15th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2011, Prague, Czech Republic, 12-18 September 2011

APPLICATIONS OF WASTE HEAT RECOVERY IN AUTOMOTIVE MANUFACTURING RELATED INDUSTRIES

D. Paul Mehta, Ph.D.
Professor & Chairman
Bradley University
1501 W Bradley Ave
Peoria, IL 61625
USA

Ryan Esch
Graduate Student
Bradley University
1501 W Bradley Ave
Peoria, IL 61625
USA

ABSTRACT

Heat treatment is a vital process in the manufacturing of automotive parts. Heat treatment is needed to alter the physical properties of the materials used for manufacturing the parts. The need for altering the physical properties of the materials is governed by some specific processes such as cutting, machining, drawing, and properties needed during service.

Heat treatment ovens/furnaces use a large amount of energy. An improvement in the energy efficiency of these ovens/furnaces can result in significant energy savings. There are several proven technologies which are available for improving the energy efficiency of these ovens/furnaces including but are not limited to: combustion efficiency improvements, minimizing flue gas losses, change of furnace/oven indoor atmosphere, oxygen enrichment, plugging of unwanted openings, and minimizing wall losses. Supply chain industries to support the implementation of these energy efficient technologies in some cases can be very energy intensive themselves. For example, minimization of wall losses requires improving the integrity of the oven/furnace shell. This in turn requires the installation of good high temperature refectories. Manufacturing of high temperature refectories itself is a very energy inefficient process because a lot of waste heat is generated during this process and is not recovered.

The current paper describes a case study involving waste heat recovery in a high temperature refectories manufacturing plant. The study was based upon the applications of Process Heating Assessment and Survey Tool (PHAST). The objective of the study was to make the manufacturing process of high temperature refractory energy efficient so that the cost of refurbishing the ovens/furnaces used in the automotive industries can become more affordable and ultimately result in reducing the energy costs making automotive industries more competitive.

1. INTRODUCTION

Heat recovery can substantially lower the operating costs for an automotive parts manufacturing facility by utilizing the heat generated from one process for another. Most processes such as heat treatment require a specific amount of heat by elevating the temperature of a fluid or a substance to a given level and once that heat is used for the process it is rejected to the atmosphere. Generally only a small portion of the energy is used for the actual process. It seems illogical to utilize only a portion of the energy and wasting the remaining which could be used for something else. Heat recovery systems use that energy being rejected, which was already paid for by the company, for additional purposes that will lower the company’s cost of operation. Heat can be extracted from solids, liquids, and gaseous media. The classifications of waste heat recovery are low, medium, and high temperature ranges which fall within the temperature ranges of below 450°F, 450-1200°F and 1200° + °F respectively. For the low temperature range there is no applicability for recovering work, and the heat that is recovered is used for things such as preheating the intake air, heating domestic water supplies, or producing low pressure steam. The medium temperature range can be used to produce some mechanical work. However, the high temperature range could be used to produce a substantial amount of mechanical work that could possibly be used to drive a steam turbine through the use of an industrial boiler. [1]

Several heat reclamation devices are available commercially. The efficiency of these devices involves some of or all of the following factors: [2]

- The temperature difference between the heat source and the heat sink
- The latent heat difference between the heat source and the sink
- The mass flow multiplied by the specific heat of each source and sink
- The efficacy of the heat transfer device
- The extra energy required to operate the heat recovery device
- The fan or pump energy used as heat by the heat transfer device (which either enhances or detracts from performance)

2. BACKGROUND

Heat treatment is a vital process in the manufacturing of metal products. Heat treatment is needed to alter the physical properties of the materials used for manufacturing the parts. The need for altering the physical properties of the materials is governed by some specific processes such as cutting, machining, drawing, and properties needed during service.

Heat treatment ovens/furnaces use a large amount of energy. An improvement in the energy efficiency of these ovens/furnaces can result in significant energy savings. There are several proven technologies which are available for improving the energy efficiency of these ovens/furnaces including but are not limited to: combustion efficiency improvements, minimizing flue gas losses, change of furnace/oven indoor atmosphere, oxygen enrichment, plugging of unwanted openings, and minimizing wall losses. Supply chain industries to support the implementation of these energy efficient technologies in some cases can be very energy intensive themselves. For example, minimization of wall losses requires improving the integrity of the oven/furnace shell. This in turn requires the installation of good high temperature refractories. Manufacturing of high temperature refractories itself is a very energy inefficient process because a lot of waste heat is generated during this process and is not recovered.

