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Experimentation of Grate Combustion of Municipal Solid Waste in Ouagadougou: Influence of Primary and Secondary Air Flow on Thermal Potential

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Authors' contributions

This work was carried out in collaboration among all authors. Authors ARAAV, HC, OZ and JFN have contributed to the design study, the statistical analysis, the wrote of the protocol and the manuscript. All authors read and approved the final manuscript.

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Short Research Article

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ABSTRACT

The present work concerns the study of the influence of combustion air flows on the thermal potential during the combustion of a 2 kg mixture of solid model waste from the city of Ouagadougou. This mixture consists primarily of wood, cardboard and plastic. The prototype model is a natural laterite internal-walled grate furnace. During these investigations, we were interested in the temperature variation measured by 4 thermocouples K1 to K4 placed respectively from the

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waste bed to the top of the furnace. These variations are considered according to a variable primary and secondary air flow. The maximum primary and secondary airflow is 3000 L/min. Measurements are taken throughout the experiment at a step of 18 seconds and a maximum duration of 3 minutes for each case of flow considered. Maximum temperatures reaching 450ºC are observed following the injection of secondary air only. This is explained by the supply of oxygen making the combustion more complete. The results show that the injection of primary and secondary air at a flow rate of 1500 L/min gives a more stable temperature result, i.e. 362,18ºC 186,82ºC 109,27ºC 72,41ºC respectively for the thermocouples K1, K2, K3, K4. An increase in the primary and secondary air flow to a maximum of 3000 L/min leads to a drop in temperatures due to the dilute internal atmosphere. These results allow to set the optimal operating parameters of the furnace in order to produce more heat for its recovery into electricity through a heat exchanger and a steam turbine.

Keywords: Air Flow; combustion; grate furnace; thermal potential; thermocouple.

1. INTRODUCTION

Many developing cities face a major challenge when it comes to municipal solid waste management, including Ouagadougou. The rapid increase in population and increasing urbanization accentuate the amount of waste produced in this city. Poor waste management and uncontrolled waste disposal cause pollution and blocked drainage facilities, leading to flooding and water stagnation, increasing the risk of diseases, and eroding local progresses toward achieving the Sustainable Development Goals (Sanfo et al, 2022). According to (Teixeira et al, 2014) waste gasification by plasma has been validated but the economic viability of this technology must be proven before to be accepted by the industry in Portugal. Grate combustion is a promising solution for reducing the volume of waste while producing energy among the different waste management approaches. According to Onibokun (2002), this method offers significant benefits in terms of efficient waste treatment and the reduction of environmental consequences related to other methods, such as landfilling, which can lead to pollution and public health problems (Onibokun, 2002).

The objective of this study is to represent the combustion of municipal solid waste in Ouagadougou, with a focus on the impact of primary and secondary air flows on the thermal potential incurred. According to NZIHOU (2005), a study on waste combustion in Ouagadougou showed that the proper design of incineration systems, including airflow control, is essential to improve thermal performance and minimize harmful emissions. It is essential to improve combustion efficiency, reduce pollutant emissions and maximize energy recovery by optimizing these airflows (Menard, 2003). Based on previous research, it has been proven that dividing air into primary and secondary streams can greatly improve combustion efficiency and reduce emissions of pollutants such as CO and NOx (Jian et al., 2023). For example, a study conducted by (Eggleston et al. 2006) indicated that optimal combustion conditions, characterized by well-regulated airflows, lead to a significant reduction in emissions of dioxins and furans, which are hazardous by-products of incineration.

Using simulation methods and experimental tests, this study aims to provide valuable data on the optimal combustion conditions for Ouagadougou's waste. By exploring the complex interactions between airflows and the combustion process, we hope to contribute to more sustainable waste management and renewable energy production, while addressing the environmental challenges facing the city. This research is part of a broader context of research into waste treatment methods that are both efficient and environmentally friendly (National Research Council 2000).

