ENERGY MANAGEMENT SYSTEM HELPS REFINERIES TO REDUCE EMISSIONS AND ENERGY COSTS

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Abstract

Utilities and energy systems are often the major source of SO_x, NO_x and CO_2 emissions, therefore, emissions control and the management of credits and quotas are tightly interrelated with energy management.

In the case of refineries, chemical and petrochemical plants, energy represents the main cost (second to feedstock) and therefore its reduction has become a bottom line business decision. The energy systems at these sites are inherently complex, with the emissions cost analysis and limits compliance introducing an additional factor to the complexity of the energy costs reduction challenge.

Process plants use different type of fuels, they often operate cogeneration units, their steam networks consist of several pressure levels, there are different types of energy consumers and there are emission limits to be observed. Import or export of electricity in deregulated markets, which could also be traded off with more or less CO_2 and other contaminant gaseous emissions, increase the optimization problem complexity.

In the case of SO_x emissions, they can be predicted based on each individual fuel composition.

On the other hand, NO_x emissions depend not only on the individual fuel composition but also on the equipment in which the fuel is burned and on the use of burning additives; therefore, equipment-specific correlations need to be added to the model.

The SO_x and NO_x limits can be imposed as total emitted mass rate and concentration in flue (exhaust) gases. Additionally, an annual quota limiting the total mass emission of SO_x and NO_x can be enforced. Allowed emission limits can also change with respect to the

liquid/gas fuels ratio used at a given boiler or heater (or a set of them associated to a given stack).

Several application examples and results corresponding to refineries around the world are presented and discussed.

How to integrate the emission costs and constraints within the overall energy system on line real time modeling and optimization is also explained.

1 Introduction

Refineries face increasing governmental regulations and tax pressure to reduce emissions. They are challenged to optimize their energy systems costs with the additional goal of maintaining or reducing their SO_2, NO_x and CO_2 emissions and, at the same time, increasing their competitiveness.

As the utility and energy systems are often the major source of SO_x, NO_x and CO_2 emissions, the appropriate control of these emissions and management of credits and quotas are tightly related with energy management.

Refineries usually operate complex energy systems, SO_2, NO_x and CO_2 emissions introduce an additional factor to the complexity of the energy costs reduction challenge. Moreover, since energy represents usually their main cost after feedstock, its reduction is more of a bottom line business decision than a challenge.

Refineries use different type of fuels, they often operate cogeneration units, their steam networks consists of several pressure levels, there are different types of energy consumers and there are emission limits to be observed. Import or export of electricity in deregulated markets, which could also be traded off with more or less SO_2, NO_x and CO_2 and other contaminant gases emissions, increase the optimization problem complexity.

2 A Comprehensive Modeling and Optimization Tool for On Line Real Time Energy and Emissions Optimization and Management

In order to successfully address the energy system and emissions management, the Visual MESA software is widely used (Ref. 1). It is a Real Time Optimization application that is saving refineries all over the world millions of dollars per year by advising on optimal operating conditions of their utilities systems, comprising steam, fuels, electricity, boiler feed water, condensates and emissions. Visual MESA has been adopted by the leading refiners worldwide and is the first choice in the segment of online energy optimization.

At the sites were Visual MESA is in use, operators always have a set of recommendations available to help them operate the energy system at the minimum cost under the current site production scenario and respecting economic, contractual and environmental constraints. The tool also acts as a “watch dog” since supervisors can evaluate how operators manage the energy system based on the Key Performance Indicators being generated. In the vast majority of cases we have seen that, before applying the optimizing recommendations (or when they are not taken into account), high variability in the way the energy system is operated and large potential benefits are frequently found. As soon as Visual MESA is commissioned and routinely in use, variability is noticeably reduced or eliminated, as it was reported by many implementations (see References 2, 3, 4, 5, 6 and 7).

Figure 1 shows an example of the savings found in a refinery during a shift period (savings are expressed as a % of the total energy cost). Each point in the plot corresponds to an automatic Visual MESA execution. Note the decrease in the potential savings when operators begin to apply the recommendations (last three hours of the shown shift) meaning the savings were truly captured.

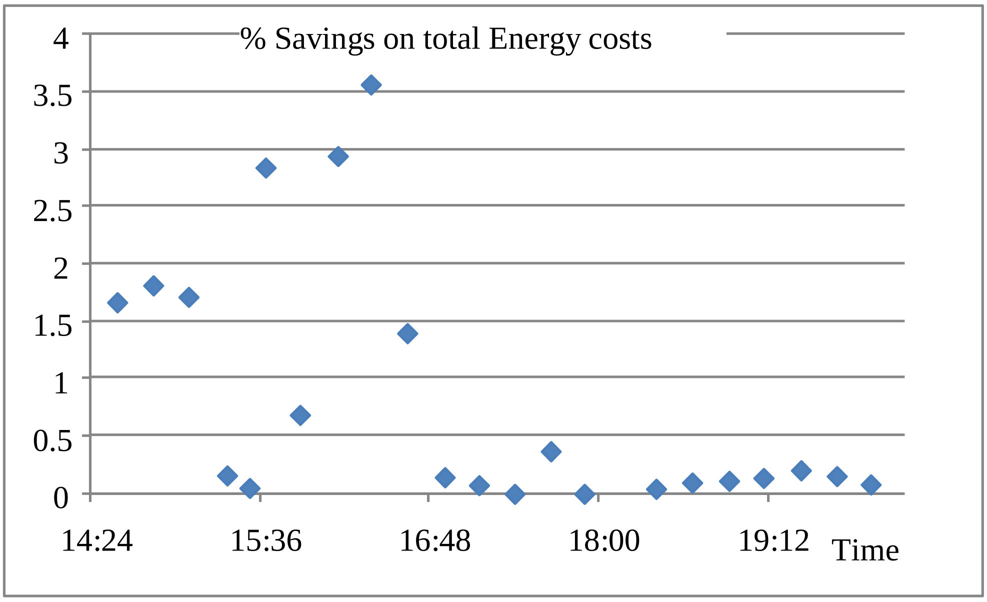


Figure 1. Identified savings along a shift

3 Emissions Optimization

Figures 2, 3 and 4 show respectively the corresponding potential reduction in CO_2 emissions (t/h), SO_2 and NO_x emissions (in terms of concentration with data corresponding to one of the main stacks) found during the same operational shift period applying the optimization recommendations.

Energy costs reduction in the order of 3% on total energy costs were obtained in this particular example. They imply an associated reduction in CO_2 emissions, in the order of 2 t/h. Additionally, and in this case also due to fuel management, a reduction in SO_2 (200mg/Nm3 less) and in NO_x (50 mg/Nm3 less) in one of the main stacks has been also obtained.

