CHAPTER 1

INTRODUCTION

Study of combustion process in all combustion systems is one of the most important and complex problems. Generally, the main objective is to achieve a stable combustion proves that appears in industrial furnaces, gas turbine combustors and boiler furnaces. The conditions of reaching stable flame differ according to the type of flame.

This part introduces the basic definitions of flame types and their classifications. The stability concepts and stability methods are indicated. Among these methods are two opposed flame stability means, bluff body and sudden expansion. All these methods are discussed in detail in the following section.

1.1 Flame Definition

The flame is self-sustaining propagation of a localized combustion zone at subsonic velocity. Flame can be classified based upon how the fuel and oxidizer reach the reaction zone; these are non-premixed flames and premixed flames. Also, the flame can be classified according to the flow characteristics of incoming reactants into turbulent and laminar flames. A detailed description of these two categories will be discussed.

a) Non-premixed flames

In this type, the fuel and oxidizer are coming in either side of the reaction zone and the products go out of the reaction zone. In such flames the reaction zone is established at a location where the total enthalpy of the

reactants present balances the total enthalpy of the products generated plus any energy losses. Thus, for non-premixed flames the reaction ideally takes place at stoichiometric conditions thereby producing the maximum possible flame temperature for a given combination of the reactant species.

b) Premixed flames

The flames in this type can be classified into; fully premixed flames and partially premixed flames as described below:

i) Fully premixed flames

In this type the fuel and the oxidizer are thoroughly mixed prior to reaching the reaction zone, also known as flame front. In these flames the position of the reaction zone is not defined by the diffusion of reactants, but occur due to balancing of the local convective velocity of the reactants with the rate of consumption of the reactants popularly known as the flame speed. Based on the stabilizing method, fully premixed flames can be burned at equivalence ratios other than 1. Thus, lower flame temperatures can be achieved in this type of flames.

ii) Partially premixed flames

Here the fuel is injected into the oxidizer flow just upstream of the flame or part of combustion air is added to the fuel. Under such conditions, there is not enough time for the fuel and oxidizer to mix thoroughly and thus, concentration gradients across the flow are generated in the reactants stream that enter the flame front.

1.2 Flame Stabilization

Flame stabilization is of fundamental importance in the design, the efficient performance and the reliable operation of high-speed propulsion

systems. In gas turbines and other combustion equipment, the velocities at which the gases flow are much higher than the maximum flame speeds and the burner should be insensitive to large excess air as the power output is regulated by the fuel mass flow rate.

It is found that, the flow velocity and burning velocity are the most important factors that the flame stabilization depends on. The burning velocity should be equal to the flow velocity for a stationary flame front. In house and industrial applications flame stability is achieved by attaching the flame to a simple device known as a burner.

Flame stabilization is usually accomplished by causing some of the combustion products to recirculate and hence to continually ignite the fuel mixture. The hot recirculating gases transfer heat to the colder ones ignite those and initiate flame spread. The burnt gases transfer heat to the recirculation zone to balance the heat lost in igniting the combustible gas. Sufficient energy must be fed to the stabilization region to continuously ignite the coming gas flow.

1.3 Parameters Influencing Flame Stability

There are many factors that affecting on the stabilization of flames are described here, these include:

a) Blockage effect

If flame holder is located in a duct, which is the normal case, then an additional parameter controlling its stability characteristics is known as the blockage ratio, (BR). This is defined as the ratio of the area of projected flame holder to the cross sectional area of the duct. All stability theorems show that stability limit is widened as the characteristic dimension of the flame holder increases.

b) Flame holder size

An increase in flame holder size improves stability by extending the residence time of reaction in the recirculation zone.

c) Flame holder shape

The shape of flame holder affects its stability characteristics, which influences the size and shape of the wake region.

d) Fuel type

The fuel type has an effect on stability limit as for kerosene type fuel, it's found that combustion can be sustained at leaner mixture strengths with fuels of lower specific gravity. The paraffin fuels will operate at lower fuel air ratio than aromatic fuels.

The stability is further improved with:

1. The increase in fuel volatility.
2. Finer atomization and reduction of the mean drop size of fuel.

e) Stream velocity

Any increase in stream velocity invariably has an adverse effect on flame stability. Any increase in velocity reduces the range of mixtures strengths over which combustion is possible and increases the weak extinction limit.

f) Pressure

The increase in the reactants pressure always improves flame stability. The studies performed, by several investigators on bluff body flame holders in can-type, burners, and stirred reactors have fully confirmed the beneficial effect of increased pressure in extending the range of stable

operating conditions. For the gases mixture, the increase in the pressure expands the stability loop by enhancing the blowout velocity, especially for rich and near stoichiometric mixture.

1.4 Flame Stabilization Methods

Free jets flames are hardly stable, so some mechanisms are needed to enhance the flammability limits of the flame such as using a bluff body, a swirler, a pilot flame, a counter flow technique, by fixing putting flame holder in the combustible mixture flow.

1.4.1 Flame stabilization by using a bluff body

Bluff bodies are used to stabilize flames in high velocity flow in variety of propulsion and industrial combustion systems. These can be employed for supplementary firing in industrial boilers and heat recovery steam generators, and also used in ramjet and turbojet after burner system. In addition, these flame holders are used to study the fundamentals of turbulent flame characteristics or as computational test cases, and have been targeted as one of the three stationary laboratory premixed flame configurations for study.

