Effect of Steam and Carbon Dioxide on Naphtha Cracking to Mitigate Cracked Gas Compressor Fouling, Coke Accumulation and Energy Resources

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Abstract

The naphtha cracking process experiences problems such as fouling in the cracked gas compressor, and the accumulation of coke on the furnace coils, which require the use of exhaustive energy resources and costs to maintain the process. Several attempts have been carried out to solve this process in ethylene plants, but reducing fouling and energy costs during naphtha cracking remains a challenge. This study involves a simulation experiment that covers the addition of steam and carbon dioxide to the naphtha cracking process based on real-world data extracted from an ethylene plant in Libya, in order to investigate the effects of the addition of CO2 towards mitigating fouling in the cracked gas compressor, as well as coke accumulation on the coils inside the furnace, and in turn the energy resources and costs involved in the process. The key role of the addition of steam is the fractional elimination of the accumulated coke that leads to various issues within the reactor, such as the low heat transfer and the decrease in pressure. In this study, the diluting media CO2 is employed along with steam in order to investigate its effect on operating conditions and the main products' yields. Two simulation models were constructed to investigate the thermal cracking process of ethylene in the existence of CO2 and steam. The first model involved only steam, and represented the standard design. The second model involved the addition of both CO2 and steam. After evaluation and comparison of both models, promising results reveal that the addition of CO2 and steam during the naphtha cracking process mitigate costs and energy resources required to maintain the operation, as well as achieve higher yields of ethylene, propylene, methane and hydrogen. The run time of the furnace and reactors was also increased.

Keywords: naphtha cracking, cracked gas compressor, coking

1. Introduction

Thermal cracking is an important process in olefin production. During this process, a mix of hydrocarbons and steam are input into furnaces, with olefins produced as an output. There are several parameters that affect the product distribution, which are the feed composition, the furnace temperature, and the steam ratio. Many researchers have attempted to enhance the modeling of the thermal cracking process by considering modifications in these parameters

Naphtha and steam increase coke accumulation, and thus polymers are increased. This results in increased fouling, since more energy is needed to increase the suction pressure and maintain lost efficiency. Therefore, there is a need to reduce coke accumulation, and in turn fouling. This has a direct effect on the energy costs required to maintain the naphtha cracking operation. This study involves a simulation model that is used to investigate the impact of the addition of CO2 and steam to the naphtha cracking process. Before starting with the experiment of adding steam and CO2 to this process, we first investigated the issues of (1) fouling in the cracked gas compressor (CGC), as well as (2) coke accumulation on the coils in the furnace.

(1) Fouling. An ethylene plant's economic situation can be negatively impacted because of fouling. Figure 1 shows the decrease in efficiency due to the increase in polymer and coke accumulation in all four stages in the compressor. But this does not greatly result in increased costs, given the condition that there is sufficient turbine capacity. An increase in the speed of the turbine stops lost production. However, in most cases, the turbine is limited, and the decrease in efficiency causes a decrease in throughput, which requires additional costs to maintain the throughput to a normal level, since more steam consumption takes place during cracking, as well as an increase of the suction pressure in the first stage. The increase in suction pressure has a negative effect on the final product yields (i.e., ethylene, propylene, etc.).

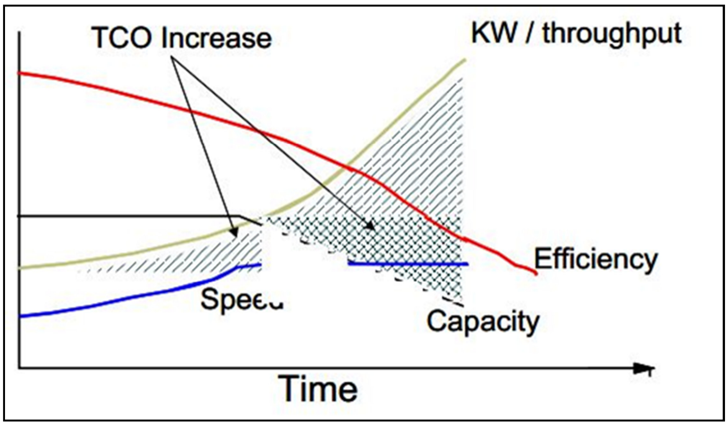

Figure. 1 Impact of CGC fouling

Besides production loss, a fouled CGC is at a high risk of unscheduled shutdown. Sometimes the CGC is maintained at a high suction pressure to preserve the required discharge pressure. The increase in the suction pressure at the first stage causes an increase in the furnace pressure. This also results in low product yields, which is considered among the main problems in an ethylene plant.