The current paper describes a case study involving waste heat recovery in a high temperature refractories manufacturing plant. The study was based upon the applications of Process Heating Assessment and Survey Tool (PHAST)[1]. PHAST can be used to survey all process heating equipment within a manufacturing plant, select the equipment that uses the most energy, and identify ways to increase efficiency. It can also be used to identify ways to increase efficiency.

The U. S. Department of Energy (DOE) Industrial Technologies Program (ITP) has developed a tool to survey all process heating equipment within a facility, select the equipment that uses the most energy, and identify ways to increase efficiency. This software analyzes the processes' current operation and compares that cost to the cost of operation for hypothetical situations where energy efficiency practices have been utilized. PHAST can also assess equipment performance under various operating conditions and "what if" scenarios. The software provides instructions on how to obtain data for each step with commonly available instruments without affecting production. [2,6]

The objective of this study was to use PHAST to make the manufacturing process of high temperature refractory energy efficient so that the cost of refurbishing the ovens/furnaces used in the industries can become more affordable and ultimately result in reducing the energy costs making manufacturing sector more competitive.

3. REFRACTORY FACILITY

The facility which was selected to apply PHAST in order to implement an optimal heat recovery plan produces Toll firing and high temperature refractories.

Typically 16 employees are involved in producing 173,000 pounds. The estimated annual sales for this company are approximately $2.5 million. The plant operates 52 weeks per year. Approximate operating schedules of the various areas considered in this paper are given below:

---

[1] For an access to PHAST at no cost, contact 1-877-EERE-INF(1-877-337-3463) or www.eere.energy.gov

OPERATING SCHEDULE BY AREA

Area	Operating Schedule	Days Considered	Annual Operating Hours
Offices	7:00 a.m. to 6:00 p.m.	Monday to Friday	2,860
Warehouse	6:00 a.m. to 4:00 p.m.	Monday to Friday	2,600
Slip Casting	6:00 a.m. to 4:00 p.m.	Monday to Friday	2,600
Heavy Casting	24 hours a day	Sunday to Friday	6,240
Custom Firing	24 hours a day	Sunday to Friday	6,240

The facility is only one building with a total area of approximately 66,000 ft^2 with only 6% of the space being for office purposes. Figure 1 shows the layout of the facility.

