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ACOUSTİC SİGNATURE OF TWO CUTTERS AND FOUR CUTTERS EV SWİRL STABİLİZED GASEOUS BURNERS

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ABSTRACT

Today's gas turbine technology is established in a wide range of applications, including (i) the production of electrical power, (ii) thrust generation in turbojets and (iii) driving large size pumps and compressors. The greatest advantages of gas turbines against other prime mover systems e.g. steam turbine systems and piston engine systems, lie in its higher specific power, compact design and low initial costs based on power output.

A major problem in gas turbine combustors is combustion instabilities which may cause many undesirable effects including; (a) increased noise levels, (b) oscillating thrust, (c) mechanical vibration that may lead to serious damage and even total loss of the system. These instabilities are characterized by large oscillations of the flow parameters, which in many circumstances may result in the inability of the combustion process to sustain these large oscillations; leading to partial or total flame blow-off. These combustion oscillations could, however be desirable as in pulsed combustors; as it enhance combustion intensity, increase thermal efficiency and reduce the emission of pollutants like NOx, CO and soot.

In light of the above mentioned concepts, the present study is directed towards extending the previous studies on the recently introduced turbojet EV burner having two-circumferential swirling entry air passages by a four-circumferential swirling air entries configuration.

This burner design concept appears to offer many advantages, including: The replacement of the traditional fixed vane swirler by circumferential swirling air passages; and hence not only minimizes blockage and allows prior premixing of fuel and air within the conically shaped entry section to the combustor but also eliminates possible risk in case of swirler blade damage.

The study is an experimental investigations of the acoustic signature of a newly designed 4-slot EV burner. All the results are to be compared with those obtained by the previously developed 2-slot configuration. This allows the identification of the merits and/or drawbacks of both designs.

KEY WORDS

EV Gaseous Burner, Turbulent Flame,

INTRODUCTION

Combustion instabilities are a major problem in the design of high performance propulsion systems (rocket motors, jet engine afterburners, ramjets). Instabilities are also observed in power plants and in various industrial processes. They are characterized by large oscillations of the flow parameters, which have many undesirable effects. Low frequency oscillations induce large mechanical vibrations in the system, including the combustion chamber, [1, 2] the feeding lines and the connected rotating machinery. Unstable operation enhances, the heat transfer rates at the combustor walls and in extreme cases this may lead to serious damage and even a total loss of the system. In many circumstances the combustion process is unable to sustain large oscillations inducing a partial or total flame blow-off. While instabilities are considered to be a problem when they are found in continuous combustion devices, oscillatory combustion is the normal operational mode of pulse combustors because it enhances the combustion and thermal efficiency and reduces the emission of pollutants like NOx, CO and soot. [3, 4] Pulse combustion concepts are also studied in the area of solid fuel combustion and incineration of waste material. Unsteady combustion effects are encountered in many practical applications which are facing the design engineer and the problem deserves a continued research effort. [5, 6].

The main aspect in furnace, boilers and gas turbines design to obtain an efficient, stable and quiet flame, with higher combustion efficiency and minimal noise level at a wide range of operating conditions. Such flame, with higher combustion efficiency would allow for more energy savings and for lower environmental pollution. [7, 8]

The core of any combustion system is its burner. Continuous research and development work are carried out by the burner manufacturers in order to achieve the above aims. A large amount of information and research work are available for single fuel burners. [9, 10]

The demand for gas turbine engines, boilers with reduced emission levels, stable combustion conditions and low specific fuel consumption is the goal at the past two decades. [11,12],many researchers investigated emissions from burners and solved part of this problems by using many of techniques one of this by using environmental (EV-environmental V shape burners)(EV-10) with a cross-sectional area expansion ratio of four for flame stabilization It consists of two halve cones shifted with respect to each other in radial direction. The main goal for this study to describe modification design and manufacture a new four cutters EV-10 swirl stabilized burner and 2 cutters, get acoustic signature of two cutters and four cutters EV swirl stabilized gaseous burners.

