Design, Implementation, Evaluation of an Up-to-Date Low Swirl Burner*

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Abstract– In recent years, combustion projects have taken a new concern which prioritizes the environmental safety along with keeping the combustion efficiency as high as possible. In the following study, a very modern combustion method is discussed which focuses on obtaining a single digit level of NOx emissions. This innovative technology system is using a partially premixed lean mixture of fuel and air as well as staging low swirl combustion process. With this configuration, a clean thermal power generation that complies with the worldwide standards of gaseous emissions of nitrogen oxides and carbon monoxide (5ppm) was achieved. The targeted industrial projects are sea water desalination processes - agricultural crops drying processes - steam furnaces and boilers - poultry farms heating operations in addition to air-conditioning operations for factories halls using thermal absorption chiller systems. The proposed burner design can be fueled by natural gas, diesel, biofuel, or syngas from organic wastes, within the national system for solid waste management and align with Egypt's vision 2030 and its environmental commitments in the 2015 Paris Climate Agreement, according to the "carbon neutral" standard.

Keywords—Renewable Energy, Low swirl burner, Stratification, Lifted stable flame, NOx emissions.

I. Introduction

Low-swirl combustion is a relatively recent development. It is an excellent tool for laboratory research on flame/turbulent interactions. Its operating principle exploits the "propagating wave" nature of premixed flames and is not valid for non-premixed combustion. Premixed flames consume the reactants in the form of self-sustained reacting waves that propagate at flame speeds controlled by the mixture compositions, the thermodynamic conditions, and turbulence intensities. [1]

A. Concept

This study was carried out to precisely investigate the effect of turbulence by swirler and stratification on stability map, flame shape and NOx emission. The most important component of the burner is a vane-type swirler with a central channel. Air/fuel mixing is not performed in a premixed chamber (pre-mixer). Instead of that, it occurs in the mixing length inside the pipes to ensure full premixed conditions and uniformity in inner and outer tube. The flow through the central channel remains straight while the surrounding vanes impart swirl to the annulus stream. Thus, it promotes the flow divergence and inhibits vortex breakdown at the same time. All components of the burner for reacting test are manufactured using steel. Both the vane swirler and perforated screen are interchangeable. Swirler "Fig.1" has different stagger angle of vane such as 30°, 45° and 60°. The stagger angles of the vane are designed to investigate the effect of the swirl number on the flame stability. The equivalence ratio of the premixed mixture is adjustable for both the inner and outer streams. The CO emission increases because of the decrease of the swirl number and the mixing rate of reactants. As the equivalence ratio increases, the NOx emission increases due to the increase of flame temperature. As the porosity increases, the NOx emission slightly increases. This is so, because of the influence of outer recirculation is reduced, and the flame temperature is increased.

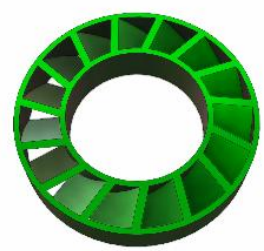

Fig. 1 Swirler 45°, 15 blades.

II. Theoretical Background and Literature Review

Peter l. Therkelsen [2], was aiming to develop a more specific guideline by investigating the effects of varying geometry, i.e., vane angle, vane shape, and centre channel size

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on the LSI performance as shown in “Fig. 2”, The key component of the LSI is a swirler that separates the flow of the fuel/air reactants into two passages: an outer swirl annular section with guide vanes to impart swirl and a center-channel to allow a portion of the reactants to remain un-swirled. The key design parameter is the swirl number, S, which controls the divergence vanes and its curved vane variant. Self-propelling in the divergent flow, the LSI flame is detached from the nozzle to generate a "floating flame" which is the signature feature of the LSI.