2. EXPERIMENTAL DETAILS

2.1 The Combustible

The physical and chemical properties of solid waste play a crucial role in its management and recovery. In Ouagadougou, the average density of waste is estimated at 0.57 kg/L, which has significant repercussions on its transport and storage (Borduas & Trottier, 2000). A lower density usually implies a larger volume for a given mass, which can affect costs and waste management methods. Changes in waste composition do not have a significant impact on the combustion process and on the formation of pollutants (Tezanou et al, 2007). The following figure shows the proportions of the municipal waste categories in the city of Ouagadougou, considering waste with fine particles (Haro et al. 2918), (Spinato et al. 2011).

For the modelling, a number of assumptions are made considering the dry season without fine particles, as it is the longest to arrive at a distribution of solid waste in cardboard, wood and plastic in the Table 1.

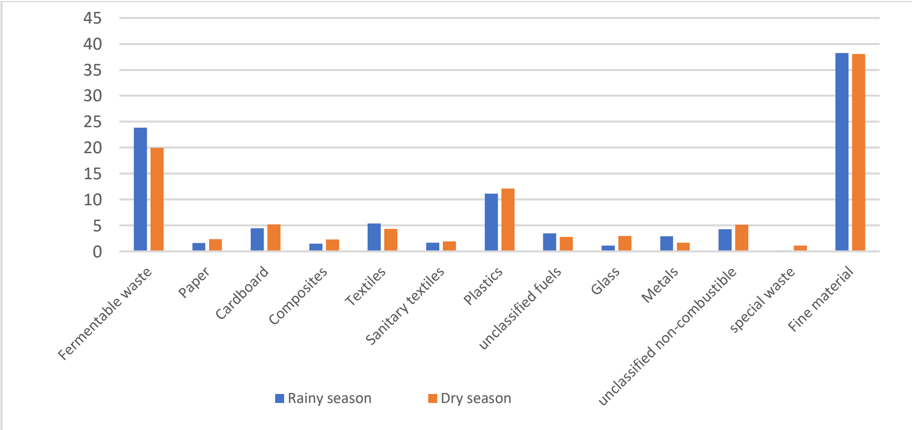

Fig. 1. Categories and proportions of municipal waste in the city of Ouagadougous

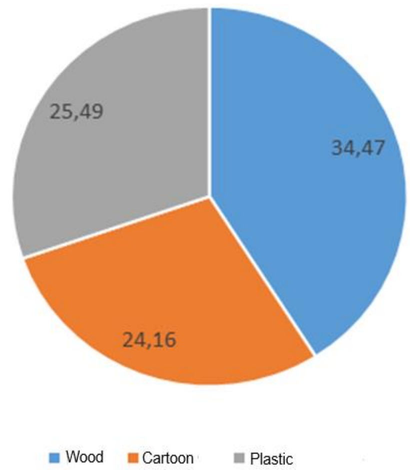

Fig. 2. Percentage composition of waste in the city of Ouagadougou

Table 1. Percentage composition of dry season waste without fine particles

Waste category	Wood	Cartoon	Plastic	Total
Fermentable waste	32,2			32,2
Paper		3,83		3,83
Cardboard		8,39		8,39
Composites		1,84	1,84	3,68
Textiles		6,97		6,97
Sanitary textiles		3,13		3,13
Plastics			19,54	19,54
Unclassified fuels	2,27		2,27	4,54
Glass				4,85
Metals				2,77
Unclassified fuels				8,27
Special waste			1,84	1,84
Fine materials	-	-	-	-
Total	**34,47**	**24,16**	**25,49**	**84,12**

Thus, for the experiment, a quantity of 2 kg of waste was used, as shown in the table below:

Table 2. Quantity of material to be burned according to the proportions

Matter	Proportion in Kilogram (kg)
Wood	0,82
Cardboard	0,57
Plastic	0,61
Total	2

Fig. 3. Weighing wood, cardboard and plastic and mixing

2.2 Oven Model Overview

The dimensions of the furnace are quite average, in the sense that we consider the raw material to be incinerated, which is municipal solid waste, to be available or in variable quantities.

