



Research Article

Aspen HYSYS Simulation of Reformer and Heat Recovery System

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ARTICLE INFO

Keywords:

MIDREX Plant, Reformer, Energy Saving, Heat Recovery System, HYSYS Software.

Article history:

Received 10 July 2023

Received in revised form 27

October 2024

Accepted 06 April 2025

ABSTRACT

This research develops a simulation model for new design of reformer and heat recovery system (HRS) in the direct reduced of Khuzestan steel company in Iran. The endothermic reforming reactions in the reformer tubes, the natural gas, and fuel gas combustion in the burners were considered. A part of the combustion energy in the reformer box is absorbed by the reformer tubes while the rest of the energy enters the HRS at 1100 °C. The outlet fuel gas from HRS enters the stack at 325 °C. Equations of energy, mass, and momentum were together solved in the Aspen HYSYS software. The profiles of temperature, pressure, and components percentage are obtained in the reform and fuel gas. According to the results, an improved HRS can increase the reformer efficiency and reduce the temperature of the exhaust gas of the stack, as well as the refractory improvement. HRS reduced its energy loss from the body by half in spite of a two-fold increase in its heat transfer surface. The fuel gas temperature rose from 48 to 200 °C by raising tube bundle at the end of the HRS. The exhaust gas temperature from the stack also showed a decline from 311.5 to 261.3 °C. The flow rate of natural gas can be increased by 20% due to increased energy input to the reformer combustion chamber, enhancing the production of reduced gas by 7%. This increase in the amount of reducing gas can increase the tonnage production from the average 103 Ton/hr to 110 Ton/hr. However, the amount of stack flue gas carbon dioxide decreased by 7.29%.

1. Introduction

At present, the international community has to tackle two major issues: the global warming; and the reduction of fossil fuels. Carbon dioxide is a greenhouse gas with

key role in global warming. The concentration of greenhouse gases in the atmosphere was 270 ppm prior to the industrial revolution which reached 380 ppm with an increasing rate of 1/5 per year [1]. Ravenscroft reports an increase in the warming trend since 1880 [2].

In the past decade, energy consumption and greenhouse gas emissions have been favored in response to the numerous issues introduced by the United National Framework Convention Change (UNFCCC)[3], which was signed in 1997. In 2015, in Kyoto, Japan and Paris, the signatories confirmed the protocol outlining emissions reduction objectives. Over 150 countries were committed to stabilizing greenhouse gas concentrations at a level that would prevent dangerous anthropogenic

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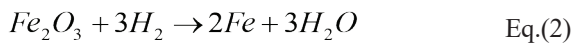
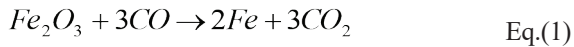
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DOI: <http://10.22034/IJISSI.2025.2006686.1268>

Published by ISSI (Iron & Steel Society of Iran)

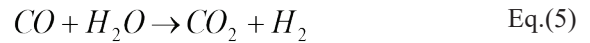
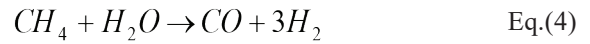
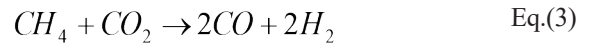
interference with the climate system [4, 5]. It has been shown that the world DRI production increased by more than 14 million tons over 2016, exceeding 87 million tons in 2017 [6]. The direct reduction process has gained attentions in the last decades as a source of metallic units for electric arc furnaces for steel production. Midrex technology is the key DRI process covering about 58 % of the global total DRI production [modeling-Ajbar].

DRI are mostly produced in Iran and India. Iran produced 20.5 million tons of DRI/HBI in 2017, up 28.3% year-on-year. More than 20.5 million tons of DRI was produced in Iran in 2017, which was 4.5 million tons over the previous year mainly due to launching new plants [6]. PERED® direct reduction technology is an emerging innovation. Iran developed this technology for decreasing capital cost, operation and maintenance costs, energy saving, and electricity consumption. This innovation involves arrangement of tube bundles and increasing bundle of steam tube [7]. Steel industry is the key producer of carbon oxide with high energy consumption, accounting for 5% of the global greenhouse gases [8]. In the direct reduction plant (Fig. 1.), pellet (oxide iron) is reduced in the shaft furnace with CO and H₂ gases. After reacting with the reduced gases, the pellets leave the shaft furnace (gravitational force) and produce DRI. Reduction reactions are as follows:[9]



The overall MIDREX plant and heat recovery system is shown in Fig. 1.

