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COMBUSTION STUDY OF DISPOSAL LUBRICANT OIL

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دراسة خصائص لهب أحتراق مخلفات زيت التزييت

يتناول هذا البحث عملية تطوير أحتراق مخلفات زيت التزييت من خلال تحسين رذاذ الزيت وتدويمه وخلطه بالهواء وذلك بتصميم وتصنيع حارق خاص لحرق الزيت الثقيل.

تم اجــراء العديد من التجارب المعملية بغرض التوصل الى تصميم رشاش مناسب وغرفة احتراق مناسبة وكذلك ظروف تشغيل مناسة وذلك لامكانية الحصول على لهب مستقر من حرق مخلفات زيت التزييت بعد استخدامه. وكــذلك تم دراســـة امكانيــة تحســين ذلك اللهــب باضافة تأثير دوامي لرذاذ الوقــود الخارج من الرشاش .

فلقــد تم تصنيع غرفة أحتراق مكــونه من ماســورة معدنيــة مبــردة بالهــواء بقطــر داخــلى 40 سم وطول 150 سم ومزودة من الأمام عند المدخــل بجزء معدنى مخروطى الشــكل مبطن من الداخل بمادة حرارية لتمتص الحــرارة ثم تشعها مرة ثانية وذلك لتسخين الوقــود الطــازج وتهــيئته للاحــتراق. تم تصميم وتصنيع الرشــاش المســتخدم وهو ذو فتحة واحــدة بقطر 1 مم لخروج نافــورة الوقــود منها بتأثير أنسياب الوقود بتأثير الجاذبية من ارتفاع 5 متر. يتم تــذرية الوقــود نتيــجة اندفــاع الهــواء المضغــوط من الفــراغ الحــلقى حــول فتــحة الوقــود مســببة تذرية الوقــود لقطرات صغيرة جدا. كما تم تصنيع ثلاثــة مدومــات لهــواء الاحتراق بزوايا ميــل للريش قــدرهــا 30، 45 ، 60 درجة. كما تم تصنيع ثلاثة أجزاء مخروطية الشــكل من الداخــل بزاوية نصف رأس مخروط مختلفة القيم بمقدار 30، 45 ، 60 درجة و كل منها مزودة باربــع ممــرات تســمح بمرور هــواء مضغوط مماس لســطحها الداخــلى مما ينتج عنة اكساب رذاذ الوقــود حــركة دواميــة وقوة طرد مركزية.

وجــد أن أضافة الحــركة الدوامية لرذاذ الوقــود تزيد من شــدة الاحتــراق وتــؤدى لكــبر حجم اللهــب الناتج وكذلك تزيد من قيم درجات حــرارة الغازات القــريبــة من ســطح أســطوانة الاحتــراق بنســبة 27%. وأن أكبر درجات حرارة للغازات تم الحصول عليها فى حالة زاوية نصف رأس المخروط 45 درجة والمرتبطه بزاوية تدويم الهواء 45 درجة وبالتالى تكون عند تلك الحالة أكبر كمية انتقال حرارة متوقعة لسطح الفرن.

ABSTRACT

The current paper was dedicated to improvement of combustion process of disposal lubricant oil through enhancing dispersion and mixing process by means of a special designed burner.

Numerous experimental trials were carried out in order to investigate the ability of burning disposal lubricant oil steadily. Three combustion air swirlers were manufactured with vanes angles 30°, 45° and 60° which were assembled co-axially with a single-hole externally mixed atomizer. In order to improve the combustion process, three hollow

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conical spinning elements were designed and installed at the atomizer exit with half cone angles 30°, 45° and 60°. Each conical element has four passages through which compressed air was discharged tangent to the inner surface of the hollow-cone. Consequently, the disposal oil droplets became finer and were provided with swirling motion. Each element was conjugated to the corresponding combustion air swirler with the same angle and direction in order to enhance the swirling and turbulent effects of the mixture. As a result; more-stable flames were successfully attained and gas temperature values along the combustor were increased remarkably.

Keywords: Combustion, Disposal Lubricant Oil, Fuel Spinning Motion, Air Swirl.

1. INTRODUCTION

Experience has shown that with the pressure type atomizer combustion at high pressures is characterized by high soot formation in the primary burning zone, leading to problems of carbon deposition and excessive exhaust smoke. This has led to a renewal of interest in the airblast atomizer. Several investigations have been done on airblast atomizers, which were concerned with atomizer geometry and operating conditions [1-3] on the mean droplet size and its distribution and effect of the properties and type of fuel injected [4]. Swirl combustors are widely used to produce high intensity flames for industrial applications. The effect of varying the conical angle of a coaxial swirling oil-fired burner on the flame characteristics was investigated [5]. Many studies were directed to understand the fuel/air mixing [6], governing parameters for flame structure [7-9] and stability [10-13]. Effort in the area of flame stabilization and propagation in spray flames interacting with an air co-flow [14-17], understanding and quantifying the unstable modes of combustion [18], chemical kinetics [19], and aerodynamics of ignition [19-20], and flammability limits [21] were investigated.

