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Development of a novel catalytic burner for natural gas combustion for gas stove and cooking plate applications

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Abstract

On the request of Gaz de France Research Department, Catator AB has designed, constructed and evaluated a catalytic burner, based on Catator's patented wire mesh catalysts, for natural gas combustion in gas stoves or cooking plates. The results have shown that burner operation results in extremely low NO_x emissions (1–3 mg NO_x/kWh), acceptable CO-levels (0–15 mg CO/kWh), relatively high thermal efficiencies over a broad range of power inputs (40–50% for 1–4 kW) and a long catalyst life-time (>10 000 h). Other advantages of this burner design are its compactness and ease of cleaning. The critical concern is the high emissions of unburned hydrocarbons measured at slow cooking mode (<1 kW), which is believed to be overcome by developing and implementing an appropriate heat-exchanger with the burner.

Keywords: Catalytic burner; Wire mesh catalyst; Natural gas; Cooking plate

1. Introduction

Gas catalytic combustion for gas stoves or cooking plates is a very promising technique in terms of ease of cleaning, power modulation and emissions [1]. Previous investigations have shown that wire mesh catalysts, prepared and supplied by Catator AB, seem to be very well suited for such applications [2,3]. In addition to significantly reduce the unhealthy NO_x-emissions [4,5], these catalysts offer important advantages such as good design flexibility, low pressure drop and high heat transfer capacity, where the latter leads to a quick thermal response (in this case a quick start-up).

This work has been a collaboration project between Catator AB and Gaz de France. Its objective was the design, the construction and the evaluation of new catalytic burner(s), based on Catator's wire mesh catalysts, used for the combustion of natural gas in gas cooking stoves. More specifically, this new burner should provide with:

1. a high thermal efficiency;
2. low emissions;
3. a long life-time (≥5000 h);
4. a power input ∼4 kW with a burner size of approximately 15 cm;
5. a good turn-down ratio (∼0.3–4 kW);
6. a low pressure drop;
7. an easy cleaning (flat ceramic plate);
8. a thin design, i.e. ≤10 cm.

In this work, the evaluation of different burner designs were performed by the use of theoretical simulations, using a computational fluid dynamic model (CFD) developed in ANSYS^{TM} and a dynamic model written in Ithink^{TM}, and experimental verification tests. Since the performed experimental work was motivated and based on prevailing simulation results, we have in this paper chosen to entirely focus on the experimental results obtained with that burner concept with

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which the most promising results have so far been obtained, without going into any details of the theoretical part.

2. Experimental

The support material of the wire mesh catalysts evaluated in this work consists of a woven wire mesh made of high temperature resistant iron alloy (Kanthal AF). To increase the surface area and the adhesiveness of the substrate, a porous layer of metal was thereafter deposited onto the material according to Catator's patented thermal spray technology [6]. The substrate was then wash-coated with a ceramic layer of 50/50 wt.% ceria/γ-alumina (approximately 130–150 g/m^2), which was thereafter impregnated with 0.5 M Pd(II)-acetate ($Pd(OAc)_2$), resulting in the approximate Pd-loading of 1.4–1.7 wt.%.

A schematic drawing of the burner prototype is shown in Fig. 1. As can be seen, it included a fuel distribution plate and in most tests, two wire mesh burner catalysts where the latter were held in fixed positions by placing O-rings of high resistant steel between the meshes. For improving the emissions and to some extent also, recuperating heat from the exhausts, emission catalysts (platinum-impregnated wire mesh catalysts) were placed in the outlet. The ceramic plate of the burner was made of Neocerum-0, which is an IR-transparent and heat resistant ceramic material (tolerates up to ≈740 °C) commonly used in wood stoves and gas fire applications.

The performance of the burner prototype was evaluated by determining the thermal efficiency, the emissions and the pressure drop as a function of input power load, both at transient and at steady-state conditions. Some optimization work of the burner prototype was carried out by investigating the influence of parameters such as the number of wire meshes incorporated inside the burner, the wire mesh structure (mesh number, planar/folded structure), the critical distances inside the burner, and the operation conditions such as the fuel-to-air ratio (i.e. lambda value). Evaluation tests were carried out at both Catator AB and Gaz de France facilities, using compressed air and natural gas as fuel. The fuel–air mixture was controlled by mass flow controllers. For calculating the input power corresponding to each fed flow rate, the low heating value (LHV) of the fuel was used, which for the natural gas in this case was equal to 11.1 kWh/Nm^3.

The thermal efficiency was estimated by water heating according to a standard procedure: 1 kg of water was heated from room (approximately 20 °C) to 100 °C with a thermocouple inserted into the water, see Fig. 2a and b. The efficiency was measured in cold (i.e. for a burner ignited at room temperature) and in hot conditions (i.e. at steady-state), without having a lid on the top of the pan. The pan used for the water heating measurements was made of stainless steel 18/10 and had the same diameter (170 mm) as the ceramic glass plate.

The concentrations of NO_x, CO, unburned hydrocarbons (UHC) and O_2 in the exhaust gas were continuously measured during burner operation. The NO_x was analyzed by either an electrochemical device (Testo 350, Nordec instrument) or chemiluminescence (Ecophysics NOxMAT), CO and O_2 by IR (Siemens Ultramat 5 series and Siemens Oxymat 5 series) or an electrochemical device (Testo 350, Nordec instrument), and finally unburned hydrocarbons (UHC) by either IR (Siemens Ultramat 5 series) or a Flame Ionization Detector (FID model 3006, PALGO).

The pressure drop was measured under steady-state operation by the use of a differential pressure meter. The position of the differential pressure meter is indicated in Fig. 1.

Life-time tests of Catator's wire mesh catalysts were also performed. These measurements were, in contrast to all the other evaluation tests of this work, run in a prototype burner

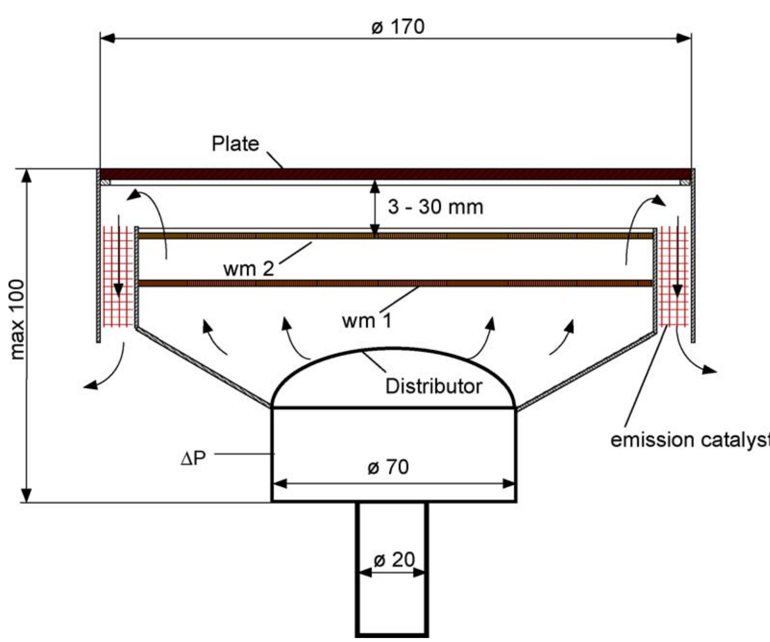

Fig. 1. A schematic illustration of the burner prototype developed for natural gas cooking plates. ΔP indicates the point at which the differential pressure meter was placed for measuring the pressure drop over the burner system under operation.