APPLICATION OF PINCH TECHNOLOGY TO CO_2 REDUCTION IN OIL REFINERIS

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ABSTRACT

A simple model for the estimation of CO_2 emissions associated with operation of heat-integrated distillation systems as encountered in refineries is introduced. The case study is ISFEHAN refinery crude oil distillation unit. In conjunction with a shortcut distillation model, this model has been used to optimize the process conditions of an existing crude oil atmospheric and vacuum tower to achieve at minimization of CO_2 emissions. COLOM and STAR programs are used to carry out energy and CO_2 optimization. Simulation results indicate that the total CO_2 emissions of the existing crude oil unit can be cut down by 39%, only by changing the process conditions accordingly, and that the gain in this respect can be doubled by integration of a gas turbine. In addition, emissions reduction is accompanied by substantial profit increase due to utility saving when the gas turbine is integrated, the initial total heat load of 78.2MW in the furnace, which includes stripping steam load, is distributed into two parts. The gas turbine provides 18.6MW; the furnace supplies the remaining 59.6MW. As shown in result, the total CO_2 of the refinery site reduces by 8%, for the optimized unit included a gas turbine. in total operating cost, including the value of generated power is about seven millions $/year.

***Index Terms**:* Crude oil distillation, Heat Integration

1. INTRODUCTION

Carbon dioxide as a greenhouse gas plays a vital role in global warming; studies show that it is responsible for about two-thirds of the enhanced greenhouse effect. A significant contribution to the CO_2 emitted to the atmosphere is attributed to fossil fuel combustion. Reducing CO_2 emissions is expensive, because industries are required to implement capital-intensive technologies.

Distillation is without doubt the most energy-intensive separation process utilized in practice. Atmospheric crude oil distillation towers with their heat exchange network and auxiliary units belong to largest consumers of utilities in process industries and therefore complex distillation-based operations are the first to be addressed regarding the energy savings-oriented efforts in the short and long term. Although energy saving is accompanied by a corresponding reduction in emissions, there is increasing need for explicit estimation of the emissions associated with various energy-intensive distillation-based operations in process industries

2. SOURCE OF CO_2 IN CDU REFINERY

Crude oil distillation units consist of columns, using pump-arounds and contain different types of energy inputs such as stripping steam and reboilers. The distillation columns are directly connected to heat recovery systems Crude oil feed is heated to an intermediate temperature in the exchanger network in which the distillation heat sources reject heat to the heat sinks Then, the feed is heated further to the processing temperature in a furnace or a fired heater. The heat sources in crude oil distillation columns include the overhead condenser, the hot liquids recycled in PAs, and the hot distillation product streams. The heat sinks are the crude oil feed, the stripping steam, the cold liquids recycled in side-heaters and the reboilers. Some main resources of CO_2 represents in Fig.1.

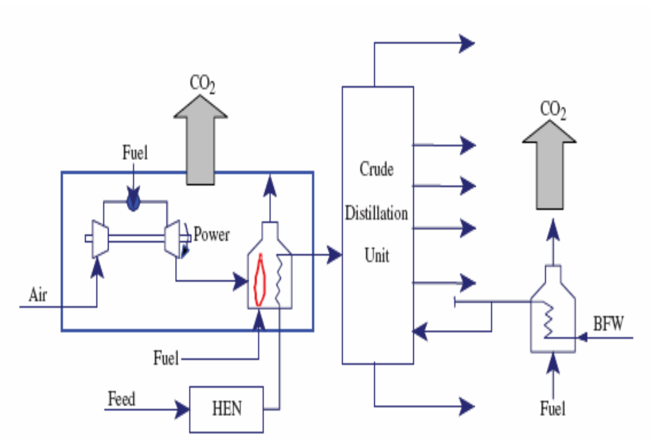

Fig.1. Sources of CO_2 emissions from a CDU

3. MODELING OF CO_2 PRODUCTION

3.1 CO_2 Emission form furnace

The combustion of fuels with air produces hot flue gases that can be used for heating the process feeds such as crude oil. Theoretical flame temperatures of the flue gases are usually in the region of 1800 1C. The heat provided by flue gases is the heat released when they are cooled from the flame temperature to the stack temperature. Stack temperature should not be lower than the corrosion limit; a typical stack temperature of 160 1C is adopted . The amount of fuel burnt in a furnace can be related to the heat duty required by the process [1,2], $Q_{Process}$ (kW), and the efficiency of the furnace, as follows:

$$Q_{Fuel} = \frac{Q_{process}}{\eta_{Furnace}} \tag{1}$$

$$\eta_{Furnace} = \frac{T_{TFT} - T_{stake}}{T_{TFT} - T_0} \tag{2}$$

3.2. CO2 emissions from steam boilers

Boilers produce steam from the combustion of fuel. This steam is delivered to the process at the temperature required by the process or obtained at a higher pressure and then throttled. In distillation systems, steam is used either for heating. The stack temperature of 160 1C is also used in the calculations.[1,3] The amount of fuel burnt can be calculated from :

$$Q_{Fuel} = \frac{Q_{Process}}{\lambda_{Process}}(h_{process} - 419)\frac{T_{FTB} - T_0}{T_{FTB} - T_{Stake}} \tag{3}$$

3.3. CO2 emissions from gas turbines

Integration of a gas turbine with a process enables refineries to produce electricity for the same heat requirement. The generated power can be either consumed in the refinery site or exported to other consumers. The Integration of gas turbines then leads to a reduction in the operating costs. the amount of fuel burnt can be calculated from the relationship between the efficiency of a gas turbine due to fuel savings, and it also provides flexibility in importing and exporting power.

$$Q_{Fuel} = \frac{Q_{process}}{\eta_{GT}} \frac{1}{1 - \eta_c} \tag{4}$$

The Carnot factor for a gas turbine is defined as

$$\eta_c = \frac{T_{in} - T_{out}}{T_{in} + 273} \tag{5}$$

3.4. Global CO2 emissions estimation

We considered only the process plant including the furnace, boiler and the gas turbine. The emissions calculated in this case are called local emissions], since we account only for the process plant. The power generated from the gas turbine is either consumed at the site itself or exported to other consumers. In both cases, the central power station, which is situated outside the plant boundaries, has the possibility of reducing electricity production by the amount that can be generated by the gas turbine. Thus, certain amounts of fuels can be saved at the central power station. This leads to a reduction in the CO2 emissions, or in other words, a saving in the emissions at the central power plant. Therefore, integration of a gas turbine with a process enables the central power station to reduce its emissions. So, we should consider the central power station together with the process plant as one unit in emission calculations.[4]

The CO2 emissions calculated in this case are called global emissions. The reduction in fuel consumption at the central power station calculated as follow:

$$\Delta Q_{Fuel} = \frac{W_{GT}}{\eta_B} \tag{6}$$

The global CO_2 emission from the process plant and the central power station is defined as:

Global emissions = Emissions from process plant - Emissions saved at power station. (7)

The capital cost of the gas turbine, calculated form:

$$\mathrm{Cost}_{GT} = 195.1(10)^{-3} W_{GT} + 2529.2 \tag{8}$$

The value of electricity generated by gas turbine defined as:

$$\mathrm{Cost}_{Power} GT = P_{COST} W_{GT} \tag{9}$$

When a gas turbine is to be integrated with a process, the CO2 emissions can be calculated locally or globally and, at the same time, the capital investment and the value of the power generated are evaluated. In summary, the overall model for CO2 emissions calculation in heat-integrated distillation systems comprises of all the equations presented above to estimate the emissions from all the individual devices, furnace, boiler and gas turbine. For an existing crude oil distillation plant, the CO2 emissions will be calculated individually for each device. Then, the total emissions are determined for the process plant and for the process together with the central power station. The capital expenses and process income can also be evaluated.

4. OPTIMIZATION OF ENERGY SAVING

This case includes shortcut retrofit models for representing the existing distillation columns, and a simple model to account for the details of the associated heat exchanger network. It also includes cost calculation models and uses a successive quadratic programming (SQP) solver. The objective function is the total annualized cost of utility consumption, including the capital cost associated with the modifications to the heat exchanger network. To include emissions related components of the total cost, relevant cost models are added to calculate the cost of utility consumption, additional exchanger units and areas, extra equipment and the costs associated with carbon tax [1]. The objective function in this case is the total annualized cost of utility and carbon tax and capital cost of gas turbine and exchanger modifications, less the value of the power generated by the gas turbine. The optimization can change all the process conditions of the existing CDU for minimizing either energy consumption or emissions. COLOM [4] software is used for optimization purpose. In addition pinch analyses carry out with STAR [5].