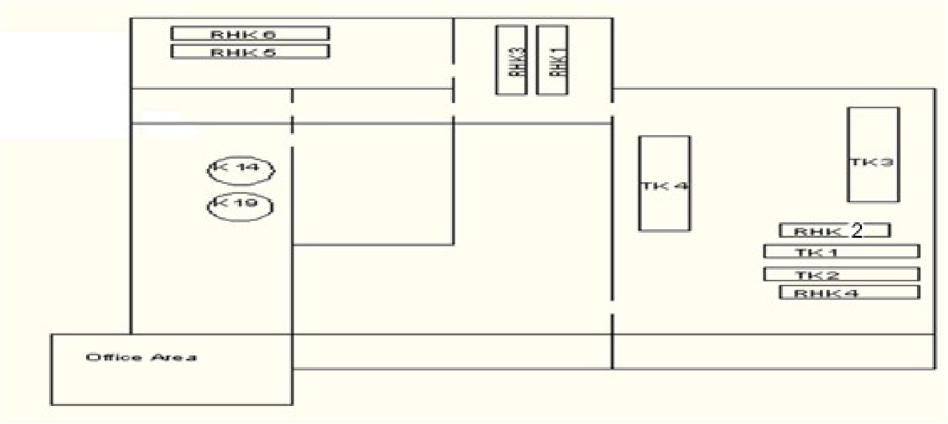


Figure 1. Facility Layout

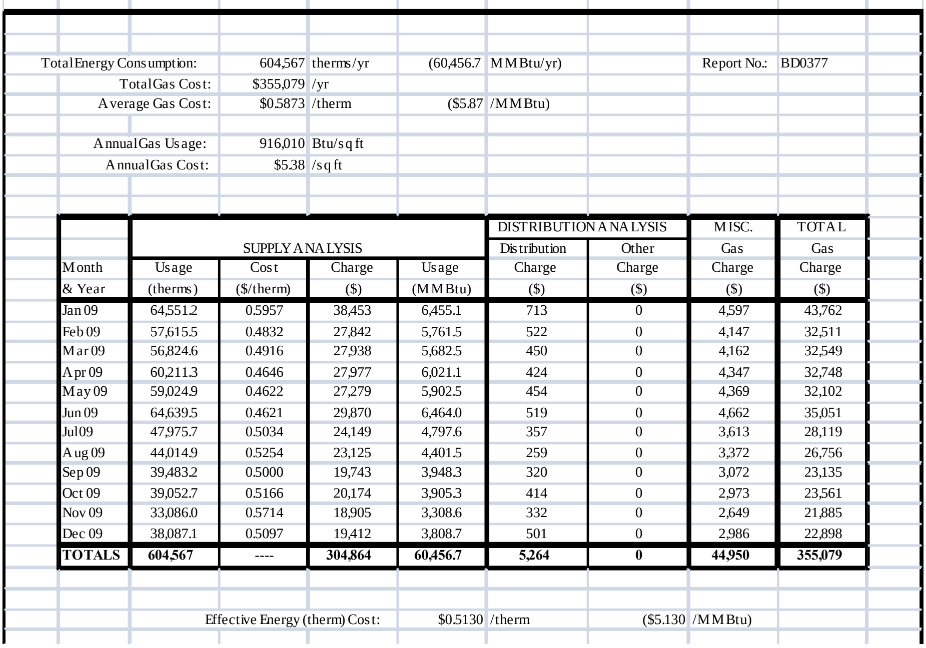
4. UTILITY BILLS

Electric consumption for the year 2009 for this facility having an area of 66,000 ft^2 was 740,773 KWh at a cost of $50,795. The gas consumption for the same period was 604,567 Therms at a cost of $355, 079. Monthly break down of the gas consumption is shown in Table 1 below.

CONTENTS

AUTHORS

Table 1. Gas Summary



Total Energy Consumption: 604,567 therms/yr (60,456.7 MMBtu/yr) Report No.: BD0377
Total Gas Cost: $355,079 /yr
Average Gas Cost: $0.5873 /therm ($5.87 /MMBtu)

Annual Gas Usage: 916,010 Btu/sq ft
Annual Gas Cost: $5.38 /sq ft

	SUPPLY ANALYSIS				DISTRIBUTION ANALYSIS		MISC.	TOTAL
					Distribution	Other	Gas	Gas
Month & Year	Usage (therms)	Cost ($/therm)	Charge ($)	Usage (MMBtu)	Charge ($)	Charge ($)	Charge ($)	Charge ($)
Jan 09	64,551.2	0.5957	38,453	6,455.1	713	0	4,597	43,762
Feb 09	57,615.5	0.4832	27,842	5,761.5	522	0	4,147	32,511
Mar 09	56,824.6	0.4916	27,938	5,682.5	450	0	4,162	32,549
Apr 09	60,211.3	0.4646	27,977	6,021.1	424	0	4,347	32,748
May 09	59,024.9	0.4622	27,279	5,902.5	454	0	4,369	32,102
Jun 09	64,639.5	0.4621	29,870	6,464.0	519	0	4,662	35,051
Jul09	47,975.7	0.5034	24,149	4,797.6	357	0	3,613	28,119
Aug 09	44,014.9	0.5254	23,125	4,401.5	259	0	3,372	26,756
Sep 09	39,483.2	0.5000	19,743	3,948.3	320	0	3,072	23,135
Oct 09	39,052.7	0.5166	20,174	3,905.3	414	0	2,973	23,561
Nov 09	33,086.0	0.5714	18,905	3,308.6	332	0	2,649	21,885
Dec 09	38,087.1	0.5097	19,412	3,808.7	501	0	2,986	22,898
TOTALS	**604,567**	----	**304,864**	**60,456.7**	**5,264**	**0**	**44,950**	**355,079**

Effective Energy (therm) Cost: $0.5130 /therm ($5.130 /MMBtu)

As shown in the table above, the company spent $355,079 in the 2009 calendar year or natural gas. It is also noted that the facility personnel mentioned that productivity for the 2009 year was scaled down due to the economic downturn. It can be seen from Table 1 that for the months from June 2009 through December 2009 show a decline in consumption of natural gas. Also there is little difference between the winter month's consumption and the rest of the calendar year. Normally, there is a distinct increase in natural gas consumption for a facility during these months. However, for this facility, the natural gas consumption for the facility's processes is much greater than that required for heating. Also the facility has reduced production as demand has decreased during this economic downturn. These two combined make it difficult to decipher the data acquired for finding how much energy is used for space heating.

