

Project Title: Plant Wide Assessment of Energy Usage Utilizing SitEModelling as a Tool for Optimizing Energy Consumption
Project Applicant: Evonik Degussa Corporation
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Abstract:

The Evonik Degussa Corporation is the global market leader in the specialty chemicals industry. Innovative products and system solutions make an indispensable contribution to our customers' success. We refer to this as "creating essentials". In fiscal 2004, Degussa's 45,000 employees worldwide generated sales of 11.2 billion euros and operating profits (EBIT) of 965 million euros.

Evonik Degussa Corporation has performed a plant wide energy usage assessment at the Mapleton, Illinois facility, which consumed 1,182,330 MMBTU in 2003. The purpose of this study was to identify opportunities for improvement regarding the plant's utility requirements specific to their operation. The production is based mainly on natural gas usage for steam, process heating and hydrogen production. The current high price for natural gas in the US is not very competitive compared to other countries. Therefore, all efforts must be taken to minimize the utility consumption in order to maximize market position and minimize fixed cost increases due to the rising costs of energy.

The main objective of this plant wide assessment was to use a methodology called Site Energy Modelling (SitE Modelling) to identify areas of potential improvement for energy savings, either in implementing a single process change or in changing the way different processes interact with each other. The overall goal was to achieve energy savings of more than 10% compared to the 2003 energy figures of the Mapleton site. The final savings breakdown is provided below:

- **4.1% savings for steam generation and delivery**
These savings were accomplished through better control schemes, more constant and optimized loading of the boilers and increased boiler efficiency through an advanced control schemes.
- **1.6% savings for plant chemical processing**
These saving were accomplished through optimized processing heating efficiency and batch recipes, as well as an optimized production schedule to help equalize the boiler load (e.g. steam consumption).

Approach:

This Evonik Degussa developed methodology allowed for the prediction of the theoretical energy usage of the total site, allowing for the development of a complete energy usage map. Thus far, this is the first implementation of this specific technology to a US site. However, good results have been achieved in Germany for different plant sites by using this SitEModelling methodology. This methodology is applicable for continuous as well as batch operated plants.

The key to SitEModelling is the development of a model to demonstrate the load dependent energy usage for each process required across the entire production site. Evonik Degussa believes that only a plant wide assessment can lead to the necessary energy savings. Optimizing single processes can save some energy, but it does not reflect the plant wide interactions of different producer and consumer systems. Only the optimization of the plant wide (overall) system, with all the interactions being considered, can bring the expected benefit. Because no site is operated with a constant energy load at all times, it is difficult to predict how

much energy should indeed be used. Therefore, one can only compare relative numbers (current vs. last year) without finding a lever to improve. This technique allows for a proactive approach to energy conservation, giving up to date forecasting of energy demands. This provides an important advantage to implementing this methodology, energy monitoring. By using only relative number key process indicators, high energy demands are discovered only after the events have occurred. The SitEModel can predict high energy consumption and allow management to counteract or prepare for the occurrence and minimize the utility effects. This is accomplished by utilizing the SitEModel to influence the production scheduling to allow for more uniform energy consumption. This results in a more constant load to the steam boiler system and thus a higher efficiency in steam production.

SitEModelling utilizes well-known Pinch Technology to optimize the model for a single plant/process and identifies the potential for process improvements. However, Pinch Technology only targets the local optimum for each of the analyzed plants. A global optimum can only be achieved with a plant wide assessment showing all of the interactions of the different processes being analyzed.

SitEModel:

The scope of the plant wide assessment is very broad in terms of involved and studied systems. First, the steam generation systems were considered. This represents the biggest user of natural gas. Next, a hydrogen plant producing hydrogen from natural gas was considered. This supplies hydrogen for the hydrogenation reactions mainly in the facility as well as provide steam to the steam generation system by means of an excess heat boiler. Finally, the satellite boilers which produce hot oil (heat transfer fluid) or high pressure steam for specific processes in the process plants were introduced to the SitE Model. The production area of the FAP-section and the DP-section is the main user of the produced boiler house steam (300 psi). Both sections contain reactor systems (with separation units like distillation columns and filter systems) as well as steam-driven vacuum systems. The scope is to map the energy flow within the overall system and determine the exact usage by coupling production data with natural gas usage. An example of the developed SitEModel is shown in Figure 1. The SitEModel methodology included the following steps:

- Conducted an energy optimization study of all essential plants using pinch technology and process simulation. This step required a validated mass and heat balance of the processes.
- Examined plant regions and the whole site. Generated source-sink-profiles to check whether heat transfer between plants can be considered.
- Determine the economic benefits of the projects derived in step 1 and 2 create a total site model. This overall model includes:
 - ❑ energy model of each plant
 - ❑ models of the energy equipment (e.g. turbine, boiler house)
 - ❑ the site infrastructure (e.g. steam mains)
 - ❑ models of each important project
 - ❑ factors which influence the analysis (e.g. efficiencies, cost data).
- Created a program that is based on the models.(EXCEL™ based)
- Performed case studies to evaluate the real primary energy savings of the projects. The program was used as an analysis and planning tool as well.