(2) Coke accumulation. Coking results from the thermal cracking of hydrocarbons, and its intensity and rate of accumulation rely on the parameters that are input to the furnace. Coking has bad effects on the pyrolysis process, such as a reduction in the temperature of the furnace. In order to maintain the heat transfer at the level required, the temperature must be raised at certain intervals. Coil metallurgy is a core limitation for temperature increase on the tube walls. Also, the rise in temperature leads to a higher rate of coke accumulation. Additionally, the cross section reduction of coils, as a result of coke accumulation, creates a decrease in the pressure in the tubes, higher maintenance expenses for the ethylene plant, as well as more energy consumption in order to preserve the furnace temperature.

Coking also results in furnace shutdown. During decoking, the furnace is stopped completely. The average run time of the furnace is about 45 days, and is based on several factors including type of furnace, operating conditions, and type of feedstock. The removal of coke, or decoking, is done with the use of both air and steam. Sometimes excess coke accumulation results in blockage in the coils, and this requires cutting parts of the coil and welding on a new part, which is highly costly and takes longer to perform than only decoking.

This study primarily aims to reduce fouling in the GCG, which in turn reduces operation and maintenance costs, as well as coke accumulation. This paper is organized as follows: Section 2 presents the related work. Section 3 involves the methodology. Section 4 presents the results and discussion. Section 5 presents a conclusion and recommendations for future work.

2. Related Work

Several studies have been carried out to investigate factors that impact operating conditions of the furnace and cracked gas compressor (CGC), such as feed composition, steam ratio, and temperature. Lee and Aitani (1991) have studied the feed composition and its effects on ethylene production. Keyvanloo et al. (2010) has investigated several parameters, which are the effects of steam ratio, temperature, and run time on the production during the steam cracking of naphtha. Numerous studies have revealed that coke is formed because of either reactants of products (Virk et al. 1979; Kopinke et al. 1993; Kumar and Kunzru 1987).

The primary parameters that influence and impact the product distribution are the feed composition, the furnace gas temperature and the overall steam ratio. Over the past couple of years, numerous investigations had been conducted on the modeling of thermal cracking operation for several hydrocarbons. Lee and Aitani (1991) studied the impact of feed composition for ethylene production. Also, Keyvanloo et al. (2010) investigated the impact of steam ratio, temperature and the residence time on the yields in the steam cracking operation of naphtha. Additionally, Belohlav et al. (2003) introduced a model to describe thermal cracking of ethane, petroleum gases, and naphtha. Ghassabzadeh et al. (2009) studied the process of ethylene and propylene with use of kerosene thermal cracking in a practical setup. They made use of several simplification considerations to show a suitable kinetic model that estimates product yields effectively. Impacts of temperature, time of residence and overall steam ratio on the products in gas and oil thermal cracking operations were investigated by Depeyre et al. (1989). They implemented a system for product distributions based on radical mechanisms. Towfighi et al. (2002) showed a reaction network system for simulation of LPG cracking plants. Also, many other scholars introduced mechanistic systems for the atmospheric gas and oil cracking operations based on experiments. Choudhary et al. (1995) demonstrated that the addition of carbon dioxide is a suitable alternative to steam in the process of pyrolysis.

After a review of the literature, it is clear that there is a lack of studies that focus on the addition of CO2 and steam to the naphtha cracking process, in an attempt to reduce fouling and coke accumulation of coke on the coils in the furnace. In this study, two simulation models were constructed to investigate the thermal cracking process of ethylene in the existence of CO2 and steam. The first model involved only steam, and represented the standard design. The second model involved the addition of both CO2 and steam. This is followed by a comparison of the findings of the two simulation models. The simulation aims to demonstrate and investigate the effects adding CO2 and steam to the naphtha cracking process, and is predicted to generate positive results that mitigate fouling and coke accumulation. The next section presents the steps involved during the experiment.

