3er Foro Regional IMIQ, Coatzacoalcos, México,13 y 14 Octubre, 2005.

REFINING / PETROCHEMICAL ENERGY COSTS REDUCTION BY USING AN ON-LINE SIMULATOR AND OPTIMIZER

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Resumen

Los sistemas de energías y servicios de las refinerías / petroquímicas son grandes y complejos, por lo que el control de los costos energéticos y su adecuada auditoría constituyen un desafío importante.

El presente trabajo describe las actividades que se llevan a cabo para reducir los costos energéticos del refinado / petroquímica mediante una moderna herramienta de optimización e información que opera en línea.

Se construye un modelo completo del sistema energético de la refinería / petroquímica (vapor, agua de alimentación de calderas y la porción del sistema eléctrico que interacciona con el sistema de vapor). Todas las restricciones relevantes se incluyen en el modelo que es poblado continuamente con datos vivos y validados, en tiempo real. Se incluyen también en el modelo índices para la monitorización del desempeño del mismo. Entre otros se incluye la monitorización de eficiencias de equipos calculadas a partir de los datos validados mencionados antes.

También, cuando los usuarios finales así lo requirieron, se incluyeron detalles completos de los sistemas de combustibles y de los costos y restricciones de las emisiones de dióxido de carbono.

Mediante la auditoría del sistema de energía se pueden detectar y diagnosticar los desbalances "aparentes" o reales. Por consiguiente, los datos pueden ser empleados para evaluar adecuadamente tanto la producción como los usos reales de la energía y los desperdicios pueden ser eliminados.

Los modelos pueden ser empleados en modo fuera de línea para planificar la mejor manera de operar el sistema energético. Finalmente, es importante mencionar que la optimización de las operaciones se lleva a cabo día a día, continuamente, recibiendo el modelo los datos de la operación real. Se presenta un ejemplo con los resultados típicos de un día operativo.

Como resultado de los proyectos, se identifica dónde ubicar nuevos sensores y se consiguen ahorros substanciales en los costos energéticos totales.

Abstract

Refinery / Petrochemical energy systems are large and complex, therefore the auditing and control of energy costs are a real challenge.

This paper describes the tasks performed to reduce refining / petrochemical energy costs using a modern on line information and optimization system tool.

A full model of the refining / petrochemical energy system is built (steam, boiler feed water and electrical system that interacts with the steam system). All the constraints have been included and the model is continually populated with live, validated, real-time data. Performance monitoring indexes are included in the model. Amongst others, they include the follow up of calculated equipment efficiencies using the validated data mentioned before.

Fuel system details, including cost and constraints on the carbon dioxide emissions were also included, when requested by the final users.

By auditing the energy system, imbalances can be detected and diagnosed. Therefore, the data can be relied on for evaluating the value of energy production and usage, and waste can be eliminated. Planning for a better operation of the energy system by performing case studies is usually done by using the validated model in off line mode. Finally, it is important to mention that the optimization of operating conditions is performed on a continuous, day to day basis. An example of the results obtained during a typical operative day is presented.

As a result of the projects, new sensors have been located and substantial savings in global energy costs have been achieved.

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1. Introduction

Our clients operate big and complex refineries / petrochemicals with a combined capacity of several million tons a year. Its energy systems are large and complex, requiring specific tools to help in control and auditing them.

Refineries and petrochemical complexes usually operate complex energy systems. They utilize different kind of fuels, operates cogeneration units, have several steam pressure levels, feed different types of consumers and there are emission limits to be observed.

These complex energy systems have several degrees of freedom. Manipulating these degrees of freedom with a cost based optimization program usually can result in significant savings in operating costs. This is particularly important within current deregulated electrical markets. Since the electrical system poses one of the main economic trade-offs with a steam system, electrical deregulation provides many new challenges to operate the overall combined system at minimum cost.

Other important aspect is that utilities systems are continuously evolving (there are frequent changes) and also, sometimes there is a lack of sensors that need to be addressed properly.

Furthermore, utilities systems have several constraints coming usually from the operations side. For example, maximum flows and steam production cushions.

