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EXPERIMENTAL INVESTIGATIONS OF VALVELESS PULSED COMBUSTORS OF INDUSTRIAL HEATING FURNACES

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ABSTRACT

The variations of pressure amplitude , static thrust, heat flux, operating frequency, wall and gas temperatures with fuel flow rates are determined experimentally for a propane-fuelled SNECMA- Lockwood valveless pulsed combustors .Wall and gas temperatures , static thrust, pressure amplitude, and heat flux in the combustors increased with fuel flow rate. The values of gas temperature and thrust produced show that this combustor is suitable for melting and heat treatment furnaces. Despite the high convective heat transfer in the pulse combustor, only about 10% of the heat generated is lost through the wall-the rest being available in the exhaust jets for heating in the furnace.

INTRODUCTION

Pulsed combustors have been used in domestic heating units, as propulsive devices and in gas turbine applications. Work is being done in developing this type of combustors that can run on the liquified petroleum gas available in Nigeria , to serve as hot gas generator in drying and heating application (1).

A lot of interest has been shown in this type of combustor due to their advantage such as enhanced heat transfer through the wall due to flow pulsations, high combustion intensities , low NO_X emissions and improvement in thermal efficiency of gas turbine plant due to stagnation pressure gain (2,3,4 and 5).

A pulsed combustor has three major parts, namely: an inlet, a combustion chamber , and a tail pipe (Fig.1). The inlet may be equipped with valves or it may be valveless, the inlet being designed in that case to function as an aerodynamic valve.

A U-shaped valveless pulsed combustor was developed for use in a fruits and vegetable dehydration unit (6). It was proved experimentally that a U-shaped valveless pulsed combustor could be used to power vertical take-off and landing (VTOL) aircraft (7).

A pressure gain of 4% was reported with a propane-fuelled SNECMA-Lockwood pulsed combustor fitted to a CUSSONS P9000 small, educational gas generator (5).

The work reported here is a preliminary study of the SNECMA-Lockwood valveless pulsed combustor aimed at assessing its possible use in heat treatment and melting furnaces.

To produce a sound casting, molten metal of the right temperature must be produced by using appropriate furnace equipment. Many types of melting furnace such as open-hearth, rotary and crucible furnace can be designed to be gas- or oil-fired. Some of the combustors for those furnaces which are normally steady flow systems can be replaced with pulsed combustors. Components to be heat treated can also be heated using the products of combustion obtained from a pulsed combustor.

MATERIALS AND METHODS

The geometry of the combustor used in this work is shown (Fig.1). The inner diameter of the combustion chamber (d) is 73mm and the combustor wall is made of a rolled stainless steel sheet of thickness 1.59mm.

The combustor was equipped with a spark plug and an air-flow jet from the laboratory compressed air line, both of which were only required for starting the combustor. The fuel propane, was metered with choked nozzles (AMAL jet type 187/001 No. 300 or 500, depending on the operating conditions).

The static pressure, heat flux, gas and wall temperatures were measured at six ports labelled 1-6 (Fig. 1). A photograph of the experimental rig is shown (Fig. 2). KISTLER model 601BI water-cooled quartz pressure transducers were used for pressure measurements. HP 3310B function generator was used to supply the calibration time-base signal. The output of the transducers and the function generator were fed to Model 504A KISTLER charged amplifiers and the output were recorded with model 1508B HONEYWELL Visicorder.

The external wall surface and the mean gas temperatures were measured using Chromel-Alumel (Type K) Thermocouples with beaded junctions. A FLUKE 2200B data logger equipped with a cold-junction-compensation isothermal block was used to record the temperature measurements. Precautions were taken to maximise the thermal contracts of the beads with the wall surface while minimising the heat losses at the beads and through the leads.

For he mean gas temperature measurements, only the beaded junctions were allowed to project into the flow, to ensure that they could handle the flow reversals in the combustor with minimal disturbance.