The present study is dedicated to improvement of combustion process of disposal lubricant oil through enhancing dispersion and mixing process by means of a special designed burner. The ability to burn disposal lubricant oil steadily with that burner was investigated. Also, the effect of adding spinning-motion to the spray of the disposal lubricant oil on thermal flames characteristics was investigated.

The environmental impact including different emissions will be investigated later on.

2. EXPERIMENTAL ARRANGEMENT AND TEST PROCEDURE

Numerous of experimental preliminary trials are done in order to attain stable flame of burning disposal lubricant oil. Several atomizers design and combustor tube with different operating conditions are tested. The experimental arrangement is shown in Fig.1. It is consists of: a combustor tube, a system for supplying fuel, combustion air swirlers, cooling air jacket, compressed atomizing air and compressed spinning air. The following described items were chosen.

A horizontal steel tube of 40 *cm* inner diameter, 150 *cm* length and 12 *mm* thickness is selected to be a combustor which is cooled with an air jacket. A divergent cone made of steel is installed at the combustor inlet. The steel cone is lined with a refractory material to absorb and then emits heat to heat up the fresh fuel droplets. Thirteen in-line tapings of 12 *mm* diameter were drilled at equidistance of 5 *cm* (upstream) and 10 *cm* (downstream) along the combustor for the gas temperatures and species concentrations measurements. A single-hole (1 *mm* diameter) externally mixed type atomizer is designed and manufactured as shown in Fig.2. The fuel-jet which is exited from the hole is subjected to a compressed atomizing air which is discharged through the atomizer narrow-annular gap causing atomization of the fuel-jet to fine spray. In order to possess the fuel-spray swirling motion, three hollow-conical elements are designed and manufactured such that they have half cone angle $\Phi/2 = 30^o$, 45^o and 60^o. Each is installed and conjugated to the corresponding combustion air swirler with the same angle in order to enhance the swirling and turbulent effects of the mixture. Each conical element is provided with four circular passages (0.7 *mm* diameter) which have been drilled such that all the passages have a constant inclination angle with the perpendicular plane to the atomizer axis with 30^o and the discharged spinning compressed air must be tangent to the inside surface of the hollow conical elements. Consequently, that ensures a swirling and a centrifugal effect to the fuel (oil) spray. The disposal oil droplets become fine and more-stable flames are successfully attained.

Three combustion air swirlers are manufactured with vane angles 30^o (S=0.46), 45^o (S=0.79) and 60^o (S=1.36) assembled in turn coaxially with the fuel atomizer. The blockage ratio of each swirler is kept constant at 0.33 (plane area of the vane/cross section area of the air supply pipe).

The test rig is equipped with: (1)- a compressor to supply the atomizing and spinning air, (2)- blowers to supply the combustion air and cooling air, and (3)- storage fuel tank to supply disposal lubricant oil with a constant velocity under constant gravity head of 5.0 meter. The fuel flow rate was 3.84 *kg/hr* and the total combustion air was 71.04 *kg/hr*, this resulted in an overall air-fuel mass ratio of 18.5. The pressure and the flow rate of the atomizing air were 1.5 *bar* and 1.0 *L/s*, while they were 0.5 *bar* and 0.4 *L/s* for the spinning air. The combustion air velocity is determined by using U-tube manometer which was calibrated with thermal Anemometer. The compressed (atomizing/spinning) air flow rates are determined using U-tube manometer which was calibrated with air rotameters.

To start-up burning of the disposal lubricant oil, firstly Kerosene fuel was supplied to the atomizer then ignited and the Kerosene flame which existed was used as a pilot flame. Then, disposal lubricant oil is gradually admitted to replace the Kerosene until Kerosene is shut-off within 5 minutes. The disposal lubricant oil feeding is kept constant and stable continuous oil flame is obtained.

The disposal lubricant oil is analyzed by NASR PETROLEUM COMPANY at Suez, Egypt. The list of specifications is:

Test	*Method*	*Result*
Density at 15 °C	ASTM D 1298	0.9052
Ash content %wt	ASTM D 482	0.696
Water content % vol	ASTM D 95	0.05
Viscosity index	IP 226	107.8
Calorific value cal/g	ASTM D 240	10640

Effect of changing the angles of the fuel spinning cones and their conjugated corresponding combustion air swirlers on flames structure were investigated. The experimental investigated runs were divided into two groups. In the first group, the effect of changing the swirl vane angles of the combustion air from Ψ= 30° to 45° and 60° (Runs-1, 2 and 3 respectively) was investigated. While in the second group, the effect of adding spinning motion to the atomized fuel spray using the conical elements with different half spinning cone angles $\Phi/2$ of 30°, 45° and 60° (Runs-4, 5 and 6 respectively) was investigated also. The schedule of the experimental runs is shown in table-1.

