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GHG Emissions Reduction Via Energy Efficiency Optimization

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1. Introduction

There are three major sources of GHG; carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). The world's CO₂ emissions into the air have been increasing drastically over the past century. The industrial revolution and exploitation of natural resources such as coal and oil have greatly contributed to CO₂ emissions. The world's CO₂ emissions due to fuel utilization such as natural gas, liquid fuels such as oil, and coal has resulted in CO₂ emissions due to energy usage of about 45 billion metric tons by the year 2030. In Japan, for instance, more than 80 % of its GHG emissions are due to energy-based sources resulted from fossil fuel consumption and a boost to the energy efficiency of a single refinery in Japan can result in a reduction of at least 50,000 ton CO₂/year.

It is not a matter of indifference or/and skepticism any more, the majority in the world scientific communities do subscribe now to the fact that, the world's environment has been negatively affected by the global warming phenomenon which has caused the average temperature of the earth's surface to increase during the last century due to the irresponsible release of greenhouse gases (GHG) into the atmosphere. From GHG perspective, energy efficiency optimization is not only a fast track approach to reduce energy-based GHG/CO₂ emissions but also a cost-effective option towards such endeavor. It does not need behavioral change, which is sometimes difficult to achieve on the short run. It does not also play on the people's level of romance regarding the health of our beloved universe. It touches the heart of mankind's old and new motivations and aspirations for better life. It is industrial people's own benefit. Energy efficiency optimization solution approach as a quick answer to energy-based GHG emissions reduction simply enables us attaining the "water-oil-impossible-mix" via mixing the useful, exhibited in saving money, with the beautiful of saving more than the money, the environment.

At the equipment level, process equipment becomes inefficient when it uses higher energy than the designated one at the same feed and production rates. Extra energy consumption by equipment can be related to aging, part deterioration, process related causes, fouling and so on. Such reasons need to be scrutinized on timely basis in any industrial facility to avoid excessive energy consumption and consequently more GHG emissions. Equipment normally has its standard causes and characteristics for energy efficiency degradations and it can be captured through detailed analysis of its parameters change along the historical

sequence of events during its operation. The relation between GHG emissions and energy efficiency is subject to some factors, such as equipment and drivers types. Gas compressors are driven by electrical motors; steam turbines; and gas turbine drivers. Compressor's driver selection is a major contributor to gas emissions. Electric motors are the least emitters and gas turbines are the most among other drivers.

Industrial community is systematically practicing online equipment-based performance monitoring and diagnosis functions to measure, analyze, improve and control equipment's energy usage to keep its energy consumption under tight control. Although the motivator to steer the equipment energy consumption towards the design figure is to reduce the energy operating cost; that result is also contributing to the reduction of GHG emission. It is the industry practice to identify energy savings opportunities in equipment operation by taking proactive maintenance steps, applying advanced control strategies and real-time optimization. For example oil and gas equipment/units operation load management make reductions in energy usage and greenhouse emissions. Constantly invented/developed new materials, technologies, hardware and design software are also improving equipment's energy efficiency. For instance, materials scientists have helped steam power plant designers to design steam boilers for subcritical and super critical steam generation levels, which were not possible decades ago. Many successful efforts in capital allocation in many industrial facilities are also preventing energy inefficient equipment of being introduced to new industrial sites and/or phasing out inefficient ones in existing facilities before its designated retiring date, is also getting steam every day.

However, for decades ago energy efficiency optimization was merely addressing the energy efficiency of standalone process equipment. Since late seventies in the last century, the landscape has changed. It is not only energy efficiency for the standalone equipment/unit but also for subsystems, systems, complexes and even mega sites as well as industrial cities. This chapter is presenting the impact of adapting the state-of-art in energy efficiency optimization on the GHG emissions reduction. The chapter starts with intra-process integration and clean development mechanism application in refinery Hydrocracking unit (HCU), followed by a method and case study for inter-processes integration in oil refining and then is closed with brief industrial utility system retrofit case study in an oil plant using combined heat and power concept.

2. Intra-process integration and clean development mechanism (CDM)

Oil refineries market is currently undergoing a significant reorientation, with demand moving away from the traditional strongholds of Europe and North America to other regions of the world. This transformation, which began before the recent economic recession, but was accelerated by its effects, both creates a number of opportunities and poses many number of threats to companies involved in the industry and to the environment. Refining operations are a vital aspect of any modern, industrialized economy, and hence much is being invested in trying to produce products that do not rely on refined fuels, we are a little away from a point at which these developments will significantly reduce the market for refined products. Refineries are as usual going to be influenced by environmental regulations, technological innovations, and other important factors and trends which are changing the dynamics of the industry. Oil refining business is likely to see significant investment over the next ten years, where growth will be unevenly spread

throughout the world and consequently generating GHG. The impact of oil refining industry on the environment is becoming more and more apparent nowadays. Industrial emissions contribute to the climate change by emitting green house gases (GHG) into atmosphere. Pollution prevention measures must take place in industrial sector to lower emissions especially in oil refineries which consume huge energy derived from fossil fuels. Pollution prevention is an adequate method for managing the environmental impact associated with industrial facilities. The right pollution prevention strategy aims to eliminate potential pollution from the process at the source before it is being emitted into the environment. Pollution prevention can be in form of energy demand reduction inside process plants. The reduction in energy demand will eventually lead to lower fuel consumption that will result in lower GHG emissions. Such reduction in energy-based GHG emissions will ultimately reduce the environmental impact of industrial facilities. The application of clean development mechanism (CDM) to an oil refinery presented here is confined to only one major unit in the oil refineries called Hydrocracking unit (HCU). The aim is to reduce energy generation-based CO₂ emissions at the source via reducing the energy consumption of the HCU. The reduction in fuel usage can be achieved by better integration of the heat exchanger network of the unit to reduce fuel demand in the process by increasing the process-to-process heat exchange duties. Pinch technology is used in this context due to its applicability and practicality to process plants energy reduction. The reduction in energy demand, of a major oil refinery unit presented in this chapter, is an application that has potential implementation as a small scale CDM project. The CDM application/project introduced quantifies the potential CO₂ emissions reduction resulted from energy consumption reduction in the HCU.

The oil refinery used in this study is a medium size one, processes 120 000 bbl/d of crude oil. As usual the feed to the refinery is first stabilized by stripping off acid gases and other volatile compounds and then introduced to the atmospheric distillation column followed by vacuum distillation column. The distilled products are then introduced to different process units to produce a variety of petroleum products. The refinery is divided into several process areas. Those process areas are the stabilizer, the atmospheric crude distillation Unit, the vacuum distillation unit, the asphalt recovery, the amine gas treating, the gas concentration unit, the naphtha and kerosene Hydrotreating, demex, Platformer, hydrogen plant, hydrocracker and finally the utilities. The HCU is a major process unit in any refinery. It receives heavy oils and produces more valuable products such as diesel and fuel oil. The purpose of the HCU, presented in this chapter, is to process vacuum gas oil (VGO) from the Vacuum distillation unit (VDU) and De-metalized oil (DMO) from the asphalt oxidization unit. These two low value feed streams are converted into useful products such as liquefied petroleum gas (LPG), light naphtha, heavy naphtha, kerosene, light diesel oil (LDO), and heavy diesel oil (HDO) products. The HCU is divided into two main sections; the first section is the reaction section and the second is the fractionation section.