Water-cooled HY-CAL model C -1340-b-60-072 heat flux transducers were used for the heat flux measurements. The output signals of the transducers were read on FLUKE digital multimeters. The mass efflux thrusts at the inlet (due to flow reversal during part of the cycle) and at the tailpipe exit were measured using thrust plate meters placed 330mm from the tailpipe and inlet exits. Each thrust meter is a vertical 687 mm x 487 mm flat plate welded to a horizontal bar which is hung with two chains in a frame.

RESULTS AND DISCUSSION

The pressure ranges obtained are shown at the six ports for various fuel rates (Figs. 3 a and b). The normalized pressure range is $(P_{max} - P_{min})/P_0$, where P_{max} = maximum pressure, P_{min} = minimum pressure and P_0 = ambient pressure. The normalized mass flow rate of fuel $M_f = m_f a_0/(P_0 d^2)$, where m_f = mass flow rate of fuel, a_0 = speed of sound in ambient air, and d = diameter of combustion chamber.

The operating frequencies of the conmbustor obtained from the pressure-time traces recorded at different fuel flow rates are shown (Fig. 4). The corrected gas temperatures are presented in Table I while Table II shows the wall temperatures.

Since the pulsed combustor operated in self-aspirating mode and there was strong flow reversals in the inlet, it was not possible to measure the flow rate of air into the combustor. Results obtained from numerical simulation of the pulsed combustor for air/fuel ratio at different fuel flow rates are shown in Table III (8).

The total rate of heat loss through the wall of the combustor, the percentage of the heat generated by combustion lost through the wall, and the mass flow rate of exhaust gas at various fuel flow rates are shown in Table IV. The values in the last column are estimated from Table III.

The thrust producing performance of the combustor operating with self-induced airflow in a laboratory at an altitude of 1096 m above sea level, and ambient pressure and temperature of 88 kPa and 298 K respectively is shown (Fig. 5).

Pressure amplitude, wall and gas temperatures generally increased with fuel flow rate at each port as expected (Figs 3 (a) and (b), Tables I and II).

The shape of the operating frequency versus fuel flow rate is somewhat similar to a variation of flame temperature with equivalence ratio of a fuel-air mixture. The plot of frequency versus equivalance ratio in a Helmholtz pulsed combustor is also similar to Figure 4 (9). This means that this self-aspirating valveless pulsed combustor inhales fresh air in such a way that the equivalance ratio of the fuel-air mixture varies automatically with fuel flow rate.

The heat fluxes measured using HY-CAL transducers differed from those calculated since the low surface temperature of the water-cooled transducer and its higher absorptivity caused it to absorb higher heat flux. The heat fluxes measured with the transducers serve as useful check on the calculated values. The trends as regards heat flux variation at a port with fuel flow rate as well as heat flux variation from port to port at a given fuel flow rate for the measured and calculated values agree remarkably well as can be seen (Fig. 6 and 7).

The static thrust generated at the inlet (due to flow reversal) and the tailpipe exit increase with fuel flow rate. The static thrust generated is a measure of the ability of the combustor to pump its own air against a back pressure and also induce large flow of secondary air when it is equipped with thrust augmenters.

There are several advantages in using a furnace fired with pulsed combustor. It is cheaper than the conventional steady flow blower and burner system to which it is equivalent. The pulsed cmbustor is only a hollow tube which aspirates its own air required for combustor by means of its intermittent operations. Heat transfer to the metal being melted or heat-treated is enhanced due to the pulsations in the flow.

The only disadvantage associated with the use of pulsed combustors is the high noise level generated. However, the furnace connected to the tailpipe exit will act as a sound dampener giving a reduced noise level.

CONCLUSION

The local pulsation amplitude, wall and gas temperatures, and heat flux from the hot gas to the wall generally increase with fuel flow rate in the SNECMA-Lockwood pulsed combustor.

The application of valveless pulsed combustors in melting or heat treatment furnaces can be expected to give enhanced heat transfer to the metal in the furnace with the advantages low capital and operating cost when compared with conventional burners and blowers used in gas-fired furnaces.

