Clean Power Generation from Wastes using High Temperature Air Combustion Technology

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1. Introduction

The flameless oxidation of fuels or high temperature combustion is new and innovative means for the conversion of chemical energy to thermal energy of fuels. In excess enthalpy combustion the thermal energy released is fed back to the fresh reactants so that the temperatures obtained with excess enthalpy combustion are much higher than its counterpart with normal temperature air. However, flameless or colorless oxidation of fuels is obtained by using the fundamental design principles of High Temperature Air Combustion (HiTAC) technology in which high temperature combustion air at low oxygen concentration (obtained by heat and gas recirculation) is used in the combustion chamber. High temperature of the air is obtained by preheating the air with the exhaust gases from a furnace or reactor. The peak temperature in the flame zone is much reduced with the use of diluted low oxygen concentration combustion air even though the air is preheated to high temperatures. This low oxygen concentration (or diluted) air is obtained from the exhaust gases by recirculating part of the combustion products into the incoming hot combustion air. The combustion air is preheated to temperatures in excess of 1000C, depending on the application, using honeycomb type or ceramic ball type heat exchangers. Honeycomb type heat exchangers are more effective than the ceramic ball type heat exchangers. Most of the previous research activities have been focused on gaseous fuels, such as, methane, propane, liquefied petroleum gas (LPG) and process gases. The HiTAC technology has also been demonstrated to provide significant benefits with wastes and low grade fuels for applications to various processes, and industrial and power systems.

Waste generation is one of the main environmental problems faced by almost all countries around the World. The waste problem is of serious concern in almost all the developed countries, including UAE. Stable and increased annual solid waste generation imposes new challenges for waste management. In the traditional solution of landfill one can find either new terrains or overload the existing landfills. One of the solutions is to decrease the volume of wastes disposed at landfills sites by recycling selected materials (e.g., glass, metals, paper, etc.) or use some thermal destruction method to destruct the waste. Incineration is a feasible method since municipal solid wastes are characterized by an average heating value of 5,500 Btu/lb (or 12,793 J/g). Selected wastes can also be used as co-firing fuels in furnaces and boilers. Some of the methods in thermal destructive option include pyrolysis and gasification of wastes. Gasification is thermochemical conversion of any solid, liquid or gaseous carbonaceous material by means of free or bound oxygen at increased temperatures, usually in the range of 700-1800^{o}C. High temperature air combustion technology offers clean energy conversion of wastes and low grade fuels to gaseous fuels.

2. Key Features

Highly preheated and oxygen deficient air as the oxidizer using regenerative combustion systems has provided strong interest worldwide for many industrial and power systems. Various names have been given to this combustion technology includes: mild combustion, colorless combustion, flameless oxidation, distributed combustion. The technique, named High Temperature Air Combustion (HiTAC), has demonstrated evidence of significant benefits as compared to traditional combustion techniques. They include: significant energy savings, downsizing of the equipment and pollution reduction. Fuel energy savings directly translates to a reduction of CO_2 and other greenhouse gases to the environment. A higher and more uniform heat flux distribution provides reduced size of the equipment in industrial installations or increased production rate. Waste heat from a furnace in high temperature air combustion technology is retrieved and introduced back into the furnace using regenerator. These features help save energy, which subsequently also reduce the emission of CO_2 (greenhouse gas) to the environment. No other previous combustion technology has provided such significant and simultaneous accomplishments.

Qualitative and quantitative results will be presented for several gas-air diffusion flames using high temperature combustion air. A specially designed regenerative combustion test furnace facility, built by Nippon Furnace Kogyo, Japan, was used to preheat the combustion air to elevated temperatures. The flames with highly preheated combustion air were significantly more stable and homogeneous (both temporally and spatially) as compared to the flames with room-temperature combustion air. The global flame features showed the flame color to change from yellow to blue to bluish-green to green over the range of conditions examined. In some cases hybrid color flame was also observed. Under certain conditions Green flame and also flameless or colorless oxidation of the fuel has also been demonstrated. This has not been observed with hydrocarbon fuel before. Information on global flame features, flame spectral emission characteristics, spatial distribution of OH, CH and C_2 species and emission of pollutants has been obtained. Low levels of NO_x along with negligible levels of CO and HC have been obtained using high-temperature combustion air. The thermal and chemical behavior of high-temperature air combustion flames depends on fuel properties, preheat temperature and oxygen concentration of air. Waste heat from a furnace in high temperature air combustion technology is retrieved and introduced back into the furnace using regenerator. These features help save energy, which subsequently also reduce the emission of CO_2 (greenhouse gas) to the environment. Flames with high temperature air provide significantly higher and uniform heat flux than normal air, which reduces the equipment size or increases the process material throughput for same size of the equipment. The high temperature air combustion technology can provide significant energy savings (up to about 60%), downsizing of the equipment (about 30%) and pollution reduction (about 25%). Fuel energy savings directly translates to a reduction of CO_2 and other greenhouse gases to the environment. Examples will be shown on the high temperature steam gasification of paper, woodchips and other fuels using the basic principles of high temperature air combustion technology to produce clean syngas while minimizing pollutant emissions, hydrocarbons, tars and solid residue by-products. The gaseous fuel flame characteristics with high temperature combustion air have been examined in the test furnace facility using several advanced diagnostics. The flame stability limits as a function of air-preheat temperature and oxygen concentration in air is shown in Fig. 1. The flame stability limits increase significantly at high air preheats. It is to be noted that very wide flame stability limit occurs even with low oxygen concentration air. Under HiTAC conditions (high temperature and low oxygen concentration) the flame stability are infinite.