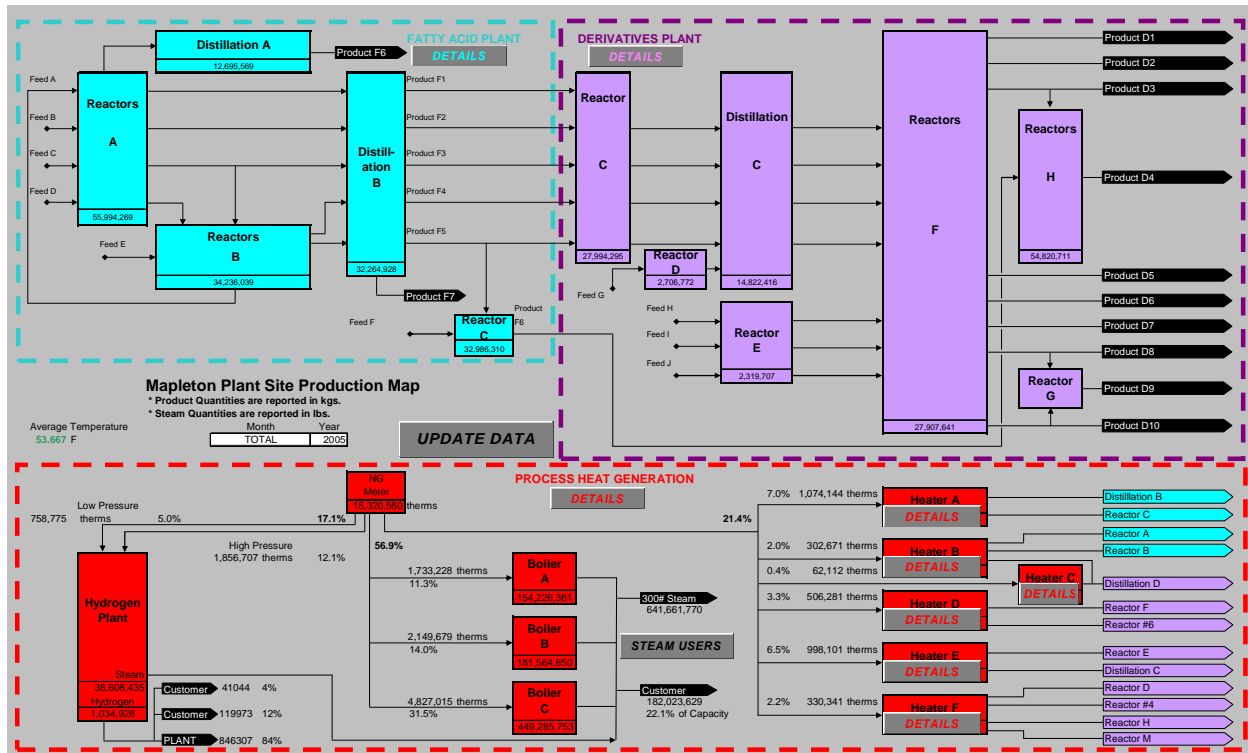


Figure 1: Production Plant SitE Model

Process Energy Analysis:

Once the SitEModel was completed, the resulting database of process information was analyzed to determine potential energy conservation opportunities. This analysis was split up into two parts, steam generation and production processes.

Steam Generation

The first step for energy analysis was to identify the relevant data required to study the steam generation equipment of the plant. Starting from the complete process flowsheet, using information about material flow and energy transfer, the flowsheet was reduced to a 'relevant energy flowsheet' (REF). This type of flowsheet contains only the extract of streams, units and utilities which are necessary for a successful energy analysis. An example of the steam production REF is presented in Figure 2. Multipurpose plants or plants which show different structures at varying production rates may lead to different REFs. The REF was filled with real process data at a characteristic plant setpoint (production rate). Many of the necessary data (e.g. flows, temperatures and pressures) are available from the distributed control system (DCS). Note that it is important to run the process at a steady state to get consistent data for all process units. That means using data from an unsteady process state, feed and product streams, temperatures and energy consumption do not fit together.