Finally it is important to mention that, given the complexity of the system, the handling of the utilities optimization is managed at the level of refinery areas. But the individual areas optimization gives not necessarily the true global optimum refinery optimum.

In order to successfully address all the items mentioned above, a tool called Visual MESA has been used as the model and optimization engine. Visual MESA is a computer program designed to model steam, Boiler Feed Water (BFW), condensate, fuel, and electrical systems used in more than 30 petrochemical and refining Sites around the world. It is an online program that receives live plant data from the steam, BFW, and electricity plant information system.

Visual MESA can help reduce costs by performing the following tasks:

Optimization:

Visual MESA helps to find the most economical way to run the utilities system, while remaining within the real operating constraints.

Visual MESA enables to:

- Understand steam/electrical system operation
- Rapidly evaluate the economics of a change in operation

- Optimize the overall cost fuel for steam generation and electricity, including the choice of the most convenient combination of turbines and motors
- Improve data quality

Monitoring:

Visual MESA provides a number of monitoring features that help to access data, control data quality, and alert of changes to the system.

- Plant, Equipment and Stream Information
- Trending Data
- Alerting
- Data Quality (Mass Balance Balloons)

Case Studies ("What If?" Planning):

Visual MESA allows to perform and evaluate "What If?" cases that enable to find ways to operate more efficiently and at less cost.

- Front-end loading on projects
- True "Plant-Wide" project evaluation
- Steam, BFW, condensate, and electrical system improvements
- Shutdown planning: Reduce down time and ensure steam is available when needed

Auditing & Accounting:

Visual MESA helps to find where waste steam is occurring in the steam system.

In this work, implementation of Visual MESA to audit and control energy costs and the main benefits already obtained are summarized. After a description of the implementation tasks, some results are commented. Finally, conclusions are presented.

2. Implementation Description

Soteica has worked together with our clients' Operations and Process Departments in the implementation projects, which included the following general activities:

- Data collection;
- Model building;
- Linking of VISUAL MESA to the Plant Information System;
- Build on-line optimization;
- Model and optimization review,
- Training for VISUAL MESA's users,
- Reports generation, and

- On Line, day to day optimization

In the following paragraphs, first the model build and optimization implementation are briefly described. Then, the reports generation and their use for auditing and control of energy costs are explained.

2.1. Model Building

A ***complete*** model of the overall Energy System was built on each case. The model includes the whole fuel, steam, boiler feed water, condensate and power system. Steam is generated in several different Units, with conventional boilers, heat recovery steam generators and a cogeneration unit with possible steam injection.

All the steam pressure levels were modeled and all the units considered with high detail, including all the consumers and suppliers to the respective steam, BFW and condensate headers.

Detailed efficiencies curves of the biggest turbines were included in the model and they are adjusted continuously with on line validated data.

Electricity and fuels supply contracts details have been included in the model.

Figure 1 shows a typical view of Visual Model at the highest Plant level (ref. 1). By navigating through the model, each individual Unit of the system can be monitored in detail.