3. Methodology

In this section, the methodology is presented, which involves the addition of CO2 and steam to naphtha during the naphtha cracking process. In this simulation experiment a liquid furnace is considered. Table 1 presents information on feed analysis of the feedstock used in the simulation, based on real-world data taken from a petrochemical plant based in Libya. The feed analysis shows the composition of the naphtha feedstock used in the simulation.

Table 1 Feed analysis of feedstock used for simulation

component	**Mass (dry %)**	**Mass (wet %)**	**flow(ton/h)**
Water	0.00	34.01	22.19
Hydrogen	1.14	0.74	0.494
methane	20.03	13.02	8.820
Carbon monoxide	0.134	0.087	0,041
Carbon dioxide	0.03	0.03	0.004
Sum c1	21.05	48.05	32.05
acetylene	0.86	0.54	0.377
ethylene	33.17	21.77	15.17
Ethane	3.58	2.38	15.08
C2,s	39.05	25.071	17.02
C3H4,s	1.16	0.86	0.536
propylene	16.54	11.25	7.05
propane	0.95	0.66	0.388
C3,s	17.54	11.65	7.85
butadiene	4.65	3.15	2.065
butanes	4.01	2.61	1.717
butanes	1.51	1.05	0.685
Sum C4,s	10.35	6.85	4.585
C5,s	2.45	1.65	1.05
benzene	5.15	3.45	2.35
C6 non-aromatics	0.45	0.35	0.226
C6,s	5.71	3.76	2.56
toluene	1.55	1.05	0.657
C7 non-aromatics	0.13	0.07	0.389
C7,s	1.77	1.27	0.737
xylenes	0.27	0.16	0.112
C8 non-aromatics	0.001	0.001	.003
C8,s	0.90	0.60	0.38
C9,s	0.25	0.17	0.786
C10,s	1.79	1.21	0.785
	100.00	100.00	66560

Naphtha is one of the most beneficial feedstock for the process of thermal cracking due to its high ethylene selectivity when compared with other paraffin. The pyrolysis is less costly than other hydrocarbons. In the simulation, a mix of naphtha and steam move through two rounds in the liquid furnaces.

The Matlab software application was used for the simulation models. The design of the first simulation is standard and readily available. Therefore the standard parameters were used for the first simulation model, which involved only steam during the naphtha cracking process. The results from the simulation were recorded for comparison to the second model.

The second model involved adding CO2 and steam to the naphtha cracking process. The process of thermal cracking is generally an endothermic one, where molecules are split up into smaller parts. The main operation of the liquid cracker within an olefin plant is simulated. In the simulation a blend of CO2 and steam are put through into the liquid furnaces. The main naphtha feed is input into the convection area, with a steady temperature in the range of 20 to 50 degrees oC, and a pressure of 1.2 to 3 Kg/cm2. At the middle of this area within the reactor, the steam has a temperature of 250 degrees oC, and 2.5 Kg/cm2 is introduced to the feed (The ratio of steam to feed is 0.6 kg steam per every one kg of naphtha) as a main diluent to mitigate the pressure of the hydrocarbons.

After that, it goes down into the radiation section. It is worthy to note that there is no cracking reaction that takes place within the convection area in the simulation. In the radiation area, the cracking reactions occur in the tubes positioned in a vertical manner in a gas-operated furnace with a temperature of 1200 degrees oC, and the feed is split up into ethylene, propylene, butadiene and pygas, among several other secondary products. The needed heat to maintain the overall temperature in the required level is given by a total of 166 burners.

It is crucial to preserve the temperature of the coil outlet at a level of 810 to 850 degrees oC in the simulation, since this has a great impact on the products concentration. Table 2 presents important information on the main temperature of the coil outlet and pressures taken from the ethylene plant. This information is used parameters for the simulation, during which CO2 will be introduced.