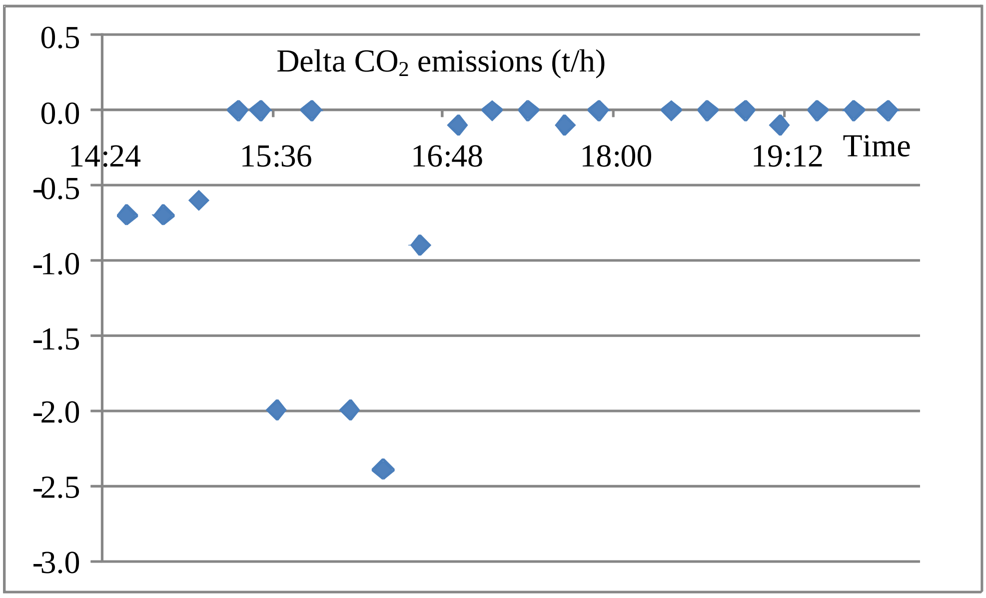


Figure 2. Identified CO_2 emissions reduction along a shift

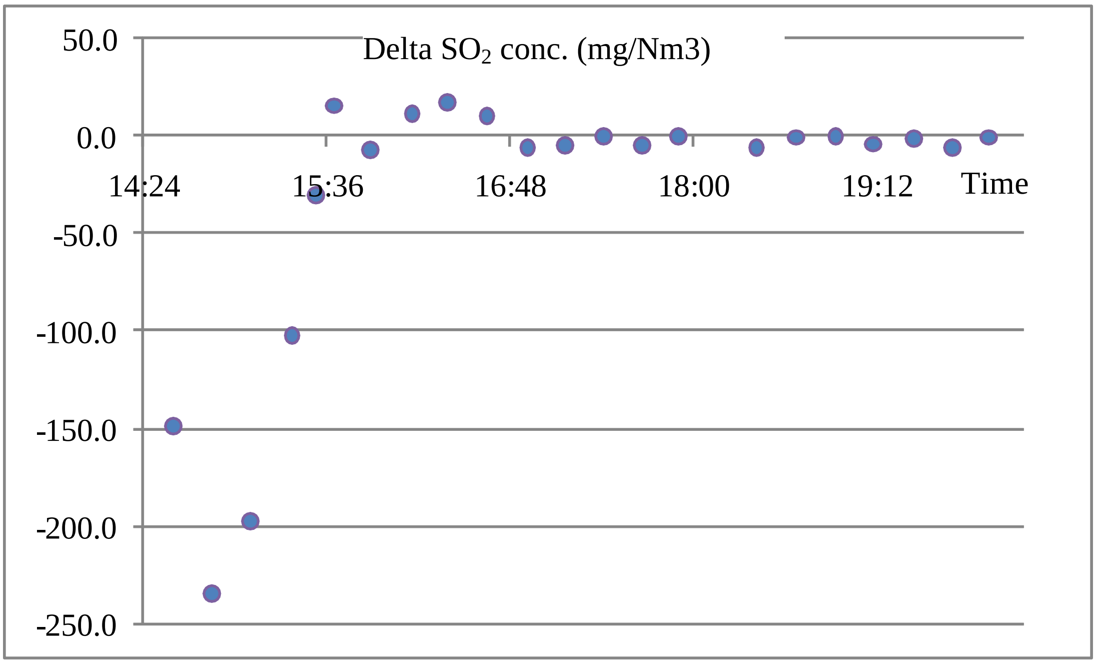


Figure 3. Identified SO_2 emissions reduction along a shift

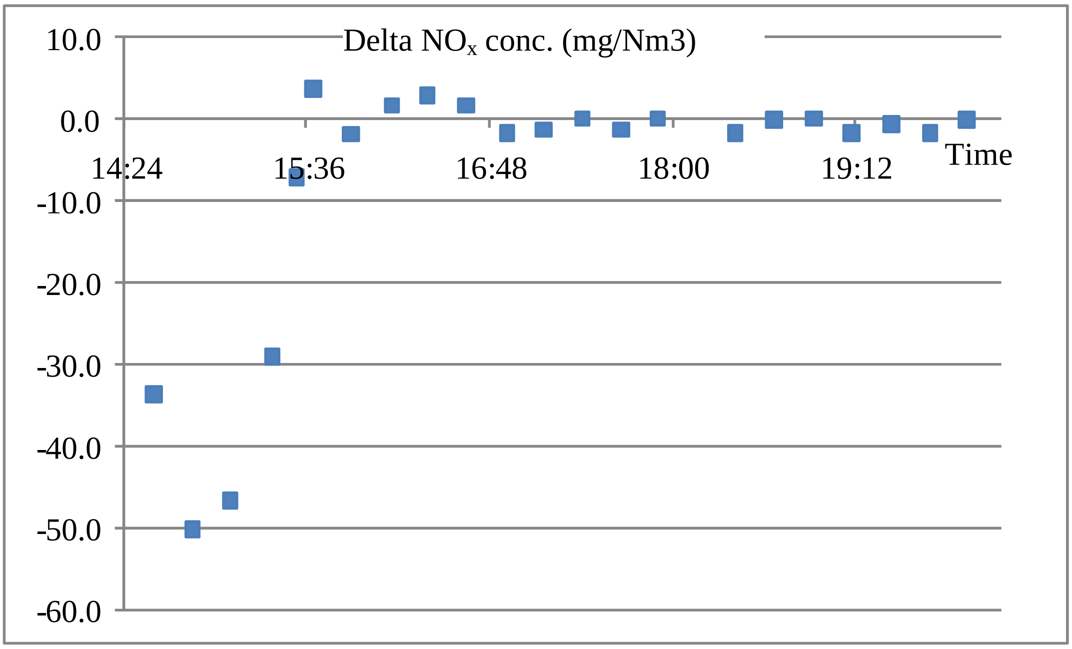


Figure 4. Identified NOx emissions reduction along a shift

Some of the procedures used to calculate, constrain and optimize the emissions within the overall Site Energy Management strategy are discussed in the next paragraphs.

4 SO_2 emissions

SO_2 emissions can be predicted based on each individual fuel composition.

SO_2 flow= %S x 64/32 x Fuel flow

In terms of concentration:

SO_2 flow / flue gases flow (e.g. mg / Nm3)

Flue gases flows are calculated based on fuel composition and excess air, since each component has a factor in Nm3/kg of burned fuel.

The concentration limits are usually standardised to a certain level of $\%O_2$ (e.g. $3\%O_2$ dry basis).

The concentration emission limit also can be function of the % of liquid or gas fuel that is burnt (variable constraint). For example:

SO_2 Conc. limit per stack (mg/Nm3) = 1700 x (%L) + 35 x (%G), where %L is the mass percentage of liquid fuel burnt and %G is the percentage of gas fuel burnt in equipment discharging to the same stack. In this example, if ratio is 50/50, the limit is 867 mg/Nm3.

Other emission limit usually imposed by the legislation is related to the total annual amount of SO_2 emitted (e.g. ton/year).

All these aspects have to be taken into account by the on-line optimization model.

Figure 4a shows an example of the representation in the model of the SO_2 mass flow calculation, which is based on sulphur balance for two boilers, with different burners, discharging to one stack.