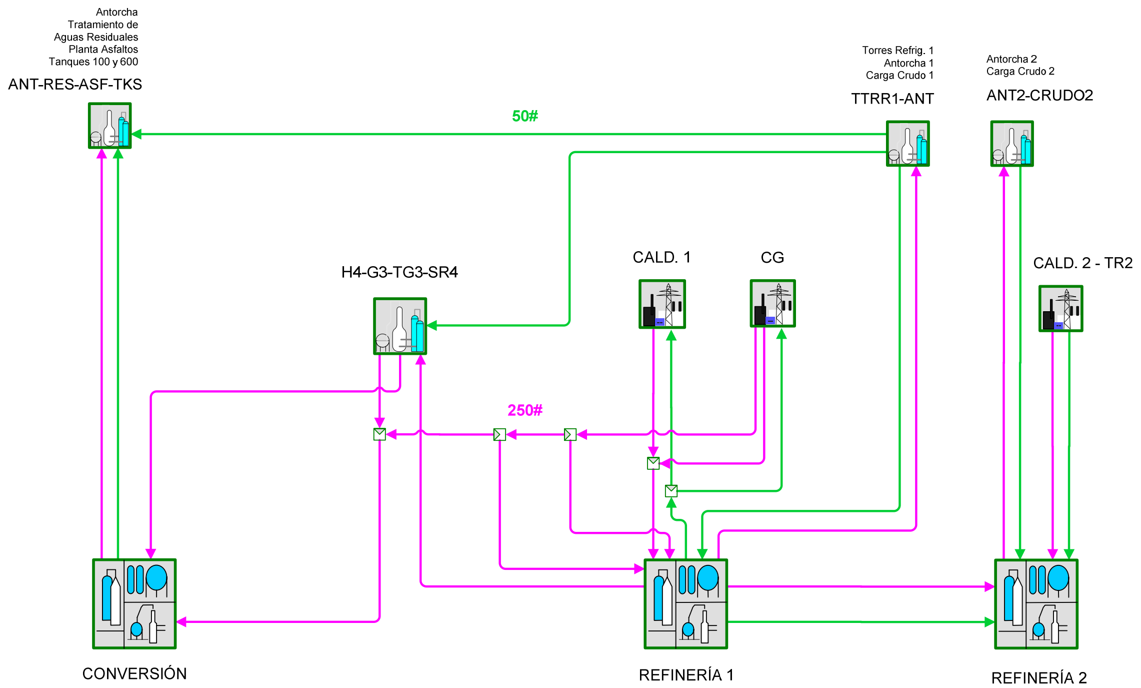


***Figure 1**. Refinery utilities system: General view*

2.2. Optimization

VISUAL MESA has built-in mathematical models and optimization routines to calculate how to run the steam and electrical systems at the minimum overall cost and still meet the required plant steam demands and other plant constraints.

The optimization determines where to make incremental steam (which boilers or steam generators) and which turbines or letdown valves will most efficiently let the steam down between pressure levels.

VISUAL MESA uses an SQP (Successive Quadratic Programming) optimizer.

VISUAL MESA optimization can be organized into four levels:

- Level 1: includes basically the pressure control related devices: boilers, letdown valves and vents are optimized to minimize cost.
- Level 2: adds the optimization of other continuous variables including turbo generators, steam injection, extraction/induction/condensing turbines, etc.
- Level 3: adds turbine-motor switching optimization (i.e., discrete variables).
- Level 4: adds equipment that would create "heartburn" if equipment moves were to be made, such as running a coker-feed pump with a turbine, with a motor standby. Running at level 4 can tell you the cost of your insurance policy.

A well running model would generally be run at level 3, with a run at level 4 once in a while to evaluate potential operational changes.

The objective function VISUAL MESA optimizes is the total operating cost of the system, which is:

$$\text{Operating Cost} = \text{Total Fuel Cost} + \text{Total Electric Cost} + \Sigma \text{ Inlet Costs}$$

The SQP optimizer's job is to minimize this objective function subject to operating constraints in the system.

Total fuel cost is determined from the fuel use of each boiler and combustion turbine times their respective fuel prices.

Total electric cost is determined from the net electric use of each motor, load, and generator times their respective electric prices. The electric generation (power selling) is just negative electric use. When running on-line, the model considers the electricity price corresponding to the actual hour of the day.

Inlet costs are normally used to charge for demineralized water coming into the system, but can be used for any other arbitrary cost.

2.3. Auditing and Control of Energy Costs

By auditing the energy system, imbalances can be identified and reduced. Therefore, the data can be relied on for evaluating the value of energy production and usage, and wastes can be eliminated.

Visual MESA helps to find where wasteful steam use is occurring in the steam system. A Balloon is a Visual MESA component used to measure steam balance closure. A Balloon performs the algebraic summation of all the flows for streams entering and leaving the balance. Since we have a value for the flow of every stream, the total should be 0.0 (all the steam that comes in must go out). If the net balance is not 0.0, there are either meters or estimated equipment flow rates in error, or there is steam leaving or entering the "balance" that has not been accounted. Balloons dynamically show error by changing size and color depending on the amount of steam imbalance. A Balloon is connected to each portion of a steam header where the possibility exists to close a mass balance. Figure 2 shows an example.