HCU consists of several process streams and not all of them are used in our case study calculation using pinch technology. The problem's streams data included in our study have, the stream supply temperature (T_s), target temperature (T_t), the heat transfer in term of thermal kW gained or released by the stream, and the heat transfer coefficient (HTC) for the heat transfer equipment. The process streams have been segregated into hot streams (any process stream that needs to be cooled) and cold streams (any process stream that need to be heated). Each stream has been assigned a name based on the content and direction into the

process. Streams are identified based on their composition, if the stream passes through another heat transfer equipment and changes in temperature, then it will be another segment of the same stream; however, if the stream changes in composition in the case of new production from the separation column it becomes different stream.

No	Stream	Name	Ts, C	Tt, C	DH kW	CP kW/C	HTC kW/m^2.C
1	COLD	VGO/DMO Feed	105.00	393.30	20196	70.05	3.41
1	COLD		393.33	437.78	14200	319.49	56.76
2	COLD	De-C4 col feed	56.67	170.56	18197	159.78	2.27
3	COLD	De-4 Reb Duty	226.11	281.11	17589	319.81	56.76
4	COLD	Frac Feed	266.11	377.22	27644	248.80	56.76
5	COLD	HN Strip reb duty	160.00	171.11	1804	162.35	5.68
6	COLD	Kero Strip Reb duty	226.67	235.00	732	87.85	5.68
7	COLD	LN feed to Frac	60.00	109.44	1092	22.09	3.41
7	COLD		109.44	265.56	929	5.95	0.57
8	HOT	DHC rxn outlet from V-1/2	468.33	385.00	16710	200.52	0.45
9	HOT	HC rxn outlet from V-3/4	426.67	180.00	20196	81.87	1.70
10	HOT	V6 overhead vapor (to V8)	165.00	60.00	37727	359.31	0.40
10	HOT		60.00	43.33	2115	126.88	1.70
11	HOT	V-14 oh vapor	71.11	48.89	1172	52.74	4.55
12	HOT	Fract OH Vapor	81.11	60.00	16353	774.62	5.68
13	HOT	De-4 OH vapor	83.89	57.22	8246	309.22	5.68
14	HOT	LiN product draw	60.00	37.78	375	16.87	2.84
15	HOT	HN product draw	160.00	60.00	3262	32.62	2.27
15	HOT		60.00	37.78	719	32.35	1.70
16	HOT	HN p/a loop	137.78	77.22	7918	130.76	1.70
17	HOT	Kero Product to Storage	227.22	60.00	2580	15.43	2.27
17	HOT		60.00	48.89	129	11.60	1.70
18	HOT	Kero p/a loop	210.00	77.22	5915	44.55	2.27
19	HOT	LDO draw	298.89	252.22	929	19.90	2.27
19	HOT		252.22	196.11	1092	19.47	2.27
19	HOT		196.11	60.00	4310	31.67	2.27
20	HOT	HDO p/a (combined)	321.11	170.56	4100	27.23	2.27
21	HOT	HDO product draw	321.11	60.00	10442	39.99	2.27
22	HOT	Frac btms recycle	362.78	121.11	18197	75.30	2.56
23	HOT	Frac btms FO draw	362.78	79.44	3951	13.95	2.56

Table 1. Problem Data for Hydrocracking Plant

The optimum ΔT_{min} for HCU is calculated to estimate the minimum temperature difference in the heat exchanger network that will lead to the lowest possible utility demand in the process. The total annualized capital and energy cost is plotted vs. several, ΔT_{min} values to estimate such optimum at the minimum annualized cost.

The optimum ΔT_{min} for HCU was calculated to be 13 °C where the total annualized cost reaches the minimum. The total annualized cost consists of the annual energy cost and the annual heat exchanger capital cost. The annual energy cost is obtained simply by multiplying the utility cost by the expected operating hours in the year which is assumed to be 8,400 hours per year to incorporate maintenance and plant shut down. The annualized capital cost incorporates the capital cost multiplied by the money borrowing annualized factor.

The energy reduction as a result of applying the minimum ΔT in the HCU can be compared to the current HCU process energy demand and current GHG emissions. The potential savings in both energy consumption and CO2 emission are then identified. Using pinch techniques, the potential reduction in energy is about 20.1 MWh annually which is equivalent to fuel gas consumption of 631 000 GJ. The potential emission reduction in the

HCU is estimated to be 38 kt of CO₂ annually. The potential reduction of the other utilities demand such as cooling water and air cooling utilities is not identified here due to its low value. This potential reduction in CO₂ emission as a result of the fuel gas reduction in the HCU due to energy efficiency enhancement can be adopted as a clean development mechanism (CDM) project.

The HCU emission reduction potential can be adopted as a small-scale CDM project. Adopting the small-scale CDM project framework has several advantages such as; ability to combine identical project as one group of project; the project design document and methodologies are simplified for a small scale project and the baseline and monitoring procedures are reduced.

The establishment of the baseline emission is an important step in any CDM project evaluation. Therefore, we need to estimate the as is CO₂ emissions without implementing the project. Fortunately, a real parameter data of fuel gas flow can be obtained because it is measured and the emission quantity is related to the fuel consumption. The fuel consumption rate can be measured for the past three years to evaluate the baseline emission situation. The current energy consumed by the HCU process heaters is 71 MWh which is equivalent to 256 GJ of fuel gas. As per given or sampled fuel composition, the CO₂ emission factor in the fuel gas is calculated to be 0.217 kg CO₂ per kWh.

The current baseline emission can be simply identified as follows:

$$PEFC_{j,y} = \sum_i F_{Ci,j,y} \times COEF_{i,y}$$

Where:

$PEFC_{j,y}$ = CO₂ emission from fossil fuel combustion in process j during the year y (tCO₂/yr)

$F_{Ci,j,y}$ = Quantity of fuel type I combusted in process j during the year y (mass or volume unit / year)

$COEF_{i,y}$ = CO₂ emission coefficient of fuel type I in year y (t CO₂ /mass or volume unit)

i = fuel types combusted in process j during year y.

For our HCU fuel gas reduction project, the above formula is used to calculate the baseline emission value.

$$PEFC_{j,y} = 71.1 \text{ MW} \times 0.217 \text{ kg CO}_2 / \text{kWh} \times 8400 \text{ h} = 12967 \text{ t CO}_2 / \text{y}$$

The i value is assumed to be 1 because there is one fuel type (fuel gas) and the CO₂ content per energy unit has been used instead of CO₂ content per mass unit.