Table-1

		Combustion Air Swirl Angle Ψ	Spinning Fuel Angle $\Phi/2$
Group 1 Without spinning effect	Run-1	30°	
	Run-2	45°	
	Run-3	60°	
Group 2 With spinning effect	Run-4	30°	30°
	Run-5	45°	45°
	Run-6	60°	60°

Measurements of gas temperatures were done using fine thermocouples wires (Platinum and 13% Platinum-Rhodium) of 100 μm diameters. Species concentration measurements of CO and O_2 were done for the swirled disposal lubricant oil flame along the combustor tube using a gas analyzer model "TESTOTERM-342". The analyzer set calculate CO_2 concentration.

3. RESULTS AND DISCUSSIONS

3.1 Combustion of Disposal Lubricant Oil

Disposal lubricant oil was delivered to the combustor via a single-hole atomizer. The fuel passes through the discharge orifice in the form of droplets which break up into smaller droplets under the action of the compressed atomizing air forming skirt of fine spray. The swirling action of the combustion airflow results in high turbulent mixing rates enclosing a central recirculation zone. The disposal lubricant oil was ignited relying on the pilot kerosene flame. Unstable flame was obtained. In order to attain a stable flame and more efficient combustion, the inlet surface of the combustor cone was lined with a refractory material to absorb and then emit heat in order to heat up the fresh fuel droplets. The comparatively high temperatures of the recirculated gases allowed chemical reaction to proceed with high intensity. This extends to the fuel spray, where the resulting high gas temperatures increased the evaporation rate of the disposal lubricant oil and tended to stabilize the attained flames.

Gas temperature and specie concentrations (CO_2, CO and O_2) across the combustor at 273 points in both radial and axial directions were measured through 13 axial locations along the combustor length with 1 *cm* radial increment in order to obtain complete feature of gas temperatures and species concentrations patterns along the combustor.

It is evident from the gases temperature contours which are shown in Fig.3 that the increase in the combustion air swirler angle from 30° (S=0.46, Run-1) to 45° (S=0.79, Run-2) causes an increase in the reaction rate at the initial and central zones of the combustor. Consequently, higher gas temperature values were covered the whole combustor. This was mainly due to the higher turbulent mixing rates. The maximum' recorded gas temperature was found to be 1240°C for Run-2 at a dimensionless radial distance of 2R/D= 0 – 0.1 and a dimensionless axial distance of x/D= 0.9 – 3.75. Further increase in the swirler angle from 45° (S=0.79, Run-2) to 60° (S=1.36, Run-3) causes a comparative reduction in the gas temperature values and a drawn of the reaction zone toward the combustor inlet. The temperatures contour lines show a reduction in the measured values at down stream and at larger radii.

Gas temperatures along the combustor centerline and the radial distribution at a certain axial section x/D = 2.5 were plotted for the three combustion air swirlers and are shown in Figs.4, 5. The results of the gas temperatures distributions for Runs-1, 2 and 3 along the combustor centerline in Fig.4 show a sharply increase in the gases temperature values at x/D = 0.0 to 0.5 and a gradual increase from x/D = 0.5 to 3.75 then it is followed by a gradual reduction at x/D= 3.75 until the end of the combustor. Also gases temperature values in the radial direction at section x/D = 2.5 for Runs-1, 2 and 3 show the same order of the centerline gases temperatures and maximum temperature values were found to be at the combustor centerline and gradually decrease by moving toward the combustor wall.

Run-2, which had higher gas temperature values, was chosen to be the run whose whole gas species concentrations are measured and contours along the combustor are presented in Fig.6. It was noticed from this figure that the trend and the order of the temperature values within the combustor are coincide with that of CO and CO_2 concentrations. Within the central region of the flame (up to x/D = 3.75), the highest values which were recorded: gas temperature was 1240°C, CO concentration was 11.9 ppmx10^3 and CO_2 was 15% but O_2 concentration was reduced to about 2 % at the same region. This implies that most of the oil spray droplets were spread in the central region also the oxidation rates of the oil in this region was sufficiently high. Accordingly, high temperature values in that region were anticipated to increase the evaporation and turbulent mixing rates of the freshly atomized droplets and consequently give high combustion intensity. Inspection of the species concentration levels throughout the combustor downstream suggests a reduction in the fuel oxidation rate (completion of oil combustion) this is evidenced by the reduction in the gas temperature to 600°C at axial distance of x/D = 6.88.

From the above discussion, it was found that the trend and the order of the gas temperatures and species concentrations both of them emphasized each other. The highest combustion intensity was found to be for Run-2 upstream the combustor at the centerline and located at x/D = 0.9 - 3.75, 2R/D = 0 - 0.1. Also, higher gas temperature values cover the whole combustor.