The outer wall is made of 6 mm iron. The inner wall is made of natural clay pottery following the results of our previous work on the study of heat transfer in a centimeter kiln with a fixed bed with pottery walls which shows that natural laterite tends to retain heat inside the kiln (Arnaud et al. 2023).

This figure gives an idea of the dimensions of the different parts of the fixed-bed rack kiln to be built. The kiln consists mainly of two parts. The first part is the ash recovery cage. It forms the base or lower part of the oven. The second part is the combustion cylinder where we will observe the combustion and exhaust of the fumes and flue gases.

Various ancillary equipment is also materialized and installed. These are:

- Thermocouples K type,
- Arduino microcontroller kit,
- Primary and secondary air blower,

This equipment will be used to monitor and collect information on the incineration process.

2.3 Parameter Studied and Experimental Procedure

The primary air is blown under the grate evenly. This allows to control the amount of incoming air and to optimize the combustion conditions (Techniques de l'Ingénieur). In addition, secondary air will be injected at a certain height above the furnace floor to improve the combustion of residual gases (Basu, 2006).

The experiment consists of studying the impact of primary and secondary air flows on the combustion of municipal solid waste in the pottery-walled grate incinerator. For this purpose, 2 kg of waste, as showed in Table 2, is mixed and placed on the kiln grate. Then, an experimental device simulating the conditions of combustion in the grate is set up. Combustion is carried out at variable primary (supplied under the grate) and secondary (blown above the grate) air flows, in order to observe their influence on thermal efficiency. Measurements are taken throughout the experiment at an 18-second step, including temperature and airflow. Each case of manipulation lasts 3 minutes before moving on to the next step, from the injection of primary air to the injection of secondary and primary air simultaneously. This approach helps determine the optimal conditions to maximize energy efficiency.