HCU exhibits, using pinch technology, an energy efficiency enhancement potential of 21 MWh in fuel. Such reduction in energy consumption can reduce GHG emissions in the HCU to 91,635 t CO₂/y from the baseline calculated above if the project is implemented. Using the emission baseline figure, the potential reduction in GHG emissions after implementing the CDM project is estimated to be 38 035 t CO₂/y.

It is important to note here that beside the benefit obtained from \$ energy saving another \$ benefit can be attained due to carbon credit concept. The price of CO₂ emission trading

nowadays can play role in determining the feasibility of HCU energy efficiency/emission reduction project. For instance, the annual potential revenue of the CDM project can be estimated to be \$ 950,000 per year using an average price of \$25 carbon credit per ton [1:3].

3. Inter-processes integration for enhanced energy efficiency and energy-based GHG emissions reduction

Pinch analysis is the technology that provides a systematic methodology for energy saving in processes and total sites. The methodology is based upon thermodynamic principles. Pinch Analysis/technology was first developed in the late 1970s as a technique for optimization of thermal heat recovery, and rapidly gained wide acceptance as a practical approach to the design of Heat Exchanger Networks (HENs). Since then, it has evolved into a general methodology for optimization, based on the principles of process integration.

The technique calculates thermodynamically attainable energy targets for a given process and identifies how to achieve them. A key insight is the pinch temperature, which is the most constrained point in the process. The most detailed explanation of the techniques is by Linnhoff et al. Other pinch analyses were developed for several applications such as mass-exchange networks (El-Halwagi and Manousiouthakis, 1989), water minimization (Wang and Smith, 1994), and material recycle (El-Halwagi et al., 2003).

Pinch analysis has been applied successfully not only to energy systems (heat recovery, pressure drop recovery, power generation), but also to fresh water conservation, wastewater minimization, production capacity de-bottlenecking, and management of chemical species in complex processes.

Applying Pinch technology in heat exchangers networks (HEN) synthesis and retrofit, enable the engineer to calculate the energy requirement for any process, and produce thermally efficient and practical designs. Energy savings are significant compared to previous best designs. Pinch technology is also applied to the optimization/integration of the supply-side, consisting of on-site utilities, such as boilers, furnaces, steam and gas turbines, cogeneration, heat pumps, and refrigeration systems [4:6].

Generally speaking, the objective of the heat exchangers network synthesis for waste heat recovery problem is to design a network that meets an economic criterion such as minimum total annualized cost. Sometimes minimum number of units and minimum energy consumption and GHG emissions in special applications become very legitimate objectives too.

The heat exchangers network synthesis is a multi-variable multi-dimensional optimization problem in which the total network driving distribution depends on each stream conditions and each hot stream minimum approach temperature for heat recovery. Such variables can contribute to number of units, shells, and both the heating and cooling utilities requirements as well as its mix. In pinch technology this multi-variable optimization problem has been reduced to a single variable optimization problem which is the global ΔT_{\min} of the problem that in pinch technology needs to be optimized.

Recent advances in the field of energy efficiency optimization advocate the need to conduct the waste heat recovery targeting phase using several ΔT_{\min} (minimum temperature approach between hot and cold composite curves) and/or using problem process conditions

soft constraints in a systematic way to find better energy targets. New method uses for each hot stream specific ΔT_{\min} and allows minor possible combinations of process conditions to be modified (e.g. $5\text{ F} \pm$ in the supply and target temperatures) to customizing the waste heat recovery problem in a way that renders better reductions in energy consumption cost (energy quantity and/or quality/work optimization). The waste energy recovery problem using such new targeting method can now has several degrees of freedom for the waste energy recovery problem optimization, instead of the one parameter problem optimization currently used [7:9].

The above mentioned energy integration targeting methods while can be used at any scale is nowadays focused only on industrial facility via direct integration between the hot and cold streams of its process units. It is usually applied at the process level; and known as intra-process integration. It has proved to be very successful to reducing both energy consumption and energy-based GHG emissions. Integration among many processes, in adjacent geographical locations, can bring in more degrees of freedom to optimize the waste energy recovery problem and consequently presents new horizon to the energy-based GHG emissions reduction to levels never thought of before. For many reasons, direct inter-processes integration is not widely practiced in industry. Many of the reasons hindering the application of inter-process integration among several processes for better energy consumption cost reduction and less energy-based GHG emissions are very valid and need to be addressed in a novel way to enable wider adaptation of direct inter-process integration in existing industrial facilities and naturally for mega facilities, zones and even cities in the future plants.

Since the emanation of the pinch technology and its evolution to pinch analysis technique for process synthesis, the direct inter-processes integration has been considered impractical. Many arguments, such as the processes are normally have different start up and shut down times; the processes can work at partial loads; the processes can have seasonal changes in its conditions; utility systems, heaters and HEN capital will not be reduced due to changes in processes schedule and operation philosophy; the disturbance in one process can propagate to another one if they are integrated; the distance-time/velocity lags affect the controllability of processes; the geographical distances among processes will cost us energy in pumping or compression and capital in piping, pumping and compression; safety might be impacted due to the travel of a fluid from one hazardous area to another; the fear of leakage and so on, are certainly valid. Therefore, direct inter-processes integration while is beneficial to energy conservation and the GHG emissions reduction, is still to date almost ignored in industrial community.

Due to those concerns most of the current methods for inter-process integration are indirect and conducted using buffer systems. Buffer systems are either steam system or hot oil system or sometimes both. However, the industrial community does agree that, direct integration approach in inter-process integration (between several plants) is more efficient and can render more saving in energy consumption and energy-based greenhouse gas emissions [10:16]. In this chapter we demonstrate, that huge potential for energy consumption and GHG emissions reduction in oil refining (more than 5 % in-house) can be attained through smart integration among processes.

It is instructive to note here that, while we agree with the validity of those arguments we believe that we can still find a room for improvement in energy efficiency enhancement and

energy-based GHG emissions reduction via identifying at the energy integration targeting phase best possible scenarios for inter-processes integration and then trying to find cost effective solutions to the above mentioned concerns via smart plants “matching”.

The general intuition regarding the integration among several processes that assumes, the more you integrate among the processes, the better you save in energy consumption and consequently in the energy-based GHG emissions sometimes are not always fully true.

3.1 Direct inter-processes integration case study data

For N plants, there will be a cretin number of possible inter-process integration combinations. Starting from 1 for a single plant, 2 combinations for two plants, 5 combinations for three plants, 15 combinations for four plants (our example) up to 4.6386x10^18 possible combinations for 25 plants only. These possible combinations are identified through Bell’s numbers. The Bell numbers (1, 1, 2, 5, 15, 52, 203, 877, 4140, 21147, 115975, 678570, 4213597, ...) describe the number of ways a set with n elements can be partitioned into disjoint, non-empty subsets [17].

