HEFAT2014
10th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics
14-16 July 2014
Orlando, Florida

THERMAL SCIENCES AND ENERGY EFFICIENCY

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ABSTRACT

Sun is the only source of energy. Following many centuries since its formation, the earth has stored a given amount of the original mass migration energy in relatively fixed or limited quantities. This stored energy is available for conversion to useful forms, generally through chemical conversion process then through the First Law of Thermodynamics to processes (building heating and thermal needs of industry), or Second Law of Thermodynamics to processes (transportation, electrical power generation, refrigeration, shaft power). It is these processes that are the rightful target of energy efficiency efforts at reducing rate of use of the limited or finite energy viz: fossil fuels stored within earth.

Developments in the fields of heat transfer and fluid mechanics have led to the design and manufacturing of equipments to carry out the above mentioned processes. These equipments such as boilers, turbines, compressors, pumps, refrigerators, chillers, furnaces, ovens, etc. have helped us to raise the quality of our life. However, these equipments consume energy and cause the energy problem viz; rapid depletion of the limited or finite energy-producing potential stored within earth and the related pollution.

These problems have been and can be changed to challenges and opportunities through the applications of HEFAT. **The objective of the work reported in this paper is exactly that.**

INTRODUCTION

Generally space heating, thermal needs of the industry, some engines for transportation, and turbines for power generation use steam.

The process of production of steam is as old as the industrial revolution. Currently, the U.S. manufacturing sector uses more energy for steam generation than for any other single purpose. In 2002, steam accounted for 31% of total U. S. manufacturing energy consumption. This high-energy demand in part reflects the reliance on an aging U. S. industrial boiler population employing designs that conceptually vary little from those used at the end of the 19th century.

As such, applications of new technologies are limited and have offered only incremental gains in operational efficiency. The U.S. manufacturing sector utilizes more than 33,000 boilers with capacities greater than 10 million But/hr. Of these, more than 80% were purchased prior to 1978, with the largest share purchased in the 1960's. However, an important window of opportunity to reduce steam generation energy use will open to U.S. manufacturers as they begin to replace their aging stock of existing industrial boilers nearing retirement.

Through the application of Heat Transfer, Fluid Flow, and Thermodynamics(HEFAT), researchers are working to develop new, breakthrough steam generation technologies that could potentially save U. S. industry billions of dollars per year in operating costs and substantially lower associated environmental impacts. By utilizing a unique boiler geometry incorporating a two-stage fire tube design and heat recovery system that are both compact and highly efficient (>94% HHV efficiency), first generation Super Boilers will offer up to 25% increases in steam generation efficiency and occupy substantially reduced footprints relative to their conventional counterparts.

* These numbers refer to the references cited at the end.

Efficiency gains alone could result in total U. S. manufacturing energy cost savings of approximately $6 billion per year. Reduced footprints also enable new opportunities for boiler modularization. In addition, the First Generation Super Boilers will integrate several HEFAT fundamentals to achieve extraordinarily low emissions NO<5 ppmv, aiding in compliance with the stringent emissions regulations.

BACKGROUND

Since the Industrial revolution began in the late 1700's manufacturing processes have steadily evolved. What were once hand production methods have since been replaced by the manufacturing industries we see today. The evolution of these processes has increased the speed and ease as to which products are created and delivered. With this speed and ease comes a downside, pollution and mass energy consumption.

From the 1800's entering the 1900's, pollution was not a subject well recognized around the manufacturing world. The United State Department of Energy (DOE) was originally formed on August 4, 1977 as a result from the 1973 oil embargo. The department consolidated the Federal Energy Administration, the Energy Research and Development Administration, the Federal Power Commission as well as various other endeavors including energy management across manufacturing industries and domestic applications. [1]*

"The mission of the DOE is to endure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions." [2]

Research Objectives

The objectives of the research work reported in this paper were to illustrate as to how the integration of the science of HEFAT and Digital Technology have lead to the development of tools which provide solutions in the field of energy efficiency.

