

COMBUSTION OF KEROSENE SPRAYS

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ABSTRACT

The combustion of the kerosene sprays inside a swirl type combustor is studied. To decrease the exhaust emissions such as NO_x , NO and SO_2 , Natural Gas (NG) or Liquefied Petroleum Gas (LPG) fuels are added to the combustion air with different ratios. The effects of different percentages of NG (10, 20, 30 and 40%), different percentages of LPG (1, 2, 3 and 4%), and thermal load (70, 100 and 130 kW) on the flame characteristics were investigated. Also, a comparison between addition of NG and LPG was carried out. During the experimental study, the air to fuel mass ratio and air swirl number are kept constants at 30 and 0.5, respectively. The experimental results show that, as the NG percentage increases from 10 to 40%, the flame lengths and the flame temperatures were decreased, so that, NO_x , NO , CO_2 and SO_2 concentrations were decreased, while CO and O_2 concentrations were increased. Also, as the LPG percentage increases, the flame lengths and the flame temperatures were decreased, so that, NO_x and NO , CO_2 and SO_2 concentrations were decreased, while CO and O_2 concentrations were decreased.

يهدف هذا البحث إلى دراسة عملية لتحسين احتراق رذاذ وقود الكيروسين بإضافة وقود غازي لهواء الاحتراق. حيث أن الوقود الغازي رخيص الثمن وله انبعاثات أقل بالمقارنة بوقود الكيروسين. نظرا إلى زيادة اكتشافات مصادر الوقود الغازي كان من الضروري دراسة خصائص لهب الرذاذ الانتشاري للكيروسين مع إضافة وقود غازي مثل الغاز الطبيعي أو غاز البوتاجاز إلى هواء الاحتراق. تم دراسة تأثير كل من نسبة الوقود الغازي المضاف والحمل الحراري على خصائص اللهب. فقد تم إضافة الغاز الطبيعي بنسب مختلفة 10، 20، 30 و 40% وإضافة غاز البوتاجاز بنسب 1، 2، 3 و 4% من وقود الكيروسين المستخدم مع استخدام أحمال حرارية مختلفة بقيم 70، 100 و 130 كيلو وات. لجميع التجارب العملية تم استخدام قيم ثابتة لنسبة الهواء إلى الوقود مقدارها 30 ورقم مدوم الهواء مقداره 0.5. أوضحت النتائج أن زيادة نسبة كل من الغاز الطبيعي و غاز البوتاجاز المضاف تؤدي إلى تقليل كلا من طول اللهب و درجات الحرارة داخل غرفة الاحتراق و بالتالي نقص نسب تركيزات كل من أول أكسيد النيتروجين و أكاسيد النيتروجين و ثاني أكسيد الكربون و ثاني أكسيد الكبريت وزيادة نسب تركيزات كل من أول أكسيد الكربون و الاكسجين.

Keywords: Gas Turbine, Spray Combustion, Emissions, Swirling.

1. INTRODUCTION

The fuel burning represents the main source of energy in the present time. The role of such source of energy somewhat decreased after the discovery of the nuclear energy and exploitation of solar energy. Also, the application of the fuel in petrochemical industries is increasing and the economical use of the fuel becomes an important parameter. However, several years must pass before fuel losses its leading position.

The exhaust combustion emissions have harmful effects on the human health, soil and plants [14]. So that, many researchers studied various techniques for reducing the combustion emissions especially NO and NO_x emissions [2,5,11,12,13,18]. The gaseous fuel additive to the combustion processes was considered as one of the most effective method for reducing NO_x emissions. This is because it can assist in the production of the radical species necessary for reducing not only NO , but also NO_2 , N_2O , and may also lead to increase the burning velocity [5,18].

Most experimental studies were mainly concerned with the flame characteristics for Kerosene fuel only [1,6,8,10] or gaseous fuel only [5,7,11,13]. It can be

seen that, the amount of information is relatively incomplete for combustion of dual fuel (Kerosene and NG). Therefore, in the present work, the flame characteristics of Kerosene fuel were studied when adding of NG and LPG to the combustion air by different percentages.

In the flame characteristic studies, temperature distributions in the axial and radial directions of the combustor were measured. In addition, the flame length and the exhaust species concentration at the end of the exhaust pipe were also measured. Temperature distributions were used to draw temperature maps. The flame length and different species concentration curves were drawn under different operating conditions. In order to study the above parameters, a test rig described below was constructed.

2. EXPERIMENTAL TEST RIG

The present experimental work is divided into two parts:

1- In the first part, NG fuel is added to the combustion air (as a mass percentage of NG to Kerosene fuel such as 10, 20, 30 and 40%). The

flame characteristics at these percentages were compared with similar conditions but without additives. The air to fuel mass ratio of 30 and the air swirl number of 0.5 were kept constants during all operating conditions for input thermal loads of 70, 100 and 130 kW.

2- In the second part, LPG fuel was added to the combustion air (as a mass percentage of LPG to Kerosene fuel such as 1, 2, 3 and 4%). The flame characteristics at these percentages were also compared with similar conditions, but without additives and with those of the first part.