Table 2 General flow rate of naphtha and steam for one round of runtime in furnace

Time/day	**Flow rate of naphtha (MT/hr)**	**Flow rate of steam (MT/hr)**	**Coil outlet temp ^{o}c**	**Coil outlet pressure Kg/cm^{2}**
2	150	90	810.0	1.51
4	149.6	89.96	810.0	1.50
6	150.01	90	810.7	1.53
8	150.2	90.72	809.6	1.51
10	149.3	90.06	810.2	1.34
12	150	90	810.00	1.41
14	149.8	89.98	810.3	1.51
16	149.9	89.98	810.8	1.5
18	149.2	88.92	810.7	1.51
20	151.0	90.98	810.7	1.51
22	149.7	89.8	810.8	1.52
24	149.96	89.89	810.1	1.51
26	149.98	89.29	810.1	1.51
28	149.98	89.29	810.5	1.53
30	149.78	89.97	810.34	1.52
32	149.9	8894	810.35	1.41
34	149.9	87.54	808.9	1.41
36	149.9	89.30	810.65	1.41
38	149.2	89.24	810.9	1.5
40	150.1	90.70	811,1	1.5
42	150.9	90.68	811.5	1.53
44	151.3	90.1	810.11	1.53
48	150.1	90.12	810.34	1.5
50	151.6	90.29	810.46	1.52
52	151.4	90.29	810.78	1.53
54	151.21	90.10	810.45	1.5
56	150.9	90.19	811.66	1.54
58	150.9	90.91	811.5	1.59
60	150	90.68	810.90	1.54

Lastly, the products at 810 to 820 degrees oC and 1.5Kg/cm2 exit this area, and move into the TLE area. To prevent side reactions, the final product is cooled to a temperature of 325 degrees oC within the transfer line exchangers, and compressed prior to passing via different separation stages. We show this in the simulation by reducing the temperature of the final product to the corresponding temperature of 325 degrees oC.

Choudhary et al., demonstrated that addition of carbon dioxide is a suitable alternative to steam in the process of pyrolysis. They claimed that the CO2 to feed weight ratio must be within 0 to 2.5 kg. In this simulation, 0.9 Kg of CO2 was introduced to the main reactor for every one Kg of naphtha; this is similar to the Kg of steam and Kg of naphtha ratio, and the impact of CO2 is investigated based on the results recorded from the simulation. All other operation conditions are maintained normally during the simulation, and the equations involved are as follows:

Naphtha $\rightarrow 0.51H_2 + 0.75CH_4 + 1.12C_2H + 0.123C_2H_6 + 0.35C_3H_6 + 0.08C_3H_8 + 0.01C_4H_{10}$ (1)
$C_2H_6 \leftrightarrow C_2H_4 + H_2$ (2)
$C_3H_6 \leftrightarrow C_2H^2 + CH^4$ (3)
$C_2H_2 + C_2H_4 \rightarrow C_4H_6$ (4)
$2C_2H_6 \rightarrow C_3H_8 + CH_4$ (5)
$C_2H_4 + C_2H_6 \rightarrow C_3H_6 + CH_4$ (6)
$C_3H_8 \leftrightarrow C_3H_6 + H_2$ (7)
$C_3H_8 \rightarrow C_2H_4 + CH_4$ (8)
$C_3H_8 + C_2H_4 \rightarrow C_2H_6 + C_3H_6$ (9)
$2C_3H_6 \rightarrow 3C_2H_4$ (10)
$C_3H_6 + C_2H_6 \rightarrow C_4H_8 + CH_4$ (11)
$C_4H_{10} \rightarrow C3H_6 + CH_4$ (12)
$C_4H_{10} \rightarrow 2CH_4 + H_2$ (13)
$C_4H_{10} \rightarrow C_2H_4 + C_2H_6$ (14)
$C_4H_{10} \leftrightarrow C_4H_8 + H_2$ (15)
$C_4H_8 \rightarrow C_4H_6 + H_2$ (16)
$C_2H_4 + C_4H_6 \rightarrow B + 2H_2$ (17)
$C_3H_6 + C_4H_6 \rightarrow T + 2H_2$ (18)
$C_4H_8 + C_4H_6 \rightarrow EB + 2H_2$ (19)
$C_4H_6 + C_4H_6 \rightarrow ST + 2H_2$ (20)

where B, T, ST and EB represent benzene, toluene, styrene and ethyl benzene.
In the simulation, ethylene, propylene and butadiene are considered coke precursors, where

Ethylene + Propylene + Butadiene = Coke (21)

