energy&fuels

DECEMBER 2016
VOLUME 30 ISSUE 12
ENFUEM 30(12) 9981–10954 (2016)
ISSN 0887-0624
Registered in the U.S. Patent and Trademark Office

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Efficiency and Sustainability

Catalysis and Kinetics

Combustion

Process Engineering

Communications

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Review on Premixed Combustion Technology: Stability, Emission Control, Applications, and Numerical Case Study

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ABSTRACT: Recently, premixed combustion dominated the field of combustion research worldwide. The current work is a review that addresses the stability, approaches, and emission control of premixed flames in different applications. The study addresses the recent developments made to overcome the combustor operability issues, including flame stability and emission control. The influences of oxidizer and fuel flexibility using oxy-fuel combustion and hydrogen enrichment on combustion efficiency and flame stability are investigated. Furthermore, the influences of operating and combustor design conditions on flame characteristics are discussed. Recent developments in swirl-stabilized combustor are analyzed and summarized. The effect of premixing on emissions is investigated, considering a variety of design and operating conditions in different applications. As per this survey, the application of fully premixed combustion in the industrial area is even so defined; all the same, promising designs are under development. The challenges regarding the application of the premixed combustion technology in the industrial field are discussed. The role of numerical CFD techniques to predict the reacting flow field and heat release in premixed combustion mode is addressed. A numerical case study is presented to address the premixed combustion characteristics in a swirl stabilizer gas turbine combustor.

1. INTRODUCTION

Power generation industries rely mainly on combined cycle steam power plants and gas turbine engines for energy production from gaseous fuels, thanks to the new heat recovery technologies which utilize the heat rejected to the atmosphere and convert it into power, which, in turn, increases the overall thermal efficiency of combined cycles to up to 60%.[1] Hence, the importance of durable and low emission gas turbine combustion systems is significantly developing. Many combustion technologies have been introduced to industries for the sake of environmentally friendly perspectives. For instance, a recent technology of the integrated gasification combined cycle (IGCC) encourages the utilization of hydrogen enrichment for many power generation strategies. IGCC systems commonly utilize syngas with different compositions from solid fuels such as coal, waste products, or biomass with different gasification processes.[2−4] These IGCC systems have lower CO_2 emissions from power generation.

During the last three decades, lean premixed combustion (LPM) technology became the power generation standard in many applications. This can be ascribed to the fact that it enables lower NO_x and CO emissions. Flame instability in premixed combustion is one of the recent major issues, especially in gas turbine applications. Therefore, homogeneous mixing of air with methane under extra lean conditions with the aid of hydrogen enrichment, as an approach for enhancing flame stability, will result in improvement in flame stability and reduction in NO_x emissions. However, operation under hydrogen enrichment brings its own challenges in terms of flashback phenomenon, due to its higher flame temperature, that causes overheating of the burner components.[5−7] Accordingly, combustion operability issues are too significant and compose the focus of the current review paper.

Gas turbine engines for power generation have used combustors operated with diffusion flames due to their reasonable performance and higher stability characteristics. Unfortunately, this kind of combustors is no longer preferred due to the associated unacceptable concentrations of NO_x. The increase in the restricted environmental regulations encouraged researchers to develop combustors that can meet such restrictions.[8,9] Hence, new technologies and concepts have been introduced in the last two decades to the stationary gas turbines for the power generation industry, such as LPM and catalytic combustion.[10,11] The catalytic combustion is found to be highly expensive and less durable with low safety as well, while in LPM, the air and fuel are introduced upstream to a form homogeneous mixture. In gas turbines, the combustion chambers are operated under excess air dilution to decrease the flame temperature and, then consequently, the thermal NO_x emissions are significantly reduced and in some applications they could be virtually eliminated. However, the LPM is associated with combustion instabilities as a result of the unsteady flow oscillations. This is a common problem while operating the gas turbines under LPM.[12] At certain levels, these oscillations could cause operation interference with extreme oscillations. This can lead to system failure as shown in Figure 1. The figure compares a damaged gas turbine burner due to combustion instabilities compared to a new burner.[13]

Received: September 19, 2016
Revised: November 1, 2016
Published: November 16, 2016

DOI: 10.1021/acs.energyfuels.6b02386
Energy Fuels 2016, 30, 9981−10014