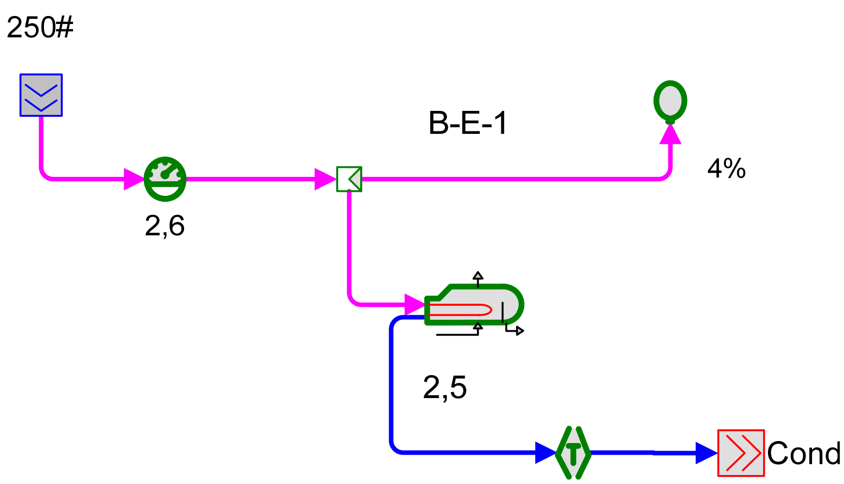


Figure 2. *Baloon location example*

A closed mass balance is formed by: A group of flow meters, Equipment with associated meters, or a combination of equipment and flow meters.

Balloons are used for two main purposes:

- To validate steam flow data

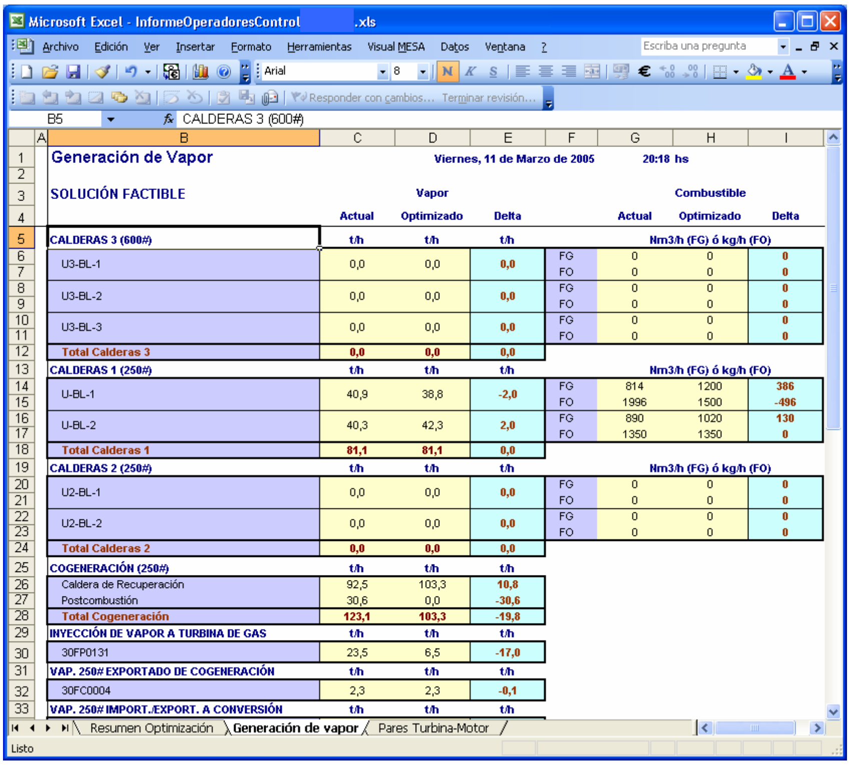
- If all of the flows in a "balance" continually add to near zero, the flow data can be relied on for evaluating the value of production and use, and waste can be eliminated.
- If the balance does not add to near zero, then meters could be bad or equipment steam flow rates could be different than estimated and there might be significant waste.