The partial removal of coke comes with the following reactions:

C + H2O -> CO2 + H2 (22)
C + CO2 -> 2CO (23)

The mentioned reactions have the following rate equations:

$$r_1 = k_1\left[\frac{F_{C_{6.5}H_{14}}}{F_t}\left(\frac{P_t}{RT}\right)\right]$$

$$r_2 = k_2\left[\frac{F_{C_2H_6}}{F_t}\left(\frac{P_t}{RT}\right)\right] - kR_2\left[\frac{F_{C_2H_4}F_{H_2}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_3 = k_3\left[\frac{F_{C_3H_6}}{F_t}\left(\frac{P_t}{RT}\right)\right] - kR_3\left[\frac{F_{CH_4}F_{C_2H_2}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_4 = k_4\left[\frac{F_{C_2H_2}F_{C_2H_4}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_5 = k_5\left[\frac{F_{C_2H_6}}{F_t}\left(\frac{P_t}{RT}\right)\right]$$

$$r_6 = k_6\left[\frac{F_{C_2H_6}F_{C_2H_4}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_7 = k_7\left[\frac{F_{C_3H_8}}{F_t}\left(\frac{P_t}{RT}\right)\right] - kR_2\left[\frac{F_{C_3H_6}F_{H_2}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_8 = k_8\left[\frac{F_{C_3H_8}}{F_t}\left(\frac{P_t}{RT}\right)\right]$$

$$r_9 = k_9\left[\frac{F_{C_3H_8}F_{C_2H_4}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_{11} = k_{11}\left[\frac{F_{C_2H_6}F_{C_3H_6}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_{12} = k_{12}\left[\frac{F_{C_4H_{10}}}{F_t}\left(\frac{P_t}{RT}\right)\right]$$

$$r_{13} = k_{13}\left[\frac{F_{C_4H_{10}}}{F_t}\left(\frac{P_t}{RT}\right)\right]$$

$$r_{14} = k_{14}\left[\frac{F_{C_4H_{10}}}{F_t}\left(\frac{P_t}{RT}\right)\right]$$

$$r_{15} = k_{15}\left[\frac{F_{C_4H_{10}}}{F_t}\left(\frac{P_t}{RT}\right)\right] - kR_2\left[\frac{F_{C_4H_8}F_{H_2}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_{16} = k_{16}\left[\frac{F_{C_4H_8}}{F_t}\left(\frac{P_t}{RT}\right)\right]$$

$$r_{17} = k_{17}\left[\frac{F_{C_2H_4}F_{C_4H_6}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_{18} = k_{18}\left[\frac{F_{C_3H_6}F_{C_4H_6}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_{19} = k_{19}\left[\frac{F_{C_4H_8}F_{C_4H_6}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_{20} = k_{20}\left[\frac{F_{C_4H_6}F_{C_4H_6}}{F_t^2}\left(\frac{P_t}{RT}\right)^2\right]$$

$$r_{21} = k_{21}\left[\left(\frac{F_{C_2H_4}P_t}{F_tRT}\right)^{1.34}\right]$$

$$r_{22} = k_{22}\left[\left(\frac{F_{C_3H_6}P_t}{F_tRT}\right)^{1.34}\right]$$

$$r_{23} = k_{23}\left[\left(\frac{F_{C_4H_6}P_t}{F_tRT}\right)^{1.34}\right]$$

In terms of fouling, the polytropic efficiency can be added as follows:

$$\textbf{Polytropic efficiency} = \frac{\ln(P_d/P_s)}{\ln(T_d/T_s)} * \frac{(k-1)}{k} * 100\% \qquad (46)$$

where Ts and Td are the temperatures of stage suction and discharge in absolute degrees, and Ps and Pd are the pressures of the stage suction and discharge in absolute degrees.

After the simulation experiment of adding CO2 and steam to the naphtha cracking process, the results generated can be compared to the standard model of using only steam during naphtha cracking, in order to investigate whether this mitigates fouling and coke accumulation. The next section presents the results and discussion based on the simulation experiment.