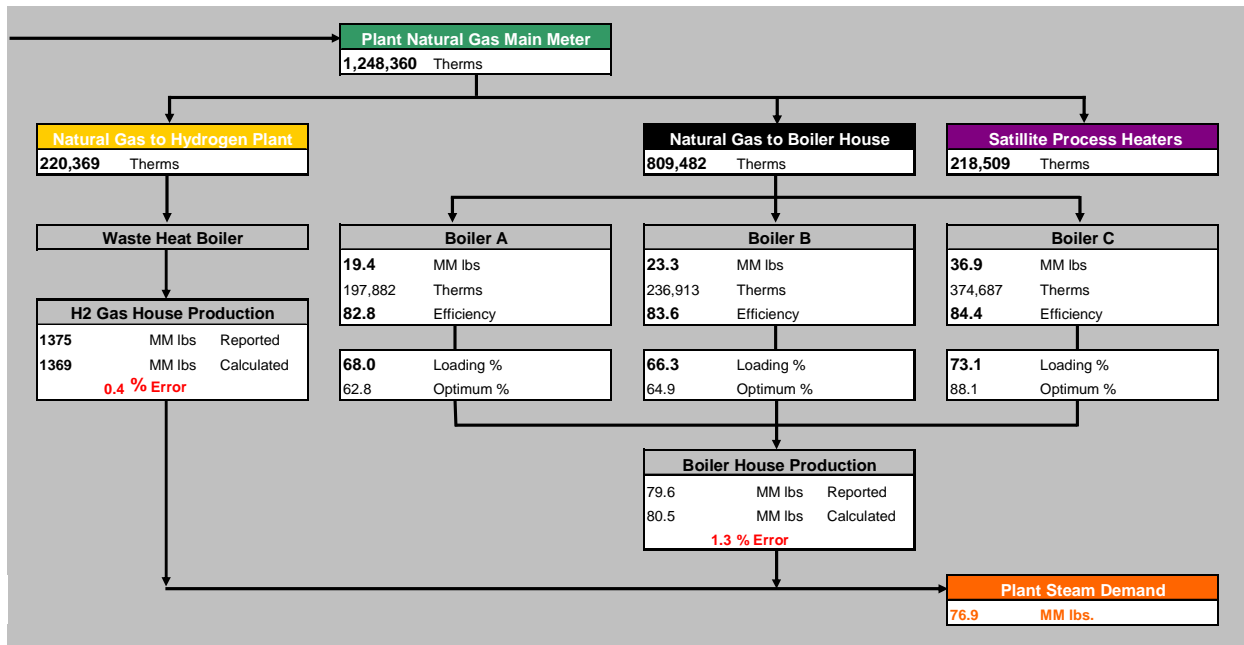


Figure 2: Steam Production REF

The last step is the validation of the energy model with real data of varying production rate scenarios. This helps to identify model errors and additional model parts like temporary higher energy consumption due to operating the process in winter. The result is a production rate and operating condition depending energy model including temporary energy consumption.

Production Processes

The production usage energy analysis was conducted in the same manor as illustrated above. The relevant data required to study the production equipment of the plant was gathered from the complete process flowsheets, using information about material flow and energy transfer. The flowsheets were reduced to a (REF) and combined with the steam generation database. The combined list of natural gas users in both the steam generation and production processes groups is outlined in Figure 3.

Natural Gas Users		
Steam Production		
Boiler House	Boiler A	300# Steam
	Boiler B	300# Steam
	Boiler C	300# Steam
Satellite	Heater B	850# Steam
	Heater C	900# Steam
Hydrogen Plant	Waste Heat	300# Steam
Process Heating		
Satellite	Heater A	Hot Oil
	Heater D	Hot Oil
	Heater E	Hot Oil
	Heater F	Hot Oil

Figure 3: Production Plant Natural Gas Users

Using the complete database allows for the production rate dependent energy model of the process to be built for any combination of required products using the linear equation

$$Q_{act} = (R_{act}/R_{ref}) * Q_{ref}.$$

Q_{ref} is the energy transfer index of each unit and R_{ref} the production rate at the characteristic (reference) set point. *act* indicates the desired production rate and calculated transferred energy. Experience shows that linear approximation is sufficient for the desired variance of production rate in many cases. Changing operating conditions at different production rates (e.g. using other utilities or units) may lead to partially different energy models for several sections of production rates. The energy-amount of each unit as well as the sum of consumption for each utility was implemented in the SitEModelling program. An example of this model is provided in Figure 4.