Digital Technology

In the 1940's the first digital computers became available in the United States. These machines were slow and took tremendous amounts of work and time to get the information needed out of the system. In the time from the 1940's to present day, the power of computers has increased more than a million times. With this increase in power, the cost, power requirements, and programming difficulties have been reduced immensely. These occurrences have led to more and more engineering problems being solved with computers. [3] With the increasing demand for computers in energy engineering there has been much advancement in software and computer technologies. For example, the DOE has developed several software packages based upon the integration of digital technology and science of HEFAT. [4] Some of them and their capabilities are:

- Steam System Modeler Tool (SSMT)

  ° Demonstrates how each component impacts the others and what changes may promote overall efficiency. [5]

- Steam System Scoping Tool(SSST)

  ° A scorecard designed to help steam system personnel perform self-assessments of the system. This scorecard compares the facilities system against certain identified best practices and self-evaluations of similar facilities.

  ° The tool asks 26 questions about different areas of the steam system and provides a score.

- Steam System Assessment Tool (SSAT)

  ° Allows steam analysts to develop models of real systems and quantify energy, cost, and emissions savings.

  ° Analyzes boiler efficiency, boiler blowdown, cogeneration steam cost, condensate recovery, heat recovery, vent steam, insulation efficiency, alternative fuels, backpressure turbines, steam traps, steam quality, and steam leaks. [5]

- Energy, Efficiency, and Economy(3E Plus)

  ° Calculates the most economical thickness of insulation to avoid the expense of over insulation. [5]

The above set of tools is called Steam System Tool Suite (SSTS). The input data for this SSTS include the utility bills and hours of operation to calculate the annual and hourly, power and water costs. Other input data are boiler fuel, boiler efficiency and blowdown rates. The input data on the steam distribution system need information on steam turbines, piping insulation, steam traps, steam leaks etc.

The SSTS uses the principles of HEFAT and calculates the savings in operational costs and reduction in plant emissions as a result of implementing certain strategies for energy efficiency.

RESULTS

Significant cost and energy savings have been documented as a result of using the above mentioned tools. Using only the SSST at 18 small and medium sized manufacturing plants, 89 improvements were found resulting in savings of $2,800,000 per year. Using the SSAT in just one assessment in the chemical production plant yielded an average energy savings of 33,000 MMBtus/yr totaling $1,565,000 annually. In 12 more assessments across different types of industries done by the Industrial Assessment Centers (IACS) program of the DOE, the total energy savings were 544,800 MMBTUs/yr and cost savings of $1,624,500.

INDUSTRIAL ASSESSMENT CENTERS (IACs) PROGRAM OF DOE

INDUSTRIAL ASSESSMENT CENTERS (IACs) is a U.S. Department of Energy (DOE) sponsored program. Currently there are 26 such centers located at the various universities in the country. Under this program teams of students with 3-5 students each under the guidance of a faculty do 1-2 days energy efficiency, waste minimization, and productivity enhancement assessments of small and medium sized manufacturing plants. One such center has been at Bradley University since 1993. A summary of the savings identified and implemented through the work of Bradley University Industrial Assessment Center (BU IAC) is shown in Appendix 1- Table 1.

CASE STUDY

The Industrial Assessment Center at Bradley University sent a team of engineering students to a Manufacturer M in Addison, Illinois. The task for this team was to perform an energy audit, suggest changes to the facility and deliver a report to the company. M uses two steam boilers for generating steam for the facility and these boilers were not as efficient as possible. The team suggested many assessment recommendations (ARs) for steam system including: insulate exposed steam pipes in boiler room, preheat boiler intake air, install turbulators in the boiler, install high efficiency burners in boilers. In order to quantify savings from these ARs, the SSAT software was used. The following information was gathered while visiting Plant M:

- Site power import (kW)
- Site power cost ($/kWh)
- Operating hours per year (hrs)
- Header pressure (psig)
- Boiler efficiency
- Blowdown Rate

Once input data were entered into the SSAT, the next step was to input the recommended projects for energy management. There are a number of options in the software, which can be selected and applied to the final results. Once all of the inputs are entered the energy and cost savings can be found on the results screen. All the three screens are shown in Appendix 2.