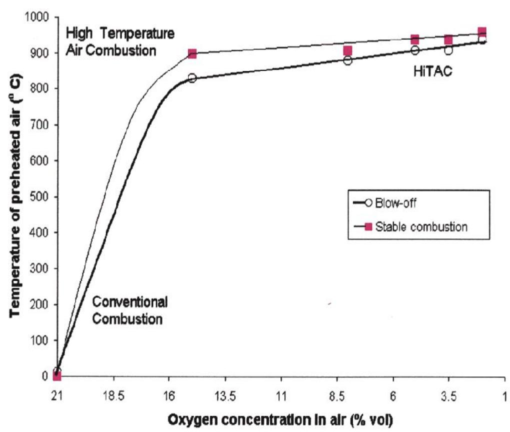

Fig. 1. Stability limits of propane air flames under high temperature air combustion conditions.

The flame structure was found to depend on air preheat temperature and oxygen concentration. The diagnostics used here include direct flame photography, spectrometry, gas analyzers for NO_x, CO, CO_2 and hydrocarbons, and flame signatures for OH, CH, C_2 using ICCD camera fitted with narrow band filters. In this paper experimental data on several non-premixed gas-air flames are presented using high temperature combustion air.

Waste gasification

Several different kinds of feedstock, representative of wide group of wastes, have been examined with steam at temperatures in the range of 700 to 1100^{o}C using high temperature air combustion technology. The steam produced was used to gasify the materials. The high temperature gasification produced hydrogen-rich syngas as shown in Fig. 2. Main components in the syngas produced under different gasification conditions are shown in Fig. 3. The gas produced is clean and can be used in many power systems. Further processing of the gas can allow near pure hydrogen gas production. If somewhat low temperature gasification temperatures are used one can obtain methane and other hydrocarbon-rich syngas

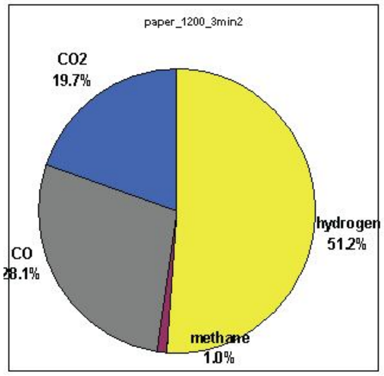

Fig. 2. Syngas composition of waste at gasification at high gasification temperatures.

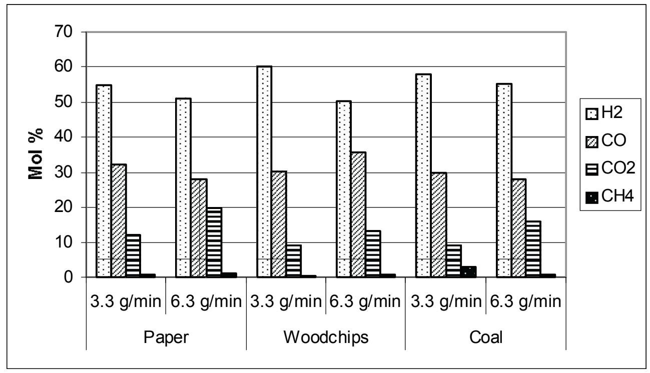

Fig. 3. Syngas composition from three feedstock at two steam flow rates at high temperature gasification.

that can be further processed to produce liquid fuel. In all cases the goal has been to produce clean syngas without the production of tars and pollutants.

High temperature air combustion technology has also used for fuel reforming of hydrocarbon fuels. In this case the yield of hydrogen is much dependent on the temperature control of the reactor tubes where the fuel reforming process occurs. Controlled temperature of the reformer tubes is critical for providing high yields of hydrogen. With the basic and applied research efforts on fuel reforming, a pilot plant unit was built to develop the process. The results obtained are now used in a commercial scale plant that has been in successful operation for some time in Japan with good success. Further details will be provided in the presentation.

3. Conclusions

High temperature air combustion has very wide stability limits and far more thermal field uniformity than ever demonstrated before on any type of combustor geometry and configuration. One can get thermal field uniformity of better than 25K in the entire combustion zone so that the entire combustion zone is a near isothermal reactor. The use of HiTAC has provided demonstrated results for the clean conversion wastes and low grade fuels, in addition to normal hydrocarbon fuels, to thermal energy without use of any post treatment device for pollution reduction. The emission of CO, hydrocarbons and NOx is very low. The technology also provides significant energy savings as much of the exhaust heat is recirculated back into the combustion zone. The wastes and other low grade fuels can be converted to hydrogen-rich syngas. The results show that high temperature steam gasification process can produce hydrogen-rich syngas containing over 50 % hydrogen with minimal CO_2 and hydrocarbons. At sufficiently high gasification temperatures, tar production can be almost eliminated from the gasification products, thus making the process attractive for the clean conversion of wastes and other solid hydrocarbon materials to clean syngas with high hydrogen content. A tenfold reduction in tar residue was obtained at high temperature steam gasification, as compared to low temperatures.

4. References and Bibliography

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Speaker's Biography

Ashwani Gupta is Professor of Mechanical Engineering at the University of Maryland, MD, College Park, USA. He received his Ph.D. in 1973 and D.Sc. in 1986, both from Sheffield University, UK. He has co-authored three books and over 400 papers. He is the recipient of AIAA Energy Systems award, and Propellants and Combustion award, the ASME George Westinghouse Gold Medal award, James Harry Potter award and James Landis award, and University of Maryland President Kirwan Research award and College of Engineering Research award. He has also received several best paper awards from AIAA and ASME. He is a Fellow of AIAA, ASME, and the Institute of Energy, U.K. He is an Associate Editor for AIAA J. Propulsion and Power and Co-editor of the Environmental and Energy Engineering series of books published by CRC Press, USA.