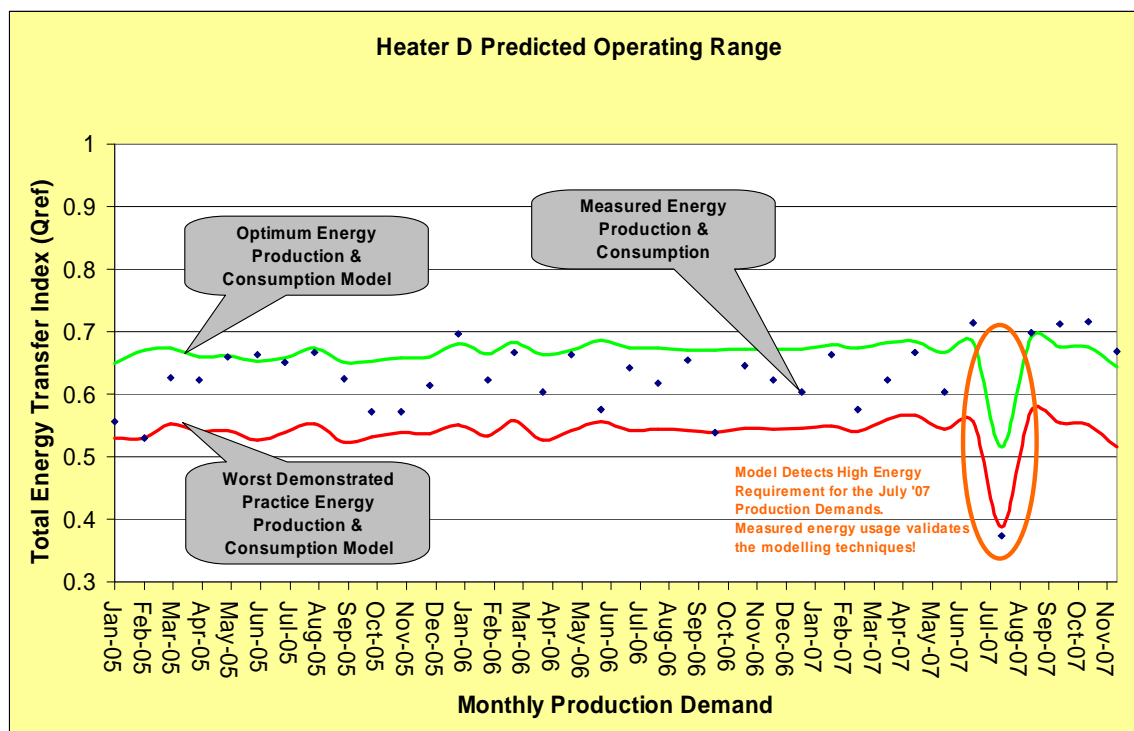


Figure 4: Unit Energy Production & Consumption Index Model

Plant Wide Energy Assessment Results:

Established methods are available to find the energetic optimum of a plant or a whole site. Nevertheless significant improvements involve process modifications and, consequently, the application of simulation programs. The economic evaluation of the derived projects is not obvious in many cases. When separate projects influence each other, the evaluation problem becomes more serious. Because of the high complexity of the site energy systems, each equipment model is unique for analysis purposes. This allows the program to determine the primary energy savings even for a combination of various projects and, therefore, gives clear answers. The following paragraphs describe the process modifications, saving potentials and the models from this work:

Steam Generation

The study of the steam boiler efficiencies was crucial in this portion of the site model. In these calculations, the SitE Model used production data to determine the actual transfer of energy from the combustion of the natural gas to the production of 300# steam. These analyses led to a number of different opportunities for natural gas conservation.

- Boiler Economizer Monitoring, Maintenance, and Replacement

The proper operation of the waste heat economizer on boiler equipment is one of the most important variables in maintaining optimum energy efficiency. This equipment removes heat from the combustion gases and transfers this energy back into the system by preheating the boiler feed water. This process dramatically reduces the necessary natural gas in steam production. This concept is illustrated in the following project examples.