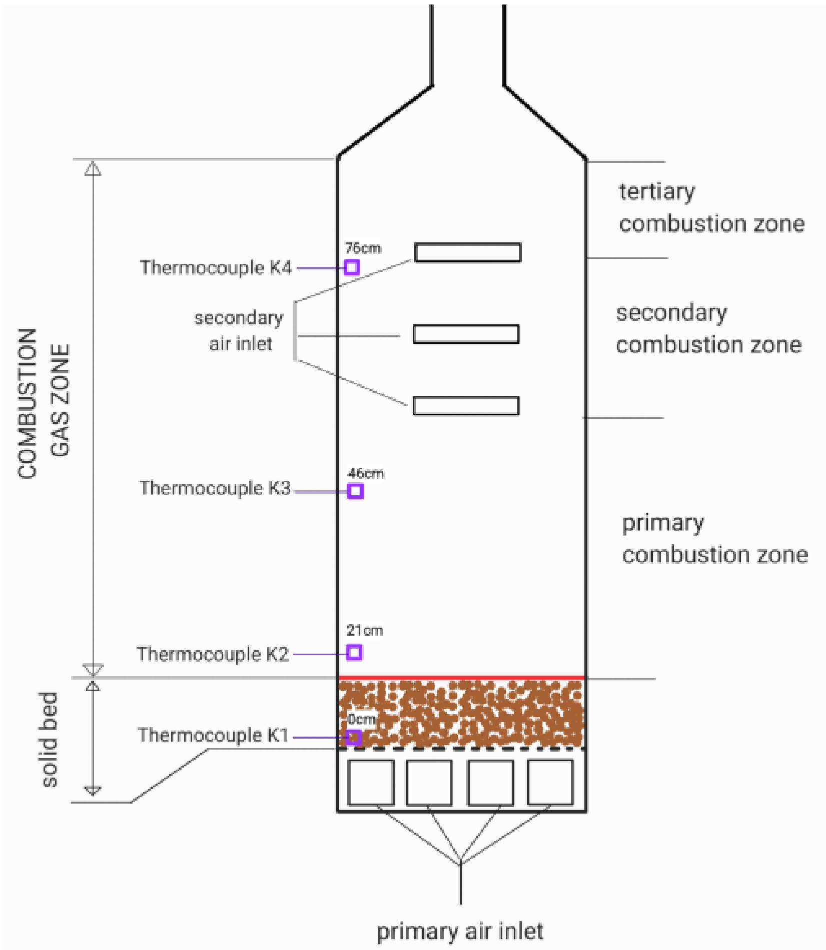

Fig. 4. Principle of furnace modeling

Fig. 5. Image of the prototype

3. RESULTS AND DISCUSSION

3.1 Influence of Primary Airflow

Primary air is introduced into the combustion chamber to provide the oxygen needed for the chemical reaction of combustion. Primary air is used to control flame stability and NOx reduction (THE JOHN ZINK HAMWORTHY COMBUSTION HANDBOOK). According to (Borduas & Trottier, 2000), (Nzihou, 2013) adequate primary airflow is essential to ensure complete and efficient combustion. Excess primary air can lead to heat losses, while insufficient air can cause incomplete combustion, resulting in emissions of pollutants such as carbon monoxide (CO) and unburned hydrocarbons (Baukal 2024).

The Fig. 6 shows us the initiation of combustion and the overall behavior of the process. Only the primary air inlet valve is open and the flow rate is set to half the capacity of the blower, i.e. 1500 L/min. In 3 minutes of operation, the results show a maximum temperature of 69.5°C at the K2 thermocouple just above the combustion bed and a minimum temperature of 0°C at the K1 thermocouple which is below the waste bed. This is because the combustion is in full swing and the air blowing cools the lower part before reaching the upper surface.

From the 3rd minute the primary air flow is set to the maximum, i.e. 3000 L/min and only the primary air valve is opened. In 3 minutes, a continuous increase in temperature is observed and reaches a maximum of 304.7°C at the K1 thermocouple and 122°C, 98.3°C, 68°C at the K2, K3, K4 thermocouple, respectively (See Fig. 7).

These results show us the importance of the quantity of primary air for the increase in the thermal potential inside the combustion chamber.

3.2 Influence of Secondary Airflow

Secondary air is usually provided to compensate for the unreacted primary air. It is generally said that it is a supplement of air that must be supplied to ensure the complete combustion of the fuel. In order to assess only the effect of secondary air, the primary air valve remained closed after the 6th minute and the secondary air valve was open. The Fig. 8 illustrate the results under different secondary air flows.

The results in Fig. 8 show a rise in temperature to a maximum of 620.2°C at the K1 thermocouple and 131.3°C, 74.8°C, 68°C at the K2, K3 and K4 thermocouple, respectively.