5. DIRECT FIRED EQUIPMENTS

The facility has a number of kilns that are used for different applications. There are the roller hearth kilns (RH or RHK), the tunnel kilns (TK), and the standard kiln (K). Each has a corresponding number to identify the equipment. The kilns' locations are labeled on the facility layout diagram in Figure 1. Each kiln has documented operating hours and natural gas consumption, which will come in handy later.

5.1. Analysis for Heat Recovery

In order to see which pieces of equipment are the best candidates for heat recovery, it is important to audit all the gas consuming processes in the facility. As stated in the previous section, the facility is a good candidate for heat recovery due to their large consumption of natural gas. However, narrowing down to which methods of heat recovery are not only technically feasible, but financially feasible, requires a more in depth approach.

5.2. Analyzing the Equipment

PHAST was used to get a profile the facility's natural gas consumption on an annual basis by each piece of equipment. The information necessary for this assessment was the operating hours of each kiln, the natural gas consumption per kiln or the MMBTU rating per burner, the dimensions of the kiln, the inlet flow rate, composition of elements being loaded into the kiln, etc. The information provided by the facility is presented below in Table 2

*Table 2. Kiln Operations. *Data taken based on inlet diameter and velocity of inlet gasses**

Kiln	Operating Percent (total hours 7500/yr)	Operating Hours	Therms/hr	Kiln Length (ft)	Kiln CFM	Exhaust Diamter (Feet)
TK 1	60%	4516.47	12	16.5	1428	2
TK 2	45%	3340.54	12	16.5	1620	2
TK 4	57%	4254.32	25	16.5	1447	2
RH 1	64%	4771.13	2	28.33	1419	2.5
RH 2	0%	0	0.86	20.4	1419	2.5
RH 3	50%	3715.04	0.2	35.16	1013	2.5
RH 4	7%	501.83	0.86	23	1013	2.5
RH 5	49%	3685.08	2	28.33	1013	2.5
RH 6	54%	4022.13	2	28.33	1013	2.5
K 14	8%	629.16	19.2	cylindrical	1571	0.67
K 19	5%	404.46	30.7	cylindrical	1178	0.67
K 9	33%	2456.72	1	cylindrical	1374	0.67

Although the operating hours are appealing, it is also necessary to look at when these individual units are firing in order to see which units could possibly provide heat to the facility during the winter months if necessary. The table given below shows the idling schedule for the kilns, which is the time when the kilns are not firing at their peak operational temperature.

Table 3. Operating time for kilns on a monthly basis.

	TK1	TK2	TK4	RH1	RH2	RH3	RH4	RH5	RH6	K14	K19	K9
January	0%	86%	100%	96%	0%	96%	57%	96%	89%	18%	0%	57%
February	100%	25%	100%	100%	0%	100%	7%	100%	64%	29%	0%	43%
March	100%	100%	0%	61%	0%	71%	0%	71%	32%	14%	0%	39%
April	86%	86%	43%	75%	0%	75%	0%	46%	64%	0%	0%	14%
May	74%	51%	86%	86%	0%	86%	9%	29%	40%	11%	11%	23%
June	75%	100%	54%	57%	0%	64%	0%	46%	61%	14%	39%	29%
July	0%	54%	0%	64%	0%	54%	0%	68%	68%	0%	0%	43%
August	40%	0%	74%	43%	0%	29%	0%	57%	60%	0%	0%	17%
September	68%	0%	82%	50%	0%	18%	7%	29%	43%	0%	0%	43%
October	57%	0%	51%	69%	0%	3%	0%	26%	63%	0%	0%	46%
November	61%	0%	29%	64%	0%	0%	0%	21%	28%	14%	0%	29%
December	63%	34%	63%	0%	0%	0%	0%	0%	31%	0%	14%	11%
Total Average	60%	45%	57%	64%	0%	50%	7%	49%	54%	8%	5%	33%

The data shows that the kilns that operate the most are TK1 operating 60.3% of the time, TK4 at 56.8%, RH1 at 63.7%, RH5 at 49.2%, and RH6 at 53.7%. This is just the operating time. In order to see which kilns are using the most natural gas, a comparison using a pie chart is shown below.

