SIMULATION STUDY ON THE EFFECT OF FUEL-INLET ANGLE ON THE SWIRLING COMBUSTION

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A project report submitted in partial fulfilment of the
requirements for the award of degree of
Master of Science (Mechanical Engineering)

Faculty Mechanical Engineering
Universiti Teknologi Malaysia

January 2017

ABSTRACT

Swirling flameless combustion has been highly concerned nowadays due to ultra-low NO_x and pollutant emission while delivering low temperature differential and stable combustion. Thanks to the rapid developed computational ability, simulation study has solved higher complexity of computational fluid dynamics problems for commercial and research aspect. In this project, the effect of swirling flameless combustion has been investigated by using computational method. In this study, a new setup has been modelled by varying fuel-inlet angle and to investigate the effect of swirling flameless combustion based on non-premixed swirling combustion furnace SFR 42 configuration. Non-premixed swirling combustion furnace SFR 42 is an asymmetric swirling combustion furnace that allows rapid mixing between air and fuel upstream of the reaction zone. The design of non-premixed swirling combustion furnace introduces visual characteristics of a premixed flame. This study shows that by changing the fuel-inlet angle to 45 degree tangentially, it will produce nine times lower NO_X emission compared to fuel-inlet angle 5 degree tangentially. Fuel-inlet angle sloped 45 degree tangentially swirling combustion also produced peak temperature approximate 1400 K which has similar result compared to other cases. This condition helps to improve combustion efficiency and less pollutant emission. Temperature result of SFR 42 was taken as data validation of this project.

ABSTRAK

Baru-baru ini, pembakaran tanpa api telah menarik perhatian ramai kerana dapat menghasil kandungan NO_x dan pencemar yang rendah serta masih dapat menyampaikan pembezaan suhu yang rendah atas dengan pembakaran yang stabil. Dengan keupayaan computasi yang cekap pada zaman ini, kajian simulasi dapat menyelasaikan masalah dalam bidang computasi dinamik bendalir dengan cekap untuk kegunaan komersial dan penyelidikan. Dalam projek ini, kesan pembakaran tanpa api akan dikaji dengan prosedur baru. Kajian ini menggunakan sudut salur masuk bahan api yang berlainan berdasarkan non-premixed pembakaran tanpa api SFR 42 konfigurasi. Non-premixed pembakaran tanpa api SFR 42 konfigurasi adalah pembakaran simetri untuk membenarkan kecampuran udara segar dengan bahan api. Rekabentuk pembakar non-premixed SFR42 konfigurasi akan menghasil ciri-ciri bersama dengan pembakar premixed. Kajian ini menujukkan penghasilan NO_X dapat dikurangkan sebanyak sembilan kali dalam kes 45 darjah sudut salur bahan api berbanding dengan kes 5 darjah. Pertukaran sudut salur masuk bahan api ke 45 darjah dapat menghasilkan suhu puncak pembakaran sebanyak 1400 K bersama dengan kas kajian lain. Keadaan ini akan meningkatkan kecekapan pembakaran dan menurangkan perlepasan pencemeran. Keputusan kajian suhu kes SFR 42 akan diambil sebagai pengesahan data dalam projek ini.

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INTRODUCTION

1.1 Studies of Swirling Combustion

1.1.1 Study of Swirling Jet

A lot of aerodynamics studies of swirling flow has been carried and published nowadays and accounted as references. An orifice upstream flow imparted from rotating motion creates swirling effect. A strong swirling jet will create the effect of destructive axial pressure gradient. These effects will result in reverse flow along the axial axis and creates internal recirculation zone (IRZ) which is also known as vortex breakdown. Many types of burners and combustion engines used swirling jet effect to control the flames in combustion chamber in order to promote better combustion efficiency. For instance, a lower NO_X emission can be yielded by independently adjusting the amount of swirl and flow for a low NO_X burner. The final induced swirling flow pattern is shown in figure 1.1. External recirculation zone (ERZ) is observed between the flame brush and swirl can. ERZ will cause outflowing jet are recycling cold products and inducing swirl can wall are much cooler. System stability may be increased based on recirculation of products within the flame.

The study from Tangirala et al. was found that by increasing the heat release accelerates the gas which helps to adjust the recirculation of products. By increasing heat release, it increases the flame stability, turbulence kinetic energy levels and the products recirculation. The recirculation process was driven by heat release which includes accelerations of gas and gas expansion.