The usual shapes of the bluff bodies used are cylindrical rods, rectangular discs, baffles, cones or “vee” gutters, as given in Fig. (1.1) which produce in their wake a low velocity recirculated flow in which combustion can be initiated and maintained. The propagation of flame to other regions is rendered possible by the transport of heat and radicals from the boundaries of the re-circulation zone to the adjacent fresh mixture.

Most of the understanding concepts of the flame stabilization process is refered to the pioneering studies carried out; these studies found that the

wake behind the bluff body can be divided into the recirculation zone and the mixing zone that keeps the recirculation zone away from the unburned reactants as shown in Fig. (1.2). The mixing zone, characterized by turbulent shear layers with large temperature gradients and rigorous chemical reaction, is fed by turbulent mixing processes with cool combustible gas coming from the approaching stream (based on the mixing model indicated by Williams [26]).

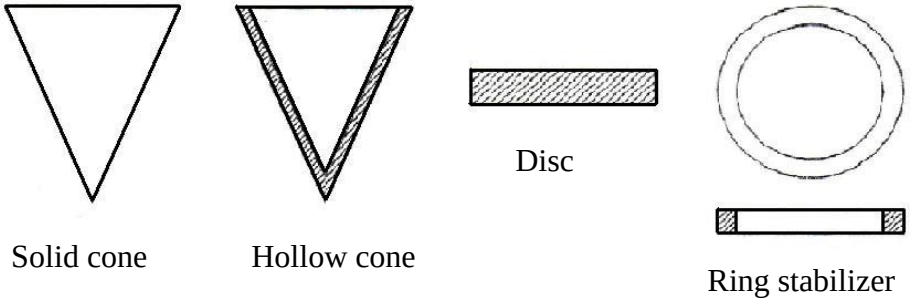

Fig. (1.1) Different bluff body shapes.

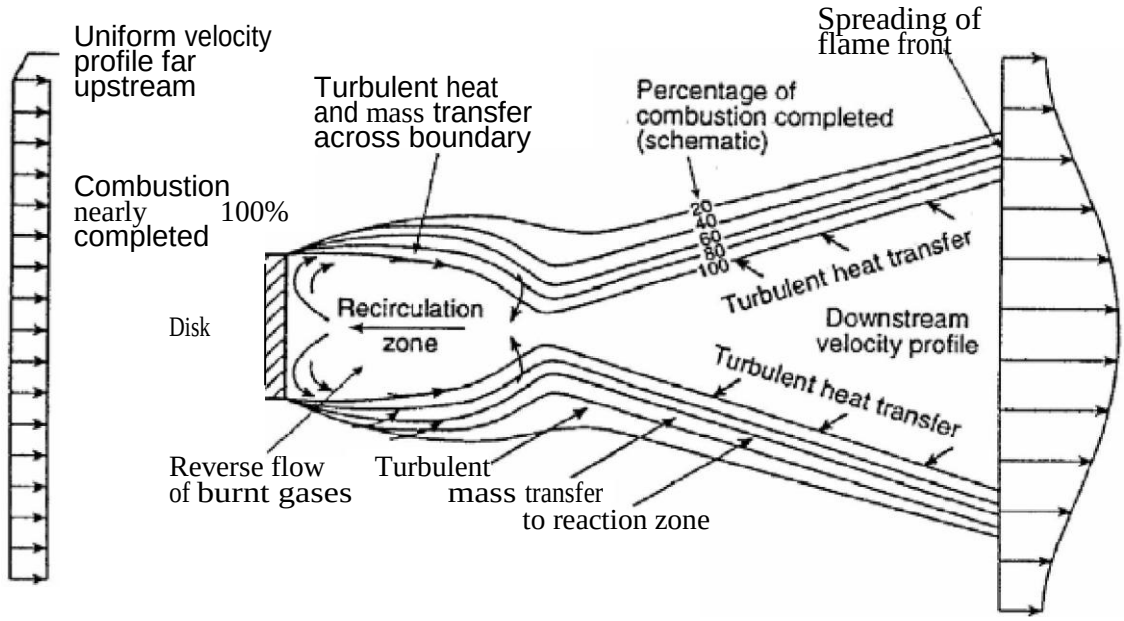

Fig. (1.2) Flame stabilization zone behind the bluff body (Williams 1966)

1.4.2 Flame stabilization using a swirler

A swirler is a number of curved swirl vanes have different angles normally 30, 45 and 60 degrees, which promotes the formation of recirculation zone and this is the essential mechanism for flame stabilization. Swirlnig flow can be produced either by tangential jet injections or by vane swirlers. The swirl angle determines the size and the strength of the recirculation zone and most of flame properties. Figure (1.3) indicates a schematic diagram of a simple swirler that used in burner.

1.4.3 Flame stabilization using a pilot flame

A pilot flame is an annular premixed flame located around the main jet flame used as a heat source to stabilize the main jet to the burner rim; the pilot flame is usually required to stabilize a jet flame due to its high exit velocity. A relative large pilot flame is used to produce a very lean jet flame. Figure (1.4) shows a photograph of pilot flame burner.

1.4.4 Flame stabilization using a counter flow stabilizing technique

A counter flow technique is to make the direction of the fuel jet in an opposite direction to the air flow, this technique reduces the flowing velocity of the combustible mixture against the burning velocity, also insures good mixing between the air and the fuel. Figure (1.5) shows a schematic diagram of a counter flow stabilized burner.

1.4.5 Flame stabilization using a transverse flow

From the recent and new techniques to form flame stability is that takes place by transversing the flow stabilizing technique, flame stability by pulsed high voltage discharge, flame stability by magnetic source at discharge.