3.2. Adding Spinning Motion to Disposal Lubricant Oil Spray

The previous three flames were improved by providing spinning motion to the sprayed oil droplets. The spinning effect was activated by passing the compressed spinning air through the four circular passages which are drilled in the conical elements. Other three flames represented by Runs 4, 5 and 6 were obtained by replacing in turn the spinning conical fuel-elements to the atomizer nozzle exit. Each element had different half cone angles of 30°, 45° and 60°. The direction of swirl of both the oil spray and the combustion air are in the same direction (co-swirl). The replacement of the oil spinning conical element of half cone angle 30° was conjugated with the combustion air swirl of 30° and so on for the corresponding other elements.

An improvement in the combustion process and enlargement in the flames volume was observed when adding the spinning motion to the oil spray. From the radial gas temperatures measurements along the combustor, the gas temperatures contours were drawn for Runs-4, 5 and 6 and are shown in Fig.7. The temperature values for these runs are higher than those corresponding to Runs-1, 2 and 3 (without spinning effect). Whereas by adding the spinning effect to the oil spray, the oil droplet diameter is reduced and the evaporation rate of the fuel was increased, consequently the combustion process improved and the rate increased. It can be noticed that the near wall region for Runs-4, 5 and 6 were dominated by higher values of gas temperatures with an increase of 100°C, 200°C, and 150°C than those of Runs-1, 2 and 3 respectively. In other words, the increase in the near wall gas temperatures for the case of adding spinning effect was 27% greater than those for the case without spinning. Also, it was noticed that the higher reaction rate regions, which were indicated by the higher gas temperatures, are sucked towards the atomizer exit and extended in larger area away from the combustor centerline, forming a hollow flame. As the half angle of the spinning cone element (spinning fuel angle) was increased from 30° to 45° the maximum recorded gas temperature was increased from 1150°C to 1200°C and the gas temperatures of the combustor end region was increased from 550°C to about 650°C. More increase in the spinning oil angle from 45° to 60° was found to lead to a reduction in the maximum temperature from 1200°C to about 1050°C, and the gas temperatures of the combustor end region also reduced from 650°C to 550°C.

A comparison was held between Run-2 (maximum combustion intensity without activating spinning oil spray) and Run-5 (maximum combustion intensity with activating spinning oil spray) regarding gas temperatures, CO_2, and O_2 concentrations in the two directions; along the combustor centerline and the radial direction at section x/D =2.5. The results in Figs.8-9 present the gas temperature values and CO_2 concentration, along the centerline of the combustor, which were increased sharply up to x/D = 1, followed by a gradual increase and then a gradual decrease until their exhaust values at the end of the flame became 600°C and 4% respectively. That means, the highest chemical reaction rate which accompanied with the highest gas temperature value, highest CO_2 and lowest O_2 concentrations was found to be upstream the combustor. It was also found that, the values of the gas temperatures and CO_2 concentrations for Run-2 were higher than those values for

Run-5, that because of the higher reaction rate.

In the radial direction at section x/D = 2.5 the trend of gas temperature values and CO_2 concentrations were very similar as shown in Figs.10-11. These values were very high at the centerline and they were reduced gradually moving towards the wall. Run-5 has higher gas temperature values, higher CO_2 concentrations, lower O_2 concentrations that means Run-5 has higher chemical reaction rate in the radial direction at that section than Run-2. Also, the figures show that the highest reaction rate was found to be around the combustor tube axis up to 2R/D = 0.2 then reaction decays toward the combustor wall.

The previous analysis emphasized that adding spinning effect to the oil spray: improves combustion, increases gas temperatures in particularly near the combustor wall region and at the end of the combustor. Also, the high combustion intensity region sucked toward the atomizer exit and away from the combustor centerline. So, the maximum gas temperature values, consequently, the maximum heat transfer to the combustor wall will be expected for Run-5 in which fuel is possessed spinning motion at cone angle 45°.

4. CONCLUSIONS

1- The obstacles of burning disposal lubricant oil steadily were defeated by means of a special designed burner.
2- Increase of the combustion air swirl angle from 30° (i.e. S=0.46, **Run-1**) to 45° (i.e. S=0.79, **Run-2**) causes an increase in the reaction rate at the initial and central zones of the combustor. Consequently, higher gas temperature values extended to cover the whole combustor. Further increase of the swirler angle from 45° (i.e. S=0.79, **Run-2**) to 60° (i.e. S=1.36, **Run-3**) causes a comparative reduction in the intensity of the chemical reaction and a drawing of the reaction zone towards the combustor inlet, associated with the lowest gas temperature values.
3- Adding spinning effect to the spray of the disposal lubricant oil for the flames of Run-1, 2 and 3 led to: (a) an increase of the values of the high temperature regions, (b) a suck of the high temperature regions toward the atomizer exit, and they extended in larger area away from the combustor centerline forming larger hollow flames, (c) an increase of the near wall gas temperatures by about 27%.
4- The maximum gas temperature values along the combustor were found to be for **Run-5.** Where the spinning effect of the spray was activated at half spinning cone angle of $\Phi/2$ = 45° and combustion air swirl angle of Ψ = 45°. As a result, the maximum heat transfer to the combustor wall is expected to be for **Run-5.**

Nomenclature:

S = Swirl Number,
Ψ = Angle of the combustion air swirler,
$\Phi/2$ = Angle of the half of the spinning cone,
x = Axial distance along the combustor,
x/D = Dimensionless axial distance,
2R/D = Dimensionless radial distance,
D =Combustor diameter,
R =Radial distance.