The schematic drawing of the test rig is shown in Fig. 1. A water cooled swirl type combustor of inner diameter 25 cm and 100 cm length was constructed to burn Kerosene fuel with air. The Kerosene fuel flow from the fuel tank and enters the combustor through a pressure swirl atomizer. The gaseous fuel was mixed with the combustion air of Kerosene fuel in the air duct at a distance of 2 m upstream the inlet of the combustor to insure good mixing with combustion air. The gaseous fuel flows from a pressurized gas cylinder, filled with NG at about 200 bar and with LPG at about 3 bar. A pressure regulator was fitted on the gas cylinder to adjust the output gas pressure and consequently the issued mass flow rate. The gaseous fuels flow rates were measured and calibrated at different pressures using a rotameter

device. The chemical compositions of NG and LPG are given in Tables 1 and 2, respectively.

Table 1 Chemical composition of the NG (Natural Gas Vehicles Co. 2003)

Substance	Chemical Formula	% by Volume	% by Mass
Methane	CH ₄	91.43	83.62
Ethane	C ₂ H ₆	4.10	7.03
Propane	C ₃ H ₈	0.99	2.49
Butanes	C ₄ H ₁₀	0.33	1.09
Pentanes	C ₅ H ₁₂	0.10	0.41
Nitrogen	N ₂	2.53	4.05
Helium	He	-	-
Carbon Dioxide	CO ₂	0.52	1.31

Table 2 Chemical composition of LPG (Egypt Gas Co. 2003)

Substance	Chemical Formula	% by Volume	% by Mass
Butane	C ₄ H ₁₀	87.1	90.83
Propane	C ₃ H ₈	7.2	5.70
Propylene	C ₃ H ₆	4.2	3.17
Methane	CH ₄	0.1	0.03
Ethane	C ₂ H ₆	0.5	0.27

- 1-fuel gear pump 2-main fuel valve 3-glass tube fuel indicator 4-Kerosene tank 5-filter 6-fuel by-pass valve
- 7-fuel by-pass valve 8-gas bomb 9-pressure regulator 10-gas inlet valve 11-U-tube water manometer 12-venturi meter
- 13-gas outlet valve 14-mercury thermometer for cooling water outlet 15-cooling water outlet 16-combustor 17-chimney 18-fuel pressure gauge
- 19-fuel fine filter 20-fuel valves 21-combustion air blower 22-combustion air control valve 23-orifice meter 24-U-tube water manometer
- 25-gaseous additives nozzles 26-combustion air swirler 27-pressure swirl atomizer 28-cooling water jacket 29-cooling water inlet 30-exhaust emissions point

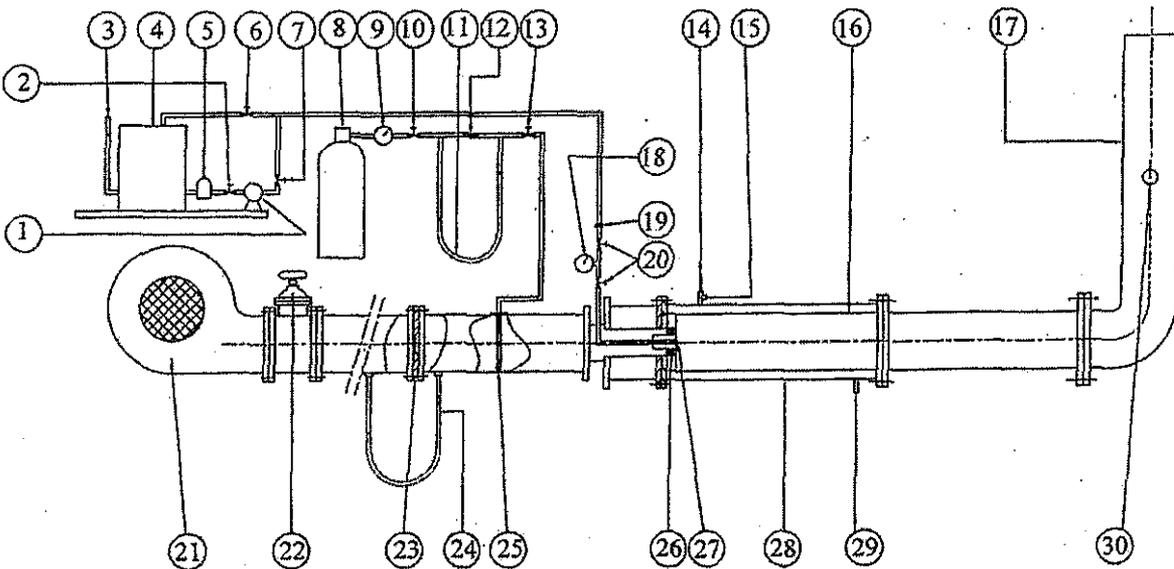


Fig. 1. Schematic diagram of the experimental test rig.

NG fuel increases the rate of evaporation of Kerosene fuel and this leads to increase in the mixing rate. That increases the chemical reaction rate or leading to improve the combustion process and consequently the flame size decreases causing the high temperature regions shift upstream.