Top gas is returned from furnace to scrubber to clean and reduce the water content. One third of gas will be used for the fuel and the remaining two third is for process gas. Process compressors compress the process gas. Process gas is mixed with natural gas preheat. Process gas is again fed to reformer after preheating. Reforming reactions are considered [10].



Reformer tubes contain nickel aluminates catalyst. Reforming reactions are endothermic. Flue gas temperature is around 1100 °C. Therefore, flue gas is vent to atmosphere after preheating the air, process, and natural gas. Iron making is the main source of anthropogenic carbon dioxide. Industrial processes deliver more than one-fifth of the world CO₂, and Iron making alone delivers more than one-fourth of the annual industrially-produced CO₂ (more than 1.8 billion tons). Natural gas-based direct reduction plants also produce CO₂ (approximately 0.5 tons per steel) in comparison with blast furnace 1.8 tons per Iron. Apparently, methane is a far cleaner fuel According to the meeting on 15 December 2015 in Paris, the temperature of Earth is increased by 3-6 °C. Following Table lists the global CO₂ emission in which, USA and Saudi Arabia had maximum emission while Iran is in the lower ranks. The aim of this paper is to study the possibility of energy saving and carbon dioxide reduction in the KSC of MIDREX plant both experimentally and theoretically. Industrial processes generate more than one-fifth of the global CO₂ emissions. Moreover, most of the global energy is consumed by iron and steel industries that generate more than one-fourth of the CO₂ (roughly 1.6–2.2 billion tons per annum). Two tons of CO₂ emissions have been reported following the production of one ton of steel accounting for as much as 5% of the global total greenhouse-gas emissions [8, 11]. In comparison with the blast furnace process that produces 1.8 tons of CO₂ per ton of iron, approximately 0.5 tons of CO₂ per ton of steel is produced by the natural gas-based direct reduction process [12, 13]. Several approaches have been developed for reduction of the CO₂ concentration in

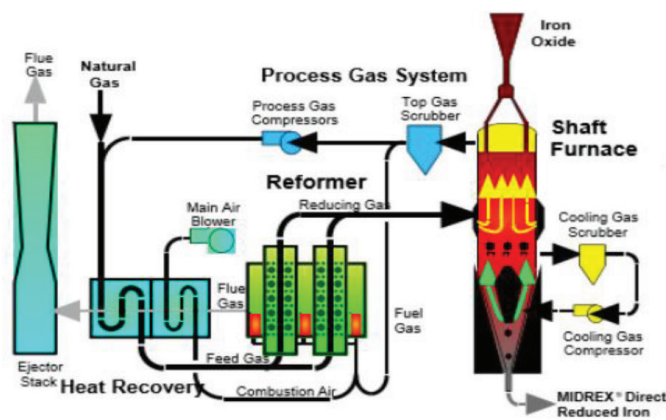


Fig. 1. Direct Reduction Plant and heat recovery system.

the atmosphere [14] including:

1- CO₂ capture and storage; which are accompanied by dangerous compression, storage, and transfer.

2- Capturing CO₂ of the environment, and producing fuels such as methane and methanol. Research activities have been developed for converting CO₂ into fuel and useful compounds using thermo chemical, biological, electro-chemical and photocatalytic approaches [15]. Olajire et al. conducted an expensive research work in this field [16].

3- CO₂ Emissions, ESSAR steel plant in India used hot link system for hot sponge iron and EAF in 2004. EAF reduced electricity consumption by 14%. Additionally, a 6% reduction was observed in natural gas consumption. Direct and indirect CO₂ emissions reduction potential of the technology is 34 Kton/year[18] (Mahlia TMI (2018))(Mahlia TMI (2018))(Mahlia TMI (2018))(Mahlia TMI (2018))(Mahlia TMI (2018))(Mahlia TMI (2018)) [18]. Aspen HYSYS software is usually applied for enhancing the performance of heat exchangers in the process. This software is capable of developing a dynamic analysis of a multi-stage heat exchanger for operational and safety studies and assessing several scenarios. This software is challenged by keeping the optimal reliability and reducing risks while reaching target production levels. The fluid type and percentage of the components in the mixture are the key factors of physical features of fluids (heat transfer coefficients and ρ , μ , Cp, Cv, K value of reaction) in the Aspen HYSYS software. Moreover, the thermodynamic features are determined according to the Peng-Robinson (PR) equation. Note that the site experimental data could specify the confirmation of the results of Aspen HYSYS simulation [19]. The results of simulation show an increase in the temperature of fuel gas with increasing a tube bundle while the stack exhaust gas

temperature exhibited a decreases. It is possible to increase the flow rate of natural gas to the process and increase the production capacity. Thus, energy consumption and emissions of CO₂ are reduced and production capacity is increased [20].