- To store model error where the error exists for use when comparing one case to another (i.e., the actual operation against the optimized one).

Reports

The Excel Custom Report provides a familiar environment for users to view information about the Simulation and Optimization of the system. It also enables users who are not familiar with Visual MESA to take advantage of the information Visual MESA provides.

Figure 3 shows an example of report generated with Visual MESA. In the worksheet shown, steam generation and fuel consumption are reported for the current values and the optimized ones.



Generación de Vapor			Viernes, 11 de Marzo de 2005		20:18 hs		
SOLUCIÓN FACTIBLE		Vapor				Combustible	
	Actual	Optimizado	Delta		Actual	Optimizado	Delta
CALDERAS 3 (600#)	t/h	t/h	t/h		Nm3/h (FG) ó kg/h (FO)		
U3-BL-1	0,0	0,0	0,0	FG	0	0	0
				FO	0	0	0
U3-BL-2	0,0	0,0	0,0	FG	0	0	0
				FO	0	0	0
U3-BL-3	0,0	0,0	0,0	FG	0	0	0
				FO	0	0	0
Total Calderas 3	0,0	0,0	0,0				
CALDERAS 1 (250#)	t/h	t/h	t/h		Nm3/h (FG) ó kg/h (FO)		
U-BL-1	40,9	38,8	-2,0	FG	814	1200	386
				FO	1996	1500	-496
U-BL-2	40,3	42,3	2,0	FG	890	1020	130
				FO	1350	1350	0
Total Calderas 1	81,1	81,1	0,0				
CALDERAS 2 (250#)	t/h	t/h	t/h		Nm3/h (FG) ó kg/h (FO)		
U2-BL-1	0,0	0,0	0,0	FG	0	0	0
				FO	0	0	0
U2-BL-2	0,0	0,0	0,0	FG	0	0	0
				FO	0	0	0
Total Calderas 2	0,0	0,0	0,0				
COGENERACIÓN (250#)	t/h	t/h	t/h				
Caldera de Recuperación	92,5	103,3	10,8				
Postcombustión	30,6	0,0	-30,6				
Total Cogeneración	123,1	103,3	-19,8				
INYECCIÓN DE VAPOR A TURBINA DE GAS	t/h	t/h	t/h				
30FP0131	23,5	6,5	-17,0				
VAP. 250# EXPORTADO DE COGENERACIÓN	t/h	t/h	t/h				
30FC0004	2,3	2,3	-0,1				
VAP. 250# IMPORT./EXPORT. A CONVERSIÓN	t/h	t/h	t/h				

Figure 3. Excel Custom report example

Data comes to Excel directly from the model. As Visual MESA is built around .NET technology, it can communicate seamlessly the Excel spreadsheet to the actual data and optimum operation calculated by the model.

3. Practical Issues

As part of the implementation, a review of the steam, power, and fuel control systems with knowledgeable experts has been performed. The goals of this Control System review have been:

- Develop a list of variables already controlled and how Visual MESA needs to relate to these
- Identify any needed control strategies or changes to existing strategies to implement optimization

As a result, the optimization suggestions can be achieved properly through the existing operating and control procedures.

Since VISUAL MESA is an operational oriented tool, the proper training of the operating personnel is a very important project step. The different shifts have been trained by using the refinery model. Feedback from the operators during and after the training classes has been very useful to easier the day-to-day application, improving the report views and the displayed information.

In order to facilitate the implementation, at the beginning the optimizer was running at level 2 (only continuous variables) so they can be handled by operators more easily. In a second stage, discrete variables are considered.

With respect to lack of sensors, VISUAL MESA utilizes calculated or estimated data in case a sensor does not exist or has a temporary failed state. The most important sensor data are any sensor variable that directly participates in the optimization: Cogeneration (steam flow rate), Boilers (steam flow rate), Letdown valves, Vents, and Motor-Turbine on-off statuses. New sensors have been located to automate the capture of the on-off status from the plant information system.

Some important data are sensors that provide data to the model that is not changed by the optimization. Optimization can still be performed and implemented without these Sensors (Reboiler Steam Flows, Temperatures and Pressures).