5. Results and Discussion

This section presents the results of the simulation experiment, along with a discussion. First, the results in terms of fouling are presented, and a discussion is given on how the simulation demonstrates a decrease in fouling in the CGC. Second, the results in terms of coke accumulation are presented, followed by a discussion of how CO2 impacts the coke accumulation.

Fouling

The parameters needed to continuously monitor the CGC are as follows:

- Discharge and suction temperature, along with the pressure at each stage
- composition of compressor gas
- mass flow rate
- performance curves for each stage
- rotor speed

Table 1 presents the Effluent composition from CGC first stage suction drum.

Table 2 The Effluent composition from CGC first stage suction drum

FEED STOCK COMPONENTS	Naphtha only (CASE 1) 31.04.2013 vol. %	Status
H2	16.57	High
CO	0.05	High
CH4	24.74	High
C2H6	7.74	Low
C2H4	26.04	high
C3H8	0.37	high
C3H6	10.22	high
C2H2	0.27	equal
C4+	3.53	Low
C5+	7.42	high
1,2BD	0.02	equal
1,3BD	2.7	Low
MAB	0.33	high

Based on the results of the simulation, after the addition of CO2, there was a drop in the suction pressure and fouling, and in turn, an increase in the yield of the main products (refer to Table 1), an increase in compressor efficiency, and an increase in run-time of the CGC. Figure 2 shows the efficiency of the CGC during normal operation, and also during the addition of CO2.

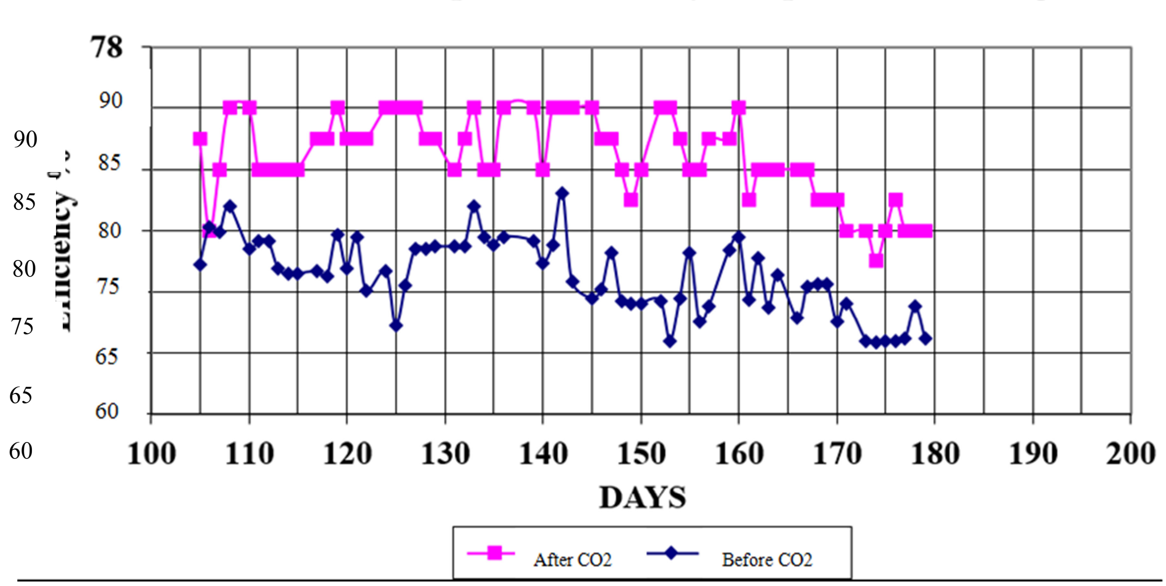

Fig. 2 Efficiency of CGC before and after introduction of CO2

As shown in the figure, the efficiency of the CGC during the naphtha cracking with only steam was in generally in the range of 65-75%. After the addition of CO2 to the naphtha cracking process in the experiment, there was an increase in efficiency, and the range of the CGC efficiency was generally in the range of 80-85%. Based on these results, there was an increase in efficiency by roughly 10% on average after the introduction of CO2. This demonstrates the positive effect in terms of the efficiency of the CGC. The next subsection discusses the results, and how the simulation impacts the coke accumulation on the coils in the furnace.