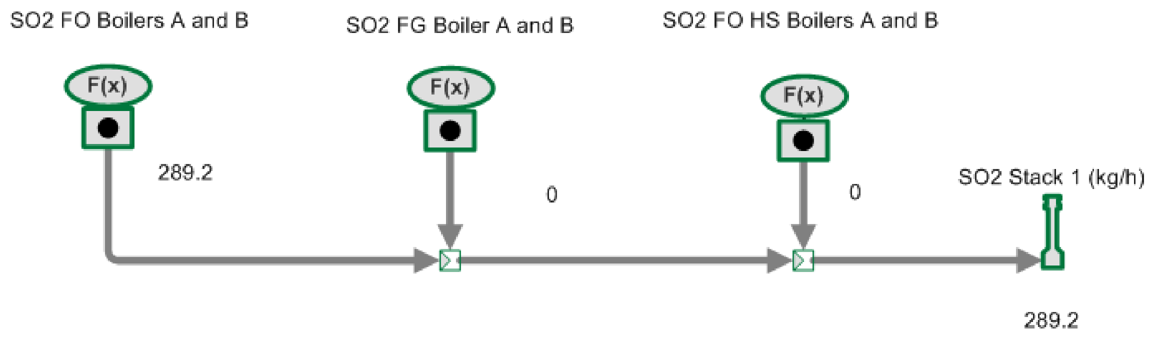


Figure 4a. SO_2 mass flow calculation

The stoichiometric flue gas production (in dry basis and normalized to 3% O_2) is calculated for each boiler, based on the fuel compositions and the stoichiometric flue gas factors. In case such flue gas is also measured, the difference (imbalance) is also calculated. The follow-up of such imbalance is useful to check measurements quality and/or adjust the flue gas production calculation. Figure 4b shows an example.

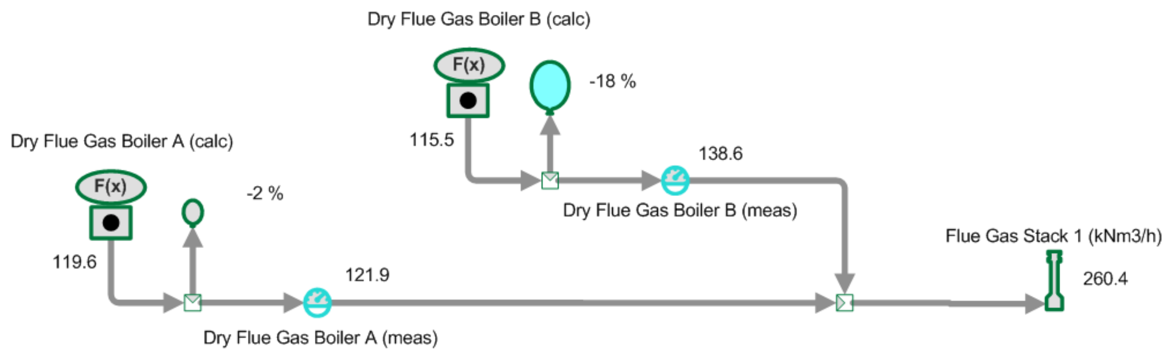


Figure 4b. Flue gas flow calculation.

Then, the corresponding SO_2 concentration is calculated based on SO_2 and flue gas flows (SO_2 flow divided by flue gas flow).

In case there is an on-line measurement of the concentration, the model calculates the bias between calculated and measured value (correction factor). Figure 4c shows an example:

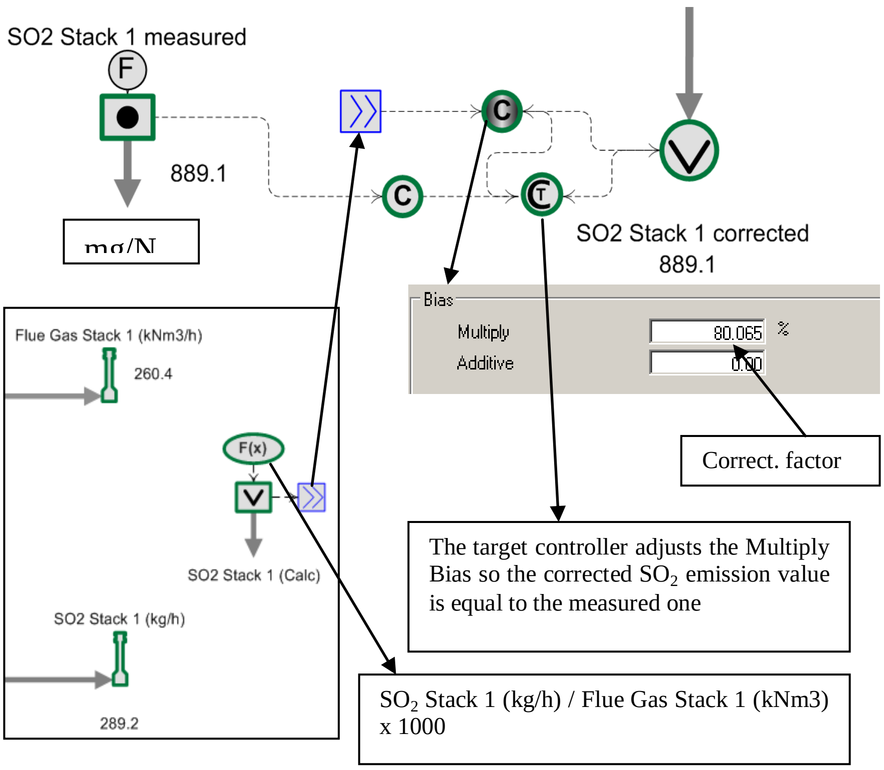


Figure 4c. SO_2 model calculation biasing when concentration is measured

When optimizing, the model predicts the emissions in the optimized situation using the calculated deviation (bias).

When the concentration limit depends on the fuel liquid/gas ratio, such ratio is calculated in current situation and it is taken into account as a constraint variable during optimization, as it is shown in Figure 4d.

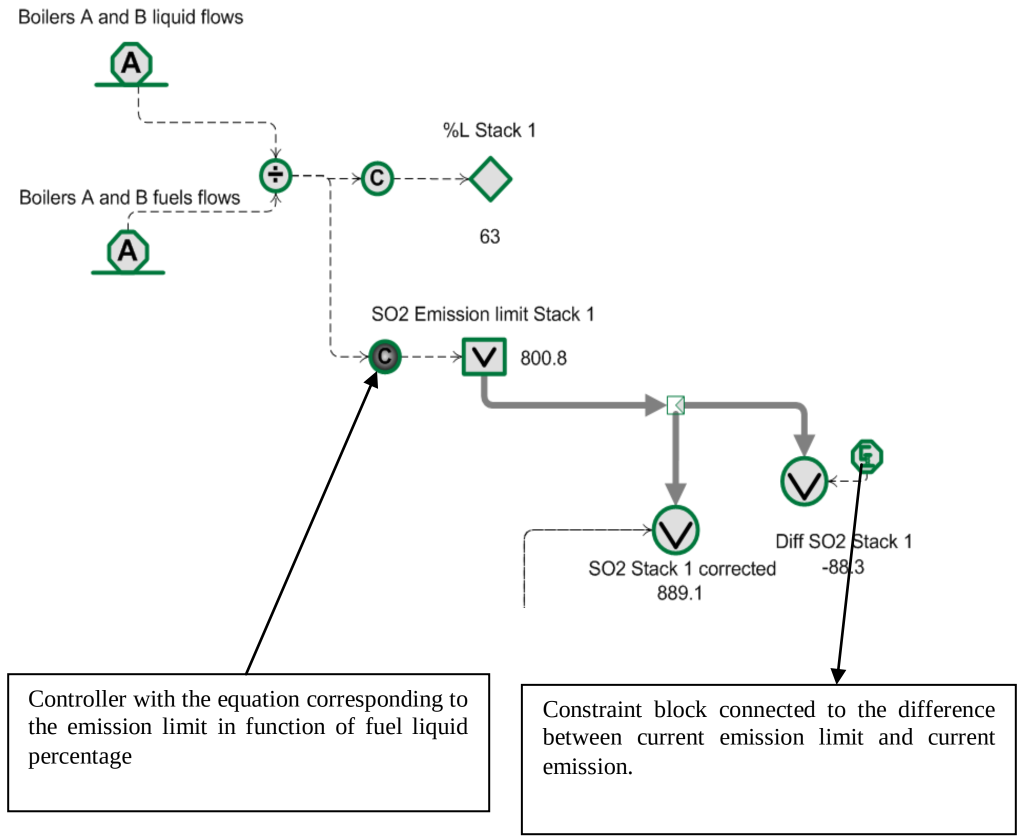


Figure 4d. SO_2 model emission limit and constraint.

