New Technologies for Reducing and Recovering Wasted Heat Energy in Industry

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ABSTRACT

According to the U.S. Department of Energy (DOE), it is estimated that up to 50% of industrial energy input is lost as waste heat in the form of exhaust gases, cooling water, heat loss from product heating. Recovering waste heat from industrial/commercial processes can be an attractive opportunity for a facility in reducing overall energy consumption. Heat recovery focuses on the utilization of a waste heat stream to do additional work elsewhere in the facility. For heat recovery to be economical, a customer facility must have a waste heat source and a simultaneous need for heating elsewhere in their facility.

There are new heat pump designs such as CO_2 based heat pumps, variable speed heat recovery heat pumps, and others which promise efficient heat recovery opportunities. This paper presents the results of the performance of a new variable speed heat recovery chiller that is currently being tested at Alabama Power's Technology Applications Center (TAC) facility. Although the individual components (i.e. compressors, drives, etc) are not a new concept, the implementation and associated control of the combined system is new as it relates to heat recovery chillers and heat pumps. This is also different from heat recovery off a chiller via a de-superheater or double bundle condenser.

The paper also presents a new electrotechnology application in medium-voltage called the 4kV electric boiler. This is the first electric resistance boiler of its kind in the world which was developed as a part of EPRI and Southern Company collaboration with Gaumer Process and Cleaver Brooks. Contrary to the fossil fueled boilers that have emissions and stack loss, the electric boilers are very efficient in converting the electric energy to steam and do not have stack loss. This product has a smaller footprint and also has higher energy efficiency over conventional fossil fuel fired industrial boilers. Performance characteristics and the results from the tests conducted by EPRI and Southern Company at an industrial customer site in Georgia are presented in this paper.

Heat Recovery Chiller

Introduction

In larger commercial and industrial facilities with central HVAC systems, heat recovery chillers (HRCs) and heat recovery heat pumps (HRHPs) can simultaneously provide both heating and cooling with excellent efficiency and economy of scale (EPRI 1993). Unlike the conventional chillers, these heat recovery chillers use the thermal products from both the evaporator and condenser. Depending on the application, the compressors may be reciprocating, screw or centrifugal units. The cooling output is usually applied to space conditioning loads, and the heat output is used for space heating, dehumidification reheat and/or domestic/process water heating. Heat recovery chillers are normally controlled by the required heating load. This paper describes the performance of the heat recovery chiller unit where a variable speed compressor is used instead of a conventional single-speed compressor.

Variable Speed Heat Recovery Chillers

Heat recovery involves the capture and utilization of a waste heat stream from one process to another process within the facility rather than the wasting of said waste stream. For heat recovery to be economical, a customer facility must have a waste heat source and a simultaneous need for heating in their facility, and that heat requirement must be at a feasible quality for the heat source. Sources of waste heat streams that may be captured can vary by facility but could include waste streams from existing chilled water systems, refrigeration, product curing systems, air compressors, and other cooling systems. Typical heating needs in industrial and commercial buildings include hot water production, space heating, process heating, boiler water pre-heating and dehumidification.

Over the last several years heat recovery has become a primary area of focus for many building owners and operators. Due to the new ASHRAE Standard 90.1-2010, new construction and major renovations require a minimum of waste heat recovery that must be incorporated in the new design. Some of the major markets for Heat Recovery Chillers (HRC) are hospitals, large hotels/office buildings, food processing plants, and other manufacturing plants. Furthermore, the opportunity for heat recovery chillers (particularly variable speed heat recovery chillers) is not to replace existing chillers but to complement the existing chiller/boiler systems. The particular heat recovery technology focused in this document is water-to-water heat recovery chiller which could be implemented into an existing boiler/chiller system. More specifically the HRC is a 19 ton chiller design manufactured by American Geothermal from Murfreesboro, Tennessee called Chillstack.

Lab Demonstration of Variable Speed Heat Recovery Chiller

The 19 ton Heat Recovery Chiller was installed and commissioned at Alabama Power’s Technology Applications Center (TAC) in November 2012.

The primary purpose of the HRC was to maintain cooling water needs to two environmental chambers that are used for testing at the TAC while also demonstrating heat recovery (via producing 120F hot water) and its benefits for Alabama Power customers. Through working with the manufacturer, it was decided to install a variable speed heat recovery chiller and perform testing on the system to better understand the advantages of the variable speed compressor. The instrumentation required for testing and data acquisition was completed in February 2013. The HRC utilizes two Danfoss scroll compressors in which one 11.3 ton compressor is variable speed and the other compressor is a 7.4 ton fixed speed. A physical picture of the unit and the installation is shown below in Figures 1 and 2.

Figure 1. 19 Ton Heat Recovery Chiller (Chillstack by American Geothermal)