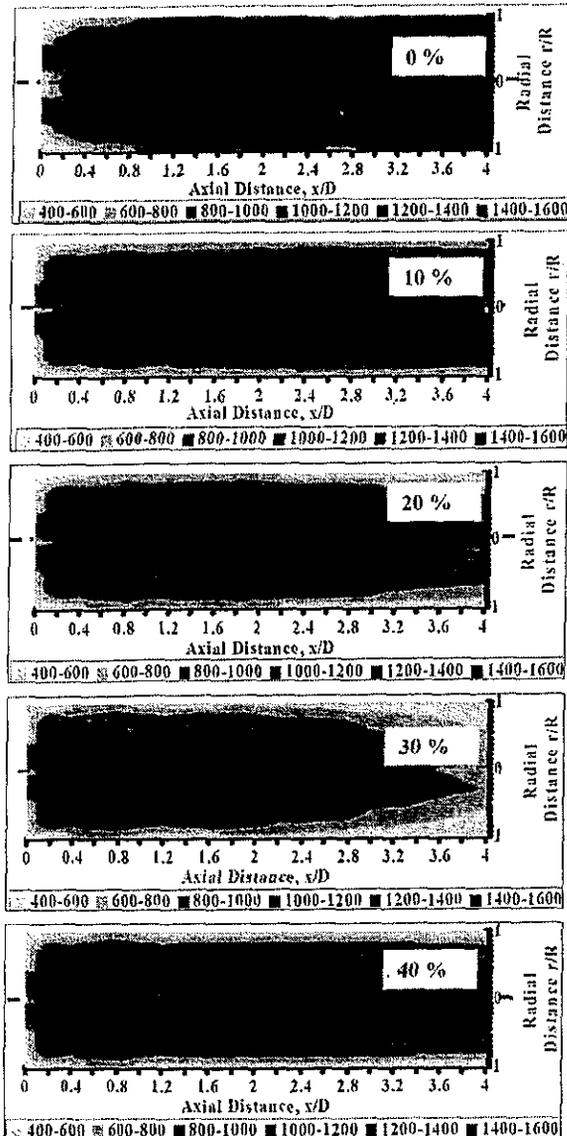


Fig. 6 Effect of NG percentage on temperatures maps in K at input thermal load of 130 kW

3.1.2 Effect of LPG addition

The effect of different percentages of LPG fuel at constants values of thermal load, air swirl number and air to fuel mass ratio on temperature distribution maps is shown in Fig. 7. The figure shows that, the heat released from the combustion of LPG fuel increases the rate of evaporation of Kerosene fuel and this leads to increase in the mixing rate. That increases the chemical reaction rate leading to improve the combustion process and consequently

the flame size decreases causing the high temperature regions shifted down stream, the same effect as the addition of the NG as described before.

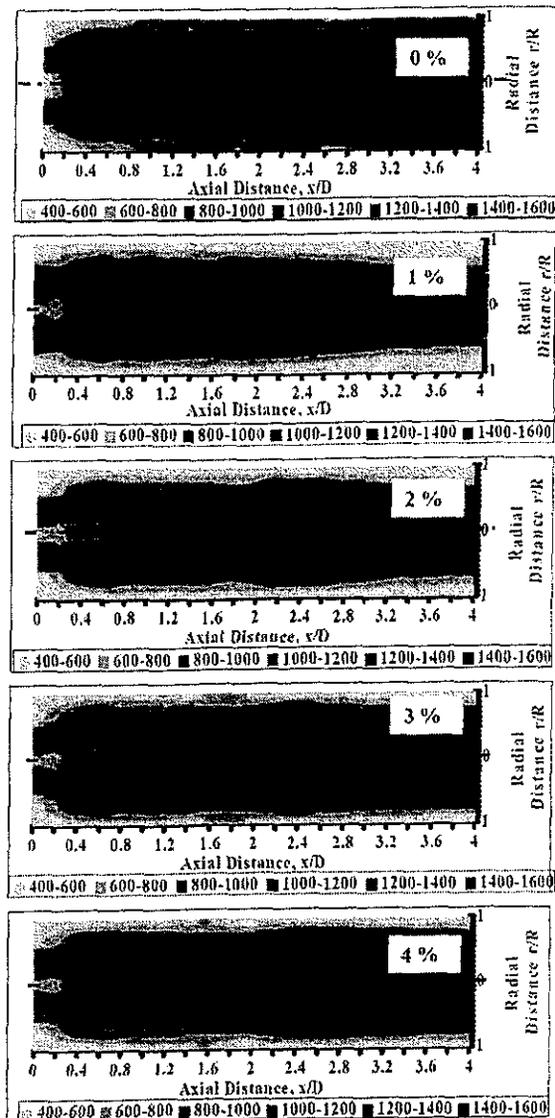


Fig. 7. Effect of LPG percentage on temperatures maps in K at input thermal load of 130 kW

3.1.3 Effect of input thermal load

The effects of the input thermal load on the temperature maps when adding NG and LPG fuels to the combustion air are shown in Figs. 8 and 9 respectively. From these figures, it can be noticed that increasing the input thermal load leads to increase in the fuel momentum as a result of increasing the fuel mass flow rate and the fuel pressure. Furthermore, the high temperature regions shifted downstream, and increased in size while the flame length is increased due to the increase of the fuel momentum.