2. Methodology

2.1. Studied Area

In direct reduction iron-making plants, iron oxide pellets are reduced into sponge iron in a gas-based shaft furnace. The pellets are put at the top of the furnace through a hopper and heated as they go downward due to gravity. The oxygen is taken away from the iron oxide through heating by counter-flowing gases containing carbon monoxide (CO) and hydrogen (H₂). These reducing components react with the Fe₂O₃ in the iron ore and convert it into metallic iron, therefore leaving H₂O and CO₂. To produce cold DRI, the reduced iron is cooled and carburized by counter-flowing cooling gases in the lower part of the shaft furnace. The heat recovery system is used for decreasing energy consumption and boosting the effectiveness of reform; thus, declining the temperature of the flue gas from the reformer. The reformer energy effectiveness is boosted by the heat recovery system. Energy is recovered from the flue gas to preheat the feed gas, combustion air, and natural gas. Fig. 2. depicts a schematic of the configuration of Heat Recovery system.

The effectiveness of the reformer can be augmented by reprocessing the top gas from the shaft furnace, which is then mixed with natural gas. This gas is fed into the reformer tubes, a refractory-lined box (reformer). The gas is heated and reformed as it passes through the tubes. The reformed gas containing 90–92% CO and H₂ (other components are CH₄, CO₂, H₂O, and N₂) is

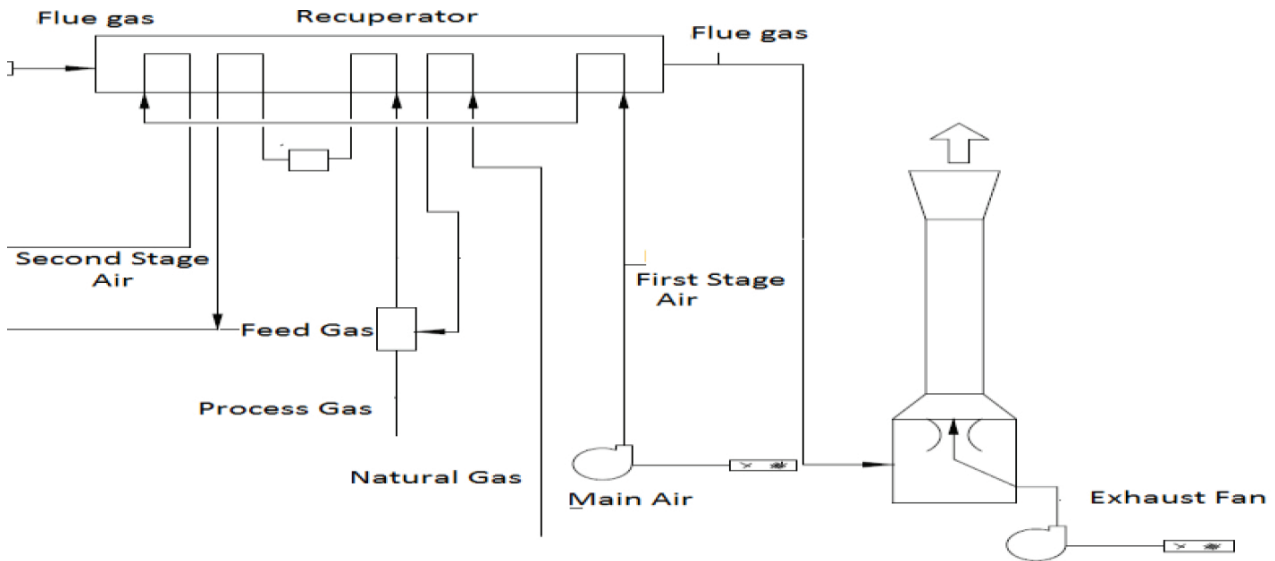
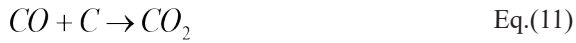
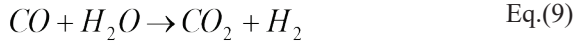
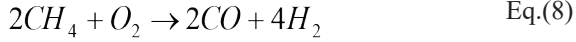
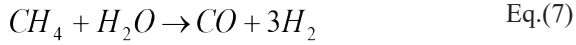
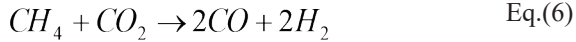