EXPERIMENTAL SET UP, FACILITIES AND EXPERIMENT PERFORMANCE

The present work aims to get an acoustic signature for gaseous swirl stabilized burner from a 2 slot and 4 slot EV burners associated with the variations of the gas constituents and flow conditions, experimentally. Using microphone and the data collected using oscilloscope for that purpose, Lpg gaseous fuel is used with different equivalency ratio (ϕ).

To ensure accurate settings of the experiments together with reliable data collection, the following considerations are taken:

1- Vertical arrangement of the burner is chosen to eliminate buoyancy effects on the developed turbulent flames.

2- The following steps are followed to eliminate the effects of natural draft on the developed flames:

(a) A co-flowing air stream at high axial velocity 28 m/s is admitted through the annular passage of the coaxial burner configuration.

(b) The burner arrangement is contained within a room with side glass walls that prevent the influence of natural draft. The size of this room ensures the proper conditions for free developed jet flames; i.e. no boundary effects on flame characteristics.

3- Ensure accurate and controllable flow rates of the various gas streams at such high flow rate values (ranging from 0- 41 Lit /min).

The schematic of the experimental set-up is illustrated in **(Fig1).** This set-up essentially consists of:

1- Fuel and air supply system.
2- The EV burners and combustor.
3- Acoustic measuring system.

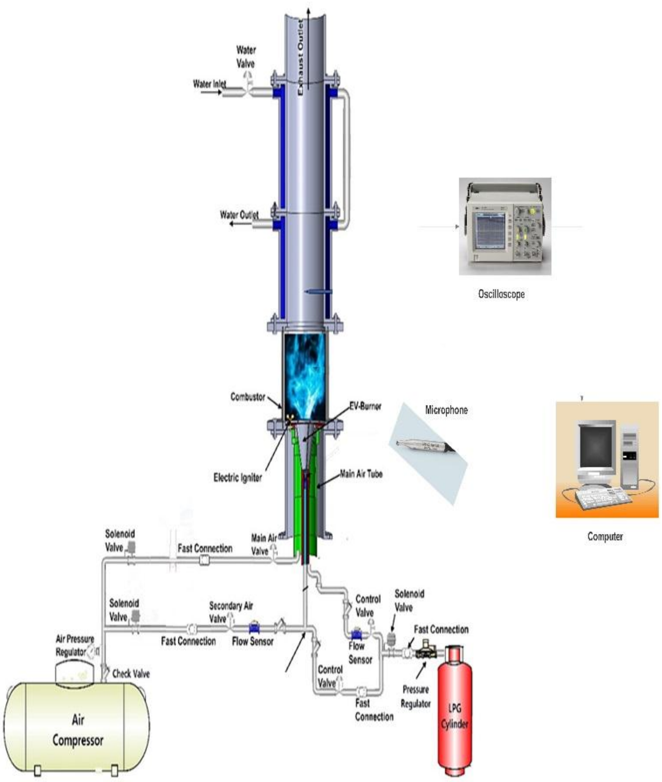

Figure1: Schematic diagram of system set-up

Fuel and air supply system

In order to admit accurate flow rates of both the gaseous fuel and the co-flowing air, measurements were made using rotameters manufactured by Dwyer Instruments Inc. Since all the rotameters used were calibrated for air at standard pressure and temperature, the flow-rate readings taken were corrected according to the calibration equations supplied by the manufacturer for the flow pressure. Solenoid valves were used and controlled by Lab View program. The rotameters of different ranges were used to measure the fuel flow rate according to their range. However, only one rotameter was enough to measure the air flow rate.

<u>Four Slot burner:</u> (Fig2)

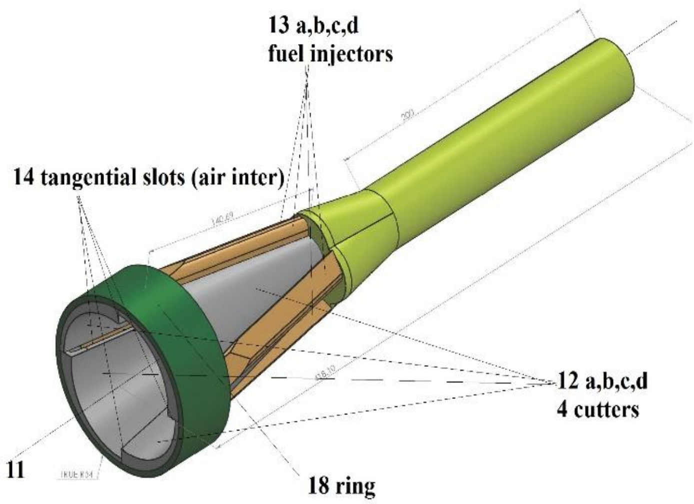

Figure 2: four slot EV burner.