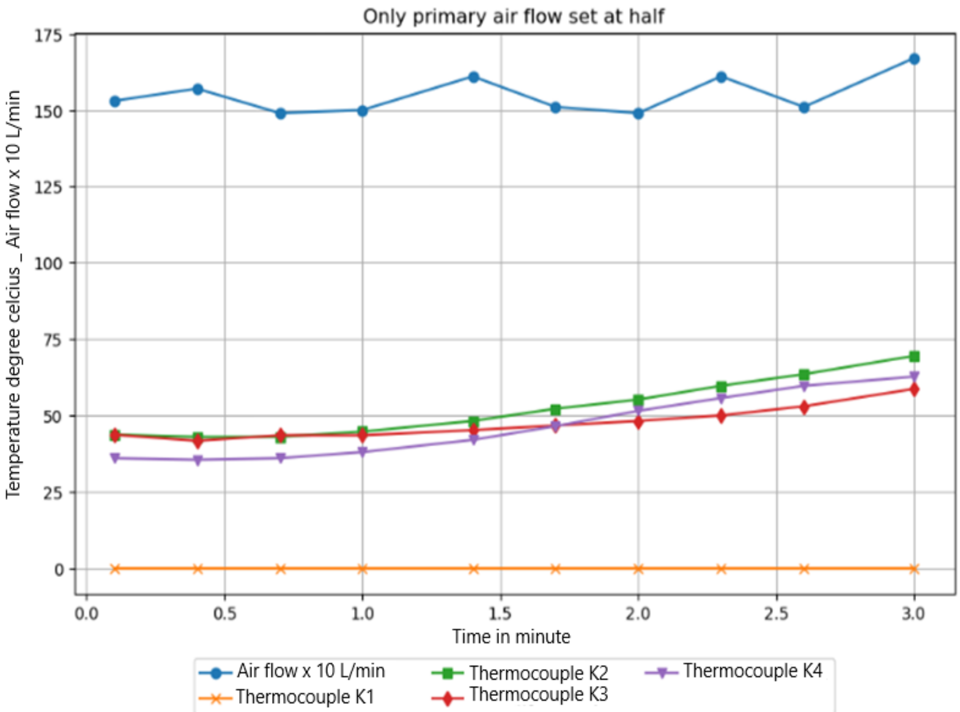

Fig. 6. Temperature evolution from the primary air flow set at half

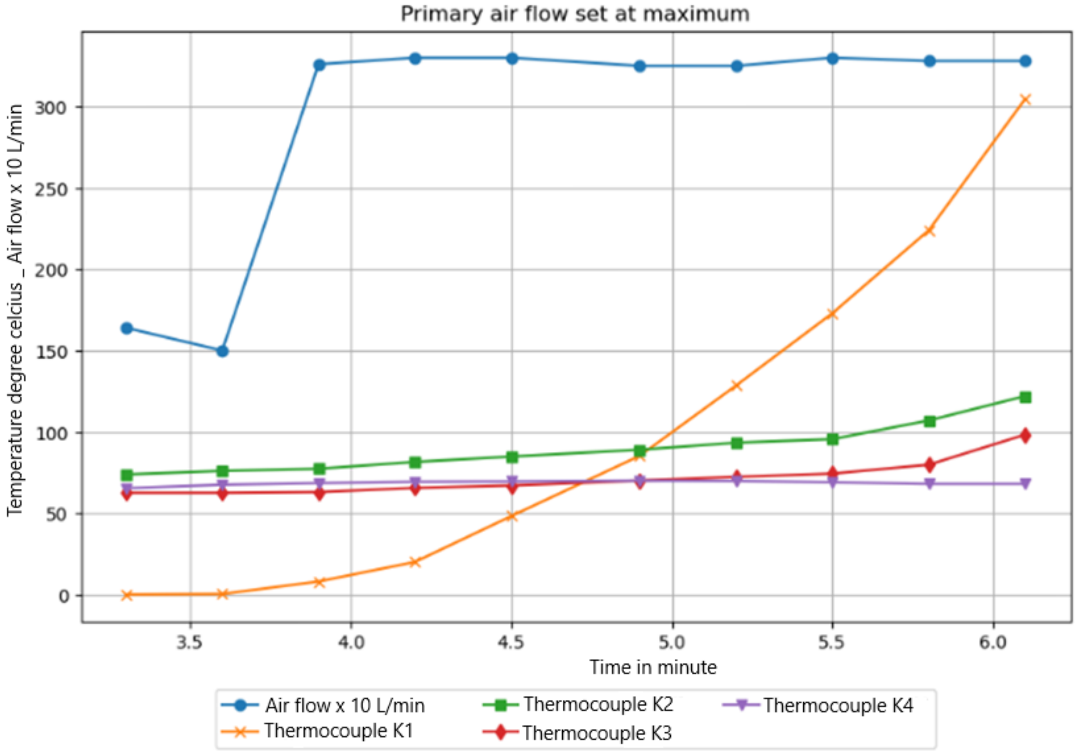

Fig. 7. Temperature evolution from the primary air flow set to maximum

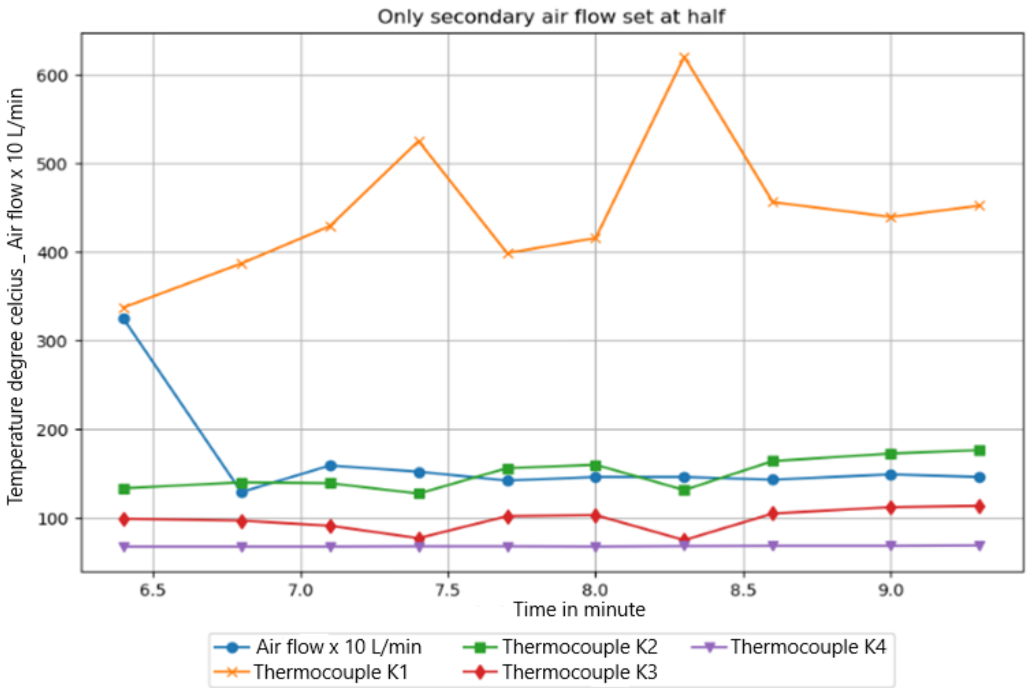

Fig. 8. Temperature evolution from the half-set secondary air flow

Fig. 9 showing the injection of the maximum air flow 3000 L/min, illustrates a stability of the maximum temperature around 460°C after the 9th minute of combustion and respectively 183°C, 118°C, 70°C for the K2, K3 and K4 thermocouples. In short, there is a slight increase in temperature in the maximum flow rate of secondary air injected.