As the results show in these screens of Appendix 2, just a few of the total changes to the boilers could result in large energy and cost savings. In this case $104,000/yr can be saved in fuel cost alone. This will reduce the CO2 emissions by 2,372 klb/yr.

As per the data from DOE, using the Steam System Tool Suite alone could save $4 billion in fuel reduction costs and 32 million metric ton reduction in emissions across all American Industries[4]. Using the merging technologies in the area of energy management in the industrial sector could potentially save billions of dollars and have a great effect on the health of the environment.

CONCLUSIONS

It has been shown in this paper that an integration of science of HEFAT and digital technology can lead to the development of useful tools in the area of energy efficiency. The potential for energy and cost savings from the applications of these tools in the area of steam generation in the industrial sector has been discussed. A case study of the work done by the BU IAC has been discussed. The case study involving Plant M shows that using the SSAT could potentially save the company $104,000 and 2372 klb/yr of CO2 emissions.

REFERENCES

[1]"United States Department of Energy." Wikipedia. Wikimedia Foundation 17 Nov. 2013, Web, 17 Nov. 2013.

[2] United States of America. Department of Energy. Mission Statement. N.p., n.d. Web. 17 Nov. 2013.

[3] Thumann, Albert, and D. Paul Mehta. "Energy Management" Handbook ofEnergy Engineering. 7th Ed. Lilburn GA: Fairmont, 2013, 317. Print.

[4] http://www1.eere.energy.gov/manufacturing/tech_assistance/software_ssat.html.

[5] United States of America. Department of Energy. Advanced Manufacturing Office: N.p., 26 Aug. 2013. Web. 17 Nov. 2013.

APPENDIX 1 – TABLE 1

Performance Summary- Bradley University Industrial Assessment Center- 1994-2014

Assessment Visits

ASiessments Completed			Implement.tionReports COmpleted
442	1D!l4 through 2014	21years	428

Assessment Recommendations

	Energy			Waste		ProducUvlty		Totals	
st.I:UI	lofAR'I	MMBTU's Saved	$Saved	ofAR'I	$SaYed	ofAR'I	$Saved	ofAR'I	$Saved
Recommended	3,303	3,834,979	$27,464,585	533	$5,686,971	321	$26,045,658	4,148	$59,241,674
Implemented	1,273	1,200,409	$8,786,785	180	$1,376,670	118	$12,912,392	1,558	$23,076,518
% Implemented	38.6%	31.3%	32.0%	33.8%	24.2%	311.8%	49.6%	37.6%	39.0%

APPENDIX 2 – SCREENS

Steam System Assessment Tool

1 Header Model

Data Entry Form for Current System

The data entry form is split into two sections.***"Quick Start"*** enables you to enter a minimum amount of information about your site and to start modeling your system right away.***"Site Detail"*** allows you to provide more detailed information about your site to improve the accuracy of the model.

Yellow shaded cells require user input.

Where different options can be chosen by the user, the required supplementary data input cells are shade green and are indicated by ***red arrows***. ←

5.11

Enter Case Description	SWD Boiler Model

Site Power Import (+ for import, - for export)		Power import + site generated power = site electrical demand
Site Power Cost		Typical 2003 value: $0.05/kWh
Operating hours per year		
Site Make-Up Water Cost		Typical 2003 value: $0.0025/gallon
Make-Up Water Temperature		

Note: Enter average values for the operating period being modeled

		Natural Gas
Site Fue Cost per 1000 s.cu ft		Typical 2003 value: $5.78/(1,000 s cu.ft)

Quic

Note: Fuel HHV is 1,000 Btu per s cu.ft (23,311 Btu/lbm)