- <u>EV Burner:</u>
  (a) <u>Conical Passage with 4-Slots</u>
  (b) <u>Air Passages</u>

Four circumferential air slots displaced (formed by quarter cones with four slots between them).Air is forced to enter into the cone circumferentially.

(c) <u>Fuel Admission:</u>

At each of burner slots, main fuel is injected through equidistantly holes located along the entry of each air passage between the apex and the burner exit.

Two Slot burner:

To perform the objectives of this study, the design of the test rig should facilitate the following:

- Co-axial jets burner.
- Double concentric tubes (centric and outer), two fluid supplies to the passages of the air jets to enable separately easy control of the air mass flow rate.
- Separated fuel supply to the first annular line to facilitate easy control of the fuel mass flow rate.
- Precise control of the fuel mass flow.
- Accurate vertically support of burners to avoid changes in jets direction.

The tested burner as shown in **(Fig3)** consists of an air jet surrounded by a fuel jet which is also surrounded by an outer air jet. The burner is made of two cast iron pipes as detailed on the figure.

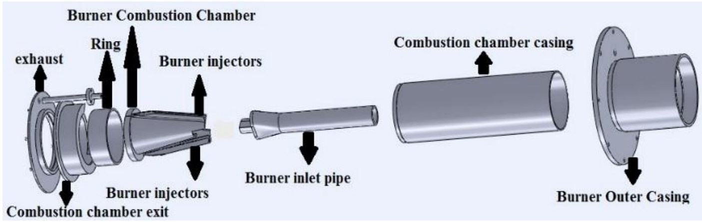

Figure3: Assembly of EV burner components

The EV-10 shown in **(Fig4)** consists of two shifted half cones with two slots between them, such that air is forced to enter into the cone circumferentially. The resulting swirling airflow generates a recirculation zone along the centerline at the EV-10 outlet.

The main fuel is injected through 62 boreholes, 0.7 mm diameter each, that are distributed equidistantly along the two air slots.

The main fuel is mixed with the swirling air resulting in a nearly premixed combustion

<u>Combustor</u> (Fig5)

The combustor is a vertically cylindrical air-cooled flame tube of 230 mm inside diameter and 300 mm long with 18 bore holes 8 mm diameter to access probe of Thermocouple to measure in flame temperature. During the combustion process, these openings are closed with 8 mm screws of stainless steel 316. The Combustor Manufactured of thick steel pipe of 5 mm thickness. a water-cooled resonance tube of the same diameter and 1050 mm in length is attached to this combustion chamber with one bore hole 8 mm diameter

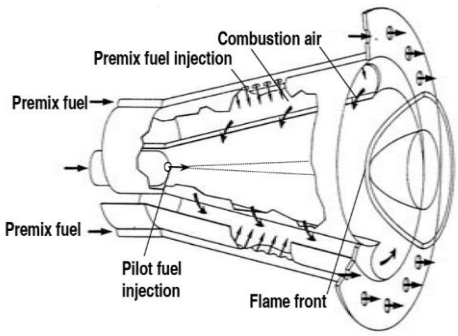

Figure 4: Two slot EV burner.