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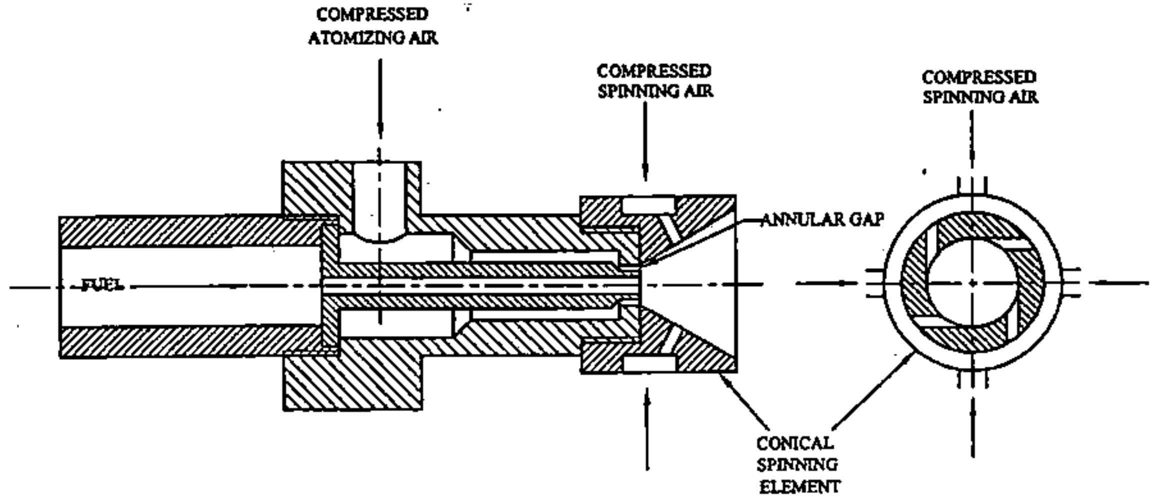
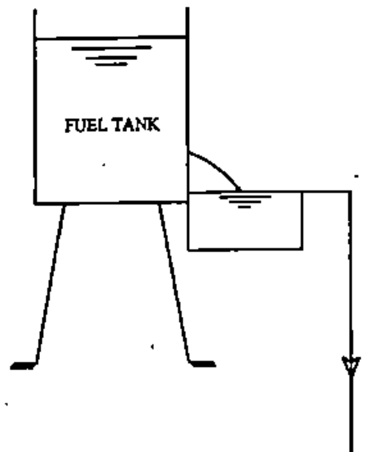