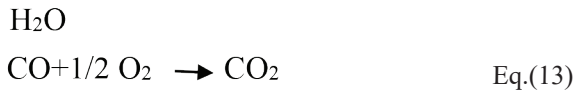
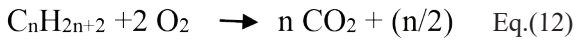
Fig. 2. Heat recovery system pfd.

then fed hot directly to the shaft furnace as a reducing gas.

Reformer tubes, burners and heat recovery are simulated by ASPEN HYSYS software considering the following reactions in reforming[21]:



The following reactions are considered in burners.



2.2. Simulation

The developed model allows the simulation of reforming, burning and heat recovery systems, and the calculation of mass and energy balance by ASPEN HYSYS.

The model can be used to simulate the proposed improvements of energy consumption in an industrial plant to predict any possible energy savings.

Reforming reactions occur simultaneously with endothermic reactions. Heat of reforming reactions is provided by burning natural gas and fuel gas in the

reformer box. Flue gas temperature is high (around 1100 °C). Flue gas is released in atmosphere after pre-heating the air and process and feed gas.

In this study, it is assumed that there is a possibility to preheat the axillary air burner, natural gas, and fuel gas by increasing their temperature from 100 to 250 °C. The effect of reducing the consumption of natural gas in the reformer will be also explored. Flue gas exit temperature difference is 152.2°C (from 484.9 °C to 332.7 °C); hence, the environmental burden is decreased which is environmentally favorable. The information of given line graph has been measured in the plant, before and after of revamp. The results are checked by HYSYS program which show the temperature of outlet stack flue gas.

Fig. 4. shows the flue gas temperature across the heat recovery system length base on HYSYS program and experimental data.

This simulation was performed to improve a plant by comparing install fuel gas preheater bundle in the end of HRS and its data with experimental results. If a tube bundle increases at the end of the HRS, the fuel gas temperature preheated from 48 to 200 °C. Moreover, it reduces the outlet flue gas temperature of HRS, while the exhaust gas temperature from the stack decreases from 311.5 to 261.3 °C. Due to increased energy input to the reformer combustion chamber, the process natural gas flow rate is enhanced by about 20%. The production of the reduced gas is increased by 7%, increasing the production capacity by 7 Ton/hr, implying the ability to increase the tonnage production from the average 103 Ton/hr to 110 Ton/hr. Reducing gas flow rate per to is considered 650 Nm³/hr. According to the results, the amount of CO₂ per ton DRI was reduced to 7.29%. Fig. 8. shows the production capacity, flue gas flow rate, flue gas temperature to stack and carbon dioxide emissions (Ton CO₂/Ton DRI) before (case I) and after (case II) the addition of a tube bundle of fuel gas.