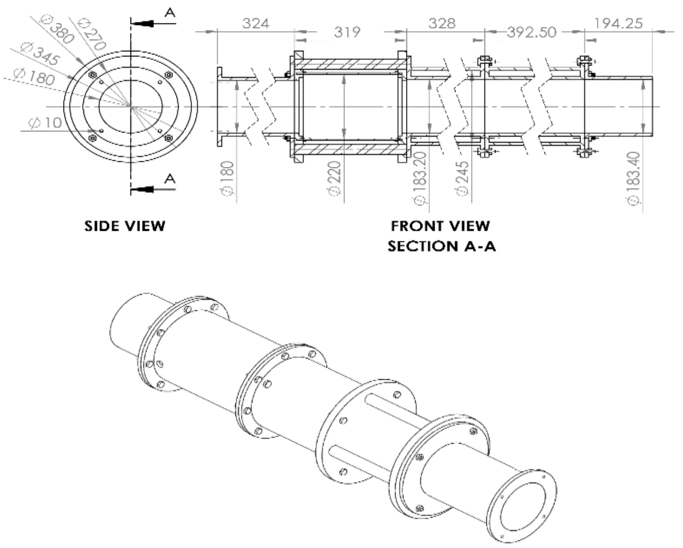

Figure 5: Combustor

Acoustic measuring system:

Microphone setup

A condenser microphone is used to measure the acoustics oscillations downstream flow. It is mounted at the position which is able to record clearly these oscillations. The used microphone is GRAS- type 26AC- S7. It is a ¼″ preamplifier with a 3-m lightweight cable terminating in a 7-pin LEMO series 1B plug and used for high-frequency measurements and high-pressure measurements with wide frequency range, low noise level and very small size. The cable is only 2.5 mm in diameter and withstands temperatures from -40°C to +150°C. The typical capacitance of ¼″ microphone capsule is 6.5 pF. The electrical circuit in this type of microphones is built on a ceramic substrate using selected low-noise components to gain very low self-noise. The electrical self-noise is very low that system noise is mainly determined by the microphone capsule's thermal noise. The dimensions of the microphone are as follows: 6.35mm diameter and 48mm length while the microphone weight is 4g in addition to 46g for cable and plug. As the size of the microphone is decreased, the useful frequency range of the microphone is increased. The frequency range, which can be obtained, is determined in part by the size of the microphone. The frequency range (±0.2 dB) is 2Hz- 200 kHz. It has a flat pressure frequency response in its entire frequency range. The frequency response of the microphone is determined by the diaphragm tension, the diaphragm mass, and the acoustical damping in the airgap between the diaphragm and the back plate see Fig.6. When the sound pressure in the sound field fluctuates, the distances between the diaphragm and the back plate will change, and consequently change the capacitance of the diaphragm/back plate capacitor. As the charge on the capacitor is kept constant, the change in capacitance will generate an output voltage on the output terminal of the microphone. The acoustical performance of a microphone is determined by the physical dimensions such as diaphragm area, the distance between the diaphragm and the back plate, the stiffness and mass of the suspended diaphragm, and the internal volume of the microphone casing.

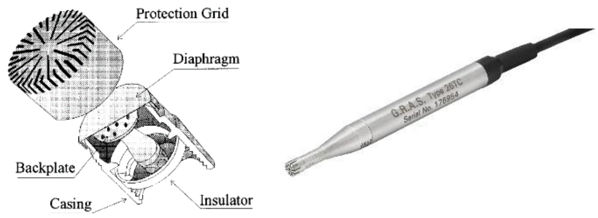

Figure 6: Basic elements of a condenser microphone

It is calibrated by using a Brüel& Kjaer pistonphone type-4228 at reference frequency 250 Hz and nominal gain of 124dB and the sensitivity was 1.152mV/pa. This type of microphones has proven to be superior with respect to temperature stability, long-term stability, and insensitivity to rough handling. It is designed and produced to ensure well-defined and accurate measurements. The operating temperature is in range of -20°C- +60°C at relative humidity of 0- 90%. The diaphragm and the back plate form the parallel plates of an air capacitor. This capacitor is polarized with a charge from an external voltage supply (externally polarized type) or by an electric charge injected directly into an insulating material on the back plate (pre-polarized type). The supply can vary between 28 VDC and 120 VDC single-sided or ±14VDC and ±60 VDC dual sided.

Signal record:

The output signal from the condenser microphone measured and recorded using Agilent 3000 Series oscilloscope (Fig.7) with up to1 GSa/s sample rate, Up to 4 kpts memory, Automatic voltage and time measurements (20) and cursor measurements, Advanced triggering (edge, pulse width, and video). Math function waveforms: add, subtract, multiply, FFT, USB ports (1 host with rear panel module, 1 device) for easy printing, saving, and sharing of waveforms, setups, screen BMP files, and CSV data files, Internal storage for 10 waveforms and 10 setups. Special digital filter and waveform recorder. Built- in 5- digit hardware frequency counter.