Less important data are any sensor that is only used for monitoring and does not participate in the modeling.

4. Results

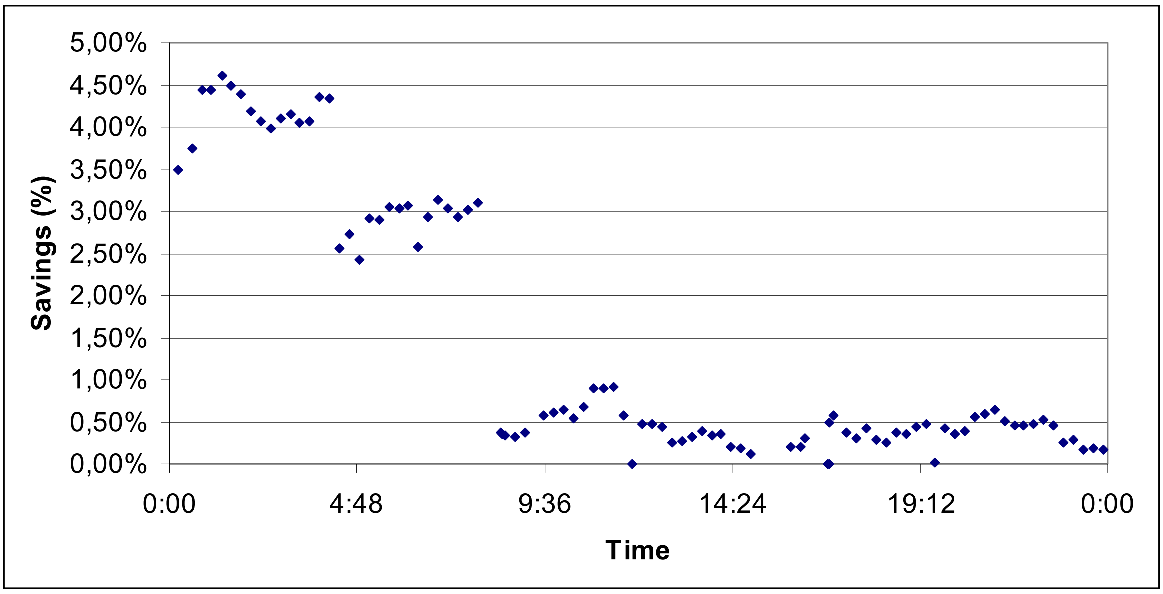


Figure 4. *Energy costs reduction performance. One day of operation*

In order to illustrate the benefits already obtained, optimization results are shown in Figure 4 (ref. 1). The results correspond to one day of operation by using Visual MESA. Savings are indicated as a percentage of total energy costs.

By implementing optimization recommendations the operation is closer to the minimum global energy cost. For example, observe the plot between 9:36 and 14:24hs. When the operator reads the report with 1% of potential savings he considers the recommendations (in this case, a combination of changes in boilers loads and steam flows among complex areas) and the global operating costs are progressively reduced.

An important aspect to be highlighted is the fact that the savings are recurrent: they can be sustained along the year representing a substantial energy costs reduction.

5. Conclusions

An on line tool for auditing and energy costs control has been installed at the refineries / petrochemicals.

Energy costs reductions have been obtained taking advantage of the VISUAL MESA software functionalities. It demonstrated to be a robust optimizer, well suited to be used on a routine basis by operators. The model is also used to evaluate a priori what-if scenarios that include modifications or different operating alternatives of the Utilities Systems. Auditing and accounting of steam and Boiler Feed Water allows reducing wasting steam and identifying imbalances. Finally, continuous monitoring allows preventing plant upsets and helps to quickly identify steam wastes.

It is important to emphasize the high involvement and motivation of plant operators since the beginning of the implementations. Coordination amongst plant areas in order to implement the proposed optimization recommendations is also a critical issue, so management involvement is crucial. The robustness of the tool helped operators to gain confidence on the system.

Final user's acceptance and widespread use, for both engineers and operators, is one of the key issues for this successful implementation.

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