About 90% of heat generated in the pulsed combustor is available for heating in the melting furnace whereas over 90% of the heat generated is available for heat treatment furnace.

This type of pulsed combustor which has very high combustion intensity is more suitable as a hot gas generator than as an immersion heater.

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Table I: Corrected Gas Temperature

Fuel flow Rate, kg/h	Gas Temperature, K					
	Port 1	Port 2	Port 3	Port 4	Port 5	Port 6
2.87	499	1365	1106	895	804	791
4.57	627	1500	1319	1121	984	940
5.97	660	1559	1416	1195	1058	957
7.24	666	1599	1482	1249	1107	963
8.50	689	1630	1541	1310	1154	958
9.80	713	1638	1585	1356	1200	949
11.03	731	1630	1617	1408	1243	939

Table II: Wall Temperature

Fuel flow Rate, kg/h	Wall Temperature, K					
	Port 1	Port 2	Port 3	Port 4	Port 5	Port 6
2.87	563	1011	856	827	764	713
4.57	674	1053	961	995	890	826
5.97	716	1060	1008	1036	932	852
7.24	742	1066	1031	1066	967	863
8.50	768	1068	1052	1100	1004	872
9.80	787	1068	1061	1132	1047	899
11.03	789	1059	1055	1160	1071	880

Table III: Fresh Air Aspiration Rate into the Combustion Chamber at Different Fuel Consumption rates (11)

Fuel flow rate, kg/h	Air flow rate from inlet into the	Air/Fuel ratio
2.16	66.06	30.6
2.99	78.01	26.1
4.43	101.17	22.8
7.05	128.49	18.2
9.45	145.48	15.4
11.08	150.68	13.6
14.65	180.55	12.3

Note: Stoichiometric air/fuel ratio for propane = 15.6

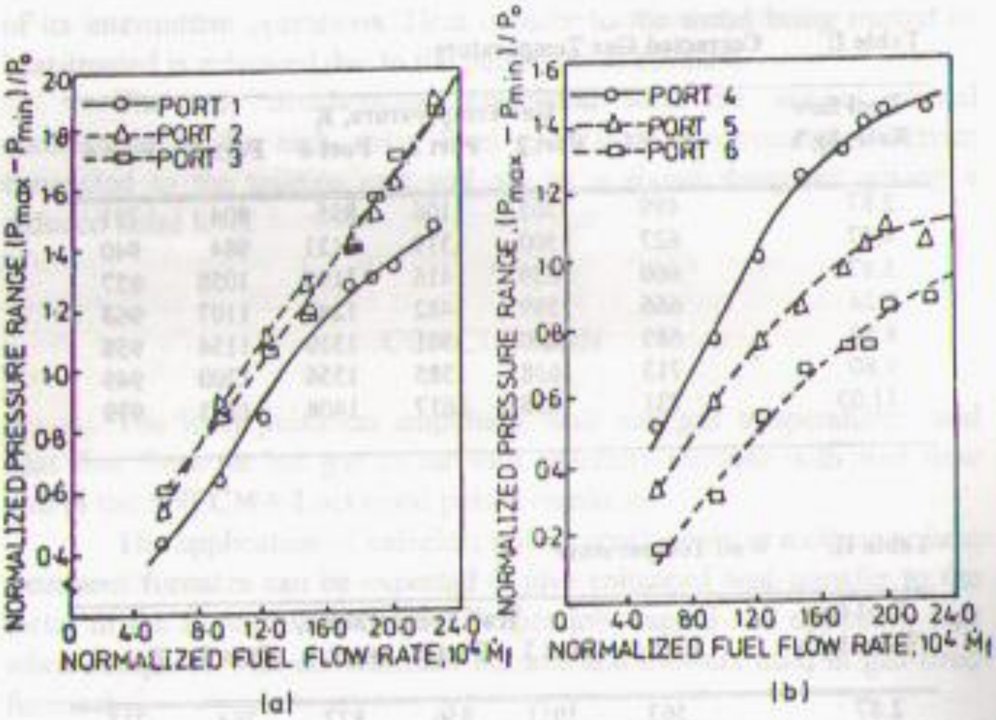

Fig. 3. Pessur range at the six ports.

