THE USE OF COAL GASES AS AN ALTERNATIVE FUEL FOR ENERGY SUPPLY

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Coal gasification

Coal gasification is a process to produce syngas fuels. Syngas is a mixture mainly consisting of carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2), methane (CH_4) and water vapor (H_2O). Historically, coal was gasified using early technology to produce coal gas (also known as "town gas"), which is a combustible gas traditionally used for municipal lighting and heating before the advent of industrial-scale production of natural gas.

Natural gas is replaced by synthetic fuels, which are generally produced by gasification process, due to depletion of fossil fuels including natural gas resources. If synthetic fuel is produced by an air-blown gasification process, it is called as low calorific value syngas and may be used mostly in IGCC (Integrated Gasification Combined Cycle). Air is directly blown over the coal in a gasification reactor resulting in the production of the syngas that is composed chiefly of high amounts of nitrogen and carbon monoxide as well as a smaller amount of hydrogen as a combustible gas.

Alternatively, coal-derived syngas can also be converted into transportation fuels such as gasoline and diesel through additional treatment via the Fischer-Tropsch process or into methanol which itself can be used as transportation fuel or fuel additive, or which can be converted into gasoline by the methanol to gasoline process.

A review of the use of coal gases as an alternative fuel

Dependence on fossil fuels has not declined recently even though most attempts are tried to find clean and inexhaustible energy resources. Because, the fossil fuels are widely used in industrial systems, domestic applications, furnaces and etc. to produce electricity or to heat any places. Especially, electricity is mostly still generated by fossil fuels at a rate of over 80% nowadays. However, rapid depletion of fossil fuels continues all over the World. Readily available fossil fuels are getting difficult. Environmental limitations are more stringent as fossil fuels are quite pollutant. For example, coal includes N and S as pollutant as well as combustible components. Coal as solid fuel is a huge challenge due to containing pollutant and burning difficulties. Because of these justifications, coal-derived fuels are very attractive in terms of pollutant and burning technologies.

Coal-derived fuels are gaseous fuels and are mostly known as syngas or synthesis gas due to gasification products. But, coal-derived gases are not only syngas. Coke oven gas is also known as coal-derived gas because that gas is obtained from coal during the carbonization. The other coal-derived gases are generally known as town gases that are principally produced by mixing with coke oven gas and gasification products. Common characteristic of coal-derived gases is to be chiefly composed of hydrogen which includes high amounts of energy. In addition to this, coke oven and town gases comprise of near about methane of 25 % that is essential component of natural gas. For these reason, these fuels have named as hydrogen-rich coal gases in the present study. Hydrogen-rich coal gases are entirely alternative to natural gas when taking into account these reasons.

Due to the growing interest regarding blending fuels such as syngas, coal gas or any blending fuels, many researchers investigate these fuels. Although many research groups have studied related to blending fuels combustion, these studies are very restricted in the literature. As researchers in this field, Joo et al. [1] have studied NO_X pollution of the syngas using artificial neural networks. This study has been performed in model gas turbine combustor. Flame temperature and NO_X level are determined as 1350 K and 25 ppm for fuel containing 75% hydrogen and 25 % methane under stoichiometric conditions. Khalil et al. [2] have designed, manufactured and performed performance experiments of low calorific value fueled in a distributed combustor under colorless distributed combustion conditions. It is concluded that low levels of NO (9 ppm) and low CO (21 ppm) has been achieved under non-premixed colorless distributed combustion conditions. Liu et al. [3] determine the effect of hydrogen and helium addition to methane on soot formation. Results show that helium addition is more effective than hydrogen addition for soot reduction. Kutne et al. [4] have experimentally investigated combustion behaviors of low calorific syngas mixture. These experiments have been implemented under the three-thermal power and different equivalence ratios in a range of 0,4 – 0,6. It is demonstrated that changes in combustion conditions such as equivalence ratio and thermal power has slightly influenced the flame shape. Ghenai [5] have determined the effect of the variability for syngas components and heating value on combustion performance and emissions. It is exhibited that the flame temperature increases with increasing hydrogen amounts in syngas. It is also concluded that the maximum flame temperature emerges as 2200 K under methane combustion conditions. Ilbas [6] have modelled the hydrogen-hydrocarbon combustion to investigate the effect of thermal radiation and radiation models on combustion characteristics. Ilbas have performed modellings without radiation and with the P-1 radiation model and with the discrete transfer radiation model. Ilbas finds out that the usage of a radiation model is highly effective for more accurate prediction. Habib et al. [7] have studied combustion and emission performances of syngas in a package boiler. Syngases having different components (67% CO:33% H2, 50% CO:50% H2 and 33% CO:67% H2) have been modelled and according to the predictions, syngas including 33% CO:67% H2 have been determined to have the shortest flame in comparison to the other syngas compositions. Louis et al. [8] have developed a model to predict nonadiabatic combustion of syngas. They have also implemented the experiments for fuel including 40% CO, 40% H2 and 20% N2 and compared with the predictions. They conclude that the predictions are in good agreement with the measurements. Ranga Dinesh et al. [9] have examined the combustion characteristics of some syngases which comprise of H2/N2 and H2/CO. They have modelled turbulent nonpremixed syngas flames using 3D large eddy simulations and used the laminar flamelet combustion model. The downstream motion is highly affected depending on fuel components. This is because of the differences in diffusivity in case of presence of hydrogen in the fuel. Lee et al. [10] have conducted an experimental study to investigate the combustion performance of syngas including hydrogen and carbon monoxide. The results are also compared with methane combustion. It is concluded that the maximum NO_X formation occurs during the hydrogen combustion. Lee et al. [11] have investigated the effect of N_2, CO_2 and steam on combustion performance of H_2 and CO in another study. They have found out that NO_X emissions decrease as the amount of diluents is increased. They have also revealed that the best diluent is steam because managed to reduce NO_X and CO emissions. Syred et al. [12] have studied flashback and blow off limits of different fuel blends that are methane, methane/hydrogen blends, pure hydrogen and coke oven gas. Coke oven gas and pure hydrogen behave prominently different as compared with the methane and methane containing up to 30 % hydrogen. Yilmaz and Ilbas [13] have experimentally examined hydrogen-methane blending fuels in a combustor. The experiments have been performed under different combustion conditions. The results show that the flame temperature increases whereas CO and CO_2 emissions decrease in flue gas when the hydrogen amount is increased in the fuel. Ziani et al. [14] have predicted combustion of CH_4-H_2 blending fuels using the PDF approach. They have used three turbulence models that are k-ε model, modified k-ε model and RSM model. They have determined that the modified k-ε model is the best selection for this kind of flame. Hasegawa et al. [15] have explored combustion characteristics of gasified coal fuel. These gases have a calorific value of 4-13 MJ/m^3. It is evidenced that the flame temperature increases as the fuel calorific value rises. They have also declared that NO_X level is higher for fuels containing nitrogen such as ammonia. Dattarajan et al. [16] have developed a combustor that can be burned the producer gas. This combustor has tangential fuel and air inlets that can be provided swirling flow. The results show that the presence of stable flame and complete combustion of fuel have been achieved in this study. Lee et al. [17] have conducted an experimental study related to combustion characteristics of coal-derived syngas. They used two different syngas type coming from Taean IGCC plant in Korea and Bugenum IGCC plant in Netherlands. They have compared with each other for cases without and with nitrogen dilution. İlbaş and Karyeyen [18] have modelled the combustion behaviors of the hydrogen-enriched low calorific value coal gases in their previous study. Results indicate that the flame temperature rises as the amount of hydrogen in the fuel is increased.