Fuels choices and fuels consumption reduction as part of energy system optimization are the typical reported ways for day to day SO_2 emissions reduction.

5 NO_x Emissions

NOx emissions depend not only on the individual fuels composition but also on the equipment where they are burnt. Specific correlations need to be considered.

For example:

$NO_x\ Conc = Sum\ (Fueltypes\ E_i * F_i * V_i) / Sum(Fueltypes\ F_i * V_i) + A * Esteam *(Fsteam - B)$

Where:

NO_x *Conc*	NO_x Concentration in the stack
E_i	NO_x Emission factor per fuel type (mg/Nm3)
F_i	Quantity of fuel burned (t/h)
V_i	Stack gases volume produced, per fuel type (Nm3/t)
Esteam	Correction factor for the feed (mg/Nm3/(t/h))
Fsteam	Production rate of steam at the boiler (t/h)
A and *B*	Correction factors

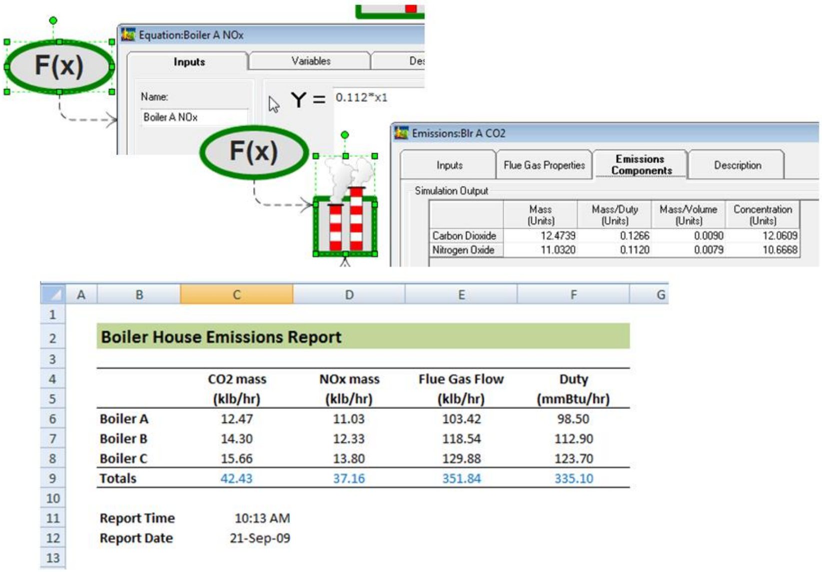
The concentration limits are usually standardised to a certain level of $\%O_2$ (e.g. $3\%O_2$ dry basis). The concentration emission limit also can be function of the % of liquid or gas fuel that is burnt (variable constraint). For example:

NO_x Conc limit per stack (mg/Nm3) = 450x (%L) + 225 x (%G), where %L is the mass percentage of liquid fuel burnt and %G is the percentage of gas fuel burnt in equipment discharging to the same stack. In this example, if ratio is 50/50, the limit is 337 mg/Nm3.

Other emission limit usually imposed by the legislation is related to the total annual amount of NO_x emitted (e.g. tons/year).

All these aspects have to be taken into account by the on-line optimization model.

Figure 5 shows an example of the representation in the model of the NO_x mass flow calculation, which is based on correlations for each boiler, with different burners, discharging to a single stack.



Boiler House Emissions Report

	CO2 mass (klb/hr)	NOx mass (klb/hr)	Flue Gas Flow (klb/hr)	Duty (mmBtu/hr)
Boiler A	12.47	11.03	103.42	98.50
Boiler B	14.30	12.33	118.54	112.90
Boiler C	15.66	13.80	129.88	123.70
Totals	42.43	37.16	351.84	335.10

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Report Date 21-Sep-09

Figure 5. NOx Model

The rest of the model is done in similar way to the SO_2 modelling already explained.

Fuels choice, fuels consumption reduction and equipment operating parameters (boiler steam production) as part of energy system optimization are the typical reported ways for daily NO_x emissions reduction.

6 CO_2 Emissions

Each fuel has associated an emission factor that can be calculated based on its % of Carbon:

Emission factor (ton of CO_2 per ton of fuel) = 44/12 x %C in fuel/100

For example, a fuel gas with 65% of C has an emission factor of 2.4 ton of CO_2 per ton of fuel gas.

Figure 6 shows an example of the calculation of emissions for a whole Site, including CO_2

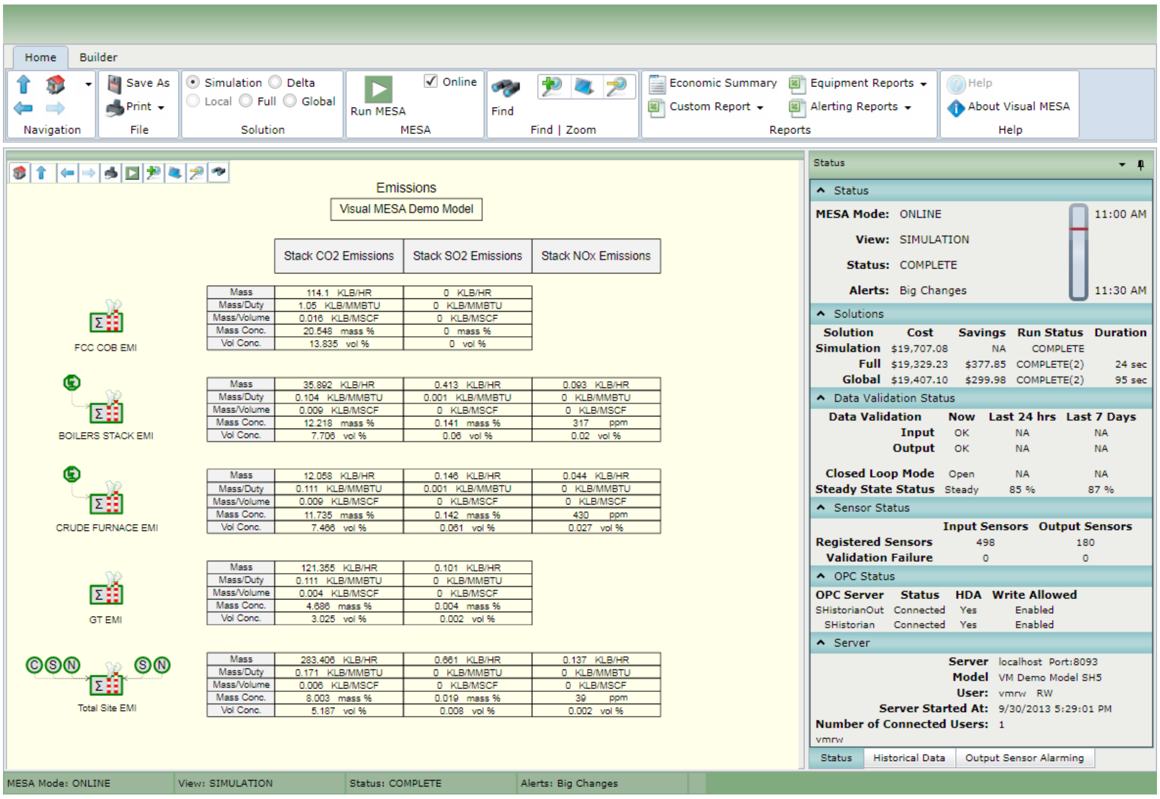

Figure 6. Detail of the stack emissions reporting, including CO_2 (web browser access)

Among the different ways of reducing CO_2 emissions, efficiency improvements, fuels substitution and crude substitution are the most commonly put in practice.