Fig. 2 Different geometry of vane swirler

TABLE I

SWIRLER GEOMETRIES, SWIRL NUMBER AND CENTER PLATE BLOCKAGE

Swirler	Centre Plate Blockage	Swirl Number
TV-α37-R67	77.2%	0.60
CV-α37-R67	59%	0.53

Another design was proposed by Zhibo Cao [3]. He wanted to investigate the flow field and flame structure characteristics of LSC, a test rig of low swirl burner was designed and developed. Particle image velocimetry measurement results show that the location and size of the recirculation zone are different, and the flow field shows typical “W” and “U” shaped distributions under various swirling flow conditions.

The vane stagger angle, radius ratio, and blocking ratio have a great effect on the swirl intensity of the flow field. The swirl intensity can be characterized by the swirl number of the nozzle, and the swirl number “S” is defined as follows Here, R, m, and α are radius ratio, flow rate, and vane stagger angle.

TABLE II

LIST PARAMETERS OF THE BURNER

Case	Vane stagger angle	Radius ratio	Flow ratio	Swirl number
1	37°	0.76	0.72	0.43
2	37°	0.60	0.72	0.49
3	37°	0.45	0.72	0.55
4	45°	0.30	0.56	0.66

Parameters which have a significant effect on performance

1. Vane shape

Vane shape does not affect performances but affects pressure drop across the LSI due to increasing or decreasing aerodynamic drag.

2. Flame

The attached and lifted flame of a LSB is highly influenced by fuel-air mixture and LSB design characteristics.

When the flame regime shifts from lifted to attached due to Φ variations, the irreversibility ratio experiences almost 13% rise relatively. This issue highlights the advantage of lifted flames in restricting the irreversibility production.

3. Swirl number

The parameter S/tanα where S is the swirl number, is a more useful design parameter for LSI than S alone.

The location and size of the recirculation zone are different on different swirl numbers. When the swirl number is 0.50, there is no recirculating zone when the number is between 0.55 and 0.59.

III. PRESENT BURNER DESIGN

A small-scale low-swirl burner has been designed to be able to investigate the LSC with stratification effect, the first version of the project got implemented. Modifications were performed on the design to get the best results before implementation and during testing. The design is made to assemble and disassemble easily. Most of the components were recycled. Those components are made of steel to test the flame results such as temperature, flame length and stability limits before using PVC material. The swirler is fixed on the top of the outer pipe and the inner pipe is the hub of the swirler to recirculate the outer stream mixture.

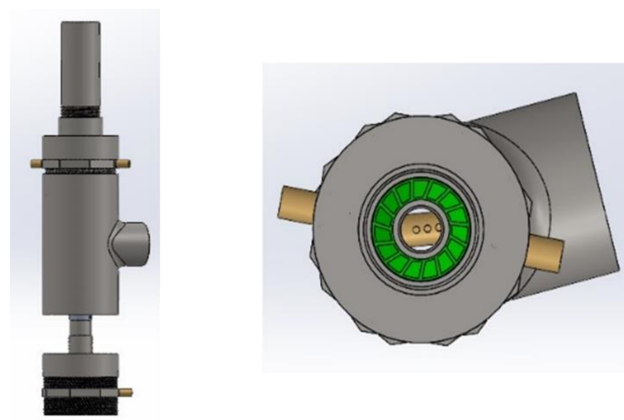

Fig. 3 Side and top views of burner’s 3D model

A. Components

Components mentioned in “Table III” are fitted using pipes, T-pipe fittings, and union fittings

TABLE III

BURNER’S MAIN COMPONENTS

Component	Specifications
Swirler	45°, 15 blades
Air control Valve	D_o=88.9 mm
Air streamline pipes	D= 88.9 mm, L=195 cm
Fuel control valve	D_o=21.336 mm
Fuel streamline pipes	D= 21.336 mm, L=43 cm
Injectors	D=13.7 mm
Reducers	Inner reducer: 88.9 to 26.67 mm. Outer Reducer: 88.9 to 21.336 mm