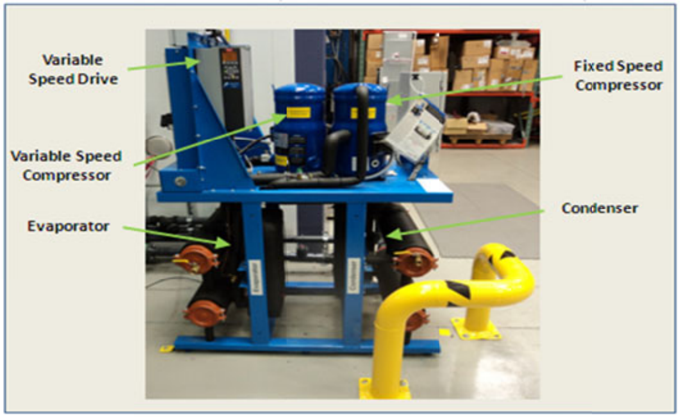
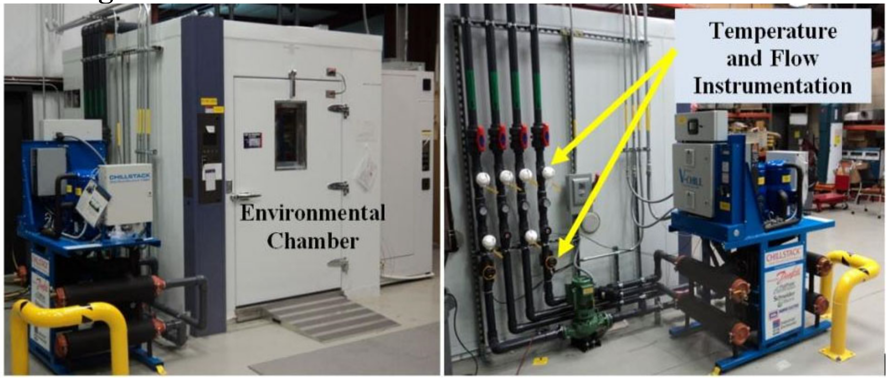


Figure 2. Installation of HRC with Environmental Chambers



Objectives and test setup description. The objectives of the laboratory testing and the detailed test setup description are covered in this section.

The objectives of the lab demonstration are as follows:

- Develop operational load profiles for the HRC to run under
- Collect vital process data from the HRC such as:
- Evaporator Temperatures (Entering/Leaving)
- Condenser Temperatures (Entering/Leaving)
- Evaporator/Condenser Flows
- Total Power Consumption of HRC
- Analyze the performance characteristics, [i.e. coefficient of performance (COP)]
- Provide management reports to all project participants
- Collect data for a minimum period of 2 months
- Analyze data for projection to customer facility savings
- Final report to be developed by EPRI

There is a 500 gallon water storage tank that provides cooling water to the environmental chambers. The discharge water from the chambers returns back to the storage tank. Once the tank temperature reaches between 72-75°F, the HRC will draw water from the storage tank and proceed to cool the water back down to 65 degree F (set point). The heat recovered from the storage tank is then sent to an air-sink fluid cooler outside the facility. This recovered heat could be used for space heating or water heating; however, there is no constant load for this heat currently installed at the TAC. Once the HRC is called to start (i.e. tank temperature at 72F or greater) by the controller, it starts the variable speed compressor first and begins to ramp up as needed until it reaches 90Hz or 11.32 tons. At this point, if more cooling is required, the fixed compressor (7.41 tons / 60Hz) would come on-line and the variable compressor would ramp down to its minimum loading of 3.3 tons and 30Hz then continue to ramp back up to 11.32 tons or 90Hz as additional cooling is required. Figure 3 shows a simple schematic diagram of how the units are interconnected.

The chart in Figure 4 shows how the fixed and variable compressors are loaded as the system calls for cooling. The ordinate represents the cooling capacity in tons.

Figure 3. Simple Layout Diagram of Heat Recovery Chiller

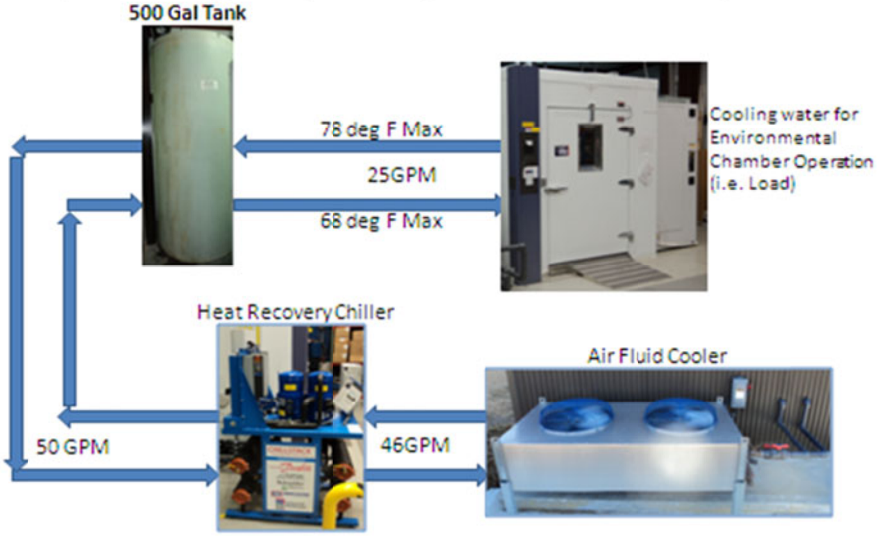
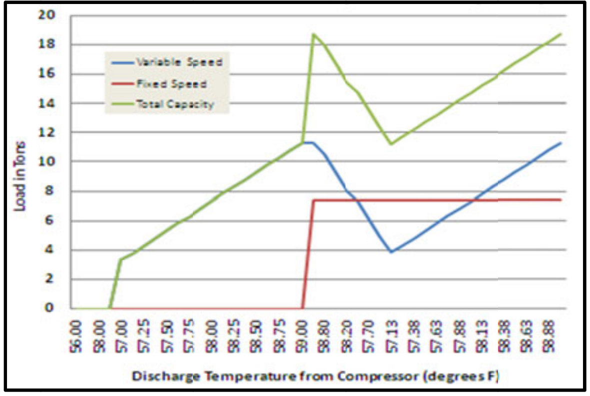


Figure 4. Heat Recovery Chiller Capacity



Variable speed chiller-test plan. Testing of the heat recovery chiller began in March and was completed in April**.**

The performance evaluation tests consisted of running the HRC at full load for a period of time, measuring the performance of the machine by calculating the heating COP and combined system COP. Due to the need to continuously operate the environmental chambers as part of the normal business unrelated to the HRC testing, the HRC was operated for a period of two weeks then turned off for a day and restarted for an additional two weeks. The sequence was repeated for a period of two months. During this time of operation, the HRC ramped up and down throughout each day at varying load conditions. This occurred over multiple days and performance characteristics were collected for the extended test. The other test parameters around the operation were that it would energize when the tank temperatures exceeded 72 ^{o}F and the hot water produced would be maintained at a temperature range of 120-130 ^{o}F. The air cooler was operated with an across-the-line starter so it was energized when the water temperature reached 125 ^{o}F and turned off when the temperature from the condenser fell below 120 ^{o}F.