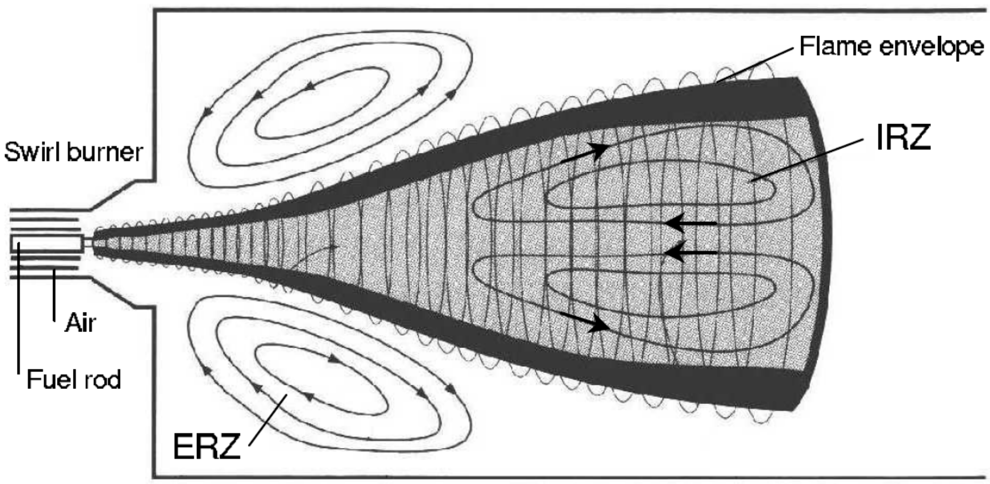

Figure 1.1 Flow pattern developed by a swirl burner (Vanoverberghe 2004)

Some swirl effect studies and experiments were conducted by Chen and Driscoll (1988), Chen et al. (1990). The main purpose of the study was to improve flame stability and mixing for swirl numbers up to one. The recirculation zone has been established at swirl number (S > 0.6). Further increasing the swirl number, it will reduce the flame stability as the flame in zero-axial-velocity line failed to overlap lower-speed flow at the recirculation zone. One of the disadvantageous of excessive swirl in burner is that the flame will move upstream due to increased of adverse pressure gradients.

Maximum possible turbulence levels can be obtained by improving mixing and shortening flame length in order to reduce NO_X emissions. It does improve the flame stability too. There are two locations where maximum levels of turbulence kinetic energy that often occurred, which are eye of vortex of the internal recirculation zone and forward stagnation zone of the internal recirculation.

In general the ideas of swirling jet flames study includes the issues of flame stabilization, NO_X emission, combustion chamber effects, flow field and technology and technique for measurement.

1.1.2 Computational Fluid Dynamics Development

A lot of new numeric methods are developing and evolving to solve problems and optimize designs. The aim of numeric methods nowadays is moving towards to more realistic modelling, increasing result accuracy and increasing the calculation performance. However, no matter how advance the computational numeric methods have been taken for calculation, experimental result still needs to be compared with simulation result. An important topic to be discussed for computational fluid dynamics simulation is to perform grid sensitivity of studies to make sure the result is independent.

In this study, the simulation model will be carried out by using ANSYS FLUENT 16 commercial software. The scope of simulation is to evaluate the effect of inlet-fuel angle of swirl combustion.

1.2 Non-premixed Asymmetric Swirling Flameless Combustion Case SRF 42

This swirling combustion furnace case SFR 42 design adopts the previous study proposed by Raid A. Alwan (2016). The concept of vortex flame provides stable flame by stabilizing the reaction zone on the boundary of a forced vortex field, which allows mixing between air and fuel upstream of the reaction zone. Interaction of axial and tangential air velocity components will generate swirl motion and axial thrust of the reacting flow within the combustion furnace.

The air flow is divided by two streams. One stream passes axially. The second stream passes tangentially. Swirl vortex flow is induced by the interaction between tangential air and circumferentially fuel. Central recirculation zone is also created by strong swirling effect in the core of the combustion furnace. The fuel is injected by 10 ports of fuel-inlet which are distributed circumferentially along the combustion furnace basement and an extra concentric axial port as shown in Figure 1.2. On the other hand, air is injected by four tangential ports and twelve co-axial ports. The configuration above successfully introduced a swirl component in the central region of the combustion furnace, along with a secondary co-axial fuel stream.

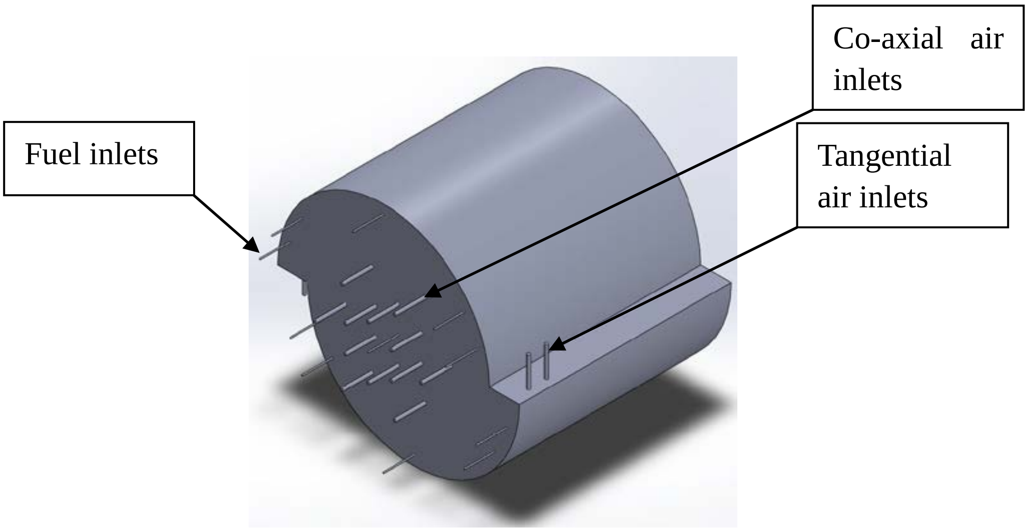

Figure 1.2 Asymmetric swirling flameless combustion case SFR42

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