By integrating CO_2 emissions in an energy costs optimization model, the cost of CO_2 emissions is taken into account by the Visual MESA model together with all the other existing purchase and supply contracts of fuels, steam, water and electricity. The CO_2 emissions modeling and economics must be configured according to each site's specific needs.

For example, the CO_2 emission cost and total quota constraint can be added to the optimization economical Objective Function (OF) so that, when an optimizer minimizes the OF, CO_2 cost is taken into account together with all the other costs (fuels, electricity, demineralized water, etc.). In this way the optimum fuel feeds to boilers and gas turbines are recommended. Of course, also the limits and/or quotas imposed to other emission gases can be taken into account at the same time.

In general, since the energy cost savings are mainly achieved by a reduction in fuels consumption, the optimization will always imply a reduction in CO_2 emission, except in those scenarios where the optimizer finds the use of a cheaper fuel that generates more CO_2 instead of using a more expensive fuel that generates less CO_2. This could be the case when replacing Natural Gas with a heavy liquid fuel. This challenging tradeoff is affected directly by both the CO_2 allowance price and the annual emission quota.

The following sections explain the importance of including the cost of CO_2 emissions and how it should be taken into account when managing and optimizing the energy systems.

Furthermore, it is shown how an optimization tool like Visual MESA helps to perform case studies to evaluate energy system modifications taking into account this aspect.

The consideration of CO_2 emissions in the energy system model for everyday usage, to perform the energy system Real Time, On Line, Optimization, is also explained.

6.1 CO_2 Emissions Accounting

In many countries, a given industrial complex has an assigned quota for total CO_2 emissions. They periodically report the total generated CO_2 related to fuels consumptions and operating processes. At the end of the year, if the quota is exceeded, each ton of CO_2 emitted above the quota has to be paid at a given market price. For instance, the price may be referred to the European Union Allowance (EUA), equivalent to one metric ton of CO_2 emissions (see http://pointcarbon.com).

In some countries, there is an additional tax, sometimes much more expensive than the allowance price, as a penalty for having exceeded the quota.

Also, if emissions are below the quota, the tons of CO_2 saved can be sold at the market price of the emissions allowance.

6.2 How CO_2 Emissions Impacts Global Energy System Optimization

The cost of CO_2 emissions in the OF can be incorporated in several different ways depending on whether the quota has been exceeded or the accumulated emissions are below the quota, at a given point of time and over a given accounting period (generally one year):

a) *For each ton of CO_2 emitted a price equal to the emission allowance price is assigned (plus the applicable taxes).* This approach could not be fully realistic from the accounting perspective, unless the plant has exceeded the CO_2 emissions quota. However, it assures that the optimization will be always focused on minimizing CO_2 emissions. This approach may influence the optimization results in those cases that a compromise between using a more expensive fuel with less CO_2 emissions and a cheaper fuel with more CO_2 emissions exists. It will, in fact, penalize the cheaper fuel.

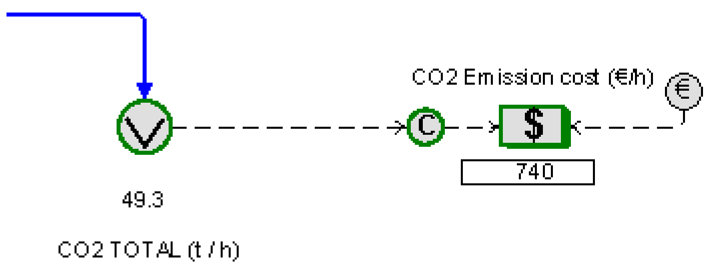

Figure 7. All emitted CO_2 has a cost.

b) *No cost is assigned to the emitted CO_2 until the quota is achieved*. In this option, if there were compromise solutions between the use of a more expensive fuel with less CO_2 emissions or a cheaper one with more emissions, the optimization would advise the second. Consequently, the quota will be achieved early in time. This approach should be only applied in those plants where, due to its particular operating conditions, the annual quota is unlikely to be achieved.

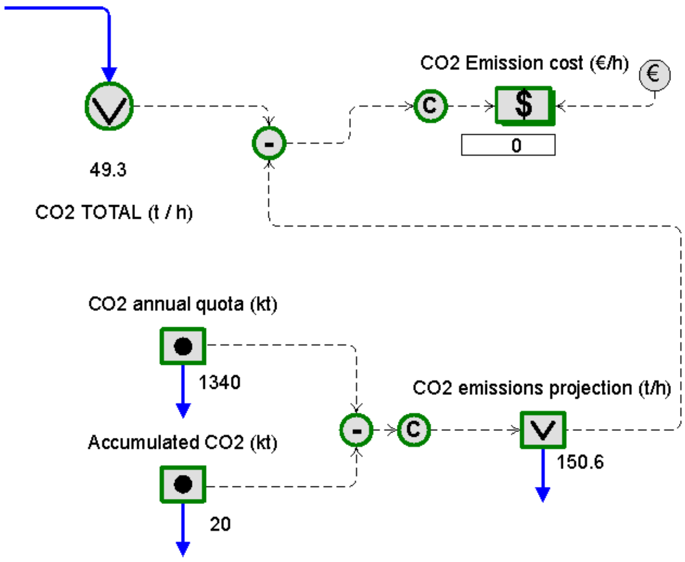

Figure 8. CO_2 over the quota has a cost.

c) The CO_2 emissions have always an associated cost, however it will depend on the emissions projection for the rest of the period (typically one year). If this projection of emissions estimates that at the end of the period the quota will not be reached, each ton of CO_2 below the quota will have a negative cost (-) equal to the price of sale of the emissions rights, which for optimization purposes will correspond to a credit (assuming this emissions rights not used will be able to be sold). If the projection foresees the quota will be reached, the price will be equal to the cost of emission (plus the applicable taxes).