Fig.2 A SINGLE HOLE SPINNING ATOMIZER



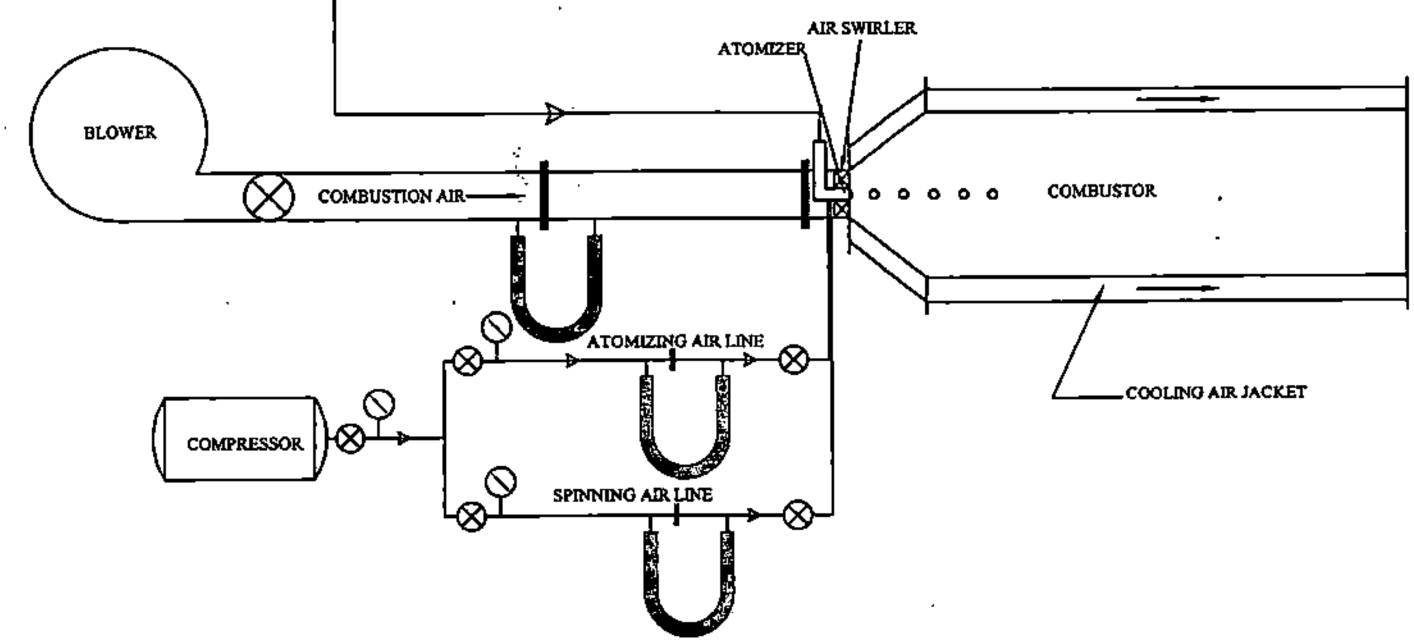


Fig.1 SCHEMATIC DIAGRAM OF THE EXPERIMENTAL ARRANGEMENT

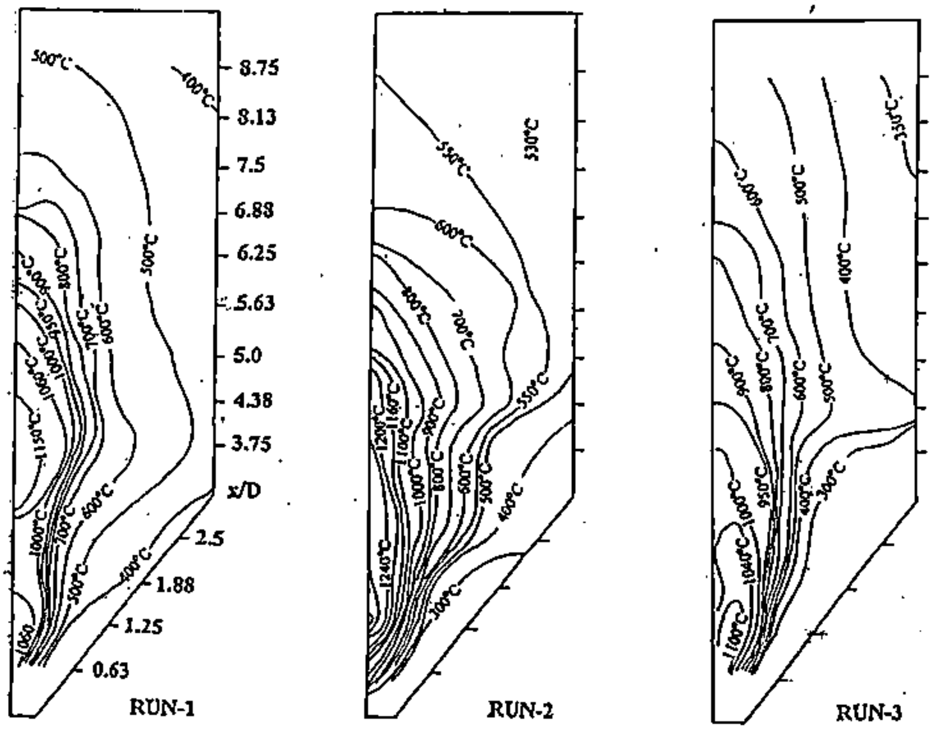


Fig.3 Gas Temperature Contours along the Combustor Tube for Runs 1,2,3.

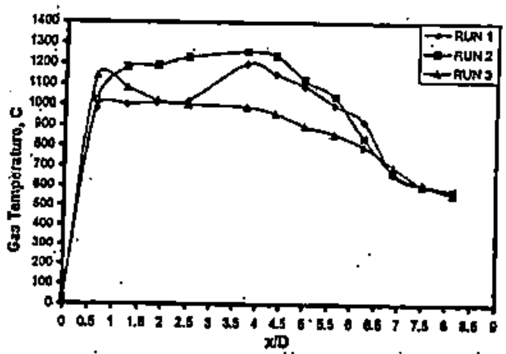


Fig.4 Gas Temperature Distribution along the Combustor Centerline (without spinning fuel effect)

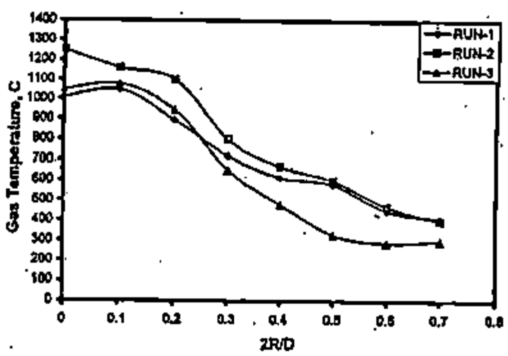


Fig.5 Radial Gas Temperature Distribution at Section x/D=2.5 (without spinning fuel effect)