Results

Overall the heat recovery chiller yielded useful data over the test period. The unit was continuously cycling to chill the cooling water supplied to the environmental chambers. This was on a 24 hour period over two months with the HRC unit being off only a couple of times while the tests were being changed out in the environmental chambers. For purposes of this report and ease of reading the results, the graphical data will be comprised of a typical 12-hour window for the HRC during the 2 month test. Average numbers and other numerical data shared will be over a longer test period.

When the Heat Recovery Chiller was running, the average combined load of the system was 22.89kW. In addition, the average condenser water exit temperature was 125.9^{o}F, and the average evaporator water exit temperature was 59.7^{o}F. The calculated average Coefficient of Performance (COP) observed while running was 4.78 (Heating only) and 8.45 (System).

The coefficient of performance (COP) is calculated as follows:

- Heating COP = [heat rejected at the condenser]/[energy added by heat pump compressor]
- System COP= ([heat rejected at the condenser] + [Cooling provided by the heat pump compressor])/ [energy added by heat pump compressor]

Figure 5 shows the HRC power consumption for a typical 12-hour period. Notice that during the late evening and early morning hours the load varies more due to the cooler air dissipating the heat in the condenser through the air cooler. As the day begins and the ambient temperatures rise the load steadies. This was a typical observation.

Figure 6 (left) shows the condenser temperatures for the HRC for the same 12-hour period as shown for the HRC power consumption. Again, due to the operation of the air cooler the temperatures vary more often in when the outside temperatures are cooler.

Figure 6 (right) shows the evaporator temperatures for the HRC for the same 12-hour period as shown for the HRC power consumption.

Figure 5. Heat Recovery Chiller Power (kW)

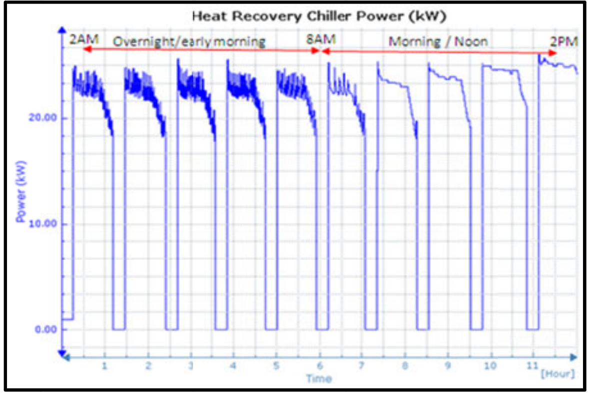
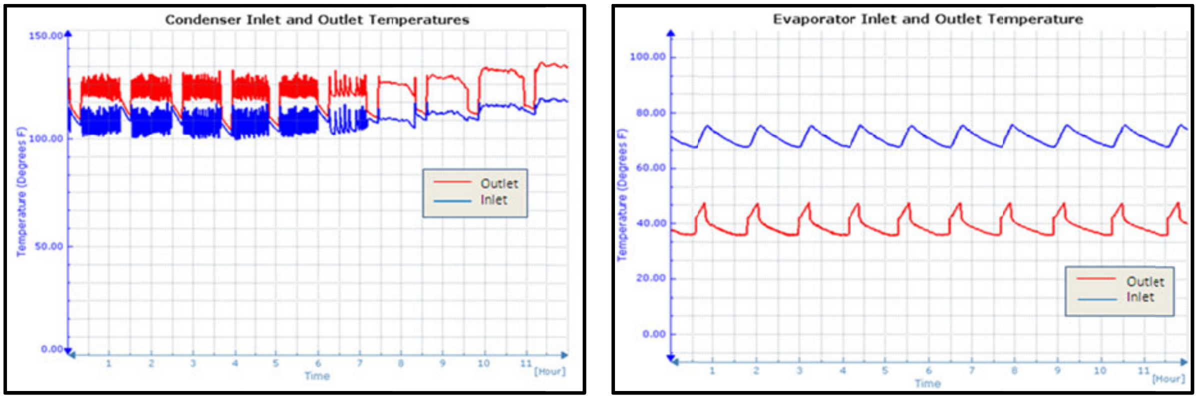


Figure 6. HRC Condenser Temperatures (left) Evaporator Temperatures (right)



4kV Electric Resistance Boiler

Introduction

Boilers are used to produce hot water or steam for a variety of industrial, commercial as well as institutional applications. Over 45% of all the fuel burned by U.S. manufacturers is consumed to produce steam. Steam is used to heat raw materials and treat semi-finished products. It is also a power source for equipment. Boilers are also used to provide space heating for manufacturing facilities. In some cases, the steam from boilers is used to drive turbines for electricity generation. Electricity can be generated in smaller cogeneration units where the heat is applied to process heating applications, and the steam is used for direct steam. It is estimated that there are almost 163,000 industrial and commercial boilers in the U.S., out of which nearly 26% of them are industrial applications (~43,000 boilers) (ORNL 2005).