5. CASE STUDY: ISFEHAN CDU REFINERY

The distillation aspects of the case study are based on ISFEHAN atmospheric and vacuum crude oil distillation. towers. ISFEHAN crude oil distillation refinery produce significant emissions and have good opportunity for heat integration with pinch analysis. The purpose of this case study is to select the operating conditions of an existing crude oil distillation unit to minimize the CO_2 emissions. The pinch analysis perform with STAR at $\Delta T = 28°C$. The heat exchanger network is represented in Fig.2. The composite and grand composite curve is shown in Fig.3 and Fig.4. The exergy grand composite curve is shown in Fig.5.

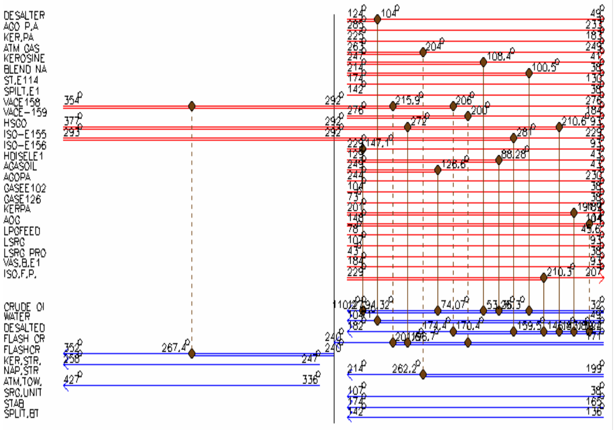

Fig.2 Heat exchanger network of ISFEHAN CDU refinery

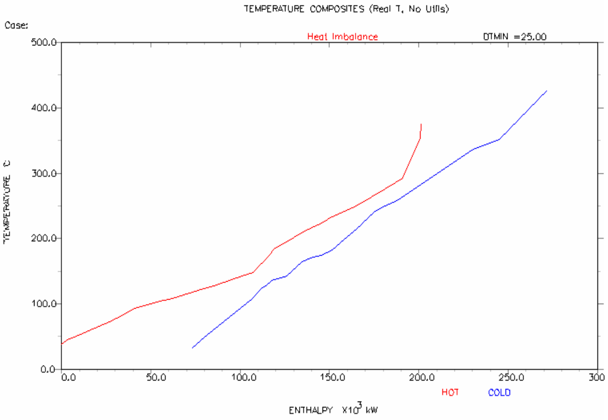

Fig.3 Composite curve of ISFEHAN CDU refinery

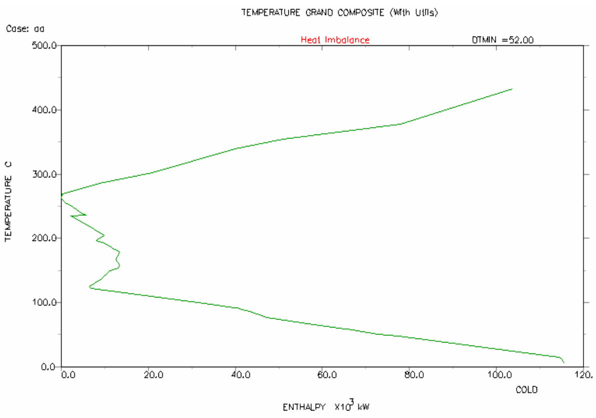

Fig.4. Energy Grand composite curve of ISFEHAN CDU refinery

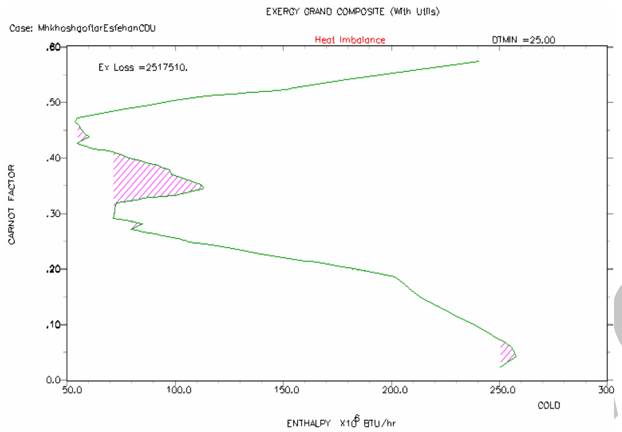

Fig.5. Exergy Grand composite curve of ISFEHAN CDU refinery

6. CONCLUSION

A model for the estimation of CO_2 emissions from existing crude oil distillation units has been proposed. Crude oil distillation in ISFEHAN refinery have good opportunity to heat integration. The energy saving due to heat integration reduce emissions. In addition with using gas turbine the power is generated . The estimation model calculates the emissions flow rates from furnaces, boilers and integrated gas turbines. Also, an optimization framework has been presented for minimizing energy and emissions from heat-integrated distillation units. If a gas turbine is not to be integrated, the existing crude unit can still be optimized to reduce the CO_2 emissions. The objective in this case will be to minimize the total annualized cost, including utility consumption, stripping steam, carbon tax and the exchanger network modifications. The optimization has been applied specifically to optimize all process conditions of an existing crude oil tower for reducing emissions, considering changes to the existing structure. The cost of fuel and economic parameters is shown in Table 1,2 and the result of optimization represent in Table3. It has been shown that existing crude oil atmospheric and vacuum units can cut down their emissions by up to 39% while the existing structure is preserved. However, these units can achieve an emissions reduction of up to 53.7% when a gas turbine is integrated. Although the emissions model and the optimization procedure have been applied in this study to an existing crude oil unit only, they are generally valid and can be used to produce new designs for all kinds of heat-integrated distillation systems employed in process industries.