For example, the set {1, 2, 3} can be partitioned in the following ways:

- {{1}, {2}, {3}}
- {{1, 2}, {3}}
- {{1, 3}, {2}}
- {{1}, {2, 3}}
- {{1, 2, 3}}.

In this chapter, the data used for the demonstration of the possible energy consumption and GHG emissions reduction due to inter-processes integration method is a four existing plants in a typical oil refinery. It is used to illustrate the useful impact of inter- process integration between different plants on both energy consumption and energy-based GHG emissions reduction. These data extracted from literature are presented below. We selected the heat recovery approach temperature for the whole problem to be 15 C [18]. Our intention for such selection is to use reasonable value for our method testing and not to compare with results of other methods. For the purpose of exhibiting the method of selecting which units to integrate inside a whole facility and the potential impact of the optimal selection on both energy consumption and GHG emissions reduction we considered from the whole refinery, the big energy consumers (the elephants in energy consumption) such as Fluid Catalytic Cracking Unit (FCCU), Crude/Vacuum Distillation Unit (CDU/VDU), Visbreaker/thermal cracking Unit (VBU) and Platformer/reformer Unit (PLAT). The four plants selected for the inter-processes direct integration targeting study presented in this chapter are numbered as per the table below.

Plant	FCCU	CDU/VDU	VBU	PLAT
Reference Number	1	2	3	4

Table 2. The four plants and their referenced numbers

The details of each stream data as presented by Fraser and Gillespie [18], are shown in tables 3, 4, 5 & 6.below.

1- FCCU				
Type	No	Ts (°C)	Tt (°C)	Heat Capacity (KW/°C)
H	1	165.5	90.0	22.616
H	2	282.0	796.5	54.389
H	3	274.0	37.5	9.163
H	4	164.0	27.0	36.141
H	5	327.0	261.0	44.321
H	6	363.0	246.0	26.76
H	7	327.0	165.0	16.772
H	8	201.0	104.0	5.405
H	9	140.9	38.0	162.055
H	10	144.5	51.0	15.252
C	11	74.0	295.0	62.462
C	12	143.0	164.0	129.383
C	13	94.0	125.0	126.44

Table 3. Stream data for the FCCU

2- CDU/VDU				
Type	No	Ts (°C)	Tt (°C)	Heat Capacity (KW/°C)
H	1	172.5	67.6	116.951
H	2	260.0	189.8	75.104
H	3	309.0	269.5	95.138
H	4	333.4	189.4	14.91
H	5	116.8	49.7	72.242
H	6	272.0	210.0	303.711
H	7	210.0	79.8	58.8
H	8	146.0	18.2	144.92
H	9	50.5	18.2	152.687
H	10	189.0	26.1	69.661
H	11	198.9	171.1	13.477
C	12	26.0	261.7	221.887
C	13	261.7	356.5	430.191
C	14	338.2	409.8	257.147
C	15	26.7	96.1	136.283

Table 4. Stream data for the CDU/VDU

3- VBU				
Type	No	Ts (°C)	Tt (°C)	Heat Capacity (KW/°C)
H	1	135.6	30.0	19.506
H	2	255.0	176.1	9.887
H	3	353.3	198.9	43.165
H	4	198.9	171.1	14.477
H	5	171.1	75.0	19.279
C	6	327.8	457.8	54.685
C	7	158.3	160.0	221.49
C	8	126.7	176.7	15.599
C	9	126.7	176.7	133.329
C	10	126.7	146.7	21.364

Table 5. Stream data for the VBU

4- PLAT				
Type	No	Ts (°C)	Tt (°C)	Heat Capacity (KW/°C)
H	1	503.9	366.1	67.382
H	2	366.1	178.9	3.807
H	3	366.1	253.9	26.094
H	4	303.3	36.7	63.175
H	5	76.7	26.7	24.568
H	6	232.2	112.2	15.107
H	7	79.4	32.2	39.78
H	8	112.0	23.9	0.738
H	9	67.2	27.2	75.556
H	10	157.2	32.2	7.905
H	11	43.3	26.3	4.773
H	12	92.0	65.0	1.773
H	13	107.0	32.2	7.671
C	14	66.1	370.6	76.121
C	15	232.2	247.2	195.269
C	16	36.7	125.6	20.378
C	17	112.0	112.8	2506.929
C	18	157.2	163.9	106.929
C	19	92.0	97.2	38.98
C	20	370.6	495.6	94.091
C	21	452.8	497.2	106.519
C	22	480.6	496.1	114.065

Table 6. Stream data for the PLAT

3.2 Direct inter-processes integration case study results and discussion

As mentioned earlier, the four plants that were considered are FCCU (1), CDU/VDU (2), VBU (3) & PLAT(4). The 15 possible combinations which include 14 possible inter-process integration schemes (A to N) are listed in table 7 below. Combination labeled O is the no inter-process integration case where each plant is in a standalone intra-process integration status.

Sets	Combination Name
{1,2,3,4}	A
{1,2,3}{4}	B
{1,2,4}{3}	C
{1,2}{3,4}	D
{1,2}{3}{4}	E
{1,3,4}{2}	F
{1,3}{2,4}	G
{1,3}{2}{4}	H
{1,4}{2,3}	I
{1}{2,3,4}	J
{1}{2,3}{4}	K
{1,4}{2}{3}	L
{1}{2,4}{3}	M
{1}{2}{3,4}	N
{1}{2}{3}{4}	O

Table 7. The 15 possible combinations for 4 plants

Before we calculate the energy targets for each combination above using pinch technology/process integration technique presented earlier in this chapter, let us try to test our intuition regarding the expected output regarding the combination that render best energy consumptions and the rank of each combination.

Our first hypothesis/intuition is that, the energy consumption values due to inter-process integration among the four units, all as one unit, is going to be better than the intra-process integration/ standalone unit integration. If there is no benefit from inter-process integration, than standalone intra-process integration. Then, there is no point to spend capital for integration among processes; complicating the plant start-up and its abnormal situations management without saving in energy consumption and reduction in GHG emissions. This correct hypothesis means that set A in the table above, where all four units are treated as one unit is going to be the best set and set O in the same table above, where each unit is handled independently, is going to be the worst set from energy consumption point of view and naturally from energy-based GHG emissions too. In other words from energy consumption and energy-based GHG emissions, combination A is the upper limit of possible energy saving and GHG emissions reduction. The same logic that advocate the integration of all units to get best energy consumption saving, will lead us to a general crude intuition thinking that always, the more we integrate plants; the better reduction in both energy requirements and Greenhouse Gases emissions as well we get. This untested second

hypothesis, is deciding the next best combination after the A combination (in which the four plants/units were all together integrated from energy consumption point of view). This hypothesis says, if you cannot integrate the four plants, rendering best energy saving, all together at least try to integrate three of them, and if you cannot integrate the three plants all together try to integrate two of them in pairs to get the best possible energy saving and energy-based GHG emissions reduction. That is the intuition obtained from combination A that shown the superiority of inter-processes integration on the standalone intra-process integration and can lead us to false conclusion, if we do not test this hypothesis.