There are two main types of boilers used in the industrial and commercial facilities: fossil-fuel-fired boilers and electric boilers. Electric boilers are available in ratings from 5 kW to 50 MW. There are two main types of electric boilers on the market: the electric resistance boiler and the electrode boiler. Electric resistance boilers use resistive heating elements to convert electric energy to heat energy while in electrode boilers the electricity is passed through stream of water, utilizing the conductive and resistive properties of water, to generate steam. Electric resistance boilers are available in capacities up to about 4 MW. In applications greater than 4

MW, the electric boiler technology shifts to electrode boilers which can provide higher heat output much quicker than electric resistance boilers. The

4kV Boiler: Background Information

The electric boilers are normally resistance heaters, and usually operate at normal building distribution voltage (480V). Such electric boilers are typically modest in size with an upper limit of approximately 4 MW. However, since several large process industries have accessible medium to high voltage connection at their service entrance, there has been increasing discussions on the possibility of operating larger MW process heating equipment at higher voltages, such as 4 kV or 12 kV. Such an approach might allow for reduction in infrastructure, due to reduction in rated current of the equipment. It is also possible that heater lifetime could increase. A workshop was organized by EPRI in 2007 and was well attended by several interested utilities and equipment manufacturers. The utilities have large industrial customers who would like to find out more about the alternative technologies and how they could benefit from them. It was found out that there is a large scope for the higher voltage (> 600 V) heater element application but more research was needed. Various issues needed to be reviewed, such as the availability of higher voltage heater element equipment, potential applications for this technology, possible field demonstration at a customer site and to understand and solve any other issues.

Field Demonstration of the World's First 4kV Boiler Installation

To show a proof of concept demonstration of this new technology, Southern Company was in search of various sites, both industrial and large commercial, which could be a best fit. In 2010 an industrial site was chosen in Georgia to demonstrate the 4kV electric boiler. Southern Company and EPRI teamed up with Gaumer Process and Cleaver Brooks to begin building the first 4kV boiler. The first installation took place at this industrial facility in December 2010, however, the initial field tests showed some shortcomings. The reasons for the shortcomings were identified as a) the heating elements b) the geometric configuration of the placement of the resistor elements and c) lower dielectric property of the insulation material used. Southern Company, EPRI, Gaumer, Cleaver Brooks and the industrial customer did not give up on this technology but started to test various other configurations and newer insulation materials as well as modification in the design of the boiler. After rigorous testing for nearly fourteen months, the final design of the resistor elements was completed and a better insulator material was identified. The newly modified resistor elements were put into the boiler on April 17, 2012 and the boiler was found to operate successfully. The performance tests are currently in progress to collect one year's data to completely understand the performance characteristics of the boiler. The tests will be completed by mid 2013.

The objectives of the field demonstration are as follows:

- Collect vital parameter data from the electric 4KV boiler
    - Analyze the performance characteristics of the boiler and the controls
    - Compare fuel to steam efficiencies of electric and gas boiler
- Provide a secure web-portal to view and download data
- Provide management reports to all authorized personnel in the companies involved.

- Collect data for a period of 12 months. Monitor "Seasonal Operational Performance" for each of the boilers will be monitored.

All of the above will be used to produce a final technical report.

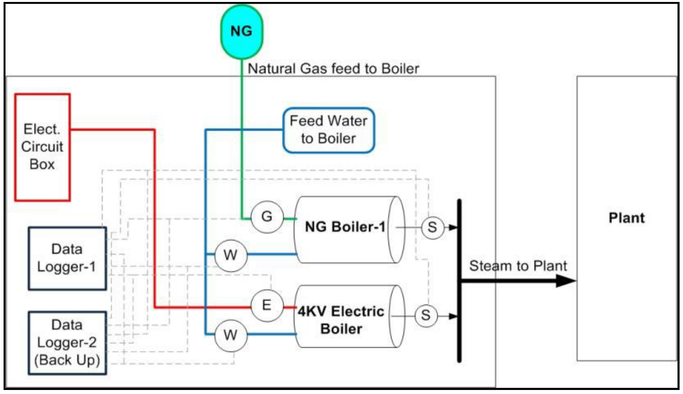
4kV electric boiler specifications. The following are the technical specifications of the 4kV electric boiler:

- Manufacturer: Cleaver Brooks
- Model: CBMVR-4160V-2-200ST
- Volts: 4160 V
- Current: 278 A
- Power: 2000 kW
- Phase: 3
- Frequency: 60 Hz
- BHP: 200
- There are two element bundles, each rated at 1000 kW.

Measurement Setup

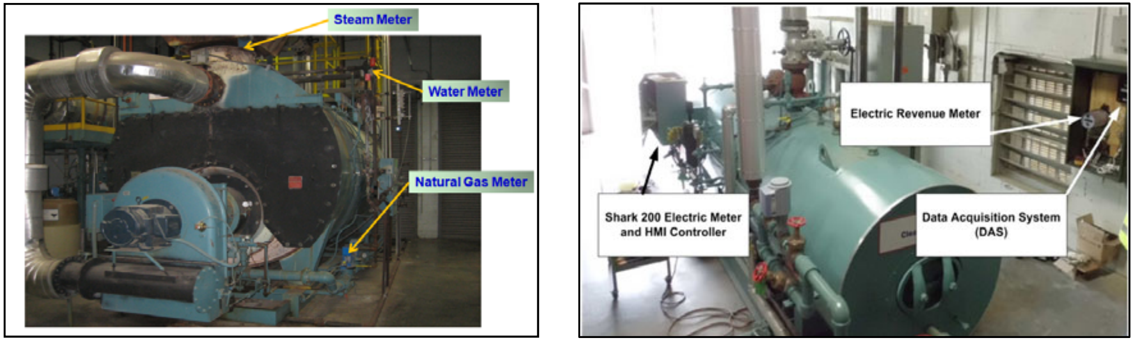
The industrial site selected for the field demonstration of the 4kV electric boiler already has a natural gas boiler to meet its current steam needs of the plant. The new 4kV electric boiler shares the loads with the natural gas boiler to meet the plant steam needs. There are two sets of data loggers connected to the boilers, one to provide online access to the plant and the authorized personnel while the other to collect the data and perform offline data analysis. The first data logger is used by Southern company to provide access to the data to its customer and the second data logger is installed by EPRI to collect data and provide a backup for the Southern company data. Figure 7 shows the schematic of the data logger setup to collect boiler operational data.