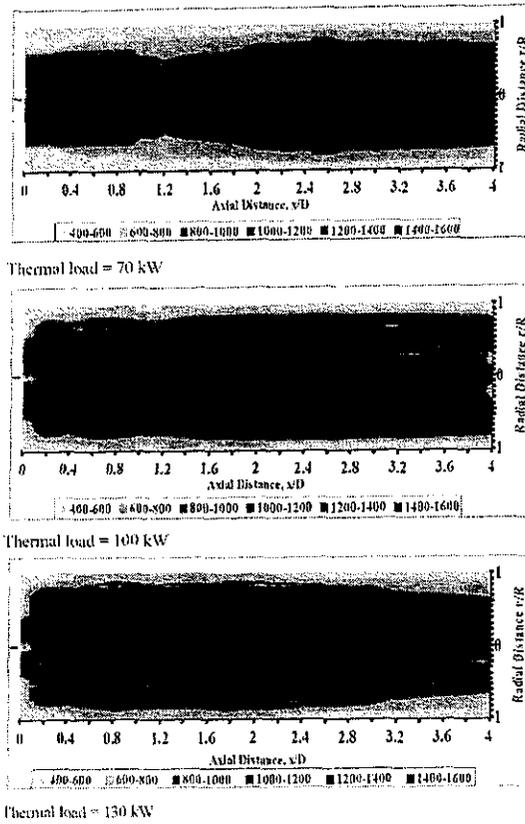


Fig. 8. Effect of the input thermal load on the temperatures maps in K at the NG percentage of 20%

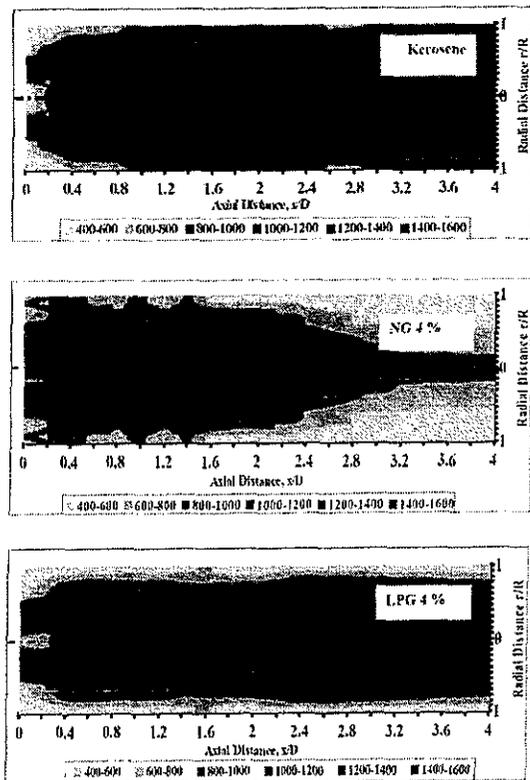


Fig. 9. Effect of the input thermal load on the temperatures maps in K at LPG percentage of 3%

3.1.4 Comparison between NG and LPG additions

A comparison between the NG and LPG fuels addition when be added by the same percentage is shown in Fig. 10. The figure shows that, for the NG fuel, the high temperature region is found between the axial to diameter ratios of 1.0 and 1.2. But this region is found between 1.0 and 2.2 for LPG. The high temperature region size is greater for LPG than that for NG and the flame size is greater for LPG than for NG (for NG, it is shorter in length but wider in diameter). For NG the temperatures are lower than that for LPG. This is because the heating value of LPG is greater than that of NG. Therefore, the heat released from combustion of LPG is greater than that of the NG.

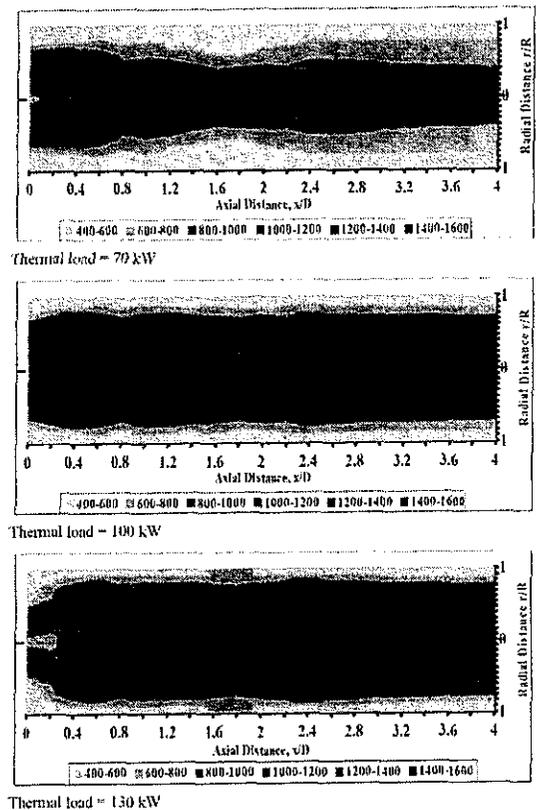


Fig. 10. Temperatures maps in K for the same percentage of NG and LPG of 4% at input thermal load of 130 kW

3.2 Effect of Adding Different Percentages of NG and LPG on:

a) The visible flame length

The effects of adding different percentages of NG and LPG fuels to the combustion air of Kerosene fuel on the visible flame length are shown in Figs. 11 and 12, respectively. It is shown that, when adding the NG, the flame length remarkably decreased as shown in Fig. 11. But when adding the LPG, the flame length slightly decreased as shown in Fig. 12.