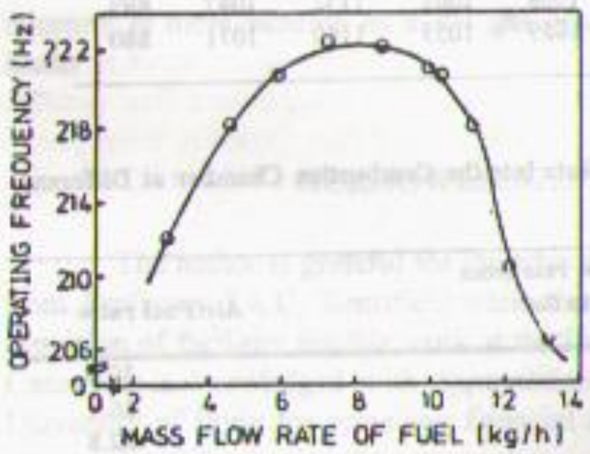

Fig. 4: Variation of frequency with fuel flow rate.

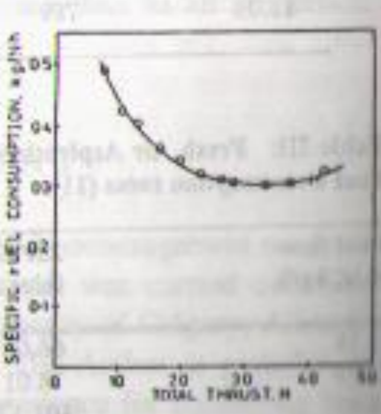

Fig. 5: Thrust producing performance of the pulsed combutor

Table IV: Variation of Heat Loss Rate, Pecentage of Energy Loss Through the Wall and Exhaust Gas Flow Rate from the Combustorr with Flow Rate of Fuel in the Combustor

Fuel Flow rate, kg/h	Rate of Heat Loss Through the Wall , kW	Percentage of Heat Generated Lost Through the Wall, %	Flow Rate of Exhaust Gas, kg/h
2.87	4.70	12.7	79.2
4.57	7.46	12.7	107.2
5.97	8.46	11.0	123.2
7.24	9.25	9.9	137.1
8.50	10.07	9.2	147.3
9.80	11.04	8.8	156.4
11.00	11.36	8.0	161.4

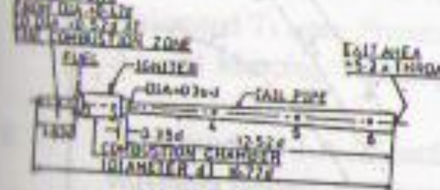

Fig. 1. Proportions of a propane-fuelled snecma-lookwood valveless pulsed combustor.

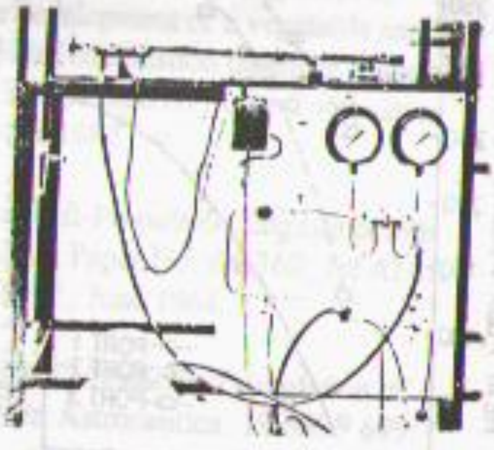

Fig.2: A general view of experimental rig.