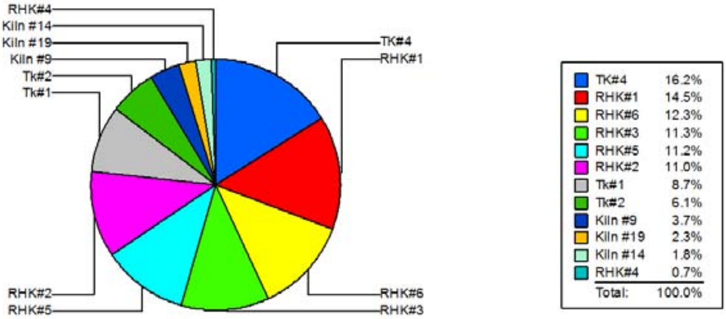


Figure 2.Facility's consumption of natural gas by kiln

CONTENTS

AUTHORS

As shown in Figure 2, the kilns that use the most natural gas are TK1, TK4, RHK1, RHK2, RHK 3, RHK5, and RHK6. These are the kilns that will be analyzed for feasibility of installing a heat recovery system.

5.3. Heat Recovery Applications

A systematic approach is used to select the candidates for using the recovered waste heat in an optimal way based on financial and technical feasibility.

5.4. Heat Recovery for Space Heating

The rooms with the kilns located inside them are already “heated” by the heat that escapes the kiln, so heat recovery for inside the facility already is not going to be financially feasible. But recovering heat for the office area could also be considered. In order to see whether this is technically feasible, the firing time of one kiln must coincide with the winter months in order for maximum benefit from the recovered heat. Based upon the idling time for the kilns during the winter months, the only kiln that satisfies this criteria would be TK4. Heat recovery for facility heating could work only if supply and demand for heat coincide Next, the proximity of the kiln and the office area must be relatively close so that minimal ductwork is necessary for the transfer of the heated air. From the facility layout it can be seen that TK4 is in proximity to the offices. However, after communicating with plant personnel, it was found that the office space requires a minimal amount of heat, where only a few rooms are being occupied. Also, kiln utilization is dependent on the demand for the products that each line produces. Fluctuation in demand may not guarantee that the kiln with the installed heat recovery system will be used during the winter months when the heat is needed. The combination of the minimal heat required for heating and the fluctuation of kiln utilization eliminates this application of heat recovery.

5.4. Preheating Intake Air

The efficiency of a kiln can be improved by preheating the incoming combustion air. Because the exhaust temperatures fall within the high temperature range, there are only a few types of heat exchangers that can be used. For high temperature range systems only ceramic heat wheels, radiation and convection recuperators can be used in these situations. Refer to equation 1 below where the amount of energy that can be recovered from the kilns is quantified. The first part of the equation $(\rho \cdot CFM)$ refers to the mass of air being heated. The $(T_2 - T_1)$ portion relates to the temperature difference between the hot and cold gases. However, there is also the need to look at the efficiency of the heat exchanger, η_{exch}.

Typically heat exchanger efficiencies vary by design, but for the sake of this paper it will be assumed an efficiency of 0.8, or 80%.

$$\dot{Q}_m = (\rho \cdot CFM) \cdot C_p(T_2 - T_1) \cdot \eta_{exch} \qquad \text{Eq(1)}$$

The calculations for how much energy can be recovered from the exhaust gasses are in Table 4.