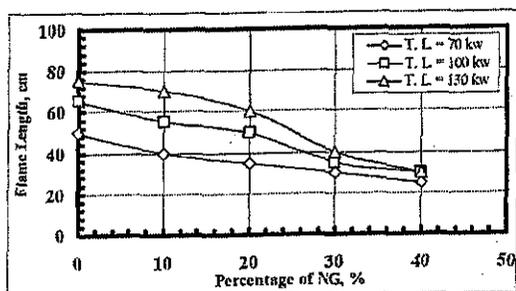


Fig. 11. Effect of adding NG fuel with different percentages on flame length

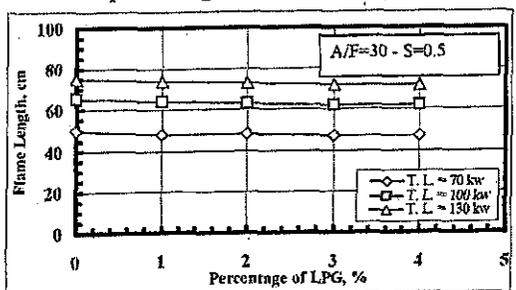


Fig. 12. Effect of adding LPG fuel with different percentages on flame length

b) The exhaust species concentration

It is important to study and discuss the experimental results reported by measuring some of exhaust species such as NO, NO_x, CO, CO₂, O₂ and SO₂ concentrations at different operating conditions. The above species concentrations were measured using digital gas analyzer (Model Testo 350). The measuring port is at the middle of the chimney to avoid the effect of the atmospheric air on the concentrations of exhaust species and to be sure that the exhaust flow is steady. The exhaust concentrations were measured radially in the port cross-section and the mean value was obtained. The effects of the different operating conditions, such as NG and LPG percentages and input thermal load on the species concentration have been investigated.

The effects of NG and LPG percentages on the species concentration are shown in Figs. 13 and 14, respectively. Figure 13 shows that by increasing NG percentage, the average exhaust temperature decreased accompanied with a decrease of NO, NO_x, CO₂ and SO₂ concentrations, but an increase of CO and O₂ concentrations [2,11,12,18].

Increasing the NG percentage from 0 to 40% - keeping air swirl number of 0.50, air to fuel mass ratio of 30 and input thermal load of 100 kW constant- it was noticed that NO, NO_x, CO₂ and SO₂ concentrations decreased by about 50, 46, 30 and 28%, respectively. While CO and O₂ concentrations increased by about 106 and 40%, respectively.

Figure 14 shows the effect of LPG fuel percentage on the exhaust species concentrations. Increase of LPG percentage leads to a decrease of NO, NO_x, CO₂ and

SO₂ concentrations, but it leads to an increase of CO and O₂ concentrations. It is shown that, increasing LPG percentage from 0 to 4% at input thermal load of 100 kW -keeping the air swirl number of 0.5 and air to fuel mass ratio of 30 constant- leads to a decrease of NO, NO_x, CO₂ and SO₂ concentrations by about 41, 38, 33 and 25%, respectively, but an increase of CO and O₂ concentrations by about 132 and 27%, respectively.

3.3 Effect of Changing Input Thermal Load and NG/LPG Percentages on:

a) The exhaust species concentrations

The effects of changing the input thermal load on the species concentration with the addition of NG and LPG fuels to the combustion air are shown in Figs.15 and 16 respectively. Figure 15 shows that, adding NG and increasing the input thermal load from 70 to 130 kW led to an increase of NO, NO_x, CO₂ and SO₂ concentrations but a decrease of CO and O₂ concentrations. At constants air swirl number of 0.5, air to fuel mass ratio of 30 and at NG percentage of 20%, by increasing the input thermal load from 70 to 130 kW it was noticed that NO, NO_x, CO₂ and SO₂ concentrations increased by about 64, 67, 15 and 26%, respectively. While CO and O₂ concentration decreased by about 23 and 11% respectively. At air swirl number of 0.5, air to fuel mass ratio of 30 and NG percentage 40% by increasing the input thermal load from 70 to 130 kW it was noticed that NO, NO_x, CO₂ and SO₂ concentrations increased by about 71, 67, 20 and 22%, respectively. While CO and O₂ concentrations decreased by about 22 and 16%, respectively.

Figure 16 shows the effects of changing the input thermal load on species concentrations with the addition of LPG fuel to the combustion air. By increasing the input thermal load, the combustion flame temperatures increased accompanied with an increase of NO, NO_x, CO₂ and SO₂ concentrations, but a decrease of CO and O₂ concentrations. At LPG percentage of 2%, air swirl number of 0.5 and air to fuel mass ratio of 30, by increasing the input thermal load from 70 to 130 kW it was noticed that NO, NO_x, CO₂ and SO₂ concentrations were increased by about 50, 44, 13 and 25%, respectively while CO and O₂ concentrations decreased by about 12.5 and 15.2%, respectively. At LPG percentage of 4%, air swirl number of 0.5 and air to fuel mass ratio of 30, by increasing the input thermal load from 70 to 130 kW it was noticed that NO, NO_x, CO₂ and SO₂ concentrations were increased by about 60, 42, 20 and 16%, respectively, while CO and O₂ concentrations decreased by about 11 and 18, respectively.