The oscilloscope's sampling and acquisition modes according to The Nyquist sampling theorem states that for a limited bandwidth (band- limited) signal with maximum frequency f_{MAX}, the equally spaced sampling frequency f_S must be greater than twice the maximum frequency f_{MAX}, in order to have the signal be uniquely reconstructed without aliasing.

$f_{MAX} = f_S/2$ = Nyquist frequency (f_N) = folding frequency

Aliasing occurs when signals are under- sampled ($f_S < 2f_{MAX}$). Aliasing is the signal distortion caused by low frequencies falsely reconstructed from an insufficient number of sample points.

Figure 7: Agilent 3000 Series oscilloscope

The oscilloscope can operate in normal, average, or peak detect acquisition modes.

The trigger determines when captured data should be stored and displayed. When a trigger is set up properly, it can convert unstable displays or blank screens into meaningful waveforms. When the oscilloscope starts to acquire a waveform, it collects enough data so that it can draw the waveform to the left of the trigger point. The oscilloscope continues to acquire data while waiting for the trigger condition to occur. After it detects a trigger, the oscilloscope continues to acquire enough data so that it can draw the waveform to the right of the trigger point.

Experimental Program

The interpretation of the experimental data integrates between the results being obtained at two stages to form a full picture of the variations in the acoustic signature of the 2 slot and 4 slot Ev burners associated with the changes of the fuel equivalency ratio and flow conditions. Particular emphasis is given to the variations in the acoustic oscillations in different conditions.

Table (1) Experimental Program

cases			2	3	4
Stage 1 2 slot EV burner	V_{air} = 873 l/min	Φ	1	0.87	0.75
		V_F (l/min)	32	28	24
Stage 2 4 slot EV burner		Φ	1	0.87	0.75
		V_F (l/min)	32	28	24

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 different gas supply passages.

2- The burner is aligned in the vertical position.

RESULTS AND DISCUSSION

- **The acoustic signature of 2-slot EV burner**

Studying the frequency domain of the liberated noise coming out from the 2 slots burner noticed the principal spectral lines as shown in fig 8 (1200 Hz ,2062 Hz, 2120 Hz ,2887 Hz , 3310 Hz,3350 Hz ,4300 Hz , 4900 Hz , 5360 Hz , 6200 Hz , 6600 Hz , 8092 Hz , 9495 Hz)

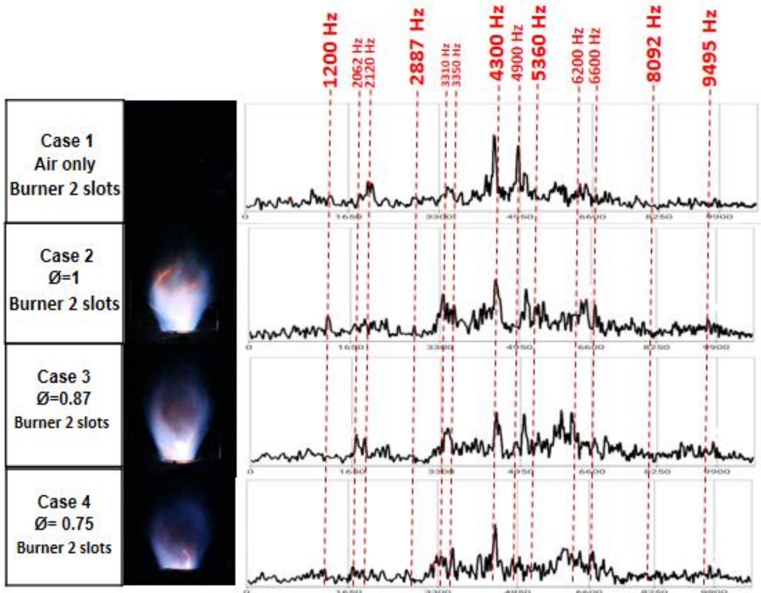

Fig 8: Acoustic signature of 2-slot burner at different equivalency ratio

Studying the effect of changing the equivalency ratio at different operating condition of 2-slots burner, deduced that:

1- At acoustic value (1200 Hz) the highest acoustic beak formed at case 2 and the lower at case 3.
2- At acoustic value (2062 Hz) the highest acoustic beak formed at case 3 and the lower at case 1.
3- At acoustic value (2120 Hz) the highest acoustic beak formed at case 1 and the lower at case 4.
4- At acoustic value (2887 Hz) the burner tends to decrease the noise value forming low peaks.
5- At acoustic value (3310 Hz) the highest acoustic beak formed at case 2 and the lower at case 1.
6- At acoustic value (3350 Hz) the highest acoustic beak formed at case 4 and the lower at case 1.
7- At acoustic value (4300 Hz) the highest acoustic beak formed at case 1 and the lower at case 3.
8- At acoustic value (4900 Hz) the highest acoustic beak formed at case 1 and the lower at case 3.
9- At acoustic value (5360 Hz) the highest acoustic beak formed at case 2 and the lower at case 1.
10-At acoustic value (6200 Hz) the highest acoustic beak formed at case 3 and the lower at case 1.
11-At acoustic value (6600 Hz) the highest acoustic beak formed at case 4 and the lower at case 1.
12-At acoustic value (8092 and 9495 Hz) the burner tends to decrease the noise value forming low peaks.

From studding the acoustic signature of the 2-slot EV burner and according to the above values the highest noise occurs at case (1) cooled flow this is due to the high escaping velocity of particles.

The minor noise operating condition for the 2-slot burner is at case (4).

- **The acoustic signature of 4-slot EV burner**

Studying the frequency domain of the liberated noise coming out from the burners 4 slots noticed the principal 13 spectral lines as shown in Fig 9 (1200 Hz ,2062 Hz, 2120 Hz ,2887 Hz , 3310 Hz,3350 Hz ,4300 Hz , 4900 Hz , 5360 Hz , 6200 Hz , 6600 Hz , 8092 Hz , 9495 Hz)

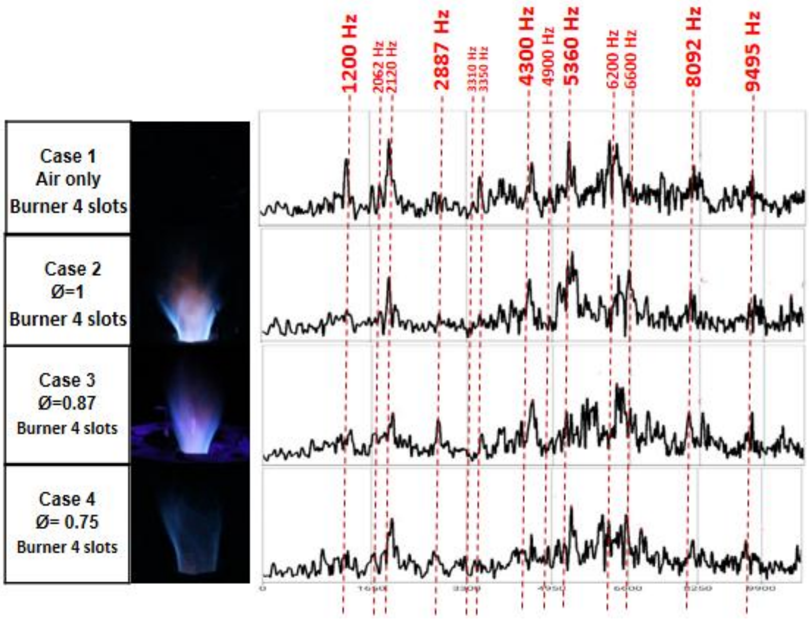

Fig 9: Acoustic signature of 4-slot burner at different equivalency ratio

Studying the effect of changing the equivalency ratio at different operating condition of 4-slots burner, deduced that:

1- At acoustic value (1200 Hz) the highest acoustic beak formed at case 1 and the lower at case 3.
2- At acoustic value (2062 Hz) the highest acoustic beak formed at case 1 and the lower at case 2.
3- At acoustic value (2120 Hz) the highest acoustic beak formed at case 1 and the lower at case 3.
4- At acoustic value (2887 Hz) the highest acoustic beak formed at case 3 and the lower at case 2.
5- At acoustic value (3310 Hz) the highest acoustic beak formed at case 4 and the lower at case 2.
6- At acoustic value (3350 Hz) the highest acoustic beak formed at case 1 and the lower at case 2.

