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Surface temperature measurement of gas turbine combustor using temperature-indicating paint

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ABSTRACT

Surface temperature measurement of a hot surface is necessary in order to determine its thermal life. The combustors used in gas turbine systems may be subject to high thermal load due to continuous combustion. In order to analyse the surface temperature distribution of combustor, temperature-sensing instruments are necessary. Temperature-indicating paint is a kind of coating to measure the temperature distribution through its colour change. Temperature-indicating paint is considered to be one of the most efficient ways for temperature measurement. The analysis of this paint can be done through the observation of irreversible colour change with temperature. This work deals with the fabrication of gas turbine combustor, investigates the thermal distribution and finds the hot spots of the combustor using temperature-indicating paint.

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KEYWORDS
Temperature-sensitive paints; temperature measurement; Thermocouples; Combustor

1. Introduction

An internal combustion engine in which continuous combustion takes place is called gas turbine (or) combustion turbine. The system consists of a compressor, a turbine and a combustion chamber. The Brayton cycle is the air standard cycle for the operation of a gas turbine engine (Lempereur, Andral, and Prudhomme 2008; Bird et al. 1998). The compressed atmospheric air from the compressor is sent to the combustion chamber where the fuel is injected (or) sprayed. The injection of fuel with the high pressurised air leads to combustion which produces high pressurised gases (Neely and Riesen 2008; Bird et al. 1998). These gases with high pressure undergo expansion in the turbine which produces work. An industrial gas turbine with the above parts has been shown in Figure 1.

2. Combustor

Figure 2 depicts the shape of the combustor along with its accessories. The combustor plays a vital role in the operation of a gas turbine engine. The combustible gases produced may increase the heat load on the walls of the liner of the combustion chamber. The combustion chamber is produced with different slots (or) paths for air circulation to decrease the heat load. (Dolvin 2008; Griffin et al. 1996; Iliff and Shafer 1993; Jones and Hunt 1964). The air flows into the combustion chamber splits itself into three types as primary, secondary and tertiary to improve the combustion and for flame stabilisation, as shown in Figure 3 (Lee, Dutton, and Jacobi 2007).

3. Combustor-design and fabrication

A combustor has been designed and fabricated, as shown in Figures 4–5, with the dimensions given in Table 1.

4. Selection of paint

MC 350–8 which is of multi-change-type thermal paint has been selected for temperature detection. The paint's initial colour is red and the colour change starts to appear only after 350°C and exhibits about 8 different colours at different elevated temperatures (Padgham and Saunders 1975), as mentioned in the datasheet. The paint consists of a resin and a pigment which is responsible for colour change (Connolly 2009; Cowling, King, and Alexander 1953). The resin is a solvent-based acrylic and silicon of composition (solids-59.5%, VOC-635 g/l, flash point 30°C) (Kojima et al. 2004; Yang and Zhi-Min 2014). The pigment consists of C.I pigment Red 104, lead chromate. The paint may be thickened if required by the addition of polymethyl acrylate. The standard colour changes have been observed when a metal coupon is coated with MC 350-8 on exposure to continuous heating as soon as the temperature is more than 350°C (Mandavkar et al. 2008) which is depicted in Figure 6.

5. Spraying and drying of thermal paint on specimens

The combustor was sprayed with thermal paint according to the following steps (Liu et al. 1997; Liu and Sullivan 2004), as shown in Figure 7.

- The surface treatment is done by polishing the metal surface using a sandpaper so that the uneven surface regions and rust can be removed.
- The polished combustor is cleaned by dipping in acetone for about 15 min so that chemical contaminants are removed.
- After the surface cleaning the combustor is heated in the furnace to 200°C to burn out the oil traces in the specimen.
- The paint is sprayed on the surface of the specimen.