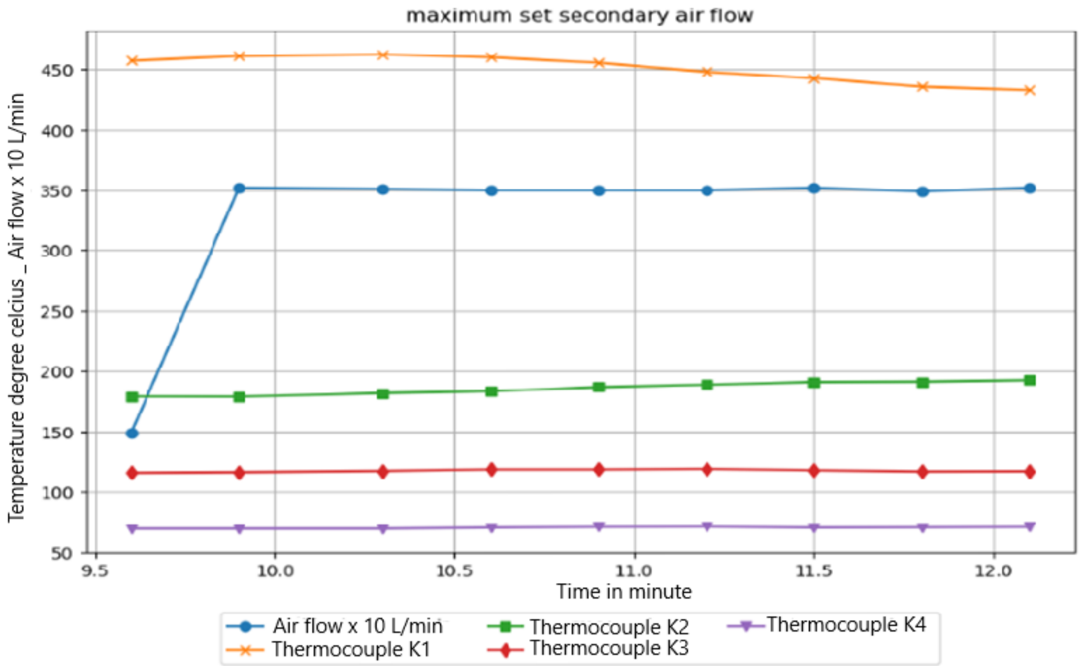

Fig. 9. Temperature evolution from the maximum set secondary air flow

3.3 Comparison of the Effects of Primary and Secondary Airflow

From the 12th minute, the primary and secondary air valve are opened and the flow rate is set to 1500 l/min. in 3 minutes, the results in Fig. 10 give an average of 362.18°C, 186.82°C, 109.27°C, 72.41°C respectively for the thermocouples k1, k2, k3, k4.