Coke

The furnace has to be terminated once the coke thickness within the furnace is approximately 10 – 25% of the tube's diameter. The cracking process with the introduction of steam can run for approximately 45 days before this unit of the plant is stopped for decoking. Based on the results of the simulation, the run time for the model will be over 80 days. Due to this, the process results in the production of higher ethylene yields with lower operating and maintenance expenses. The run time of the reactor also increases from 75 days to 140 days.

The tube wall temperature is plotted as a function of the length of the reactor and the time based on the simulation results. The run time of the furnace in a normal thermal cracking process is about 70 days, and the temperature of the tube wall reaches about 1370 K, which is just less than the maximum temperature that is allowed. However, with the presence of CO_2, the temperature reaches the maximum allowed temperature after about 140 days.

The experimental tube wall temperatures during a run time of the furnaces in the simulation involved in the study are presented in Figure 3. According to the figure, it is clear that, considering the time (in days) and the furnace length, the tube wall temperature is higher when using CO_2 instead of steam. Due to no coke accumulation for the first couple of days, the tube wall temperatures are less than 1220K. Eventually, the temperature increases to about 1380 K using only steam, and 1320 K using both steam and CO2. This shows that the tube wall temperature is slightly lower when considering CO2. The temperature in the tube wall changes dramatically as a function of furnace length and time. The reason for this is that the coke accumulation is different in different parts of the coils, and therefore, the heat transfer is not stable across the furnace.

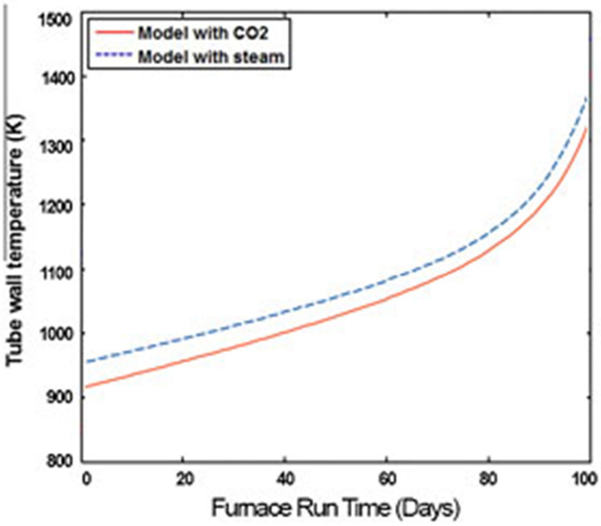

Fig. 3 Wall temperature of tube for cracking coils length and furnace run time in days using steam and CO2

Figure 4 shows the coke thickness in the coils and the furnace run time in days when using only steam, and also when using both steam and CO2. This figure shows that generally the coke thickness is reduced (about one mm) when using CO2.

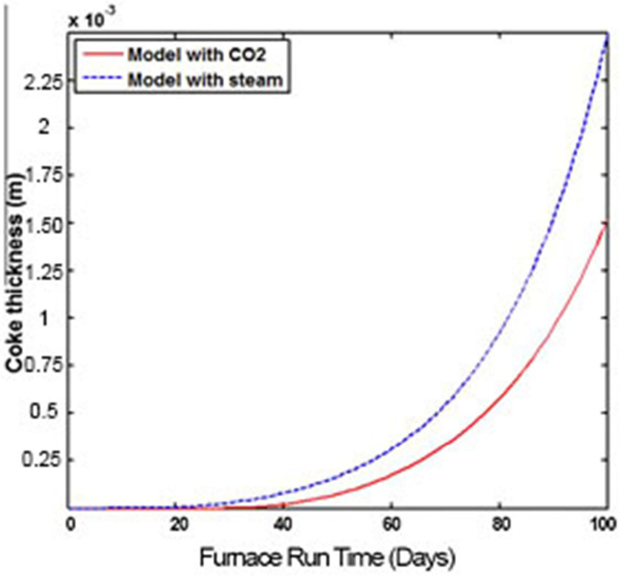

Fig. 4 Coke thickness in coils and furnace run time in days using steam and CO2

Figure 5 shows the Molar flow rate of propylene and ethylene and the furnace run time in days when using steam and CO2. Based on Figure 4a, there is an increase in the flow rate of ethylene when considering CO2. Based on Figure 5b, there is also an increase in the propylene flow rate when considering CO2. This demonstrates the higher product yields during the addition of CO2 in the simulation.