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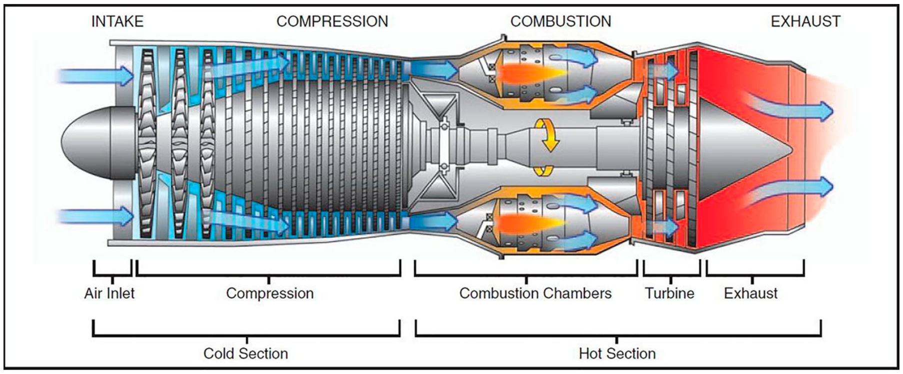

Figure 1. Industrial gas turbine.

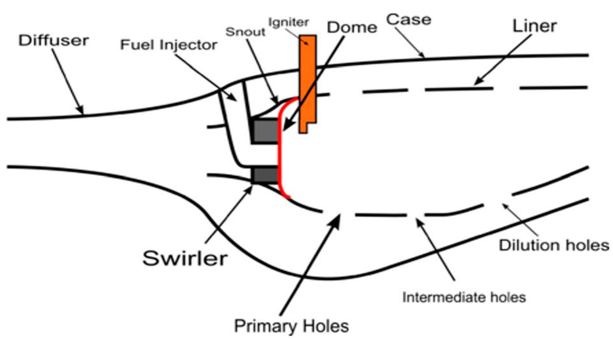

Figure 2. Components of a combustor.

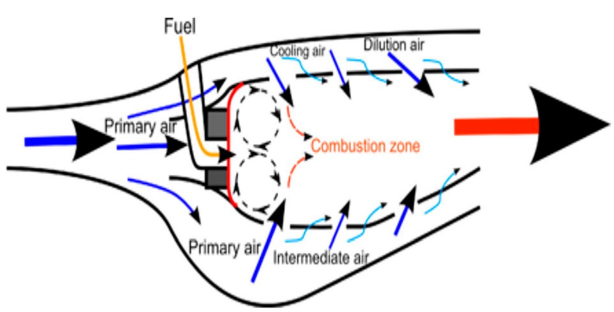

Figure 3. Airflow paths of a gas turbine.

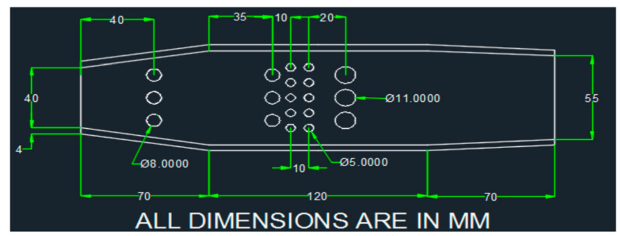

Figure 4. 2D modelling of a combustor.

Figure 5. Fabrication of a combustor.

Table 1. Specification of a combustor.

Material used	Stainless steel 304
Melting point	1535°C
Length	160 mm
Thickness	4 mm
Primary hole diameter	7 mm
Secondary hole diameter	5 mm
Dilution hole diameter	10 mm
Primary hole distance from one end	105 mm
Secondary hole distance from one end	115 mm
Dilution hole distance from one end	145 mm
No of primary hole	16
No of secondary hole	16
No of dilution hole	6

- The combustor is again heated for a curing temperature of about 250°C for about 2 h and cools to room temperature in the oven itself Figure 8.