To test this hypothesis we suggest two possible schemes. Our hypothesis is that, the next best integration among the processes may be either the one that has the highest number of integrated processes in a set or the one that has the highest number of integrations/pairings in the set. For example we need to test and find an answer to the following questions: Which combination is better, is it the B combination? where we have three units integrated together and one unit is in standalone intra-process integration status (i.e. one integration in the set) or is it the G combination? Where in this combination we have two integrations in the set (where unit 1 and unit 3 are integrated and unit 2 and unit 4 are integrated). The test procedure to the above second hypothesis will lead us to either one of the two schemes A and B shown in the table 8 below.

Scheme A			Scheme B		
#	Combinations	Mix	#	Combinations	Mix
1	{1,2,3,4}	All	1	{1,2,3,4}	All
2	{1}{2,3,4}	1-3 or 3-1	2	{1,2}{3,4}	2-2 only
3	{1,3,4}{2}		3	{1,3}{2,4}	
4	{1,2,4}{3}		4	{1,4}{2,3}	
5	{1,2,3}{4}		5	{1}{2,3,4}	1-3 or 3-1
6	{1,2}{3,4}	2-2 only	6	{1,3,4}{2}	
7	{1,3}{2,4}		7	{1,2,4}{3}	
8	{1,4}{2,3}		8	{1,2,3}{4}	2-1-1 only
9	{1,2}{3}{4}	2-1-1 only	9	{1,2}{3}{4}	
10	{1,3}{2}{4}		10	{1,3}{2}{4}	
11	{1,4}{2}{3}		11	{1,4}{2}{3}	
12	{1}{2,3}{4}		12	{1}{2,3}{4}	
13	{1}{2,4}{3}		13	{1}{2,4}{3}	
14	{1}{2}{3,4}		14	{1}{2}{3,4}	
15	{1}{2}{3}{4}	1-1-1-1	15	{1}{2}{3}{4}	1-1-1-1

Table 8. The 15 possible combinations for 4 plants

The above two schemes says that the best combinations for the inter-processes integration is naturally the 4 plants all together. The next best (2, 3, 4, 5) are either the integration of three plants all together and the fourth is a standalone one as per scheme A or the two plants integrations in pairs as per scheme B, where for instance process plant/unit 1 and process plant/unit 2 are integrated together and process plant/unit 3 and process plant/unit 4 are

also integrated together. The following next best scenarios (6, 7, 8) are the reverse of this assumption. It is important to note here that the testing of the above hypothesis based upon the two suggested schemes A and B is going to be proved unsatisfactory even though the hypothesis looks logical and we cannot use this hypothesis as a rule for inter-process integration scenario selection. We will shortly see such conclusion after calculating the energy targets for each case, in the suggested schemes A and B, and discussing the findings from these calculations. As shown in table 9, the heating (Qh) and cooling (Qc) utilities targets, (at $\Delta T_{min}=15$ C) were calculated for each set of the 15 possible combinations identified for the four plants. Then, the minimum heating and cooling requirements for each set are calculated followed by the ranking of each set based on the total minimum energy requirements. The table below shows in the first column the sets list of all possible plants integration combinations, the second column is the combination label, the third column and the fourth column are the minimum heating and minimum cooling utilities requirement Qh1 & Qc1 respectively of the whole 4 plants together. It is useful to note that, the Qh1 & Qc1, Qh2 & Qc2, Qh3 & Qc3, and Qh4 & Qc4 are the minimum heating and minimum cooling requirements for the plants between brackets {}. For instance, in combination G, the Qh1 & Qc1 are the minimum heating and minimum cooling utilities requirements of plants {1,3} and the Qh2 & Qc2 are the minimum heating and minimum cooling utilities requirements of plants {2,4}. Qh total and Qc total required in G combination are the summation of Qh1 & Qh2 and Qc1& Qc2, respectively.

Sets	Combination Name	Qh1	Qc1	Qh2	Qc2	Qh3	Qc3	Qh4	Qc4	Qh Total required	Qc Total required	Rank
{1,2,3,4}	A	99,760	43,318							99,760	43,318	1
{1,2,3}{4}	B	83,945	37,143	18,885	9,245					102,830	46,388	4
{1,2,4}{3}	C	93,993	41,151	6,944	3,344					100,937	44,495	2
{1,2}{3,4}	D	80,345	37,143	24,474	11,234					104,819	48,377	5
{1,2}{3}{4}	E	80,345	37,143	6,944	3,344	18,885	9,245			106,175	49,733	9
{1,3,4}{2}	F	53,008	27,567	55,801	24,800					108,809	52,367	11
{1,3}{2,4}	G	36,473	20,672	68,631	27,990					105,104	48,662	6
{1,3}{2}{4}	H	36,473	20,672	55,801	24,800	18,885	9,245			111,160	54,718	14
{1,4}{2,3}	I	46,514	24,673	59,401	24,800					105,916	49,474	8
{1}{2,3,4}	J	29,751	17,550	72,231	27,990					101,982	45,540	3
{1}{2,3}{4}	K	29,751	17,550	59,401	24,800	18,885	9,245			108,037	51,595	10
{1,4}{2}{3}	L	46,514	24,673	55,801	24,800	6,944	3,344			109,260	52,818	12
{1}{2,4}{3}	M	29,751	17,550	68,631	27,990	6,944	3,344			105,326	48,884	7
{1}{2}{3,4}	N	29,751	17,550	55,801	24,800	24,474	11,234			110,026	53,584	13
{1}{2}{3}{4}	O	29,751	17,550	55,801	24,800	6,944	3,344	18,885	9,245	111,382	54,940	15

Table 9. The 15 possible combinations for 4 plants

Let us now have a deep look to table 9, “Rank” column. The table gives us the answer to our hypothesis test/question regarding what is the second best inter-process integration after the all together four plant inter-processes integration?. This question is important to us since full integration among all plants might be costly and impractical. Our hypothesis suggested adapting either one of two schemes (scheme A or scheme B) depicted in table 8. It is clear now that table 9 gives us a negative answer to such hypothesis.