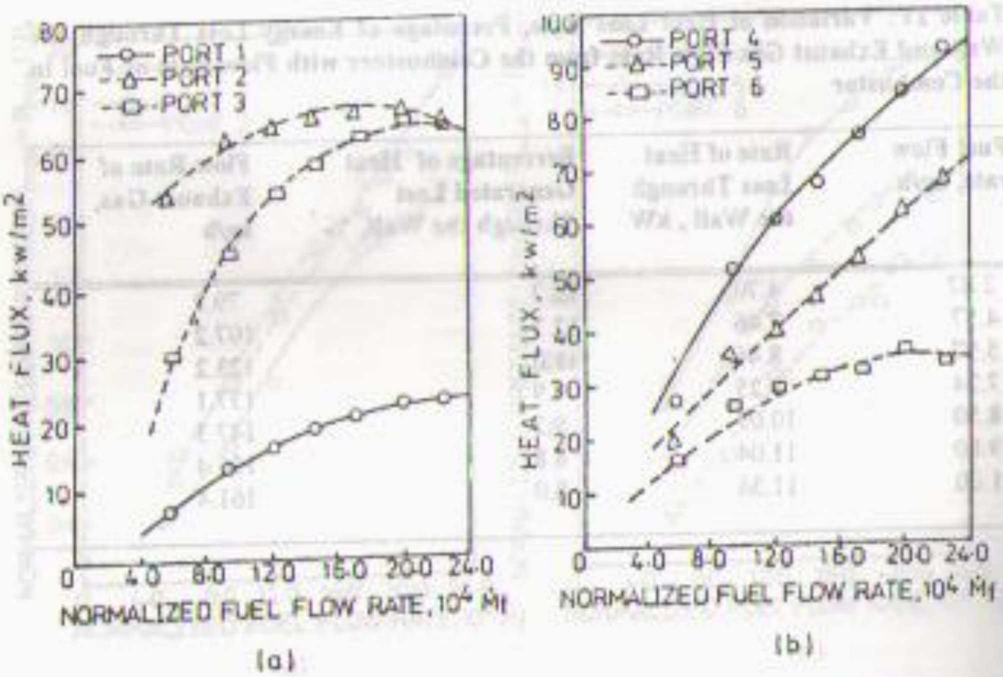

Fig. 6: **Calculated heat flux at the external surface of the combustor at the six ports.**

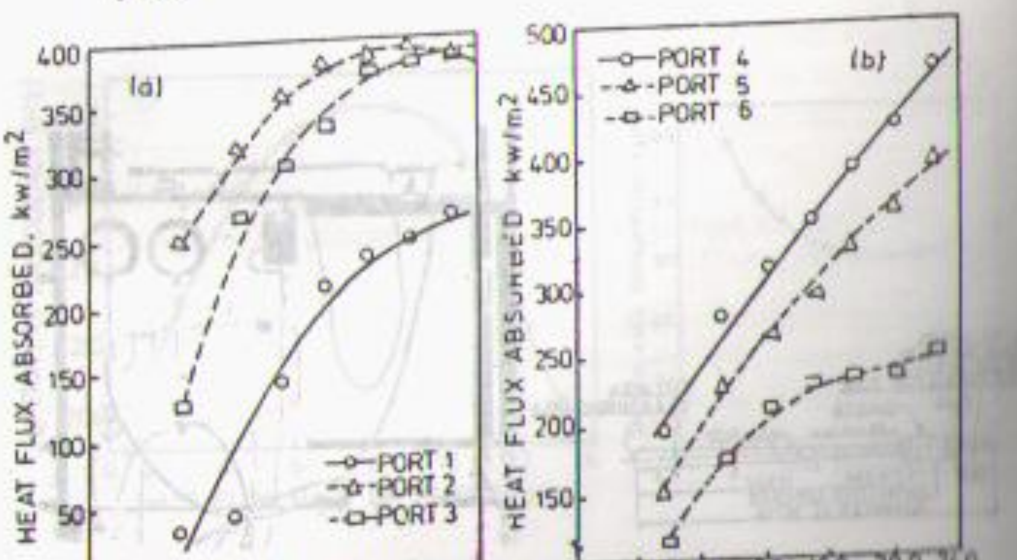

Fig. 7. **Heat flux absorbed by the heat flux transducers.**

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