6. Experimental test rig

The schematic diagram represents the actual set-up of the test rig in a schematic way. It shows how the circuit is working. Compressed air is flowed using the compressor into the casing to help the combustion process. The fuel is flowed by the gas torch nozzle into the combustor. The igniters produce a spark and start the ignition process in the combustor. Flame starts to flow inside the combustor and thermal distribution occurs in the surface.

The experimental test rig is constructed with the help of the components described above, as it is shown in Figure 9. The top view of the set-up is shown in Figure 9(a) and coupled with a compressor also shown in the side view of the set-up is shown in Figure 9(b).

7. Results and discussion

Figure 10 shows the temperature distribution in the combustor after combustion (Dolvin 2008) and temperature is mentioned by using the calibrated metal coupons. This colour in the flame tube is obtained after 300 min of combustion (Bown et al. 1994) Figure 11.

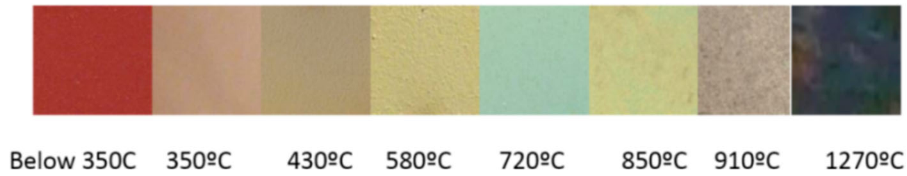

Figure 6. Standard colour changes observed at different temperatures from datasheet.

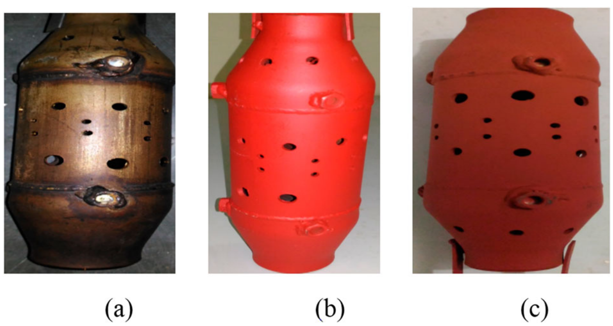

Figure 7. Combustor (a) Acetone dipping (b) After painting (c) After curing.

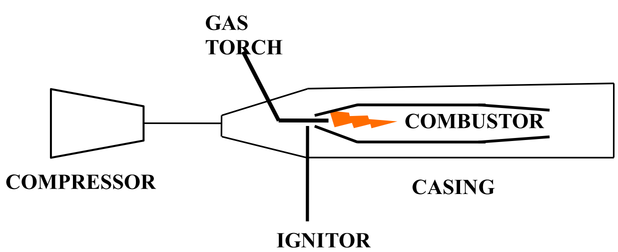

Figure 8. Schematic diagram of the experimental test rig.

Figure 10. Image after combustion of 300 min.

8. Hot spot identification in flame tube and combustor

Hot spot is nothing but unpredictable temperature difference in the surface, material defect, improper composition, improper surface, etc ... (Neely and Tracy 2006). These may be reasons behind the hot spot in the flame tube. But the temperature-indicating paint shows the thermal distribution of the flame tube very accurately in the pixel also. The hot spot in the flame tube after combustion is shown in Figure 12.