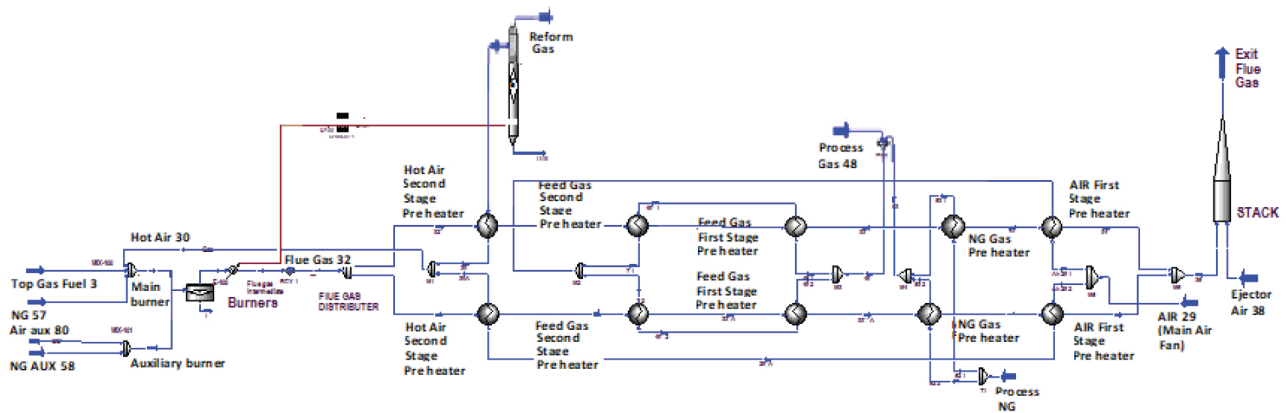


Fig. 3. Reformer and Heat recovery system simulation.

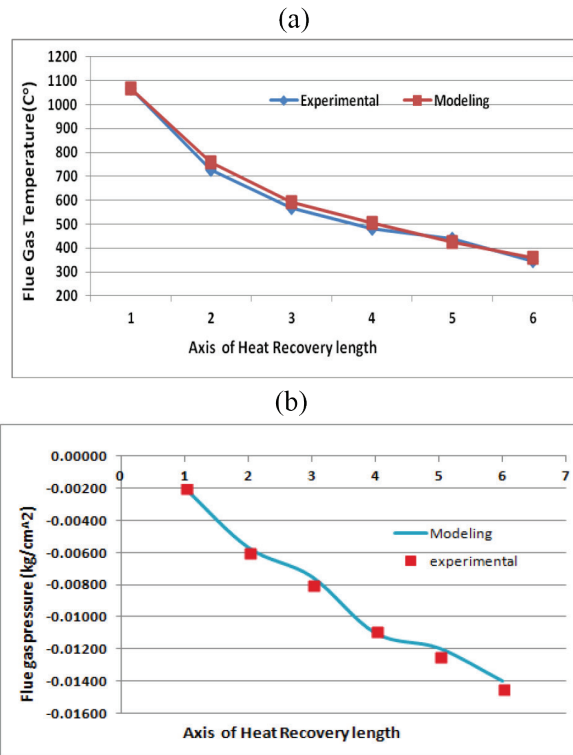


Fig. 4. (a) Comparison of flue gas temperature vs. recuperate axis (b) Flue gas pressure vs. heat recovery system axis.