Based on the calculations and numbers in the rank column in table 9, we generated table 10, to definitely answer the question of, What is the next best inter-process integration scenario? that comes after the four plants all-together inter-process integration. Table 10 shows few ranks different than our expectation. It is a fact that the optimum solution (ranked 1) happens when there is a full integration between all the four plants and the worst from energy saving point of view (rank 15) occurs when there is no integration between any of the four plants. In between these two scenarios, the sequence continues with the logic that says that better solutions are reached with the scenario that has higher number of integrated plants combinations (the ones that has three plants all together and one standalone plant) such as ({1,2,4} rank 2, {2,3,4} rank 3, and finally {1,2,3}) rank 4. However, this is not always true since rank 11 ({1, 3, 4}, {2}) broke the expected priority/sequence and half of the six 2-1-1 mix (ranks 7, 9 and 10) which contain one combination only(least possible inter-process integration), provides better energy consumption and less energy-based GHG emissions solution than it. These better combinations are as follows respectively: ({1}, {2, 4}, {3}) and ({1, 2}, {3}, {4}) and ({1}, {2, 3}, {4}). It says that for the specific refinery application data used in this chapter and the $\Delta T_{\min}=15$ C used if you only integrate the CDU/VDU with the reformer/PLAT or the FCCU or the VBU you will have less process design complication and better energy consumption saving than integrating all the plants together without the ADU/VDU, left as a standalone. Another finding from table 10 calculations ranking is that, the 2-2 inter-processes integration scenarios in which every two plants are integrated together most of the 2-2 scenarios, two out of three possible combinations, are better than the 2-1-1 scenarios of integration (six possible combinations in which only two plants are integrated and the rest are standalone plants). This one combination which is not following the hypothesis now is the 2-2 mix (rank 8) that contains the combination ({1, 4} {2, 3}). Rank 7 combination which is only one process-to process matching is better not much but it is less complication in the process design and better energy consumption saving and consequently better reduction in energy-based GHG emissions. It means that complexity in process design is not always mandatory to save energy. In our refining application here the above finding tell us that integrating the ADU/VDU with PLAT is the best scenario (when we are only allowed one process to process integration to do). integration/matching ADU/VDU with the “wrong process” such as VBU can bring in negative impact. In summary, it is clear that all 3-1 mix sets are better than all the 2-1-1 mix sets and all the 2-2 mix sets except one 3-1 mix set (rank 11) where it has higher energy requirements than three 2-1-1 mix sets (rank 7, 9 and 10) and all 2-2 mix sets (rank 5, 6 and 8). The second best sets are all the 2-2 mix sets but the rank 8 set.

In order to evaluate the concept of inter-processes integration on the energy-based GHG emissions, we calculated the energy consumption of the standalone plants at different ΔT_{\min} and listed the results in tables 11, 12 and 13 as shown below. The minimum heating and cooling requirements are shown for each plant as a standalone assuming perfect intra-process integration and with no inter-process integration between plants at several minimum approach temperatures (ΔT_{\min}) using $\Delta T_{\min}=15, 5$ and 1 C respectively. It is well known to the experienced in the field of energy efficiency optimization that when the ΔT_{\min} is reduced both the minimum heating and minimum cooling utilities requirement are reduced and the energy-based GHG emissions will be decreasing as well. It is also accepted to the experienced in the field that the heat exchangers network capital cost that achieves such saving in energy consumption, most of the time, will be increasing. For the sake of simplicity in calculating the GHG emissions reduction associated with energy saving, we are using for the energy-based

GHG emissions calculation the relationship suggested by Smith [5]. For each MW of heat saved in a furnace using fuel gas and has about 90 % firing efficiency, the fuel gas saved is going to reduce the amount of CO2 emissions from that furnace by 300 kg. We are also ignoring the GHG emissions saving due to the reduction in plant cooling utility.

Ranking of Best Scenarios		
Rank	Mix	Combinations
1	All	{1,2,3,4}
2	1-3 or 3-1	{1,2,4}{3}
3	1-3 or 3-1	{1}{2,3,4}
4	1-3 or 3-1	{1,2,3}{4}
5	2-2 only	{1,2}{3,4}
6	2-2 only	{1,3}{2,4}
7	2-1-1 only	{1}{2,4}{3}
8	2-2 only	{1,4}{2,3}
9	2-1-1 only	{1,2}{3}{4}
10	2-1-1 only	{1}{2,3}{4}
11	1-3 or 3-1	{1,3,4}{2}
12	2-1-1 only	{1,4}{2}{3}
13	2-1-1 only	{1}{2}{3,4}
14	2-1-1 only	{1,3}{2}{4}
15	1-1-1-1	{1}{2}{3}{4}

Table 10. The proposed best scenario for the 4 plants problem inter-process integration

	1	2	3	4	$\Delta T_{min}=15\text{ C}$	
	FCCU	CDU/VDU	VBU	PLAT		
Qh (KW)	29,751	55,801	6,944	18,885	Qh total=	111,382
Qc (KW)	17,550	24,800	3,344	9,245	Qc total=	54,940
Pinch Temp.	158	272	141.7	81.1		

Table 11. Minimum Heating/Cooling requirements at $\Delta T_{min}=15\text{ C}$

	1	2	3	4	$\Delta T_{min}=5\text{ C}$	
	FCCU	CDU/VDU	VBU	PLAT		
Qh (KW)	29,016	52,832	6,676	17,946	Qh total=	106,470
Qc (KW)	16,815	21,831	3,076	8,306	Qc total=	50,028
Pinch Temp.	148	266.7	131.7	79.4		

Table 12. Minimum Heating/Cooling requirements at $\Delta T_{min}= 5\text{ C}$

	1	2	3	4	$\Delta T_{min}=1\text{ C}$ (impossible)	
	FCCU	CDU/VDU	VBU	PLAT		
Qh (KW)	28,715	51,557	6,521	17,560	Qh total=	104,353
Qc (KW)	16,514	20,556	2,921	7,920	Qc total=	47,911
Pinch Temp.	144	262.7	137.7	79.4		

Table 13. Minimum Heating/Cooling requirements at $\Delta T_{min}=1\text{ C}$ (impossible)

Comparing the total heating, cooling requirements and consequently the associate energy-based GHG emissions is our next task. First we will do the comparison for the standalone intra- process integration at descending ΔT_{min} to target for best GHG emission attainable using intra-process integration. Then we will compare the best possible target with the one that can be attained using inter- processes integration at ΔT_{min} , equal to 15 C.

Using previously mentioned simple relationship between MW of heat saved and amount of CO2 reduction obtained, we can easily calculate the reduction in CO2 emissions from the refinery biggest energy consumers due to intra-process integration at descending ΔT_{min} to be 31202 tone CO2/year and 62196 tone CO2/year respectively. It is 3 to 6 % maximum. Practically we can reach the 3 % but to get better than that we need extremely expensive HEN and the 6 %, at ΔT_{min} equal to 1 C, is unattainable/impractical. To reach such 3% reduction in the GHG emissions using ΔT_{min} equal 5 C will also need costly HEN design too. The results of direct inter-processes integration at ΔT_{min} equal 15 C can render the same amount of GHG emission reduction of %3 and even better through 9 possible scenarios/combinations. Such combinations are listed and ranked from 1 to 9 in table 9. The unattainable 6 % reduction in the energy-based GHG emissions using intra-process integration can be reached and even a little better (up to 10 %) using direct inter-processes integration techniques. Four scenarios/combinations can exhibit such fact, taking the rank from 1 to 4 in table 9. These combinations are as follows: direct inter-process integration of ADU/VDU, FCCU, VBU and PLAT processes all together, FCCU, CDU/VDU and VBU together and PLAT as a standalone, FCCU, CDU/VDU and PLAT together and VBU as a standalone, CDU/VDU, VBU , and PLAT together and FCCU as standalone.