- Economizer Equipment Failure – Boiler B Optimization Project

The inlet and exit temperatures of the combustion gases of the boiler flowing through the Boiler B economizer indicated that the equipment was not operating at the optimum heat recovery. Upon further analysis into overall boiler efficiency and inspection of the equipment, it was determined that the Boiler B economizer was malfunctioning. The necessary heat exchanger equipment was replaced. The effect of the improvement project resulted in as much as 3.5% increase in boiler efficiency at high boiler loading rates. This results in an overall potential savings of 0.6% savings in the natural gas usage of the plant in 2003. The effect of proper economizer operation on boiler efficiency is illustrated in Figure 5.

- Fouling Effect in Boiler Economizer Equipment – Boiler C Economizer Optimization

The inlet and exit temperatures of the combustion gases of the boiler flowing through the Boiler B economizer indicated that the equipment was not operating at the optimum heat recovery. Upon further analysis into overall boiler efficiency and inspection of the equipment, it was determined that the Boiler C economizer was fouled. The extended continual use of the boiler led to the slow build-up of material on the heat exchanger surfaces over time. Because the reduction in the overall heat transfer coefficient was so gradual, the fouling was not easily detected. An example of this type of fouling is illustrated in Figures 6a & 6b. The effect of this phenomenon resulted in as much as 3.5% decrease in boiler efficiency at high boiler loading rates. Because this is the primary steam producer, this results in an overall potential savings of 1.7% savings in the natural gas usage of the plant in 2003.

The effect of the fouling on boiler stack exit temperature is illustrated in Figure 7.