7- At acoustic value (4300 Hz) the highest acoustic beak formed at case 2 and the lower at case 4.

8- At acoustic value (4900 Hz) the highest acoustic beak formed at case 1 and the lower at case 2.

9- At acoustic value (5360 Hz) the highest acoustic beak formed at case 1 and the lower at case 4.

10-At acoustic value (6200 Hz) the highest acoustic beak formed at case 1 and the lower at case 3.

11-At acoustic value (6600 Hz) the highest acoustic beak formed at case 2 and the lower at case 1.

12-At acoustic value (8092 and 9495 Hz) the highest acoustic beak formed at case 3 and the lower at case 4.

From studding the acoustic signature of the 2-slot EV burner and according to the above values the highest noise occurs at case (1) cooled flow this is due to the high escaping velocity of particles.

The minor noise operating condition for the 2-slot burner is at case (4).

- **Comparing the acoustic signature of the 2-slot and the 4-slot EV burner**

Studying the frequency domain of the liprated noise coming out from the burners 2 slots ,4 slots noticed the principal 13 spectral lines as shown in fig 10 (1200 Hz ,2062 Hz, 2120 Hz ,2887 Hz , 3310 Hz,3350 Hz ,4300 Hz , 4900 Hz , 5360 Hz , 6200 Hz , 6600 Hz , 8092 Hz , 9495 Hz)

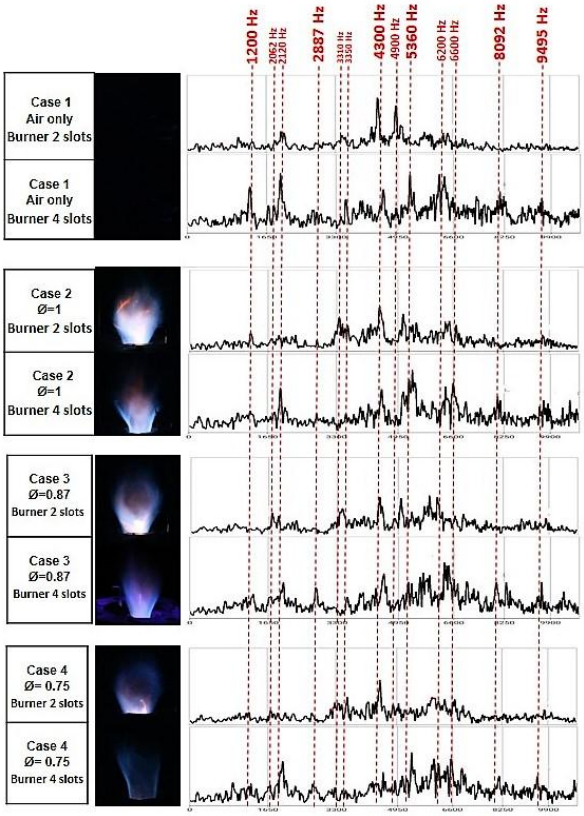

Fig 10: Acoustic signature difference between 2-slot and 4-slot burner at different equivalency ratio

Comparing the acoustic signature of the 2-slot and 4-slot burner can be compromised as follows:

1- At case (2) the 4-slot burner shows higher peaks except at **(3350 Hz, 3550 Hz).**

2- At case (3) the 4-slot burner shows higher peaks except at **(3310 Hz, 3350 Hz, 4300 Hz, 4900 Hz, 6200 Hz).**

3- At case (3) the 4-slot burner shows higher peaks except at **(3310 Hz, 3350 Hz, 4300 Hz, 4900 Hz, 6200 Hz).**

According to the comparison between the two burners the acoustic signature of the 4-slot burner gives higher peaks which indicates that the 4-slot burner is more noise than the 2-slot burner.

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