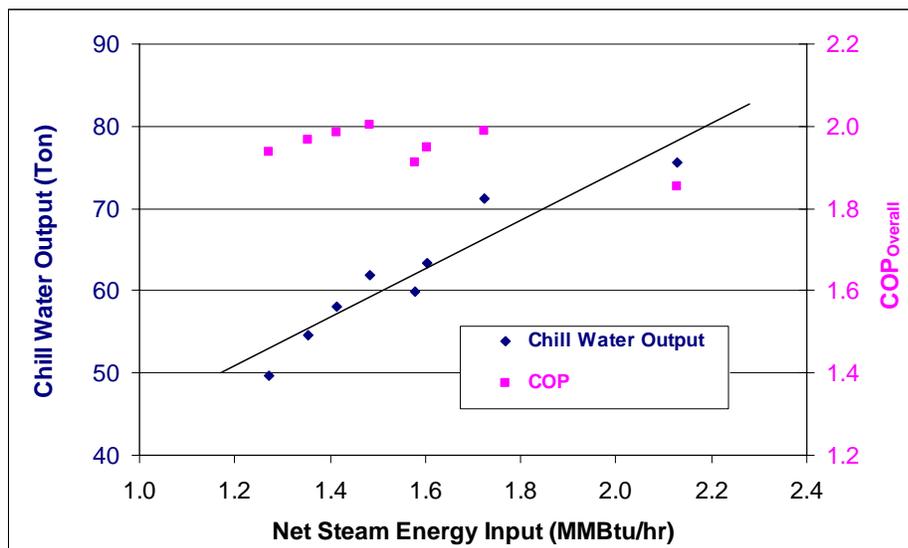


Figure 14 ThermoSorber™ performance curve

Figure 14 indicated that the lower output was mostly due to inadequate steam input. The host site maintenance personnel indicated that higher steam flow settings would lead to steam leaking into the condensate system. The host site decided to build a dedicated condensate tank for the ThermoSorber™ to handle higher steam flows. The steam leak indicated that the steam strap on the condensate line might be undersized and allowing steam to by-pass the trap. HMG project staff recommended the host site to consult the manufacturer on condensate line design and consider using a larger steam trap. The host site may also seek advice from the manufacturer to determine if a system re-commissioning is needed to achieve the rated system capacity.

Figure 14 also indicates a possible trend of slightly system efficiency decrease as the steam energy input goes up.

System Operation/Maintenance Observations

During most time of the two-month field monitoring, the ThermoSorber™ was running smoothly and little system maintenance activities were observed.

The host maintenance personnel reported occasional ammonia leak on the maintenance logs. During some of the site visits, HMG project staff sensed the ammonia smell, especially when working beneath the system. A severe ammonia leak is considered a safety hazard by California OSHA and would require the system to be shut down for personnel safety. System design or maintenance procedures that minimize ammonia leakage are desirable. It is recommended that the system be designed and have operation procedures and manuals that make it easy to comply with all state and Federal safety standards.

System malfunction occurred once on October 10, 2007, when no hot water or chilled water was able to be produced. The system was shut down for about one week. It was found out that ammonia level in one of the internal storage tanks was too low. The ThermoSorber™ manufacturer indicated that ammonia lost was due to the monthly ammonia pump filter change. It was not clear how much the small periodic ammonia leak also contributed to the total ammonia loss. Nevertheless, periodic ammonia refill seems to be required for long-term operation.

Sustainable energy savings rely on long-term term system reliability and safety. Since the host site had not received any site-specific system manuals or in-depth training from the manufacturer, the project team was not able to assess the system maintenance needs and the corresponding impacts to energy savings. For system personnel safety and system reliability, this study recommends the host site to coordinate with the manufacturer to obtain necessary operation and maintenance manuals and take necessary steps to resolve the ammonia leak issue.

The host site also raised some concerns on certain design aspects of the ThermoSorber™, which could impact maintenance costs. Many of the major heat exchangers were welded to the connecting pipes, making it very difficult and costly to service or replace. Some of the key heat exchangers, e.g. the evaporator, were not standard equipment and would be very expensive to replace. The system was designed to fit in a compact footprint which lends itself to more difficult component replacement. At this facility, the system was installed outside where a compact footprint is not needed. The manufacturer might wish to consider less compact, easier to service absorption chillers for industrial applications where the cost of space is low.

7. CONCLUSIONS

This study quantifies the energy performance of a ThermoSorber™ system under field operation conditions. The monitoring results indicate that the ThermoSorber™ system is an energy efficient technology for producing chilled and hot water. The chilled water output was less than the rated capacity because the steam input was not high enough. The host site plans to modify the condensate tank to handle larger steam flow. However, the project team recommends that host site staff or the manufacturer investigate whether installing a larger steam trap on the condensate will allow a higher steam input and thus increase the cooling capacity of the ThermoSorber™ system up to its rated value.

The ThermoSorber™ was running smoothly for most time during the field study. Occasional ammonia leaks were detected by both the HMG project staff and the host site maintenance personnel. According to the manufacturer, periodic ammonia refill may be required to make up the ammonia loss caused by the monthly pump filter change. The manufacturer should provide necessary manuals and trainings to ensure long-term system safety and reliability.

The host site staff suggested that the design of the heat exchangers inside the ThermoSorber™ could be improved for easy service and part replacement. The host site staff is concerned about the potential costs associated with replacing the custom designed heat exchangers.

To promote wider adoption of the ThermoSorber™ technology and ensure sustainable energy savings, it is important for the manufacturer to address ammonia leakage and maintenance costs.