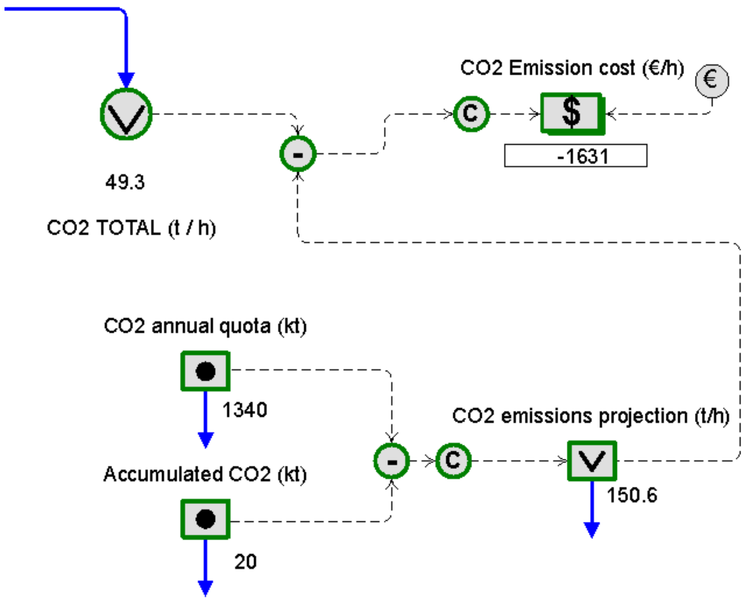

Figure 9. CO_2 cost based on projected emission

d) *In all cases a constraint can be imposed on the current CO_2 emissions*. Such a constraint should be to be equal to the projection of the future emissions calculated in such a way that the quota would be met at the end of the considered period (i.e., end of the year). This approach would help manage the fuels consumption so that the site is always below the emissions quota in order and therefore take the maximum advantage of the quota at the end of the considered period.

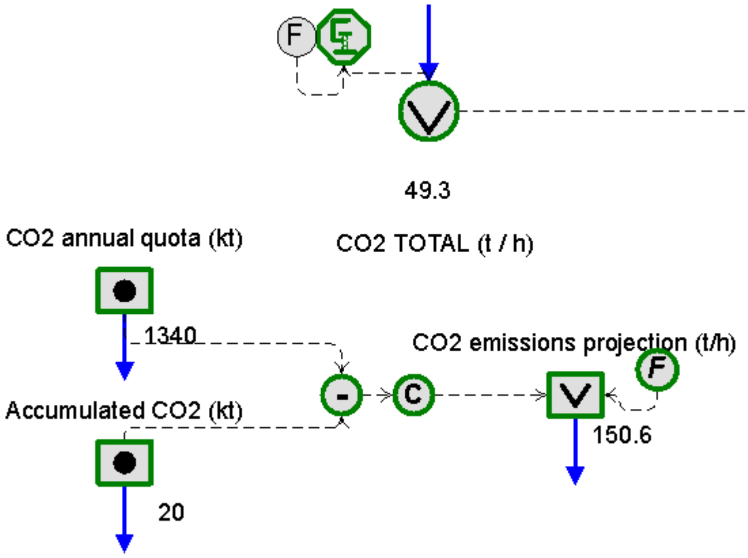

Figure 10. CO_2 constraint

If the quota eventually is exceeded before the end or the period, the additional CO_2 emissions cost will be included in the Objective Function to be minimized. Under this scenario the price of each ton of emitted CO_2 will be equal to the CO_2 emissions allowance (plus the applicable taxes).

7 Industrial Examples of Emissions Management and Energy Costs Reduction

All the examples shown in this section correspond to refineries.

7.1 Emission Management with Variable SO_2 / NO_x Emission Limits

This first example shows the effect of the optimization by using an online model which includes the emissions when the limit depends on fuels liquid/gas ratio.

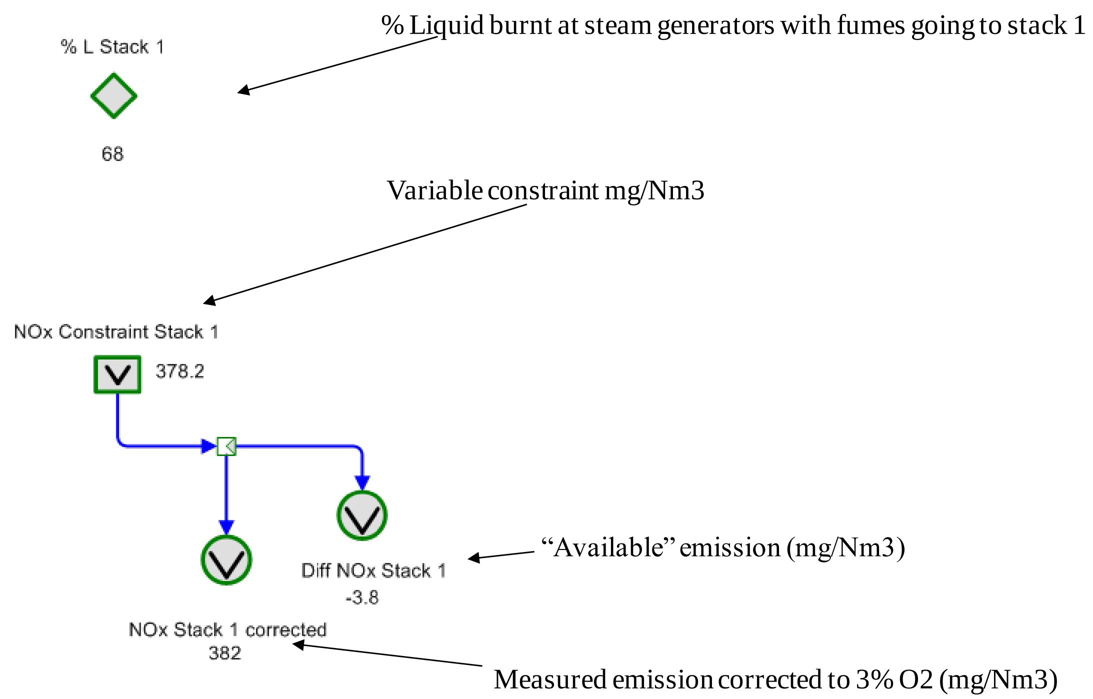

Figure 11. NO_x emissions example

When optimizing the ratio changes, so the emission limit also changes:

Stack 1		Current mg/Nm3	Optimum mg/Nm3	Delta mg/Nm3
SO2	Emission	459.1	587.7	128.6
	Limit	1170.5	1359.0	188.4
NOx	Emission	372.0	403.7	31.7
	Limit	378.2	403.7	25.6
	%L	68	80	12

In this case, an increase in the % of liquid burnt, as result of the total energy cost system optimization, implies an increase in the corresponding emissions. However, in the case of SO_2 emission, the system will work even further from the emission limit (the new emission limit is higher). In the case of NO_x, the system will operate at its new emission limit (while the simulation case was 6 mg/Nm3 far from this limit.

7.2 Daily CO_2 Emissions Reduction

In this example, a set of manual operating recommendations given by the optimizer during a shift have been:

- Pump swaps
- Fuels to boilers (i.e., FG and FO)

As a result of the manual actions, the changes performed by the control system have been:

- Steam production at boilers
- Letdown and vents rates

In summary,

- Around 1 t/h less of FO consumed
- Approx. 7 t/h less of high pressure steam produced
- Approx. 2 t/h less of CO_2 emitted
- Approx. 200 kW more of electricity imported

The following figures show the impact on steam production, fuel use and CO_2 emissions reduction.