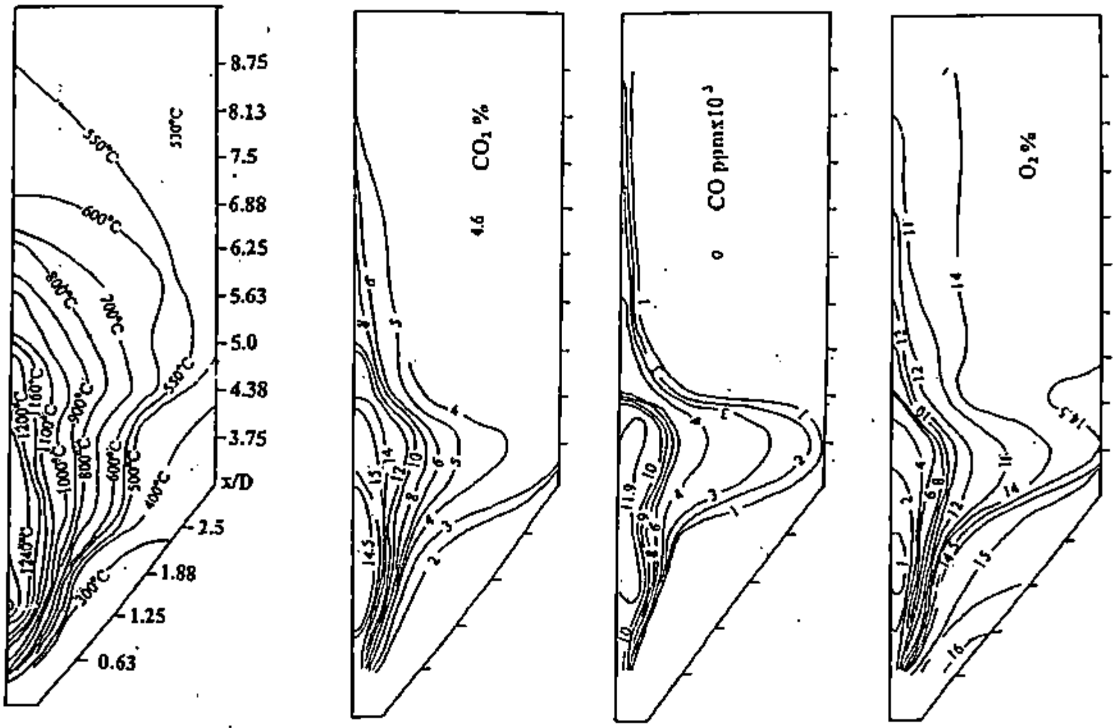


Fig.6 Gas Temperature, CO_2, CO and O_2 Contours along the Combustor Tube Run-2

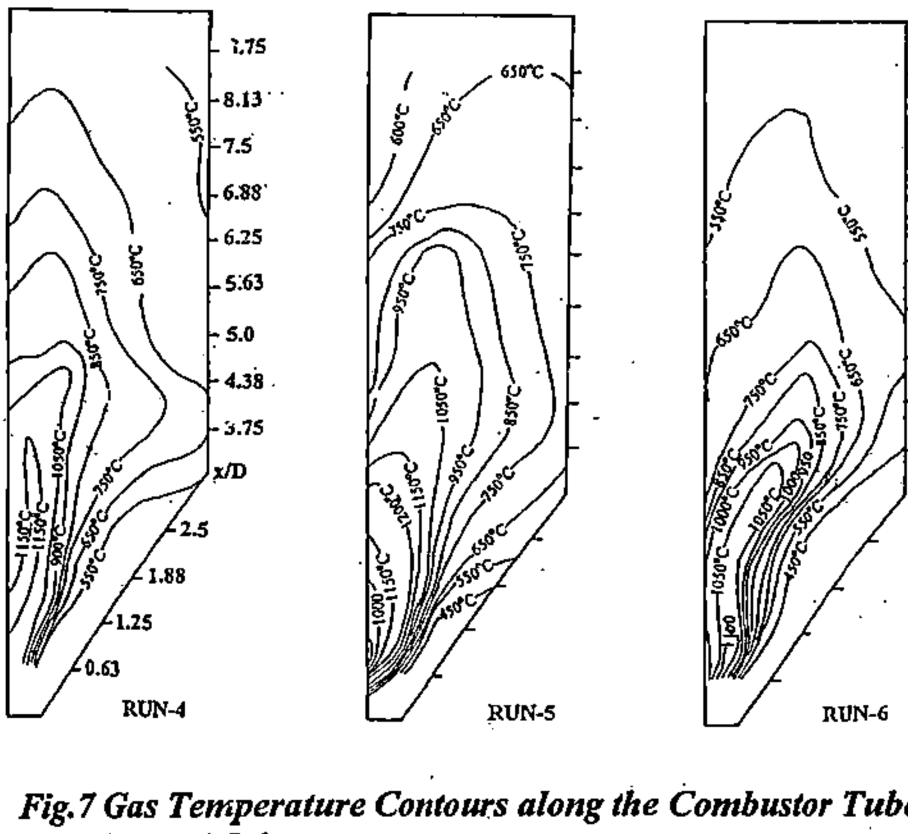


Fig.7 Gas Temperature Contours along the Combustor Tube Runs-4,5,6.