B. Assembly

LSC burner shown in "Fig.4" was employed in the present work. A blower and LPG cylinder were used to deliver Air and fuel respectively. The present burner consists of two concentric steel tubes. The first tube is the central round, has an external diameter of 48.26 mm and thickness of 3.68 mm and it holds the swirler. The second tube is an inner tube has an external diameter of 26.67 mm and thickness of 2.87 mm. The outer tube has two injectors for LPG fuel and the inner streamline has only one injector. The union fitting which contains two injectors is attached to T-pipe fitting to be connected with the outer streamline air hose and the inner pipe via square head plug. The inner pipe end is attached to a reducer to the union fitting that contains one fuel injector. The air hose is fixed into the other side of the union fitting and the other air hose is fixed to it via PVC pipe.

Fig. 4 Burner's Assembly

C. Test Rig

The present measuring systems will include measuring temperature, emission, and flame pictures of different conditions.

- Thermocouple Type-S
- Digital manometer
- Orifice plate: The orifice diameter of fuel streamline is 40% of pipe's diameter and it is made of acrylic, while the air streamline orifice diameter is 30% of the pipe's diameter and made of steel.
- Gas Analyzer

Before conducting any experiment, the following steps are followed:

1. The experimental setup is checked for leaks to ensure not only a safe working environment but also to satisfy accurate measurements of the flow rates through the air and fuel supply passages.
2. Calibrate orifice plates.

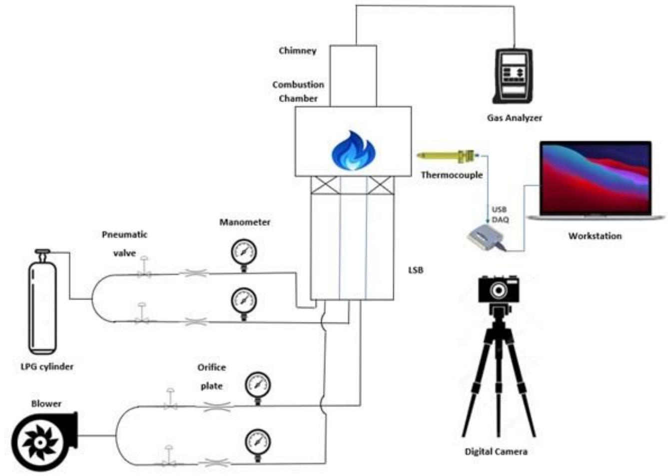

Fig. 5 Test Rig

IV. MEASUREMENTS AND RESULT

After several trials, a stable lifted flame was attained by using 45° swirler and adjusting the mixing length to 53 cm as shown in "Fig.6"

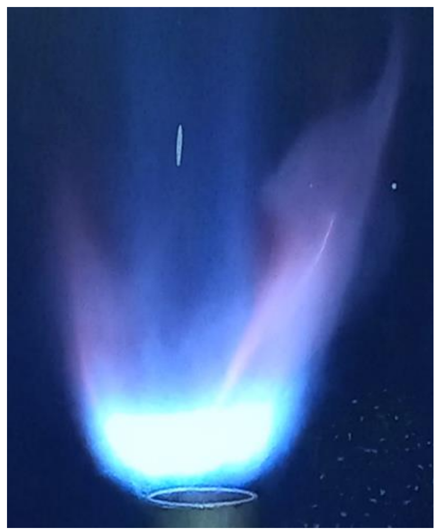

Fig. 6 Stable lifted flame

Accurate measurements were accomplished after reaching a stable lifted flame to study the different ranges of blow down. To determine the flame stability of the burner designed in the current work, experiments are performed over a wide range by measuring value of pressure difference by manometer then calculating its mass flow rate $\dot{m}$ using (1), (2)

$$\dot{m} = C_d * A_2 * E * \sqrt{2\,\rho\,\Delta P} \quad (1)$$

$$E = \frac{1}{\sqrt{1-(A_2-A_1)^2}} \quad (2)$$

Where A_2 is area of orifice, A_1 is area of pipe and $C_d = 0.6$.