Although there are some studies about combustion characteristics of coal gas or syngas as mentioned above, many challenges still remain in this field due to containing high amounts of hydrogen in coal gases. For example, combustor and burner geometries must be resigned to provide stable flame of coal gases depending on coal gas composition and examined the inside of the combustor to understand the combustion behaviors of the coal gases. A new type burner coupled with the combustor has been designed and manufactured to achieve flame stability and to reveal the combustion behaviors of the hydrogen-rich coal gases.

The hydrogen-rich coal gases compositions are given in Table 1 in volumetric basis. Coke oven gas has high amount of hydrogen and methane as shown in Table 1. Therefore, it has the maximum heating value among the hydrogen-rich coal gases. As can be also seen in Table 1, water gas is a considerable different coal gas due to containing high amount of carbon monoxide that can affect the flame structure. However, the heating value of that gas is low compared to the others as it includes miserable amount of methane.

Table 1. The hydrogen-rich coal gas compositions [19]

	H2 (%)	CH4 (%)	CO (%)	CO2 (%)	N2 (%)	LHV (kcal/m3)	Density (kg/m3)
Coke Oven Gas	55	27	6	2	10	3678	0,452
Town Gas, I	51	21	18	4	6	3434	0,539
Town Gas, II	44	24	12	4	16	3335	0,600
Water Gas	50	0,5	40	5	4,5	2385	0,659

Conclusions

- The use of coal gases in power stations and other aplications as an alternative gas fuel is an advantage for economy in the following ways.
- Turkey is a country importing 98% of its natural gas consumption. The use of coal gases will decrease the amount of natural gas importation.
- The cost of building the coal gas power stations are going to be lower than the cost of the coal power stations.
- The emission of air pollutants from the use of coal gases will be lower than that from the use of coal.
- In one of our research study, axial and radial temperature distributions have been determined in the combustor and compared with each other. The maximum flame temperature has emerged for the coke oven gas flame due to the presence of high amounts of hydrogen and methane in the fuel.
- In another work, it is concluded that the presence of hydrogen in the fuel affects considerably the high temperature regions of the coal gases in the combustor. In particular, this situation has showed up at radial temperature measurements towards the combustor outlet.
- It is revealed that NOX formation is considerable level for hydrogen-rich coal gas flames because the coal gases include a trace of molecular nitrogen and this nitrogen contributes to NOX formations due to the thermal NOX mechanism.
- It is demonstrated that molecular CO2 and CO gases in the fuel cause significantly excess CO2 and CO formations in the flue gas.
- Finally, in our research studies, the hydrogen-rich and low calorific coal gases have been properly burned in a new type burner coupled with the combustor. Therefore,

it is proved that the hydrogen-rich coal gases and coal gases in general as alternative fuels may be burned by means of the new type burner.

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