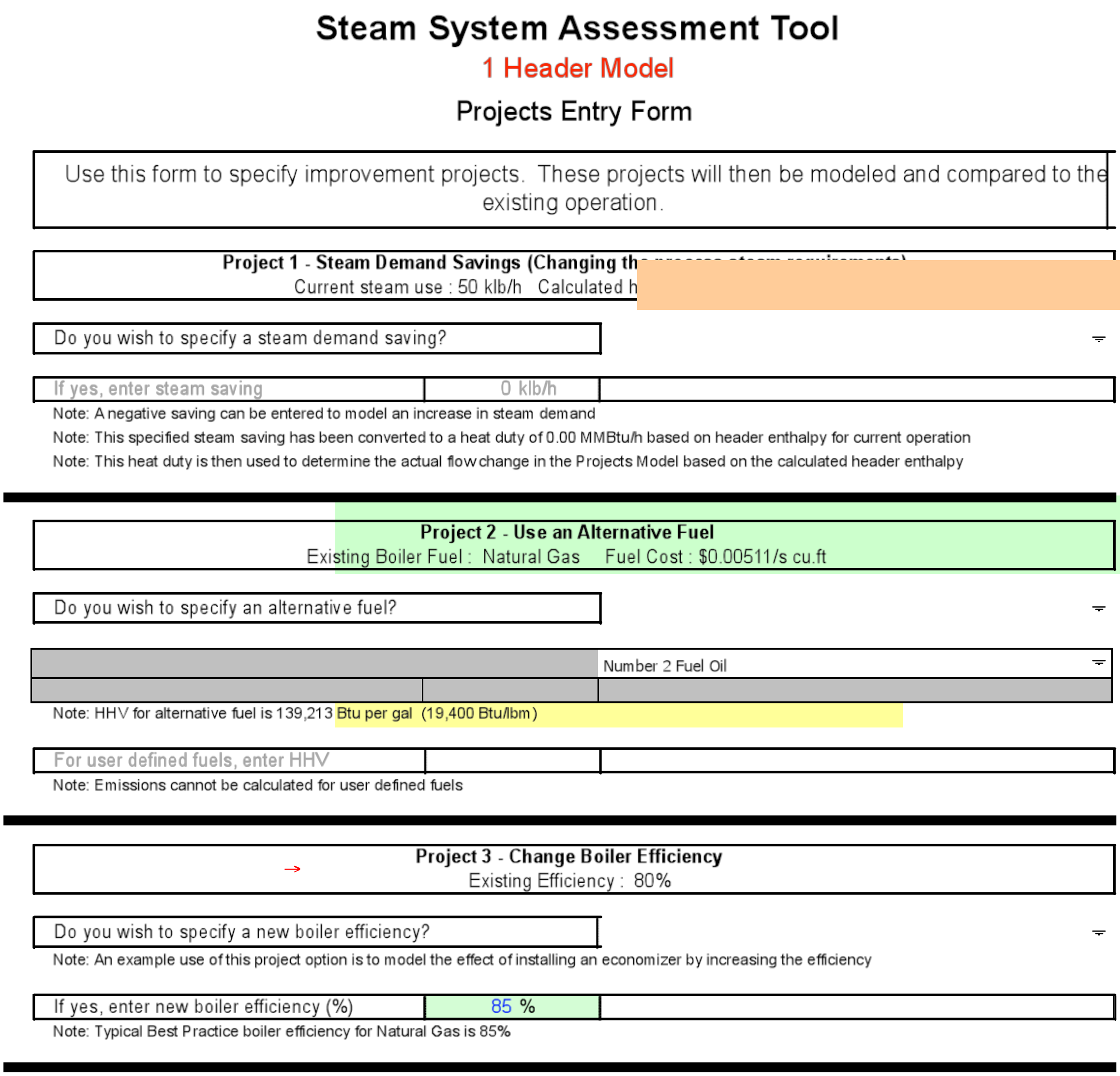
For user defined fuels, enter HHV	20000 Btu/lb →	

Note: Emissions cannot be calculated for user defined fuels

Header Pressure		
Steam Use by Processes		

Note: Enter process steam use excluding turbines, leaks, trap losses, deaeration steam and vents

Figure 1: SSAT Input Screen


Steam System Assessment Tool

1 Header Model

Projects Entry Form

Use this form to specify improvement projects. These projects will then be modeled and compared to the existing operation.