Maximum Flow rates of air delivered by blower is 62 kg/hr for inner path and 77 kg/hr for outer path. And maximum flow rates of fuel delivered by LPG cylinder is 4.5 kg/hr for inner path and 3.8 kg/hr for outer path.

A. Stability Program under free condition

Our stability program is built by keeping V_{out} =15 m/sec based on the maximum flowrate values obtained by blower and LPG cylinder. Then choosing 5 values of V_{in} which generate the "W" shape of low swirl burner flame, mass flow rate of air inner is constant for $\Phi_{out} = 0.25$, Gradually decreasing the mass flow rate of inner path of fuel till blow down, and calculating Φ_{in} ($\Phi_{blowdown}$) then drawing the stability curve as shown in" Fig.7"

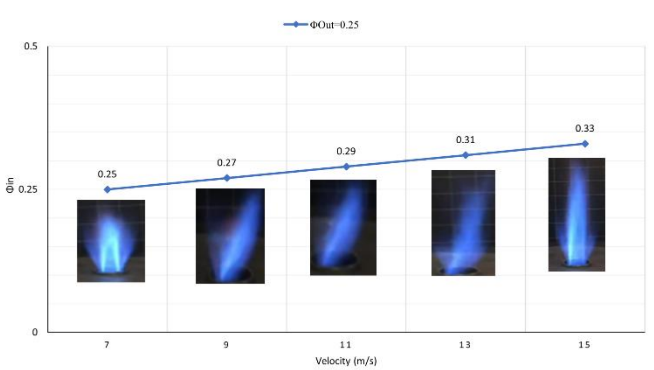

Fig. 7 Stability curve

B. Temperature Measurements under free condition

Temperatures are measured by using thermocouple type S at different axial distances under 4 conditions as shown in "Table IV" where V_{out} = 15 m/sec and $\phi_{overall}$ =0.6 throughout the different cases. And power output was calculated using (3)

$$Thermal\ output\ power = \dot{m}_{fuel} * CV$$

TABLE III

DIFFERENT CASES FOR TEMPERATURE MEASUREMENTS

-	1st case	2nd case	3rd case	4th case
V_{in}	9	7	9	7
ϕ_{in}	1.53	1.53	1.8	1.8
ϕ_{out}	0.35	0.35	0.3	0.3
Flame length (cm)	32	30	32	30
Power (kW)	41.8	40.4	41.8	40.4