It can be noticed from this discussion that in order to attain more aggressive GHG emissions reduction targets using intra-process integration techniques, even if we tried to use ΔT_{min} equal to 1 C which is currently impractical using the available state-of-art heat exchanger technology, we have no way but to use inter-process integration. There are 4 sets/combinations in the inter-process integration application at reasonable ΔT_{min} equal to 15 C, which can defeat the minimum heating and cooling requirements and consequently the energy-based GHG emissions of the almost impossible ΔT_{min} equal to 1 C in the intra-process integration application. That means, for an oil refinery with excellent intra-process integration applications; to obtain in-house GHG emissions reduction target of 6 % or more, as per the case study presented in this chapter, we have to resort to inter-processes integration application. Nowadays, the industrial community perception is that the only way to do such inter-process integration is to make it indirectly via buffer system (steam or hot oil). Such approach is currently adapted in industry but it has its limitations. Such limitations combined with the need to push the envelope and reduce the refining business GHG emissions will lead towards using more of the direct inter-processes integration.

4. Combined heat and power plant (CHP) retrofit

One of the famous options in industrial facilities to cut energy consumption cost and reduce emissions is the adaptation of the cogeneration technology. Co-generation or "CHP" is simply known as the production of two forms of useful energy from the same fuel source. Cogeneration systems are used to produce electricity, and use the excess (waste) heat for process steam generation, hot water heating, space heating, and other thermal needs.

There are several types of co-generation plants. One is the steam turbine- based cogeneration plant consisting of a steam turbine with the usual controlled steam extraction(s) for process steam supply. The other type is a gas-turbine- based cogeneration plant consisting of one or more gas turbines exhausting products of combustion through one or more heat-recovery steam generators (HRSGs), which produce steam for the heat supply [19:21]. The thermodynamic efficiency of a cogeneration plant is simply, $(P + H)/Q_1$; where; P and H are the power and heat outputs of the cogeneration plant, respectively and Q_1 , is heat input .

The oil plant, presented here, is responsible for stabilizing and shipping crude oil and this normally needs large amount of energy mainly in form of steam and power. The plant receives crude oil from different wells and then separates the gas from the oil. The crude oil is stabilized, where light components are separated, and then pumped for shipment to users. The separated gas goes to natural gas liquid process (NGL) plants. Fuel is used by boilers and gas turbine generators. The steam generated from boilers goes to high pressure steam header at 625 psig. High pressure steam is used by back pressure steam turbines throughout the plant to drive oil shipper pumps. The steam coming out from the back pressure steam turbines is sent to the 60 psig header. The 60 psig steam is used to pre-heat the crude oil stream before entering crude stabilization column.

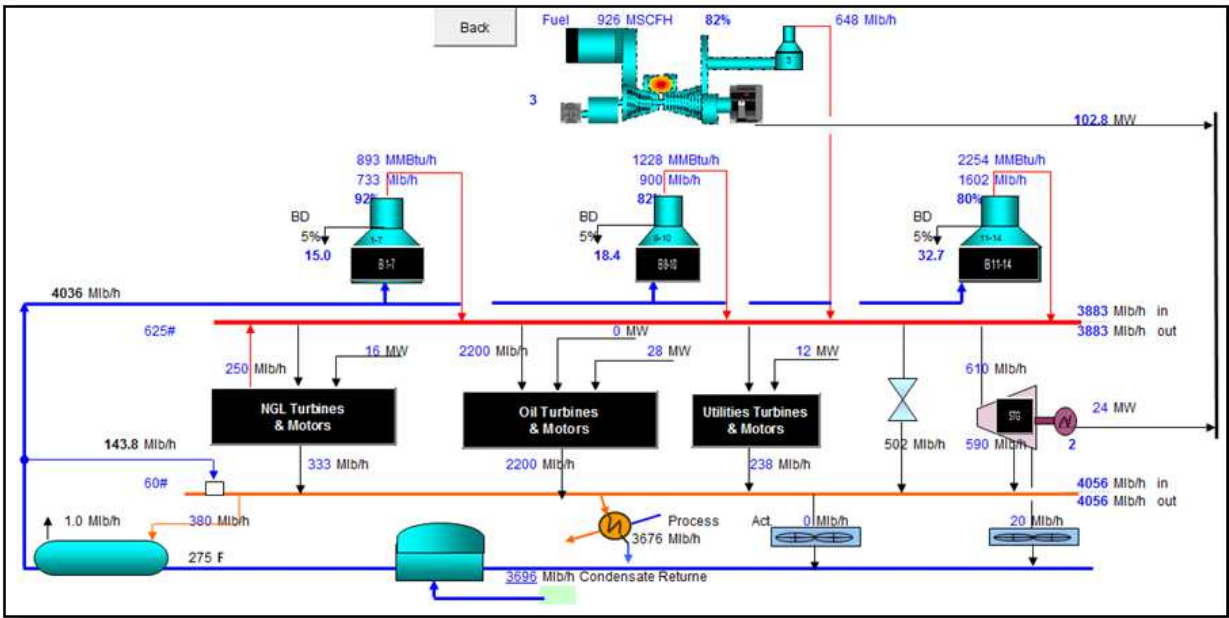


Fig. 1. Oil Stabilization Plant CHP Model

Fig.1 above gives an overview on the oil plants’ utilities model. The oil plant has 10 boilers with total steam production of 4.5 Million bounds per hour (Mlb/h). The maximum steam demand can be found in winter interval where the plant is in need of almost the full boilers capacity. Oil plant historical data shows that the maximum steam demand, at winter time, is equal to 4.4 Mlb/h, and the minimum steam demand, at summer, is equal to 3.2 Mlb/h. The oil plant has two simple cycle gas turbine generators, each capable of generating 40 MW at 38 C. The plant power demand varies between 75 MW in summer and 53 MW in winter and the average power consumption per year is about 60 MW. The oil plant is tied up to the nation-wide electricity grid. Usually the plant internal power generation units are reliable but that is made to avoid any failure that can result in any disruption to the oil plant production.

Retrofitting the existing two simple cycle gas turbines with two heat recovery steam generators (HRSGs) can result in less energy consumption and less GHG emission. The steam generated from the two HRSGs would be equivalent to a production of two old small boilers producing 340 Klb/h of steam. Thus, the fuel used in the two old boilers will be saved in addition to eliminating their emissions.

In order to calculate the fuel saving, it is necessary to have a relation between the fuel consumption and the steam generation of the two old boilers. Such relation can be developed from plant’s historical real time data via curve fitting techniques.

Boiler #	Fuel VS. Steam
B-1	Fuel (MSCFh) = 1.0917 * Stm (klb/h) + 6.4138
B-2	Fuel (MSCFh) = 1.3983 * Stm (klb/h) - 15.38

Table 14. Two small boilers fuel vs. steam equations

From plant’s historical data, the average steam produced from the two small boilers is 340 (thousand bounds per hour) Klb/h; i.e. each producing 170 klb/h.