Table 1.Data for heating fuels to determine CO_2 emissions

Heating Fuel	**NHV (kj/kg)**	**Carbon %**
Heavy Gas Oil	39.77	86.50
Natural Gas	75.40	51.60

Table2. Cost and economic parameters for CO2 emissions calculation

Parameter	**Unit**	**Value**
Electrical power	\$/MM.h	35
Carbon tax	\$/t CO_2	15
Gas turbine capital cost	k\$	$195.1\times(MW)+2529.2$
Power station efficiency	%	30
Furnace efficiency	%	90
Boiler efficiency	%	80
Atmospheric temperature	°C	25
Flue gas temperature	°C	1800
Stack temperature	°C	150

Table3.CO_2 emissions from optimum unit with gas turbine versus existing unit

Parameter	**Unit**	**Case**	**Optimum**
Utility steam heat load	MW	70.55	63.40
Flue gas heat load	MW	80.28	73.70
Heat load on gas turbine	MW	-	15.6
Heat load on furnace	MW	80.28	58.11
Total energy consumption	MW	150.8	137.10
CO2 emissions from steam from boiler	t/h	32.04	28.7
CO2 emissions from gas turbine	t/h	-	9.09
CO2 emissions from furnace	t/h	25.63	18.55
Total local CO2 emissions	t/h	57.67	52.94
CO2 emissions saved at power station	t/h	-	-13.41
Total global CO2 emissions	t/h	-	39.53
Power generated in gas turbine	MW	-	16.93
Capital cost of gas turbine	MM$	-	5.26
Value of power generated	MM$/yr	-	3.92
Stripping steam flow rate	MM$/yr	36.25	31.40
Total operating costs	MM$	-	0.43
Total operating cost saving	MM$/yr	-	6.95
Total capital investment	MM$	-	5.69
Payback	yr	-	1.32

7. REFERENCES

1. Gadallaa M.,Olujic´ Z., Jobsonc M., Smith R., Department d'Engingeria Quý´mica, Universitat Rovira i Virgili, Paisos, Estimation and Reduction of CO_2 Emissions from Crude Oil Distillation Units, 2005.
2. Gadalla M, Jobson M, Smith R. Optimization of Existing Heat-Integrated Refinery Distillation Systems. IChemE, Part A(81):147–52, 2003 .
3. Gadalla M, Jobson M, Smith R. Shortcut Models for Retrofit Design of Distillation Columns, IChemE, Part A(81):971–86, 2003.
4. COLOM Software Version 1.6, 2005, Centre for Process Integration, the University of Manchester, This Product Licensed to KNTU University, Tehran-Iran, Department of Mechanical Engineering.
5. STAR Software Version 2, 2005, Centre for Process Integration, the University of Manchester, This Product Licensed to KNTU University, Tehran-Iran, Department of Mechanical Engineering.