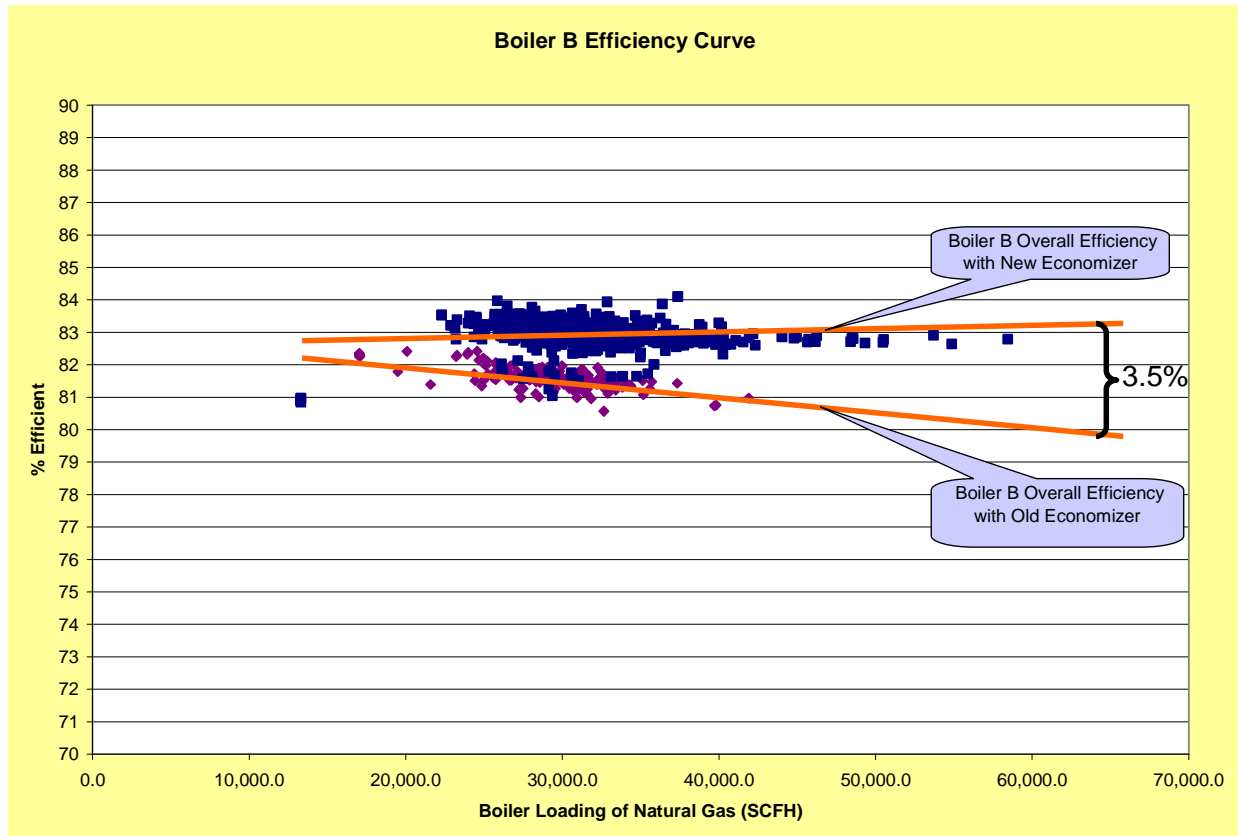


Figure 5: Multiple Economizer Operation Effects on Boiler B Efficiency



Figure 6: Example of Economizer Fouling Material

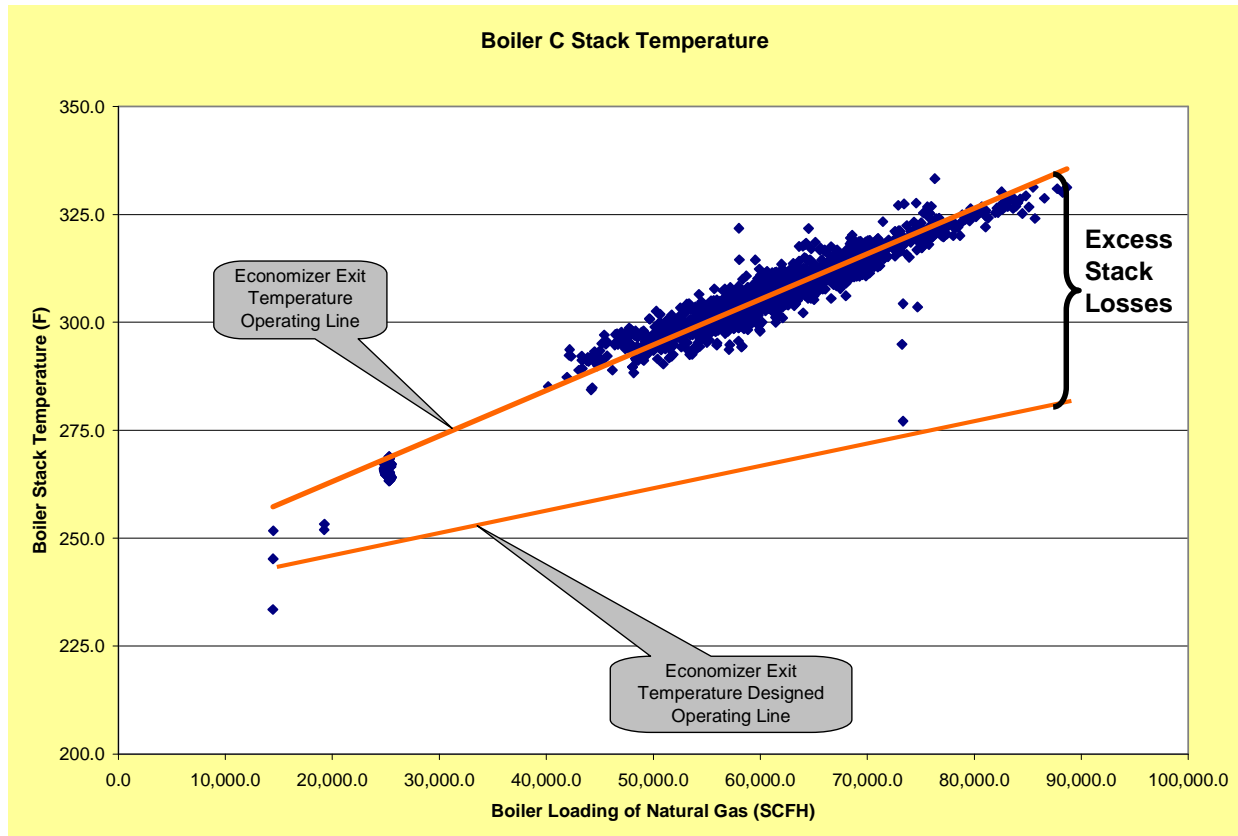


Figure 7: Economizer Fouling Effects on Boiler C Stack Temperature

- Boiler Utilization

With the boiler efficiencies known from the SitE Model, it is possible to calculate the optimum configuration and loading of the three primary boilers to satisfy the plant required steam demand. The optimum operation in any situation, from a natural gas usage stand point, would be to operate the fewest boilers possible at high capacity to fulfill plant steam demand. This optimization approach is difficult to maintain from an operational prospective because the daily plant energy demand was unknown. However, by utilizing the forecasting ability of the SitE Model, the plant energy needs can be determined from the planned production demand. This model will indicate when one of the smaller boilers needs to be operational to maintain redundancy in the steam production systems and provide adequate protection of the steam supply in the event of equipment failure. This forecasting can be seen in the optimum % block in each boiler illustrated in Figure 2.