Table 4. Annual Savings from Preheating Intake Air

Kiln	Recoverable Energy (MMBTU	Money Saved (h=55%)	Money Saved (h = 65%)	Money Saved (h = 70%)	Current Operation (annual)
TK 1	6,674	17,246	20,381	31,949	32,034
TK 2	4,169	10,773	12,732	13,711	24,014
TK 4	6,371	16,464	19,458	20,954	30,582
RH 1	10,508	27,153	32,090	34,559	56,042
RH 3	7,792	20,136	23,979	25,628	43,637
RH 5	7,729	19,974	23,605	25,421	43,285
RH 6	8,612	22,255	26,301	28,324	47,244
TOTAL	51,856	134,001	158,365	170,547	276,837

The recoverable energy is based on Equation 1 and uses the change in temperature from the exhaust gas temperature when it enters the exhaust duct and the limitations on the lowest possible temperature for the exhaust temperature, which is the dew point of sulfur dioxide at approximately 158°F. Keeping the exhaust temperature above this point is essential to acidic condensate off the equipment, which would reduce the operational life of the system. Therefore, the exhaust gasses are only allowed to reach 250°F for a 90-100°F cushion for safety of the equipment. The data used to calculate the recoverable energy are shown in Table 5.

Table 5-Values for Calculation

Density exhaust	0.069	lbm/ft^3
Density air at 60 Deg F	0.078	lbm/ft^3
Cp air at 60 Deg F	0.241	BTU/lbm°F
Cp Exhaust gases	0.25	BTU/lbm°F
Heat Exch Eff η	0.8	
Cost of Fuel	5.873	($/MMBTU)

The reason that Table 4 has savings broken down into different recovery efficiencies is due to the type of heat exchanger used. The more efficient the heat recovery, the more expensive the heat exchanger will be. The corresponding amount of energy recovered thus will heat the intake air to a given temperature level. The change in temperature of the intake air is given in Table 6 for the corresponding increase in efficiency. This shows how much temperature of the intake air will be changed from the ambient environment temperature for the combustion process.

Table 6. Change in Temperature for Intake

Kiln	At 55% recovered	At 65% recovered	At 70% recovered
TK 1	505	596	642
TK 2	1262	1491	1606
TK 4	505	596	642
RH 1	757	895	964
RH 3	1009	1193	1285
RH 5	1009	1193	1285
RH 6	883	1044	1124

5.5. Financial Feasibility

In order to see if using the waste heat is economically feasible, an analysis incorporating the cost of installation, purchasing, maintaining, personnel training, and labor costs was done. These costs are termed *Implementation Costs*. After the implementation costs are determined, the ratio of implementation cost to savings should give the payback period for the equipment.

5.6. Cost of Equipment

Each unit would require its own independent heat exchanger, ductwork, fans for the intake air and the outlet side of the heat exchanger for the exhaust, and controls for the system. The duct needs to run from the intake fan to the heat exchanger then bringing the hot intake air to the system. The fans need to be sized to account for the pressure drop across the heat exchanger. Also an exhaust fan needs to be on the downstream side of the heat exchanger to induce a draft and force the exhaust products through the stack. Controls need to be present to control the fan speeds to adjust to variable load requirements. Also, minor facility modifications will be required for supporting the heat exchanger, which will be located either directly above or adjacent to the kilns. The only requirements for placement of the heat exchanger is that it is provides easy ductwork for the exhaust and the intake and also that it does not impede with facility functionality.

The approximate implementation cost based on the purchasing of the components mentioned above and the cost of labor is estimated to be between $50,000-$60,000 per installation. This is based on a quote from a vendor where the purchase and transportation of the heat exchanger is $30,000 and the installation costs are approximately $25,000 for labor and facility modifications. The payback period based on savings is summarized in Table 7. The implementation cost for the calculation was estimated to be $55,000, and based on the savings summarized in Table 4. The reason for incrementally showing payback periods based on different efficiencies as presented in Table 7 is depending on how the system is constructed. For a good heat exchanger, efficiencies can get up to as high as 83%. However, there can also be losses to the environment due to heat transfer through ductwork. This is why the payback periods are presented in this manner. Also note that heat exchanger efficiencies and cost are directly related, where the better the heat exchanger the more costly it will be. It is recommended to incrementally install these heat recovery systems, due to the high cost of these installations. In order to see the best results first, installation of the systems with the higher savings or lower payback period should be considered first so the company gets a good return on their investment. In addition, the local utility company should be contacted if they offer any rebates for such energy efficient strategies.