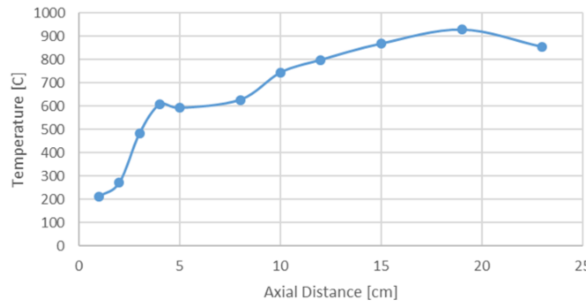

Fig. 8 Temperature curve of first case

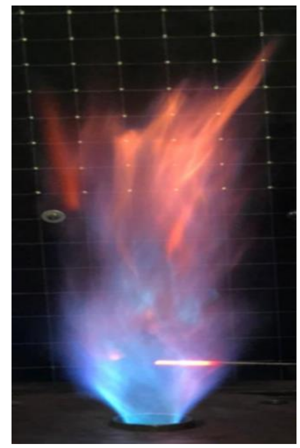

Fig. 9 Flame configuration of first case

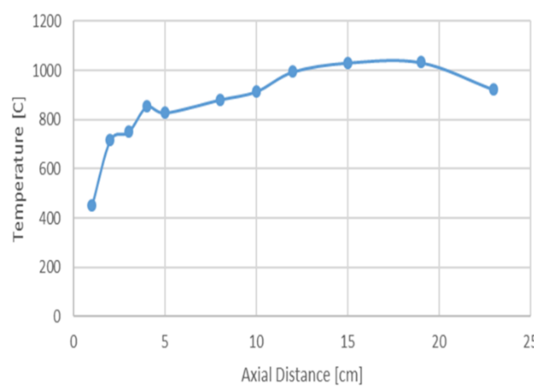

Fig. 10 Temperature curve of second case

Fig. 11 Flame configuration of second case

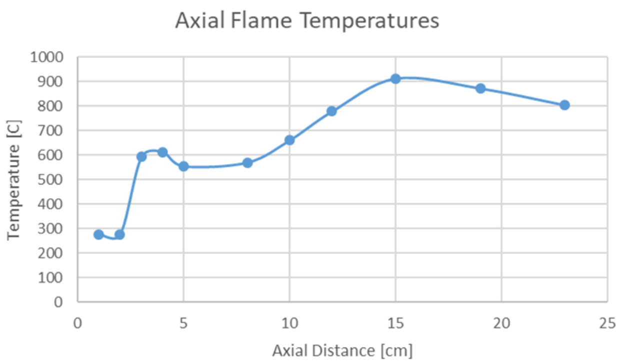

Fig. 12 Temperature curve of third case

Fig. 13 Flame configuration of third case

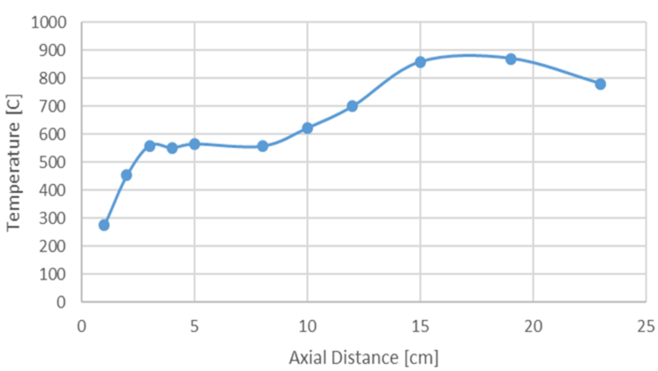

Fig. 14 Temperature curve of fourth case

Fig. 15 Flame configuration of fourth case

It was concluded that

- The mixing length is a very important influential factor.
- Reducer must be in conic shape.
- The maximum flame temperature is 1200 degree Celsius which can melt Pyrex glass.
- The maximum output load is 55 kW with flame length approximately equal 42 cm.
- The CO emissions increase by the decrease of the swirl number and the mixing rate of the reactants.
- As the equivalence ratio increases, the NOx emission increases due to the increase of flame temperature.
- NOx emissions equal approximately 5 ppm.
- Swirl number of the present design were found to be 0.3
- Upon reaching the lifted shape of flame, an industrial model of the burner from PVC can be manufactured, that would be easy to use and maintain, cheap, and with lightweight.
- Different sizing of the present design or the usage of multi-burner result in the production of various thermal output values.

V. Industrial Applications

1. Thermal desalination

Thermal desalination is based on the principles of boiling or evaporation and condensation. Water is heated until it reaches the evaporation state. The salt is left behind while the vapor is condensed to produce fresh water. The most common thermal desalination processes are:

- Multi-Stage Flash Distillation (MSF),

MSF is currently producing around 64% of the total world production of desalinated water. [4]

- Multiple-Effect Distillation (MED)

Around 3.5% of the world's desalted water is produced by MED plants.