Figure 7. Measurement Setup of Natural Gas and 4kV Electric Boilers



The parameters recorded by the data loggers are, natural gas flow (in cf/hr), feed water flow (in gpm) and steam output (in lbs/hr) for the natural gas boiler; electric power and energy measurement (in kW and kWh), feed water flow (in gpm), and steam output (in lbs/hr) for the electric 4kV boiler.

Figure 8. Instrumentation Setup, Natural Gas Boiler(left) 4kV Electric Boiler (right)



Apart from these measurements the EPRI data logger also collects vital electrical inputs from the Shark 200 meter that is located on the 4kV electric boiler. The Shark 200 meter communicates to the EPRI logger through a RS-485 modbus connection. The parameters such as phase currents, voltages, power, power factor, kVAR, kVA, etc. are recorded on a fifteen minute interval. The Shark 200 meter also captures the contactor duty cycle that control the resistor elements. Figure 8 and 9 shows the instrumentation used to collect the data from the natural gas and 4kV electric boiler.

Test Results

Performance characteristics of the 4kV boiler. In this section the performance characteristics of the 4kV electric boiler are discussed.

Figures 10 through 12 shows the various electrical characteristics of the 4kV electric boiler such as phase-to-phase rms voltage, rms phase currents, power consumed during the operation of the 4kV electric boiler. The figures represent a snapshot of the operation of the 4kV boiler. Figure 12 shows the water intake and the steam produced by the 4kV boiler.

Figure 10. Current and Voltage (Phase-to-Phase) Magnitude (RMS) Profile of 4kV Electric Boiler

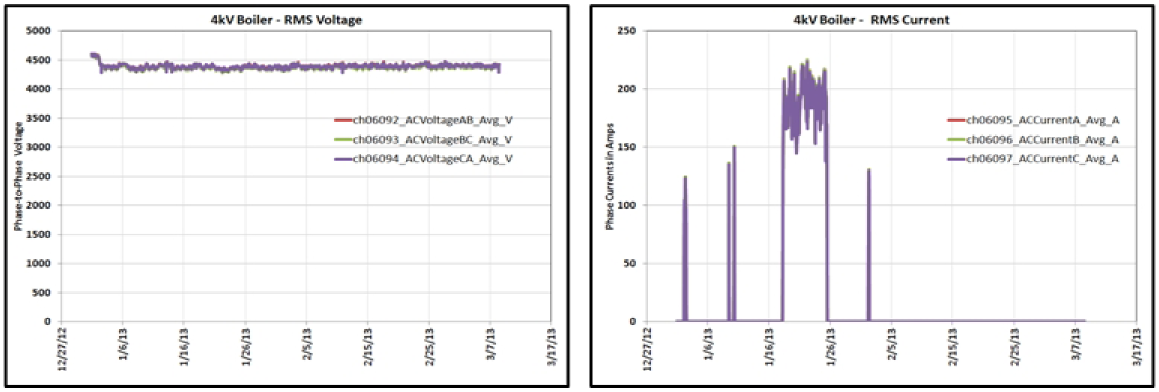


Figure 11. Power Consumption of the 4kV Electric Boiler

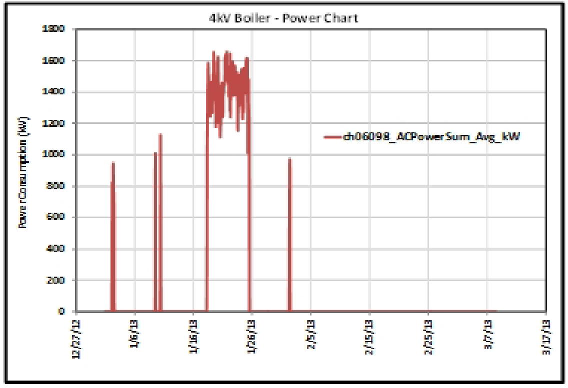
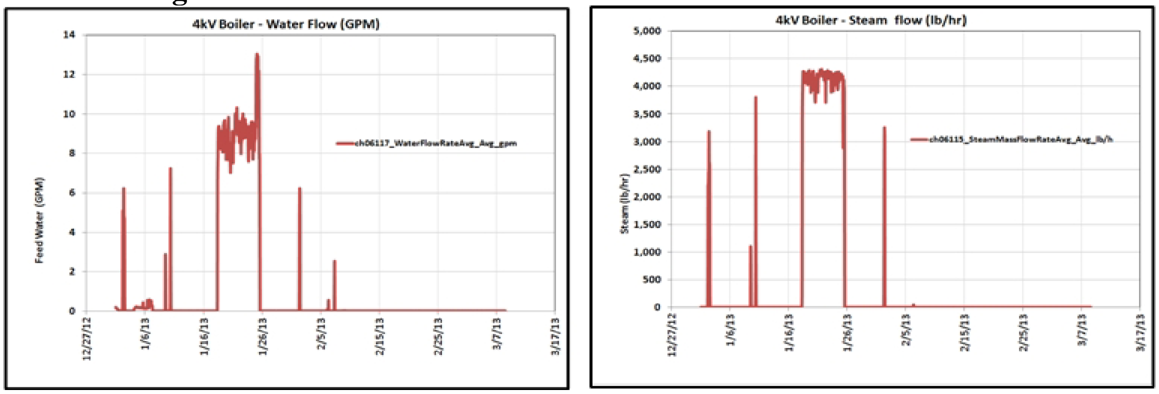