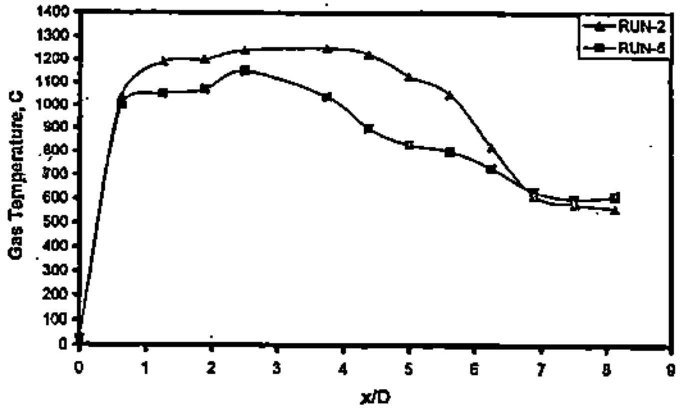


Fig.8 Comparison of Gas Temperature Distribution along the Combustor Centerline, (Without and With spinning fuel effect)

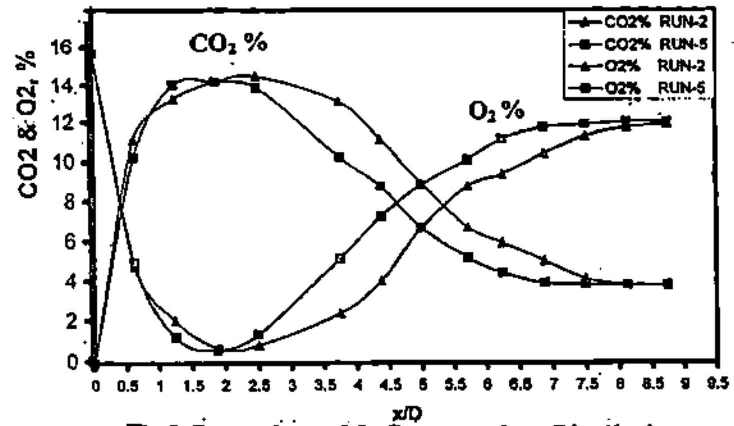


Fig.9 Comparison of O_2 Concentrations Distribution along the Combustor Centerline, (Without and With spinning fuel effect)

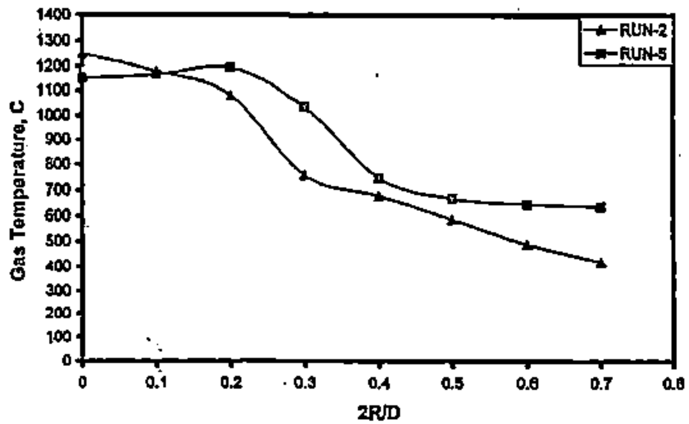


Fig.10 Comparison of Radial Gas Temperature Distribution At Section x/D = 2.5, (Without and With spinning fuel effect)

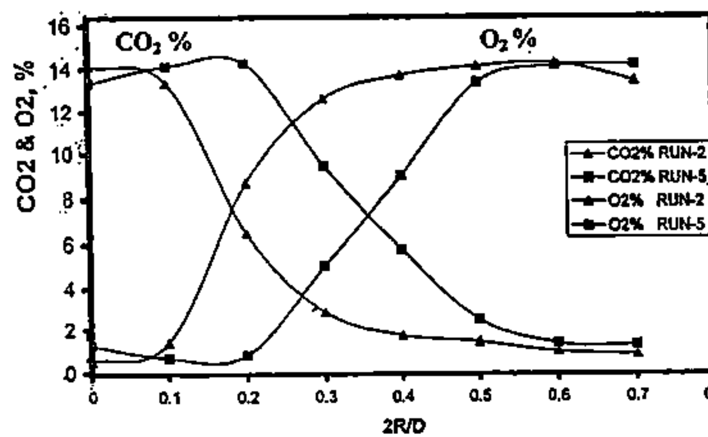


Fig. 11 COMPARISON OF RADIAL CO2 & O2 CONCENTRATIONS DISTRIBUTION AT SECTION x/D = 2.5 (Without & with Spinning Fuel Effect)