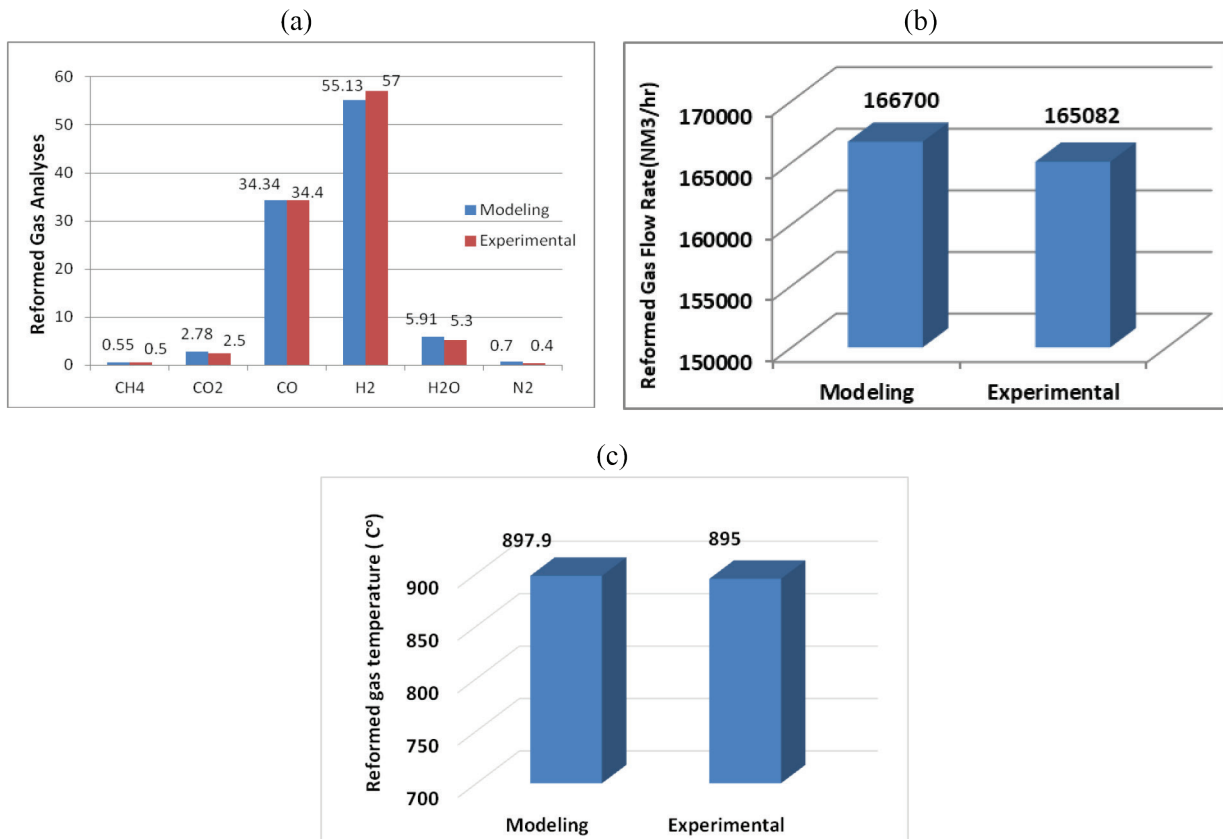


Fig. 5. Comparison between modeled and experimental data (a) reform gas composition (b) reform gas flow rate and (c) reform gas temperature.

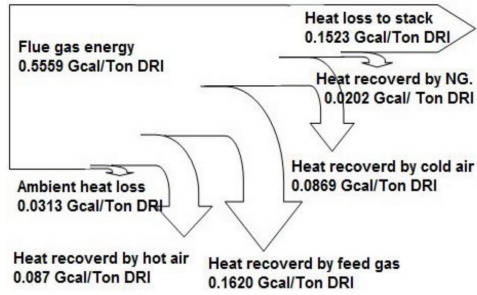


Fig. 6. Energy level in heat recovery system.

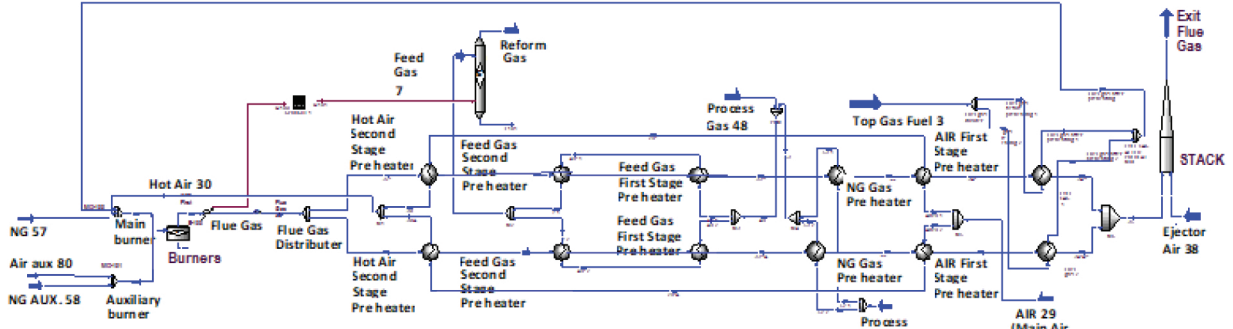


Fig. 7. Reformer and Heat recovery system simulation with fuel gas preheater tube bundle.