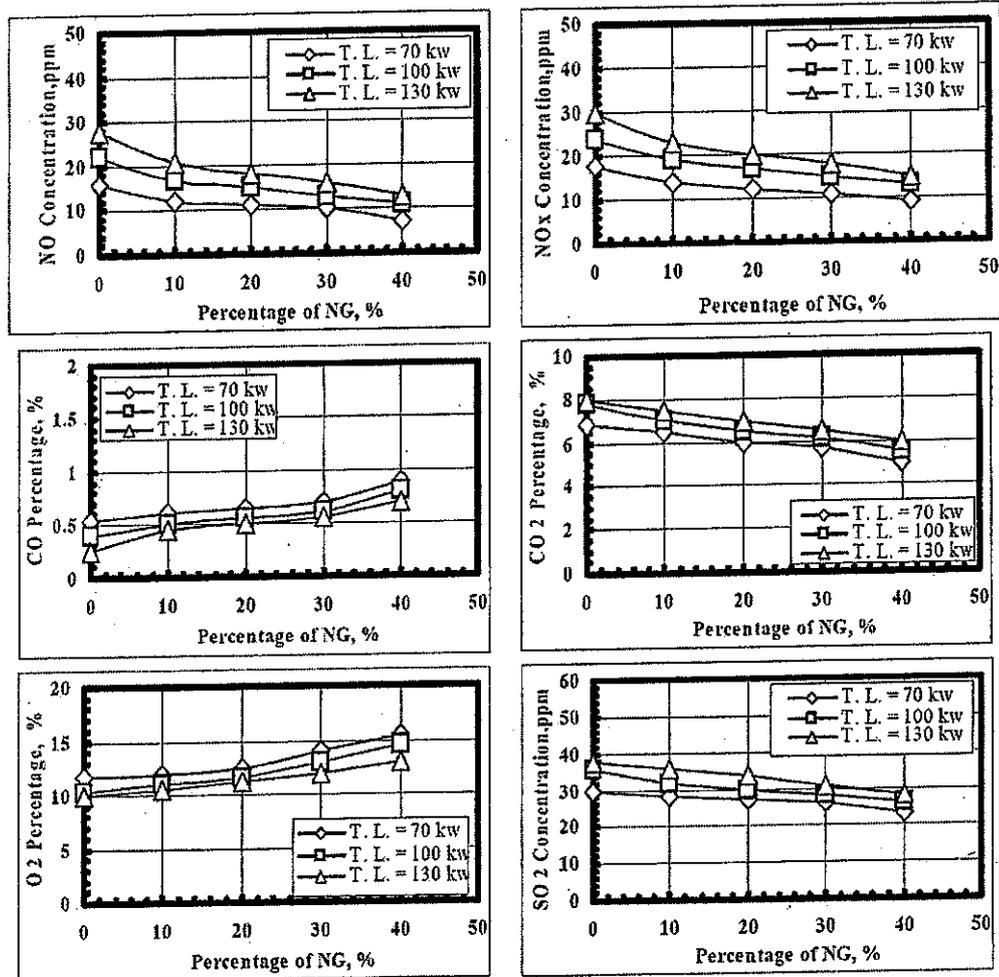
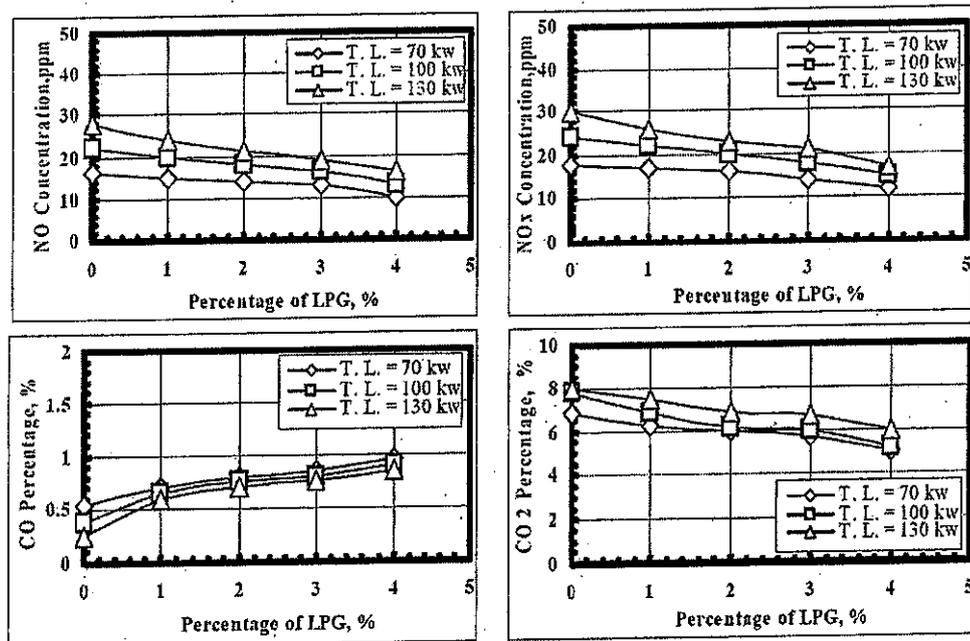


Fig. 13. Effect of adding NG with different percentages on exhaust species concentration.