Table 7- Summary of Payback Period

Kiln	Approx Payback Period (η =55%)	Approx Payback Period (η =65%)	Approx Payback Period (η =70%)
TK 1	3.19	2.70	2.51
TK 2	5.11	4.32	4.01
TK 4	3.34	2.83	2.62
RH 1	2.03	1.71	1.59
RH 3	2.73	2.31	2.15
RH 5	2.75	2.33	2.16
RH 6	2.47	2.09	1.94

5.7. Cogeneration

Cogeneration is producing electricity using waste heat. It is divided into two subcategories; topping and bottoming systems. In topping systems, the cogeneration system is designed to meet the electrical capacity required for the system, and the subsequent remaining heat is used for heating applications. In bottoming systems the unit is designed to utilize what heat is already present to generate whatever electricity can be produced with that available heat. For this facility, a bottoming system will be analyzed.

5.8. Technical Feasibility Analysis

For cogeneration to be possible there needs to be a certain amount of available heat to be able to produce the steam or water and the temperatures required for optimal operation. Also, there needs to be a coincidence of operation where the demand for electricity is at the same time as when the heat is being generated unless the local utility company buys back the generated electricity. The average temperature for a waste heat boiler for this application is approximately 1,200°F depending on the type being used. Fortunately for this analysis, a few of the kilns in this facility fall within this temperature range. The approximate exhaust temperatures for the kilns are given in Table 8.

Table 8-Exhaust Temperatures

	TK 1	TK 2	TK 4	RH 1	RH 3	RH 5	RH 6
Exhaust Temp (Deg F)	1000	2500	1000	1500	2000	2000	1750

The next step would be to calculate the thermal and electrical load factor. The load factor is defined as the average energy consumption rate for a facility divided by the peak energy consumption rate over a given period of time. If a facility has a low load factor, it indicates that there are periods of high energy consumption followed by longer periods of lower consumption. The higher the load factor, the better it is for the facility. The load factors for the electric and gas consumption are given below in Table 9 and Table 10 respectively. The electrical load factor was calculated using the information in their utility bills while the thermal load factors were calculated using Tables 2 and 3. Load factors below 50% are unacceptable because cogeneration will economically be unfeasible.

CONTENTS

AUTHORS

Table 9. Electrical Load Factor

Annual Average kWh	61,731
Annual Average L.F.	0.69

Table 10 – Thermal Load Factors "Dashes" Indicate No Kiln Usage.

	TK1	**TK2**	**TK4**	**RH1**	**RH3**	**RH5**	**RH6**
January	-	1,032,000	1,250,000	192,000	19,200	192,000	178,000
February	1,200,000	300,000	1,250,000	200,000	20,000	200,000	128,000
March	1,200,000	1,200,000	-	122,000	14,200	122,000	64,000
April	1,032,000	1,032,000	537,500	150,000	15,000	92,000	128,000
May	888,000	612,000	1,075,000	172,000	17,200	58,000	80,000
June	900,000	1,200,000	675,000	114,000	12,800	92,000	122,000
July	-	648,000	-	128,000	10,800	136,000	136,000
August	480,000	-	925,000	86,000	5,800	114,000	120,000
September	816,000	-	1,025,000	100,000	3,600	58,000	86,000
October	684,000	-	637,500	138,000	600	52,000	126,000
November	732,000	-	362,500	128,000	-	42,000	58,000
December	756,000	408,000	787,500	-	-	-	62,000
Avg Demand	724,000	536,000	710,417	127,500	9,933	96,500	107,333
Max Demand	1,200,000	1,200,000	1,250,000	200,000	20,000	200,000	178,000
Annual Thermal L.F. (no units)	0.6	0.45	0.57	0.64	0.5	0.48	0.6

The electrical load factor shows that the average kW demand is approximately 69% of the peak demand throughout the year. For the thermal load factors (L.F.), the kilns with the lower thermal LF should be eliminated. Thus TK2, RH3, and RH5 should no longer be considered to be candidates for cogeneration due to their low L.F.'s of operation.

The next step is to see if there is a coincidence of operation for the thermal and electrical utilization. For this the thermal to electric load ratio needs to be calculated. This is the ratio of the thermal demand to the kW demand. The thermal to electric L.F. are given in Table 11.

As Table 11 shows, there are some months with a higher L.F. than others. This is due to the fluctuating operating hours from month to month for the kilns based on demand for the product each kiln produces. It also shows that RH1, RH3, RH5, and RH6 have low average load factors, indicating that there is low utilization of the kilns. This is also apparent in **Error! Reference source not found.**2, which shows the idling time for the kilns on a monthly basis. Therefore, those kilns cannot be considered for cogeneration. For the kilns that showed a higher thermal to electric L.F., the annual average thermal to electric load ratio should be approximately equal to those calculated in Table 11. The annual average thermal/electric load ratio is given by the equation below and are shown in Table 12.