Figure 12. Water Flow and Steam Production of the 4kV Boiler



Steam conversion efficiency of electric and natural gas boiler. The facility has two natural gas boilers and the new 4kV boiler. The efficiency of steam conversion in each of the boilers is presented here.

The efficiency of the boiler can be computed by first converting the steam output and the electrical power input to equivalent Btu and then using the equation (1) presented below. Similarly the efficiency of the natural gas boiler can be calculated using the equation (2).

$$Efficiency\ (Electric\ Boiler) = \frac{Steam\ Output\ (equivalent\ Btu)}{Electrical\ kW\ Input\ (equivalent\ Btu)} \text{ --- (1)}$$

$$Efficiency\ (Natural\ Gas\ Boiler) = \frac{Steam\ Output\ (equivalent\ Btu)}{Natural\ Gas\ Input\ (equivalent\ Btu)} \text{ --- (2)}$$

Table 1 shows the stream conversion efficiencies of the natural gas boilers (Boilers-1 and 2) and the 4kV electric boiler. The natural gas boilers were running at partial load and the efficiencies are lower during partial load conditions. The electric meters used have 1-3% accuracy, this is the reason for the occurrences of the electric boiler efficiencies that are above 100%.

Boiler-1 is a larger natural gas boiler and the efficiency of this boiler running partially loaded is shown in Table-1. A fossil fuel boiler over sized will be less efficient because of the loading on the boiler. When a boiler runs in partial loading conditions, it will fire on and off multiple times in a 15 min period since it is trying to meet the steam demand by firing in full throttle. Full throttle will satisfy the pressure needs and the boiler will cycle off, until the steam header loses steam pressure and it calls for the boiler to go full throttle again. It is best for a boiler to run constantly in fully loaded condition than in partially loaded conditions for better efficiencies.

The breakeven point between the two boiler technologies in terms of cost of electricity and NG cost is site specific and application specific. In a deregulated environment, it is possible to have competitive fuel prices based on the NYMEX prices and the City gate charges. For example, if the NYMEX prices were $4.5 per MMBTU at the well head and $1.00 per MMBTU is the City gate charges, then the delivered price would be $5.5 per MMBTU at the point of use. In regulated environments, the prices can vary dramatically. In this case, at the NYMEX prices of $4.5 per MMBTU at the well head, the regulated utility can charge $2.00 to $3.00 per MMBTU resulting in $6.5 to $7.5 per MMBTU delivered at the point of use.

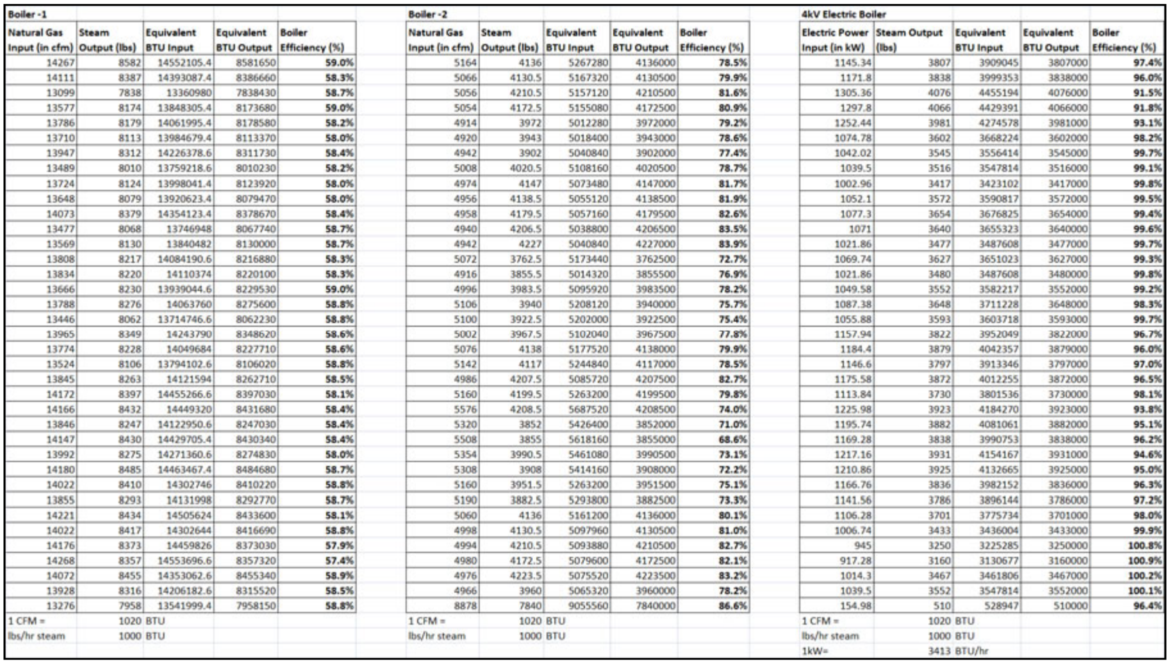
Calculated strike price for electric: assuming 60% efficiency & NG point of use price $5.5 per MMBTU = $0.0310 per kWh (3.1 cents per kWh)

Calculated strike price for electric: assuming 60% efficiency & NG point of use price $7.5 per MMBTU = $0.0422 per kWh (4.22 cents per kWh)

A common question that could be asked of electric boilers is “What would be an average cost savings by not having to install CO2/ NOx /Sox scrubbing or heat recovery equipment?”