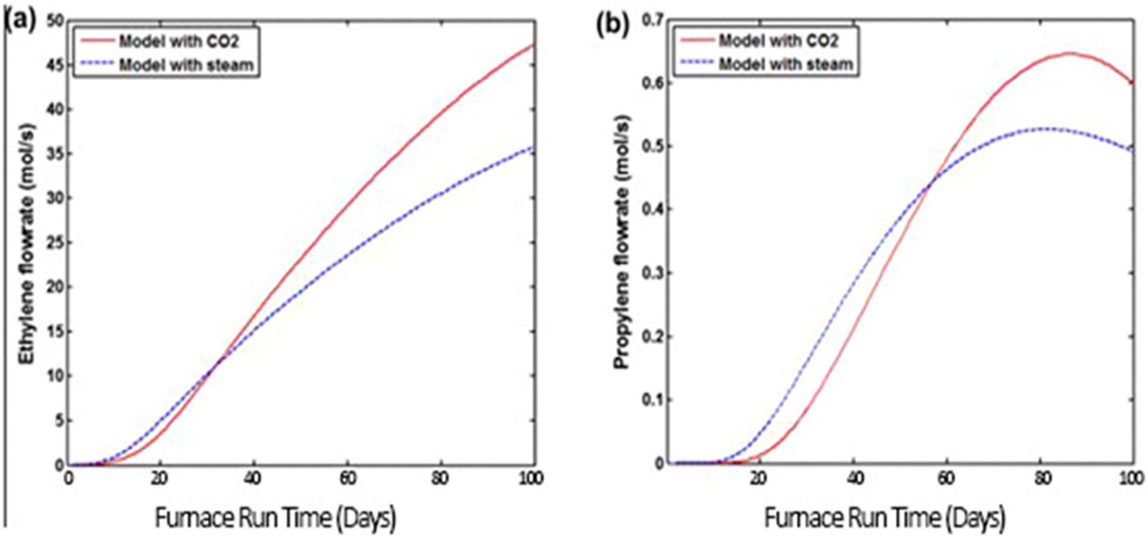

Fig. 5 Molar flow rate of ethylene and propylene and the furnace run time in days when using steam and CO2

Based on the mentioned results from the experiment, we can conclude that adding CO2 with steam during the naphtha cracking process has a several positive effects. The fouling in the CGC and coke accumulation was reduced, and in turn, the required costs and energy resources to maintain the furnace were reduced. Also, there was an increase in the final product yields, particularly for ethylene, which is considered the most important final product considered. Hence, further simulation experiments and investigations on the impact of adding CO2 during naphtha cracking are promising.

5. Conclusion

In this study, CO2 was added along with steam during the naphtha cracking process in order to investigate its effect on fouling in the CGC and coke accumulation, as well as the main products yield. Two simulation models were constructed to investigate the thermal cracking process of ethylene in the existence of CO2 and steam. The first model involved only steam, and represented the standard design. The second model involved the addition of both CO2 and steam. After evaluation and comparison of both models, fruitful results reveal that the addition of

CO2 and steam during the naphtha cracking process mitigates costs and energy resources required to maintain the operation, as well as achieve higher yields of ethylene, propylene, methane and hydrogen. The run time of the furnace and reactors was also increased. More specifically, the benefits of the use of CO2 with steam in the process of ethylene cracking show that this is a promising solution for the aforementioned issues. The benefits of the use of CO2 are the following:

- Fouling and energy costs in both the CGC and furnace is mitigated
- The rate of accumulation of coke is decreased
- The yields of main products are increased
- The run time of the furnace and reactors is increased

This work acts as a foundation for future related studies on the investigation of benefits of adding Co2 with steam to the naphtha cracking. It gives useful insights for future researchers that aim to increase effectiveness and efficiency of the ethylene cracking process. In terms of future directions, more experiments may be carried out with CO2 addition during the thermal cracking process. This study had considered a simulation based on the results from a petroleum company based in Libya, with data recorded for a period of 60 days. The same experiment may be carried out at a different plant, and with data recorded for longer periods of time.

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