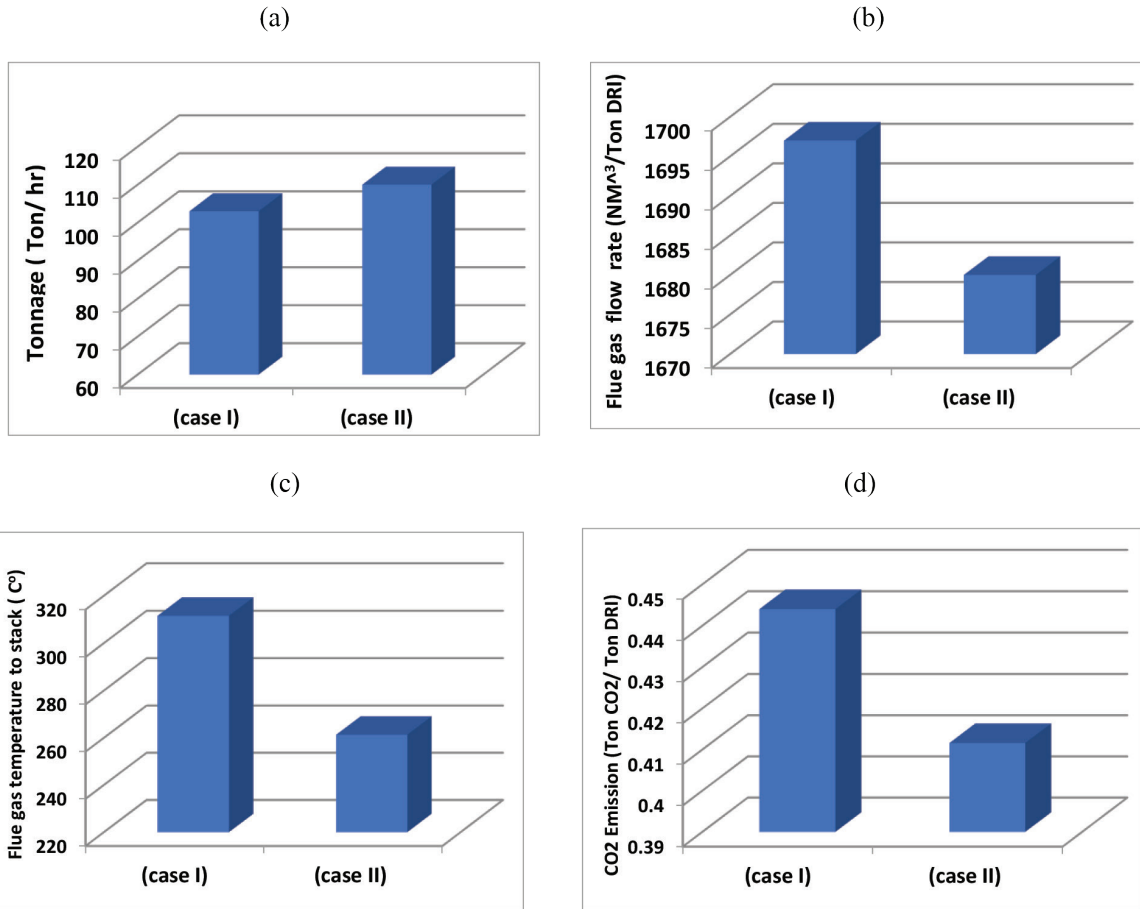


Fig. 8. Comparison of (a) production capacity (b) flue gas flow rate (c) flue gas temperature to stack and (d) carbon dioxide emissions before and after simulation.

For future energy saving and CO₂ emission reduction, following potential of the system is recommended:

-By reducing the temperature of the process gas in the top gas scrubber from 78 to 38 °C, the percentage of water vapor in the process gas is reduced from 19.5% to 4.38%, leading to a decrease in the process gas flow rate. Therefore, these compressors can compress the more gas flow rate. Water vapor is produced by adding another tubular bundle at the end of the HRS. By producing steam and injection in the process gas, feed gas water vapor percentage will be adjusted. In this case, the electrical consumption of the compressor will be decreased.

-Reducing CO₂ emission by CO₂ removal from flue gas and top gas fuel.

-Preheating of natural gas used for transition zone and enrichment.

3. Conclusions

The present research compares simulation and experimental studies on reform gas and flue gas temperatures, under different tube bundle increases, at the end of the HRS. The results show an increment in the fuel gas temperature while the exhaust gas temperature from the stack decreased. It is possible to increase the flow rate of natural gas to the process and increase the production capacity. Thus, energy consumption and CO₂ emissions are reduced while raising production capacity.

The following benefits per ton DRI can be achieved: Production capacity increased from 103 Ton/hr to 110 Ton/hr;

Fuel gas temperature preheated from 48 to 200 °C;

Stack exhaust gas decreased from 311.5 to 261.3 °C

Process natural gas flow rate increased by about 20%

Acknowledgment

We would like to thank the KSC management for providing us with the relevant and essential information for this research. It is important to mention that this research received no specific grant from any funding agencies in the public, commercial, or not-for-profit sectors.

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