Depending on the average boiler size of 300 BHP the costs to install a low NOx burner would be in the range of $45,000 to $60,000 not including economizers, conservatively. The larger boiler sizes could cost even higher than $80,000 depending on the application.

Table 1. Steam Conversion Efficiencies of Natural Gas and 4kV Electric Boiler



Boiler -1				
Natural Gas Input (in cfm)	Steam Output (lbs)	Equivalent BTU Input	Equivalent BTU Output	Boiler Efficiency (%)
14267	8582	14552105.4	8581650	**59.0%**
14111	8387	14393087.4	8386660	**58.3%**
13099	7838	13360980	7838430	**58.7%**
13577	8174	13848305.4	8173680	**59.0%**
13786	8179	14061995.4	8178580	**58.2%**
13710	8113	13984679.4	8113370	**58.0%**
13947	8312	14226378.6	8311730	**58.4%**
13489	8010	13759218.6	8010230	**58.2%**
13724	8124	13998041.4	8123920	**58.0%**
13648	8079	13920623.4	8079470	**58.0%**
14073	8379	14354123.4	8378670	**58.4%**
13477	8068	13746948	8067740	**58.7%**
13569	8130	13840482	8130000	**58.7%**
13808	8217	14084190.6	8216880	**58.3%**
13834	8220	14110374	8220100	**58.3%**
13666	8230	13939044.6	8229530	**59.0%**
13788	8276	14063760	8275600	**58.8%**
13446	8062	13714746.6	8062230	**58.8%**
13965	8349	14243790	8348620	**58.6%**
13774	8228	14049684	8227710	**58.6%**
13524	8106	13794102.6	8106020	**58.8%**
13845	8263	14121594	8262710	**58.5%**
14172	8397	14455266.6	8397030	**58.1%**
14166	8432	14449320	8431680	**58.4%**
13846	8247	14122950.6	8247030	**58.4%**
14147	8430	14429705.4	8430340	**58.4%**
13992	8275	14271360.6	8274830	**58.0%**
14180	8485	14463467.4	8484680	**58.7%**
14022	8410	14302746	8410220	**58.8%**
13855	8293	14131998	8292770	**58.7%**
14221	8434	14505624	8433600	**58.1%**
14022	8417	14302644	8416690	**58.8%**
14176	8373	14459826	8373030	**57.9%**
14268	8357	14553696.6	8357320	**57.4%**
14072	8455	14353062.6	8455340	**58.9%**
13928	8316	14206182.6	8315520	**58.5%**
13276	7958	13541999.4	7958150	**58.8%**
1 CFM =	1020	BTU		
lbs/hr steam	1000	BTU		

Boiler -2				
Natural Gas Input (in cfm)	Steam Output (lbs)	Equivalent BTU Input	Equivalent BTU Output	Boiler Efficiency (%)
5164	4136	5267280	4136000	**78.5%**
5066	4130.5	5167320	4130500	**79.9%**
5056	4210.5	5157120	4210500	**81.6%**
5054	4172.5	5155080	4172500	**80.9%**
4914	3972	5012280	3972000	**79.2%**
4920	3943	5018400	3943000	**78.6%**
4942	3902	5040840	3902000	**77.4%**
5008	4020.5	5108160	4020500	**78.7%**
4974	4147	5073480	4147000	**81.7%**
4956	4138.5	5055120	4138500	**81.9%**
4958	4179.5	5057160	4179500	**82.6%**
4940	4206.5	5038800	4206500	**83.5%**
4942	4227	5040840	4227000	**83.9%**
5072	3762.5	5173440	3762500	**72.7%**
4916	3855.5	5014320	3855500	**76.9%**
4996	3983.5	5095920	3983500	**78.2%**
5106	3940	5208120	3940000	**75.7%**
5100	3922.5	5202000	3922500	**75.4%**
5002	3967.5	5102040	3967500	**77.8%**
5076	4138	5177520	4138000	**79.9%**
5142	4117	5244840	4117000	**78.5%**
4986	4207.5	5085720	4207500	**82.7%**
5160	4199.5	5263200	4199500	**79.8%**
5576	4208.5	5687520	4208500	**74.0%**
5320	3852	5426400	3852000	**71.0%**
5508	3855	5618160	3855000	**68.6%**
5354	3990.5	5461080	3990500	**73.1%**
5308	3908	5414160	3908000	**72.2%**
5160	3951.5	5263200	3951500	**75.1%**
5190	3882.5	5293800	3882500	**73.3%**
5060	4136	5161200	4136000	**80.1%**
4998	4130.5	5097960	4130500	**81.0%**
4994	4210.5	5093880	4210500	**82.7%**
4980	4172.5	5079600	4172500	**82.1%**
4976	4223.5	5075520	4223500	**83.2%**
4966	3960	5065320	3960000	**78.2%**
8878	7840	9055560	7840000	**86.6%**
1 CFM =	1020	BTU		
lbs/hr steam	1000	BTU		