Even though the performances of the three boilers are very close in comparison with one another, savings can be generated by optimizing the boiler selections, loading rates, and production demands. One consideration is the radiation and convection losses as heat transfers through the walls and insulation of the boiler equipment to the atmosphere. These losses were determined to range between .5% and 1% of nominal boiler capacity and do not vary considerably with boiler loading. By operating only the two largest boilers during periods of low demand,

the radiation and convection loss savings from the smallest boiler would be preserved. Also, by utilizing the excess capacity in the more efficient Boiler C, additional energy can be conserved in the steam production process. This represents an extra 0.7% savings in the natural gas usage of the plant in 2003.

- Boiler Control Optimization

The excess air in the stack gases of a natural gas boiler is a key optimization point that can improve the overall performance of the steam production process. Damper control systems originally included on older boiler installations do not provide the ability for fine control manipulations in combustion air flow rates. In order to accomplish a simultaneous finely tuned control of the boiler flame quality, air/fuel mixing, and excess air, a new control scheme was implemented. The installation of a variable frequency drive on the combustion air fan motor of the boiler not only allow for better control of the combustion air, but also provided energy savings on the electricity demands of the equipment. The SitE Model as well as efficiency calculation indicates a greater than 1% improvement in steam production. By applying this advanced control system on the remaining boilers, an overall natural gas conservation of 0.8% of the 2003 natural gas consumption can be realized.

- Annual Steam Trap Surveying & Maintenance

Research indicates that a steam network that does not have a routine steam trap inspection can have as much as 50% of the traps malfunctioning. This can lead to dramatic decreases in the effectiveness of a steam production process. With proper inspection and maintenance, a less 3% failure rate of steam trap equipment can be achieved. The mass and energy balance in the SitE Model indicated that approximately 10-12% of steam introduced into the main steam header was unaccounted for. After conducting a through inspection of the steam trap and delivery network, a number of optimization possibilities were discovered. The monitoring the steam distribution, in addition to the annually scheduled trap survey, a steam savings equivalent of 0.3% of the overall natural gas usage in 2003 was achieved.

Production Processes

The study of the production process heating efficiencies was crucial in this portion of the site model. In these calculations, the SitE Model used production data to determine the actual transfer of energy from the combustion of the natural gas to the production of 850# steam, 900# steam and hot heat transfer oils. This analysis provided a basis for natural gas conservation. This project is outlined in the follow analysis.

- Process Heating Utility Optimization

The analysis of the production processes included studies into scheduling optimization, heat integration, and process utility production efficiencies. It was determined that it was possible that two of the satellite heater demands could be met using the more efficient of the two heaters. This improved the specific natural gas consumption by reducing radiation and heat losses as well as allowed the remaining heater to run with a higher efficiency. The operating lines of the production processes fulfilled by the different combinations of process heating equipment are illustrated in Figure 8. It can be seen from the SitE Model that the process heat demand can be more efficiently fulfilled by the single unit. This

process change was implemented and resulted in a savings equivalent of 1.6% of the 2003 natural gas usage.