As shown in the table, the annual average for TK1 shows the best thermal/electric load ratio, thus being the best candidate for cogeneration. Unfortunately, it may not be enough to fit the requirements for a cogeneration unit. Facilities that have a T/E load ratio above 5 are generally good candidates, and above 10 the best. But the best T/E load ratio for this facility is only 2.76. This is below the 5 requirement for the T/E ratio. Even though this analysis shows that it may not be a good investment, some of the numbers provided by the facility may not reflect the overall profile of consumption of the facility due to the lowered demand for goods from the economic downturn. Cogeneration opportunities may be available if production increases and thus more data regarding steady loads become available. The idling times in Table 2 would thus be reduced, and the annual thermal load factor would thus increase. At this time it is not recommended to pursue a more in depth analysis for cogeneration for this facility. However, if production increases as the economy improves, another detailed feasibility analysis should be considered taking into account the possibility of selling electricity back to the public utility or to an adjacent user.

Table 11.Thermal/Electric Load Factor

	TK1	TK2	TK4	RH1	RH3	RH5	RH6
Jan	-	2.75	3.33	0.51	0.05	0.51	0.47
Feb	3.14	0.78	3.27	0.52	0.05	0.52	0.33
Mar	3.28	3.28	-	0.33	0.04	0.33	0.17
April	2.77	2.77	1.44	0.4	0.04	0.25	0.34
May	6.94	4.78	8.4	1.34	0.13	0.45	0.63
June	6.98	9.3	5.23	0.88	0.1	0.71	0.95
July	-	5.45	-	1.08	0.09	1.14	1.14
Aug	4.49	-	8.64	0.8	0.05	1.07	1.12
Sept	8.24	-	10.35	1.01	0.04	0.59	0.87
Oct	1.89	-	1.76	0.38	0	0.14	0.35
Nov	2.05	-	1.02	0.36	-	0.12	0.16
Dec	2.15	1.16	2.24	-	-	-	0.18
AVG	**3.49**	**2.52**	**3.81**	**0.64**	**0.05**	**0.49**	**0.56**
Max	8.24	9.3	10.35	1.34	0.13	1.14	1.14
Min	0	0	0	0	0	0	0.16

$$\text{Annual Average}\frac{\text{Thermal}}{\text{Electric}}\text{Ratio} = \frac{\text{Annual Average mbh Demand}}{\text{Annual Average kW Demand}}$$

Table 12. Annual Average Thermal/Electric Load ratio. 1mbh=1,000BTU/hr

	TK1	TK2	TK4	RH1	RH3	RH5	RH6
Avg (BTU/hr)	724,000	536,000	710,417	127,500	9,933	96,500	107,333
Avg mbh	724	536	710	128	10	97	107
Avg kW demand	262	262	262	262	262	262	262
Annual Avg T/E Load Ratio	2.76	2.04	2.71	0.49	0.04	0.37	0.41

6. CONCLUSIONS

A manufacturing facility which manufactures components (refractories) for the equipments (ovens) used in industries was assessed for energy efficiency through the applications of waste heat recovery. PHAST was used to study the energy consumption patterns of the kilns in the facility. It has been shown that although lot of waste heat was generated by these kilns, only a few applications were found to be technically and economically feasible to use this waste heat resulting in energy and cost savings.

7. REFERENCES

[1] Thumann, Albert, and D. Paul Mehta. “Waste Heat Recovery” Handbook of Energy Engineering, Kilburn, GA; Fairmont, 2008.
[2] Fred S. Dubin and Chalmers G. Long Jr., Energy Conservation Standards, McGraw-Hill Book Company. New York, NY 10020
[3] “Boost Process Heating Efficiency”. U.S. Department of Energy, December 2008.
[4] Doty Steve, and Wayne C. Turner. “Energy Management Handbook”. The Fairmont Press. Kilburn, GA 2010.
[5] Mehta, D. Paul. Save Energy Now (SEN) ESA-056-2 Report. U.S. Department of Energy. June 2007.
[6] www.eere.energy.gov/PHAST