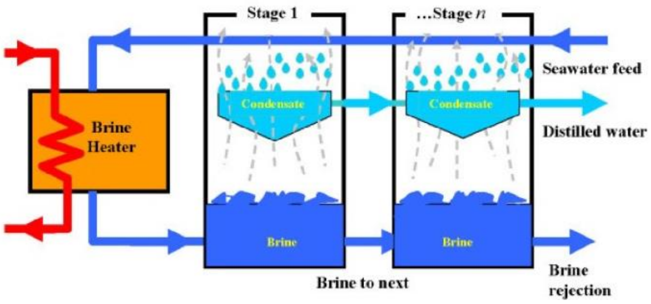

Fig. 16 Multi-Stage flash desalination

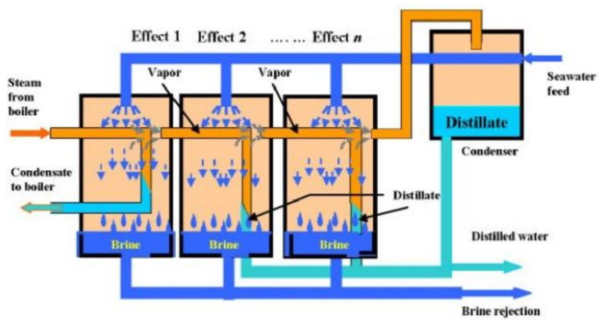

Fig. 17 Multi-Effect distillation

2. Grain drying

Flatbed dryer heated with liquefied petroleum gas

The dryer basically consists of: a drying bin where wet paddy is held during drying, a plenum chamber where the velocity pressure of moving heated air is converted to static pressure; a vane-axial fan that moves heated air in the dryer and pushes it up across the bed of the grain, an LPG burner and a tank which supplies the needed heat for drying, and a prime mover that is used to drive the fan. [5]

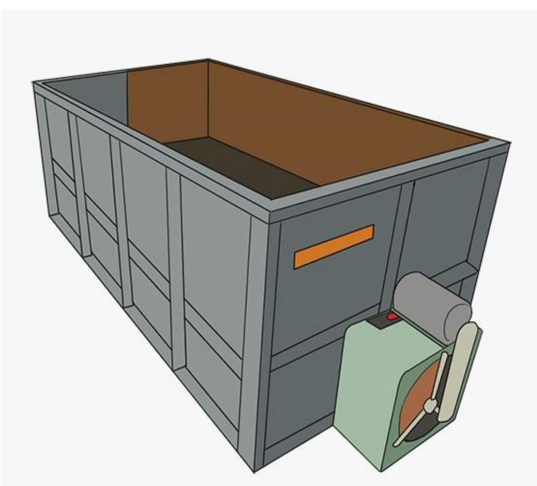

Fig. 18 Flatbed Dryer

3. Thermal heating

Gas Pool Heaters have long been recognized as a quick and reliable pool heating system. Gas pool heaters use either natural gas or LPG. As the pump circulates the pool's water, the water drawn from the pool passes through a filter and then to the heater. The gas burns in the heater's combustion chamber, generating heat that transfers to the water that is returned to the pool.

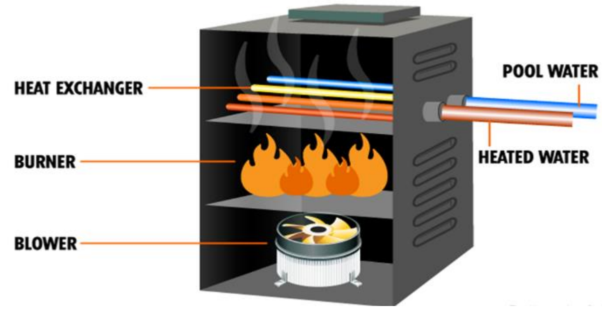

Fig. 19 Gas pool heater

VI. ABBREVIATIONS AND ACRONYMS

C_d: Discharge coefficient
CV: Calorific value
E: Velocity of approach factor
LPG: Liquified Petroleum gas
LSB: Low swirl burner
ppm: particles per matter
V: Velocity
ϕ: Fuel to Air ratio

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