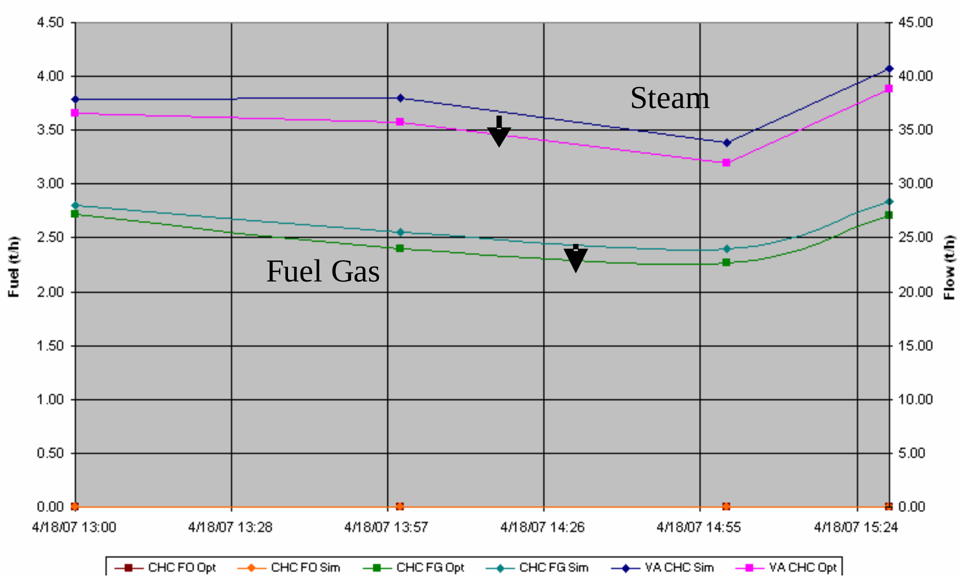

Figure 12. Boiler C (100% Fuel Gas): steam production reduced 2 t/h

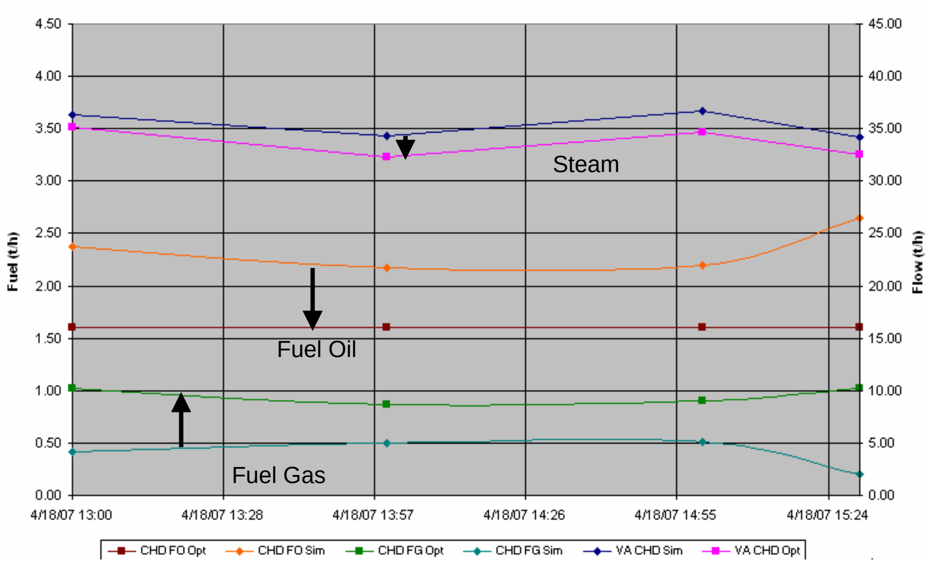

Figure 13. Boiler D (FO and FG): steam production reduced 2 t/h and FO reaching the minimum constraint

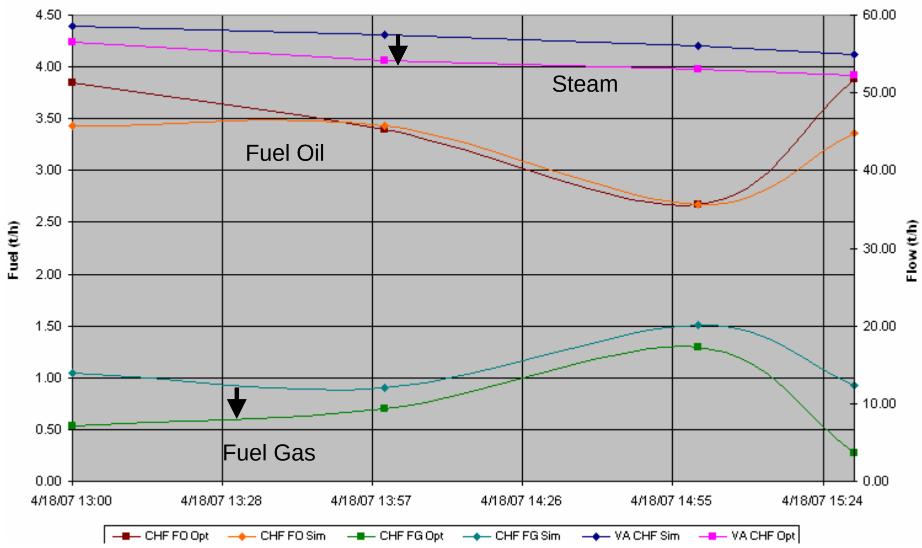

Figure 14. Boiler F (FO and FG): steam production reduced more than 3 t/h

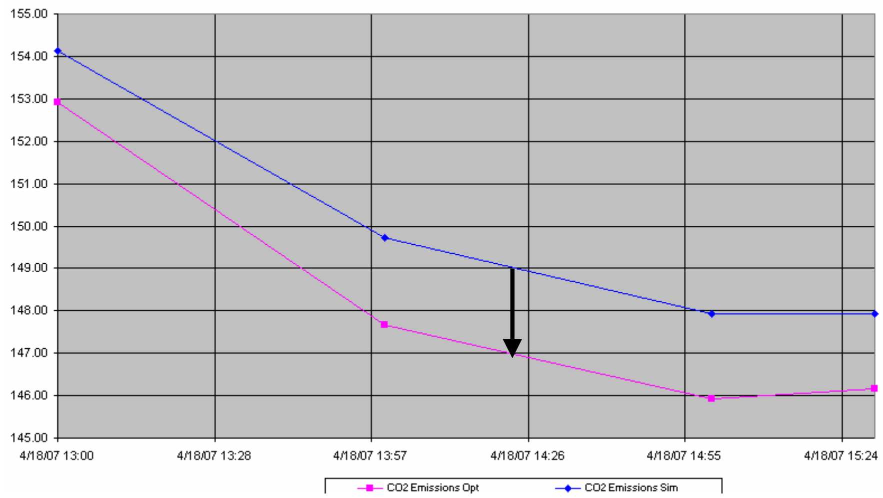

Figure 15. Overall CO_2 emissions reduced 2 t/h

7.3 Fuels Choice

When considering the CO_2 emission cost, the following is an example of the recommendation for operators:

- Fuels to boilers

As a result of the manual change in the boilers fuels diet (increase FG and decrease FO in the overall), the Fuel Gas header pressure control system made the necessary adjustments which resulted in a Natural Gas net import.

The following figure shows the fuel gas network model representation highlighting the differences between current and optimized situation (delta view, duty flows).