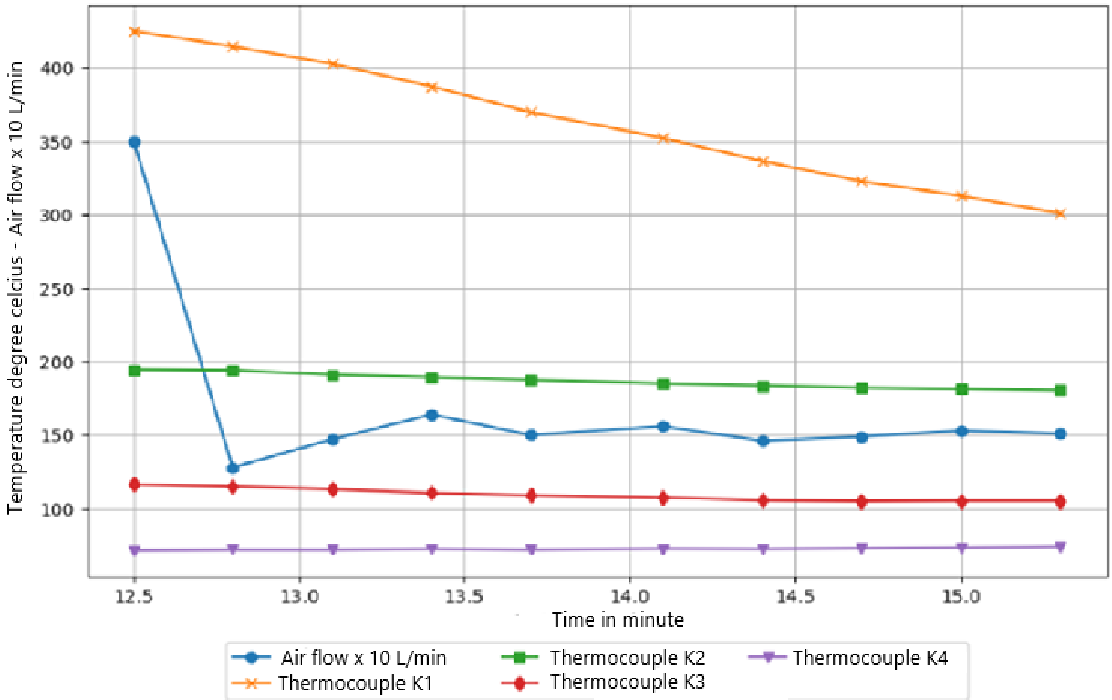

Fig. 10. Temperature evolution from the half-set primary and secondary air flow

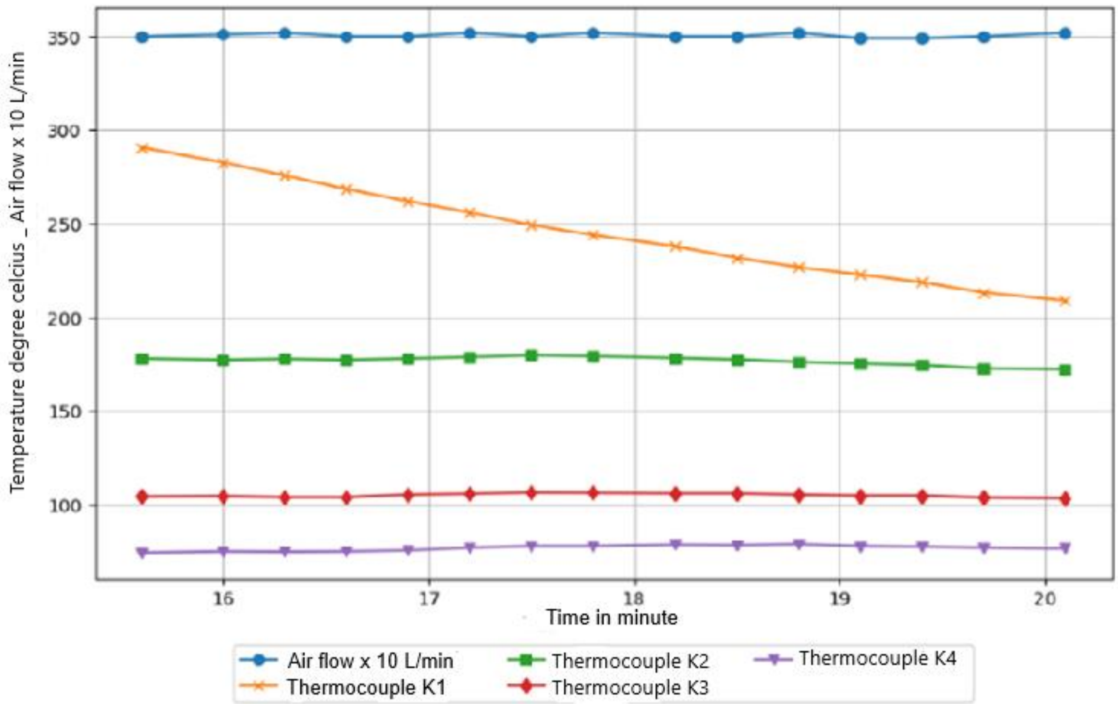

Fig. 11. Temperature evolution from the maximum set primary and secondary air flow

From the 15th minute, the primary and secondary air flow is set to a maximum of 3000 L/min and the results show us in Fig. 11 a drop in the temperature of all the thermocouples. An average of 246°C, 177°C, 105°C and 77°C was observed respectively for the K1, K2, K3 and K4 thermocouples. The increase in secondary air initially leads to an improvement in combustion and then subsequently causes a decrease in the oxygen consumption efficiency due to a cooling of the reactive medium, linked to too much dilution of the flue gases (Salifou et al. 2012). Increasing secondary air supply rate reduces the chamber temperature in both chambers and strong effect on CO reduction for waste with high combustible content (Jangsawang et al, 2005).

The injection of primary and secondary air is very important for combustion and an average flow rate of 1500 L/min gives a better thermal potential in the combustion chamber.

4. CONCLUSION

This study on the influence of primary and secondary air flow on the thermal potential during the combustion of municipal solid waste on a grate was carried out following instrumentation and experimentation on a natural laterite wall furnace. Data collection and analysis shows the importance of primary and secondary air injection. Indeed, the primary and secondary air flow is injected according to a time slot of 3 minutes in order to observe the effect on the internal temperature. Maximum temperatures of up to 450°C are observed following the injection of secondary air only. This is explained by the supply of oxygen making the combustion more complete. Primary and secondary air injection at a flow rate of 1500 L/min shows a more stable temperature result, i.e. 362.18°C, 186.82°C, 109.27°C, 72.41°C for thermocouples K1, K2, K3 and K4 respectively. However, the injection of primary and secondary air at a maximum flow rate of 3000 l/min decreases the temperatures. Excess air dilutes the internal atmosphere and creates a depression and regression of temperature. Incineration of Ouagadougou's household waste could be considered as a treatment option, with valorization of the energy produced (Hamidou et al, 2013).

This work is of interest in the process of thermal recovery or the production of electricity by steam turbines. In the latter case, the thermal potential would be an essential variable for the evaporation of the heat transfer fluid.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models

(ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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