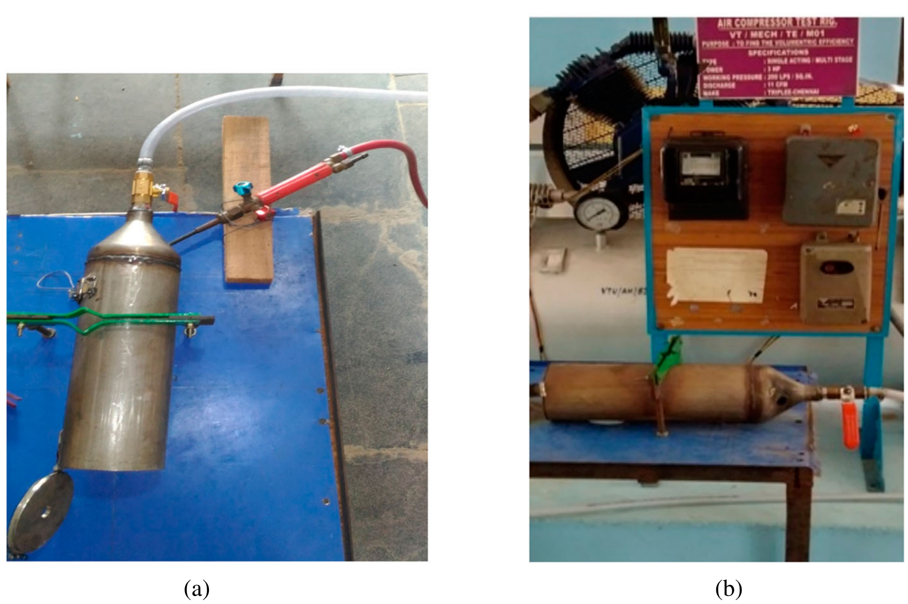

Figure 9. Experimental set-up (a) Top view (b) Side view.

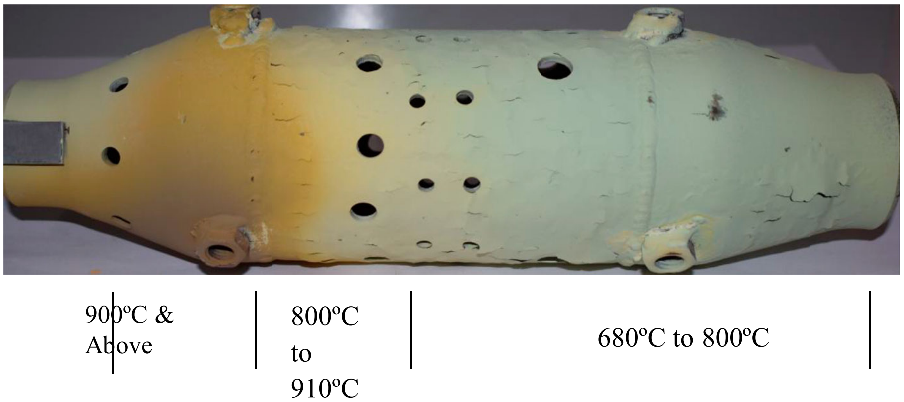

Figure 11. Temperature distributions in a combustor.

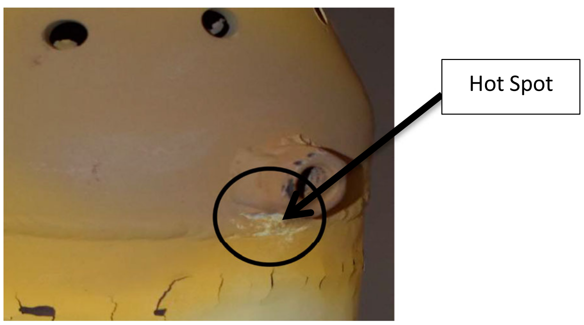

Figure 12. Hotspots in a combustor.

9. Conclusion

The high pressurised air from the compressor is decelerated through the diffuser and is distributed as primary air through the holes present in the dome of the combustion chamber. The primary air helps in starting combustion. Some of the pressurised air is bypassed and passes through the secondary holes to complete the reaction process to dilute carbon monoxide (CO) and hydrocarbon (HC) emissions. The dilution air helps in reducing the temperature of hot gases released by the combustion. This dilution makes the turbine blades to withstand the temperature of combustible gases within the permissible limit. The results and discussions observed from the above work reveal that temperature-indicating paint is affordable technique to evaluate the temperature distribution of a surface which is subjected to high temperature. MC 350-8 the thermal paint which is used in the above work has proved successful in providing the temperature distribution with distinguishable colour contours.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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