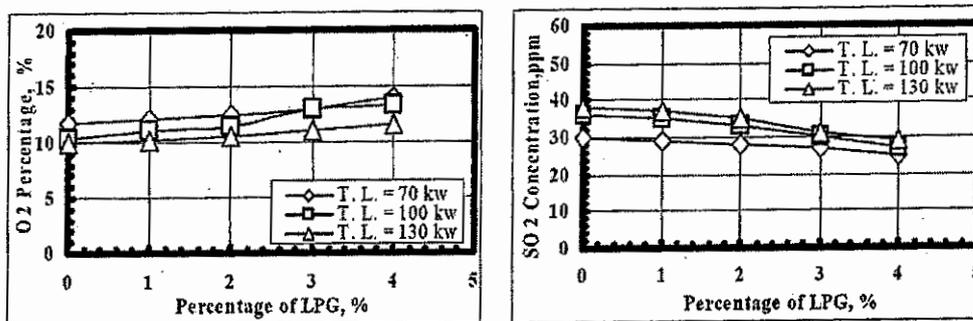


Fig. 14. Effect of adding LPG with different percentages on exhaust species concentrations.

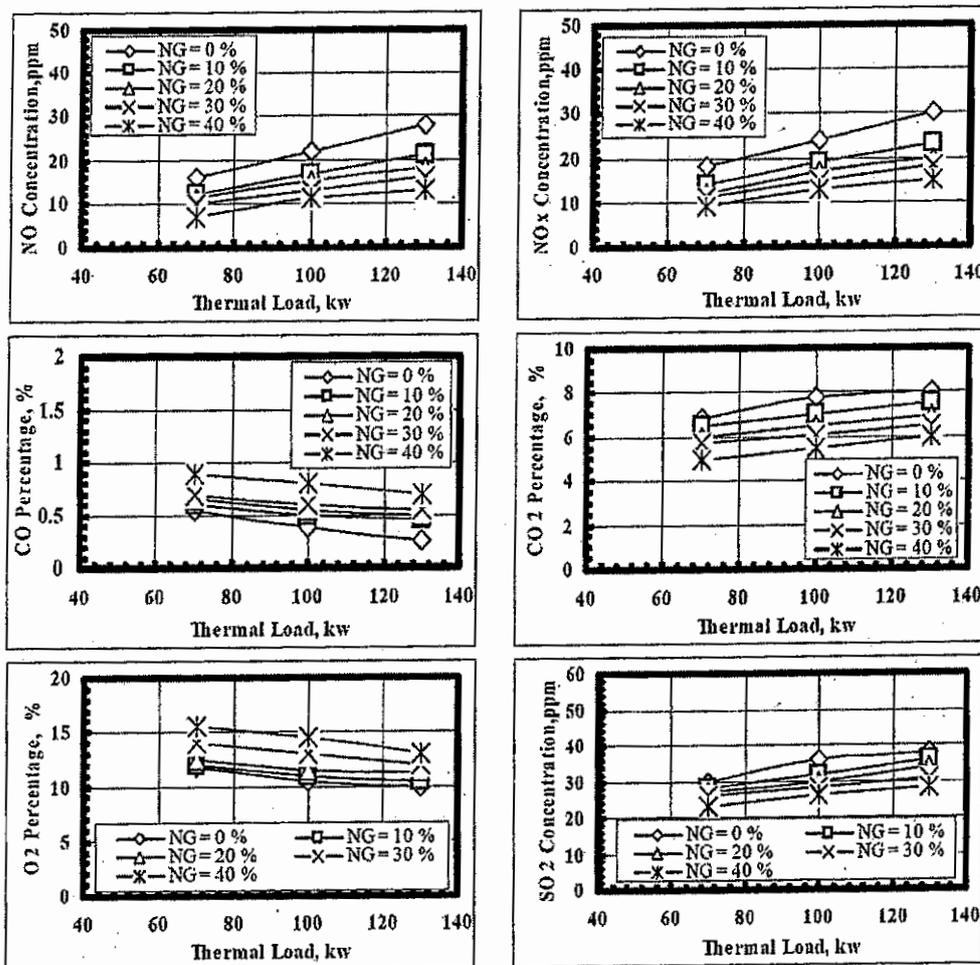
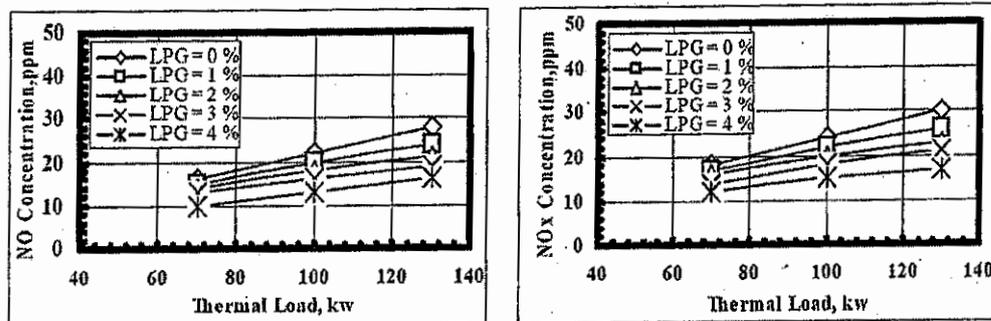