Project 1 - Steam Demand Savings (Changing th
Current steam use : 50 klb/h Calculated h

Do you wish to specify a steam demand saving?

If yes, enter steam saving | 0 klb/h

Note: A negative saving can be entered to model an increase in steam demand
Note: This specified steam saving has been converted to a heat duty of 0.00 MMBtu/h based on header enthalpy for current operation
Note: This heat duty is then used to determine the actual flow change in the Projects Model based on the calculated header enthalpy

Project 2 - Use an Alternative Fuel
Existing Boiler Fuel : Natural Gas Fuel Cost : $0.00511/s cu.ft

Do you wish to specify an alternative fuel?

Number 2 Fuel Oil

Note: HHV for alternative fuel is 139,213 Btu per gal (19,400 Btu/lbm)

For user defined fuels, enter HHV

Note: Emissions cannot be calculated for user defined fuels

Project 3 - Change Boiler Efficiency
Existing Efficiency : 80%

Do you wish to specify a new boiler efficiency?

Note: An example use of this project option is to model the effect of installing an economizer by increasing the efficiency

If yes, enter new boiler efficiency (%) | 85 %

Note: Typical Best Practice boiler efficiency for Natural Gas is 85%

Figure 2: SSAT Projects Input Screen

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Steam System Assessment Tool

1 Haadar Modal

Results Summary

SWD Boiler Model

Model sr.rus :OK

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Power Cost	1,288,706	1,288,706	0	0.0%
FuelCost	1,735	1,630	104	6.0%
Make-Up Water Co&!	37	37	0	0.1%
oto Coat In VUUaiVJI	1,290,.(11	1,290,313	104	0.0%

O•-Sit•E_ _ .aioM	C•rent Opsnti on	AfterPro_IKa	R•uc:tlon	
C02 Emissions	3::1451 kiblyr	3707::1 klb/yr	2372 klb/yr	6.0%
SOx Emissions	0 kiblyr	0 klb/yr	0 klblyr	N/A
NOx Emissions	78 klbtvr	73 klb/vr	5 klbtvr	6.0%

P— StillionE_ _ _ _ lons	Rsdudlon After Projec:ls	Total Rsdudlon
C02 Emissions	0 klb/yr	2372 klb/yr
SOx Emissions	0 klb/yr	0 klblyr
NOx Emissions	0 klb/yr	5 klbfYr

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jIhayBaiMce	C•rrent OperlItlon	After Pro_lodl	R•uc:tlon	
Power Generation	OkW	OkW	-	
Power Import	4602704 kW	4602704 kW	OkW	0.0%
TotalSe ElectricalDemand	4602704 kW	4602704 kW	-	
Boiler Duty	77.7 MMBtulh	73.1 MMBtulh	4.7 MMBtulh	6.0%
FuelType	Natural Gas	Natural Gas	-	
FuelConsumption	77715.3 9 cu.ftlh	73042.6 s cu.ftlh	4672.7 s cu.ftlh	6.0%
Boiler Steam Flow	59.::1 klblh	5::1.8 klblh	0.1 klblh	0.1%
FuelCost (in $/MMBtu)	5.11	5.11	-	
Power Cost (as $/MMBtu)	18.79	18.79	-	
Make-Up Water Flow	3386 gaVh	3382 gallh	4 gaVh	0.1%

Turbine Performance	**Current Operation**	**After Projects**
HP to Condensing steam rate	**Not in use**	**Not in use**

Marginal Steam Cost	
(based on current operation)	
$/klb	**7.79**

u.t Or liiOIOCIOCI Pro oets
Increase boiler efficiency
Install condensate tank vent heat exchanger
Improve pipework insulation

Gas Turbine Assessment

Your sMe isa qood candidate for the installation ofa gas turbine +waste heat boiler

Warninaa -Anvw.ninaa lilltad balow mr impad on thavaliditv oftha simulation

Currant Oporatlon	After Projoda
	Condensate tank vent heat exchanger not used

Figure 3: SSAT Results Screen