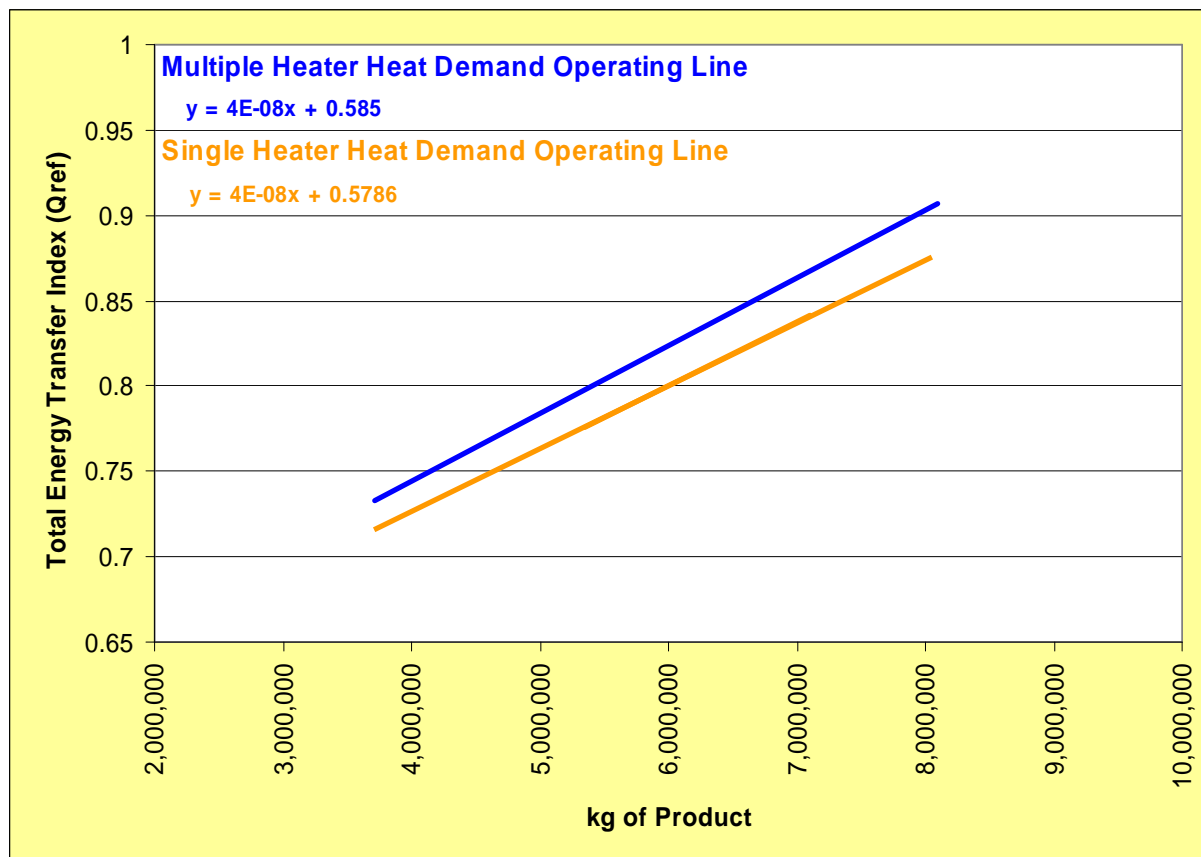


Figure 8: Required Production Processing Heating Demands as Supplied by Single and Multiple Process Heating Equipment.

CONCLUSIONS:

Within Evonik Degussa Corporation for the NAFTA region, there are three sites where replication of this PWA approach conducted at the Mapleton facility seems to be possible. The total energy consumption for the Mapleton site in 2003 was 1,182,330 MMBTU/yr. The total energy consumption of the three other plants was 845,654 MMBTU/yr, an estimated saving of approximately 5.7% as seen in this analysis would lead to a potential saving at these other plants of 48,000 MMBTU/yr. Assuming a current natural gas price of approximately 0.85\$/Therm (with a Therm being 100,000 BTU), saving approximately \$410,000/yr is estimated at these other sites.

Evonik Degussa has used several means of publishing these results and sharing the energy conservation and savings potentials information. First, a technical report was issued for the work done during the plant wide assessment giving the detailed approach and the achieved results. This report was distributed to all the engineering managers within Evonik Degussa. The report is stored in a database and can be retrieved world-wide using the following keywords: energy savings, plant wide assessment, SitE Modelling, optimization, etc. The energy saving ideas and SitE Modelling Techniques were presented at the 2007 annual technical meeting where all the technical directors of the different plant sites come together to share

information and exchange best practices. The engineering managers of the three plants identified for a possible replication were approached separately with the results of the plant wide assessment study to consider implementation of the next project at their site.

The results of the plant wide assessment will be published by DOE and by Evonik Degussa to achieve awareness within the peer group industry. Evonik Degussa will pursue presenting the achieved results during an industry-wide conference (such as those held by AIChE) or a conference specifically dealing with energy usage. In addition, Evonik Degussa will pursue publishing an article on the applied method for the plant wide assessment. It is also possible that the findings can be applied to the chemical industry in general and not just to the specialty chemicals peer group. This could lead to even more total industry savings.

A rough estimate for the total industry (in this case Evonik Degussa's peer group of specialty chemicals producers) can be determined by a comparison of the sales figures in this group. The total sales for Degussa in the NAFTA in 2004 was approximately 2.5 Billion US\$. The NAFTA-region of Evonik Degussa's peer group members report sales of approximately 16 Billion US\$ for 2004. The overall savings of Evonik Degussa Corporation was calculated to be 1 MM\$/yr. Because of the various spectrum of products representing these sales figures, we conservatively estimated the savings to be 50% of the original calculated value. We estimate the total industry (outside of Degussa Corporation) savings to be approximately 3.5 MM\$/yr for the specialty chemicals industry.