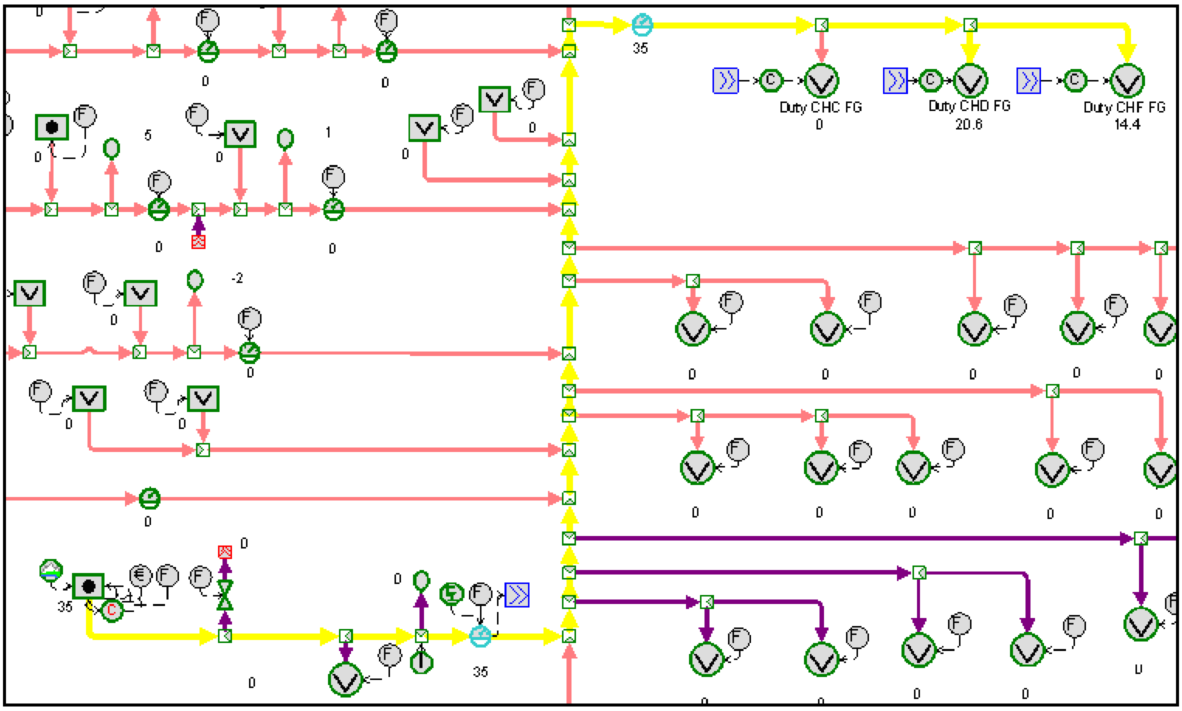

Figure 16. Changes in fuel gas network

On the left, fuel gas suppliers are represented while on the right Fuel Gas consumers are displayed. The values indicate the corresponding change, expressed in MW, after the application of the recommendations (zero value means no change).

As a result of replacing FO by FG (with the need to import more Natural Gas), CO_2 emissions are reduced in 4.7 t/h. This is important to be considered when there is a trade-off between cheaper fuels that produce more CO_2 and more expensive fuels that produce less CO_2. This is very important when the CO_2 emissions quota is expected to be exceeded by the end of the year.

7.4 Energy Costs and CO_2 Emissions Reduction

This fourth example corresponds to a Middle East refinery where the Visual MESA based Real Time Energy Management System was recently commissioned. In addition to the energy cost savings a reduction in CO_2 emissions reduction was achieved.

Figure 17 shows the reported results from one of the refineries (KNPC Mina Al Ahmadi). The base case was established when the model was completed in May 2012 with energy cost savings opportunity of about 680 $/hr. By the end of December'12 the energy cost savings potential were reduced to about 180 $/hr reflecting obtained savings of about 500 $/hr (4.4 MM$/year).

The cost savings and CO_2 emission reductions came from two main sources:

- Excess steam vent / condensing reduction (i.e., less fuel gas used for high pressure steam production because of the steam waste reduction)
- Letdown reduction (i.e., less power purchase for driving the pumps and compressors because of the use of turbines instead of motors)

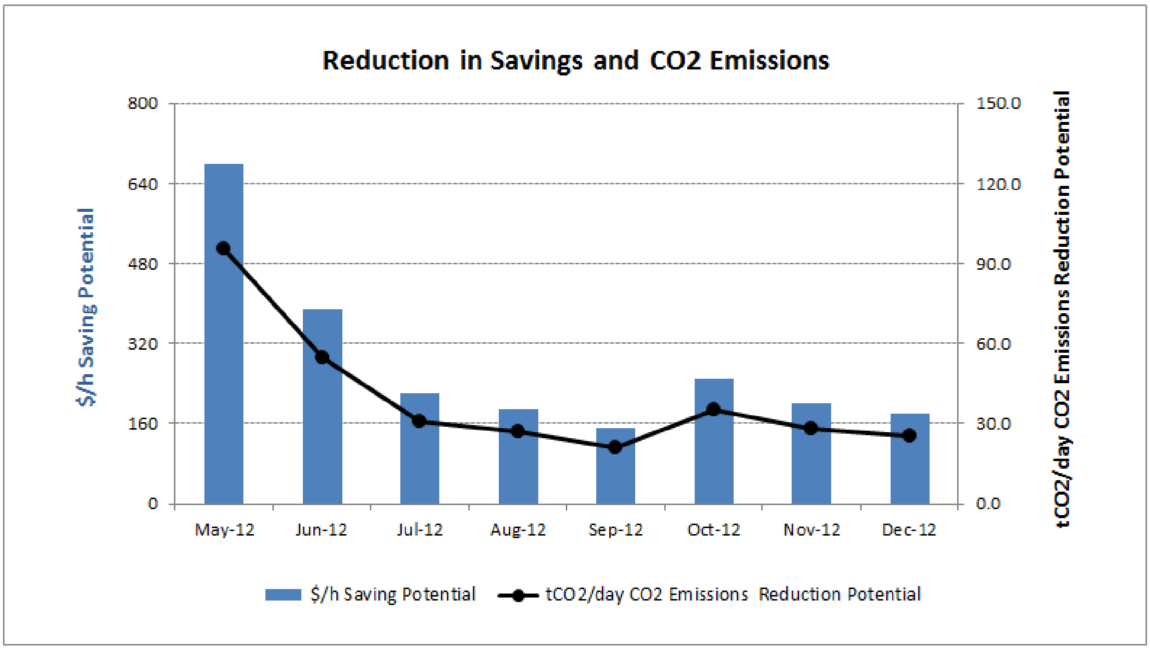

Figure 17. CO_2 emissions and economic potential savings. KNPC MAA refinery. Their reduction corresponds to captured savings.

In the following Figure 18, the CO_2 emission reduction estimation basis is presented:

MAA CO2 Emission Reductions
Visual MESA based Real Time Energy Management System (RTEMS)

Factors:

Boilers fuel emission factor:	0.2	t CO2 / t UHP steam
Imported power emission factor:	0.0007055	t CO2 / kWh
Average Steam Rate for Steam Turbines:	48	kWh / t of steam

1. Excess steam vent / condensing reduction (i.e., less fuel gas used for UHP steam production because of the steam waste reduction)

Reduction in excess fired steam:	9	t steam / h		1.8 t CO2 / h	43.2 t CO2 / day	**15,768 t CO2 / year**

2. Letdown reduction (i.e., less power purchase for driving the pumps and compressors because of the use of turbines instead of motors)

Reduction in steam letdown:	40	t steam / h	1920 kW	1.4 t CO2 / h	32.5 t CO2 / day	**11,866 t CO2 / year**
Total CO2 emission reduction:				**3.2 t CO2 / h**	**75.7 t CO2 / day**	**27,634** t CO2 / year

Figure 18. CO_2 Emission reductions estimation as a result of the optimization action

8 Conclusions

Refining examples have been presented in which, with the existing equipment and utilities infrastructure, NO_x, SO_2 and CO_2 emissions reduction were achieved while optimizing the energy system costs using a real time on line software tool.

Optimization is configured to provide recommendations to operational personnel on a routine basis.

9 References

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