4kV Electric Boiler				
Electric Power Input (in kW)	Steam Output (lbs)	Equivalent BTU Input	Equivalent BTU Output	Boiler Efficiency (%)
1145.34	3807	3909045	3807000	**97.4%**
1171.8	3838	3999353	3838000	**96.0%**
1305.36	4076	4455194	4076000	**91.5%**
1297.8	4066	4429391	4066000	**91.8%**
1252.44	3981	4274578	3981000	**93.1%**
1074.78	3602	3668224	3602000	**98.2%**
1042.02	3545	3556414	3545000	**99.7%**
1039.5	3516	3547814	3516000	**99.1%**
1002.96	3417	3423102	3417000	**99.8%**
1052.1	3572	3590817	3572000	**99.5%**
1077.3	3654	3676825	3654000	**99.4%**
1071	3640	3655323	3640000	**99.6%**
1021.86	3477	3487608	3477000	**99.7%**
1069.74	3627	3651023	3627000	**99.3%**
1021.86	3480	3487608	3480000	**99.8%**
1049.58	3552	3582217	3552000	**99.2%**
1087.38	3648	3711228	3648000	**98.3%**
1055.88	3593	3603718	3593000	**99.7%**
1157.94	3822	3952049	3822000	**96.7%**
1184.4	3879	4042357	3879000	**96.0%**
1146.6	3797	3913346	3797000	**97.0%**
1175.58	3872	4012255	3872000	**96.5%**
1113.84	3730	3801536	3730000	**98.1%**
1225.98	3923	4184270	3923000	**93.8%**
1195.74	3882	4081061	3882000	**95.1%**
1169.28	3838	3990753	3838000	**96.2%**
1217.16	3931	4154167	3931000	**94.6%**
1210.86	3925	4132665	3925000	**95.0%**
1166.76	3836	3982152	3836000	**96.3%**
1141.56	3786	3896144	3786000	**97.2%**
1106.28	3701	3775734	3701000	**98.0%**
1006.74	3433	3436004	3433000	**99.9%**
945	3250	3225285	3250000	**100.8%**
917.28	3160	3130677	3160000	**100.9%**
1014.3	3467	3461806	3467000	**100.2%**
1039.5	3552	3547814	3552000	**100.1%**
154.98	510	528947	510000	**96.4%**
1 CFM =	1020	BTU		
lbs/hr steam	1000	BTU		
1kW=	3413	BTU/hr		

Benefits of 4kV Boiler

Process heater and boilers are essential in many energy-intensive industries and comprise a significant component of US energy consumption. There are currently 163,000 boilers in operations in the USA alone out of which 26% of them are part of industrial operations.

Some of the benefits of the electric boiler are listed below:

Primary benefits

1. Efficiency improvement due to elimination of stepping down transformer since industrial customers readily get this voltage (4kV) at their service entrance; consequently efficiency of converting electric power to heat utilizing resistance heating is very high (90% and above).
2. Compared to 480V electric boilers, the infrastructure is much reduced since the current capacity of 4kV boilers are approximately ten times lower than the 480V equivalent boilers.
3. Absence of combustion in the electric boiler provides no on-site emissions or pollution. This is especially important in non-attainment areas.
4. The electric based heating method is inherently noiseless and clean thus contributes to better and safe work conditions.
5. The new control system allowed to achieved better uniformity of temperature in technological process resulting in precision control of temperature with +/- 0.5^{o}C (or 4.1^{o}F) (while for fossil-fuel based boilers it is +/- 5^{o}C (41^{o}F)). It was achieved using SCR for electronic controller design.
6. The new, medium voltage boiler system and associated elements provided better work conditions; use of higher efficiency equipment can influence and improve productivity of the plant.

Secondary benefits

1. Ability to "fuel switch" and hedge against high energy prices. Electric boilers provide the customer the ability to dispatch the boilers based on fuel costs.
2. Customers can use the electric boiler to reduce the amount of #2 fuel oil, propane as a back-up fuel source and a potential storage and environment hazard.
3. It gives the customers the ability to respond quicker to steam swings within the plant.
4. Operational Flexibility - The electric boilers are more efficient standby source than natural gas based boilers

In a fossil fuel fired boiler, the temperature and combustion related attributes of exhaust gases combine to represent the stack loss of the boiler. This is typically the dominant loss for the fossil fuel boiler. Stack loss is dependent on the operating characteristics of the boiler, the equipment installed and the type of fuel burned in the boiler. Stack loss generally ranges from as much as 30 percent for a green-wood-fired boiler, to 18 percent for a typical natural-gas-fired boiler, to 12 percent for an oil-fired boiler, to as low as 9 percent for a coal-fired boiler. It must be pointed out that the stack-loss range is wide for any given fuel.

Since there is no combustion taking place in the electric boiler, it is possible to locate the electric boiler closer to the actual steam need. This would reduce the amount of steam pipe needed to provide steam from a central plant to the actual steam user. This also would reduce the amount of steam traps needed in the system and also reduces the efficiency losses in the long steam run. A side benefit is that having the shorter steam runs would reduce the cost for insulated steam piping with the electric boiler.

Conclusion

In this paper, two innovative design technologies have been discussed to offer ways to reclaim wasted heat energy in industry. The first technology, heat recovery chiller, shows how it could be augmented to the existing chiller systems to recover wasted heat. The variable speed operation of the compressors will help in improving the energy efficiency of the system as well.

The second technology, 4kV electric boiler, shows an innovative way to use 4160V available at the industry to effectively convert water to steam and eliminate wasted heat through flue gas emissions which are typical of the natural gas boilers. This is not only efficient process but has a smaller foot print as well. They are economically more efficient to use electric in some cases. It was also noticed that another vendor has made a 10MW boiler of the 4kV boiler which goes to confirm that there is a need in the industry and we will see more 4kV boilers in production in the coming years.

References

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