Fig. 15. Effect of changing the input thermal load on exhaust species concentration (when adding NG)



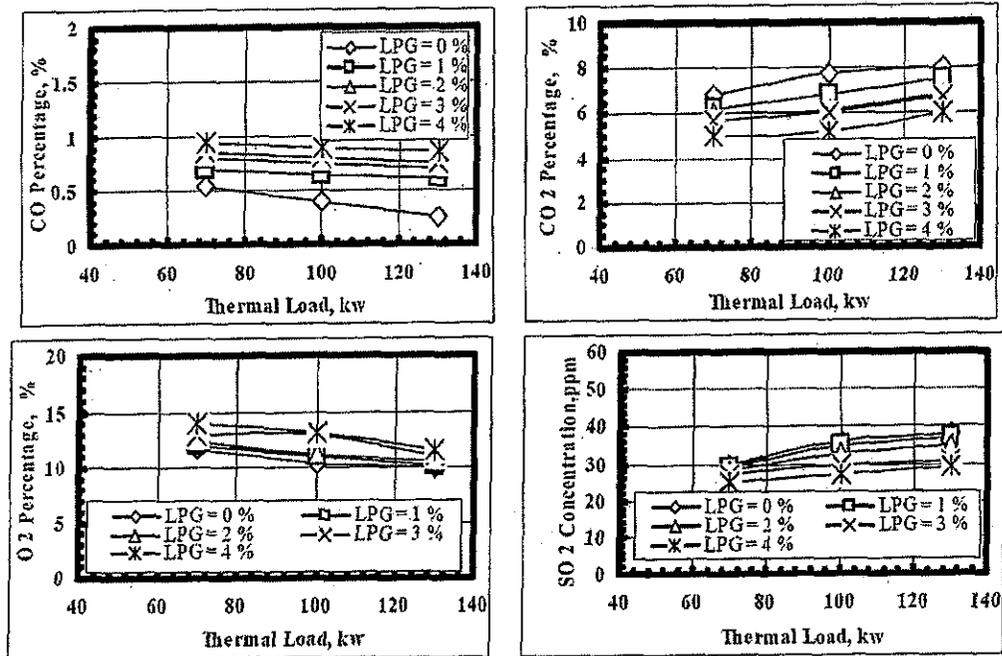


Fig. 16. Effect of changing thermal load on exhaust species concentration (when adding LPG)

Table 3 shows the effects of adding NG and LPG with the same percentage of 4% at input thermal load of 130 kW, on exhaust species concentration. For NG case, the concentrations of NO, NO_x, CO₂ and SO₂ were lower than that for LPG case. That is because the exhaust gas temperatures of NG were lower than that of LPG.

Table 3 Species concentration for NG and LPG at a percentage of 4%

Species	Kerosene	Kerosene and natural gas	Kerosene and LPG
NO, ppm	28	13	16
NO _x , ppm	30	15	17
CO, %	0.38	0.95	0.85
CO ₂ , %	8	5.5	6
O ₂ , %	10	12.5	11.5
SO ₂ , ppm	38	25	29

4. CONCLUSIONS

From the present results, the following conclusions are obtained:

- At air to fuel mass ratio, air swirl number and thermal load of 30, 0.5 and 100 kW, respectively, increasing the percentage of additive NG fuel tends to:
 - Shift the high temperature regions upstream,
 - Decrease the flame length,
 - Decrease NO, NO_x, CO₂ and SO₂ concentrations by about 50, 45, 29 and 27%, respectively,

- Increase CO and O₂ concentrations by about 100 and 39%, respectively.
- At NG percentage, air swirl number and air to fuel mass ratio of 30%, 0.50 and 30, respectively, increasing the input thermal load tends to:
 - Shift the high temperature regions downstream,
 - Increases the flame length,
 - Increase NO, NO_x, CO₂ and SO₂ concentrations by about 60, 63, 14 and 19%, respectively,
 - Decrease CO and O₂ concentrations by about 21 and 14%, respectively.
- At air to fuel mass ratio, air swirl number and input thermal load of 30, 0.50 and 100 kW, respectively, increasing the percentage of additive LPG fuel tends to:
 - Shift the high temperature regions upstream nearer to the air swirler,
 - Decrease the flame length slightly,
 - Decrease NO, NO_x, CO₂ and SO₂ concentrations by about 40, 37, 33 and 25%, respectively,
 - Increase CO and O₂ concentrations by about 13 and 27%, respectively.
- At LPG percentage, air swirl number and air to fuel mass ratio of 3%, 0.50 and 30, respectively, increasing the input thermal load tends to:
 - Shift the high temperature regions downstream,
 - Increase the flame length,
 - Increase NO, NO_x, CO₂ and SO₂ concentrations by about 46, 50, 17 and 15%, respectively,
 - Decrease CO and O₂ concentrations by about 12 and 15%, respectively.

5- For the same additive percentage 4% of NG and LPG, it was found that NG additive was more effective for the reduction of NO and NO_x concentrations than those of LPG.

NOMENCLATURE:

NG Natural Gas

LPG Liquefied Petroleum Gas

5. REFERENCES

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