Fuel savings (avoided) = Boilers Fuel consumption

$$\begin{aligned} &= (170 \times 1.0917 + 6.4138) + (170 \times 1.3983 - 15.38) \\ &= 414.3338 \text{ KSCF/h (thousand standard cubic feet per hour)} \end{aligned}$$

Energy saving (MMBtu/h) = Fuel Btu Content * Boilers fuel consumption

$$= 1.090 \text{ KBtu/SCF} \times 414.3338 \text{ KSCF/h} = 451.6 \text{ MMBtu/h}$$

Note: Assuming HHV of fuel is 1090 Btu/SCF

Now, let’s compare the efficiency of simple cycle with the expected co-generation efficiency, for simple cycle system:

$$\text{Simple cycle } (\mu) = \frac{Output}{Fuel} = \frac{Power}{Fuel}$$

Where,

Power = electrical power output in Btu/h

Fuel = Fuel energy input in Btu/h

Consider a power demand of 53 MW; the corresponding fuel input to simple cycle gas turbines is 532.86 KSCF/hr.

Power (MMBtu/hr) = 53,000 KW * 3412.14 Btu/KWh = 180.8 MMBtu/hr.

Fuel Input (MMBtu/hr) = 532,860 SCF/hr * 1090 Btu/SCF = 580.8 MMBtu/hr.

Simple cycle (μ) = 31.13 %.

For the case of cogeneration system:

$$\text{Co-generation cycle } (\mu) = \frac{\text{Output}}{\text{Fuel}} = \frac{\text{Power} + \text{Steam}}{\text{Fuel}}$$

At winter time the units have to operate at full load (40 MW each) and generate steam (340 Klb/h) of steam. The plant power need only 53 MW, so there will be an access power of 27 MW; let's assume that the excess power has no value. Calculating the efficiency:

Power (MMBtu/hr) = 53,000 KW * 3412.14 Btu/KWh = 180.8 MMBtu/hr.

For calculating the useful heat energy, assuming 100% utilization. The steam Internal energy (Enthalpy) for 625 psig, 380 F steam header is 1370 Btu/lb and BFW enthalpy is about 270 Btu/lb.

Steam heat energy = ΔH (Btu/lb) * Steam Flow (Lb/hr)

$$= (1370 - 270) * 340,000 = 374 \text{ MMBtu/hr}$$

Fuel Input (Btu/hr) = 773,075 SCF/hr * 1090 Btu/SCF = 842.6 MMBtu/hr.

Co-generation cycle (μ) = 66%

Having the two co-generation units installed, and the two old boilers demolished. Let's see the impact on the total emissions:

NOx & CO2 Emissions calculation:

$$\text{NOx (g/s)} = 0.32 * 0.126 * (\text{Fuel Gas Consumption}) \quad (1)$$

$$\text{SO2 (g/s)} = [0.126 * (16 * 32 * 2) / (0.7302 * 527) / 1000] * (\text{Fuel Gas Consumption}) \quad (2)$$

Knowing, the average availability of the two boilers per year and their consumption and using the above formulas (1) & (2) gives a reduction on total emissions of 1.25 metric ton per day. Other benefit appears when converting to co-generation cycle is that the heat going to the ambient will be significantly reduced from 1000 F to about 300 F.

In summary, the adaptation of co-generation technology in the oil plant exhibits economical and environmental benefits over the simple cycle power generation and stand alone steam boilers. Well designed and operated cogeneration plant will always improve energy efficiency for systems requiring steam and power in oil and gas facilities. The typical energy

efficiency of a co-generation system, normally between 70-90%, simply means significant reduction in CO₂, SO₂, NO_x emissions compared to other stand alone generation of power and heat in oil and gas industry.

5. Concluding remarks

GHG emission reduction can be addressed successfully using energy efficiency optimization techniques in design and operation of industrial facilities. Energy efficiency optimization in process plants, on the equipment level (compressors, boilers, furnaces and so on), sub-system level (combined heating and power CHP), complete process level (crude oil fluid catalytic cracking) and site-wide level (refinery and refinery-chemical integrated facility and even mega industrial complex) is a fast and cost effective way to reduce GHG emissions at the source.

While the industry's already adapted intra-process integration and indirect inter-processes integration bring value to the task of energy consumption and energy-based GHG emissions reduction, aggressive direct inter-processes integration can also be adapted on large scale in industrial community to boost the efforts for energy conservation and GHG emissions reduction. It can enable us stretch the envelope beyond GHG emissions targets and reach better ones in many industrial sites such as in-house oil refining GHG emissions reduction target.

It is instructive to mention that direct inter-process integration that can render us better results beyond the attainable from perfect intra process integration and indirect inter-processes integration do not necessarily have to be done using excessive connections among the plants to reach the desired targets for GHG emissions. From our industrial experience we can surly tell that in many cases two or three connections at most between plants are enough to reach reasonable level of the best desired energy consumption and GHG emissions reduction targets. The details of such finding will be presented in future work.

While we are addressing in this chapter the role of energy efficiency optimization in GHG emissions reduction, we also believe that increasing the use of renewable non-hydrocarbon based energy sources are very efficient way to tackle the GHG emissions problem even on the process plant level. Solar energy in industrial applications especially in remote areas for oil, water pumping and gas compression, and administration areas lighting and cooling can be a very viable. The utilization of solar power for water heating, steam generation and large scale air-conditioning, as solar cooling, is very valid greenhouse gas emissions reduction option. We believe that adapting both energy efficiency optimization and flexible customization of renewable as a clean source of energy at plant's level will be fast and cost-effective approach to attain desired GHG emissions reduction targets.

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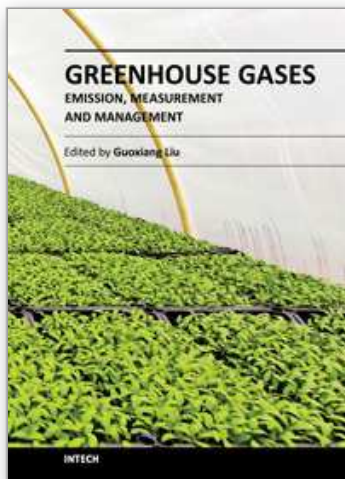
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Understanding greenhouse gas sources, emissions, measurements, and management is essential for capture, utilization, reduction, and storage of greenhouse gas, which plays a crucial role in issues such as global warming and climate change. Taking advantage of the authors' experience in greenhouse gases, this book discusses an overview of recently developed techniques, methods, and strategies: - A comprehensive source investigation of greenhouse gases that are emitted from hydrocarbon reservoirs, vehicle transportation, agricultural landscapes, farms, non-cattle confined buildings, and so on. - Recently developed detection and measurement techniques and methods such as photoacoustic spectroscopy, landfill-based carbon dioxide and methane measurement, and miniaturized mass spectrometer.

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