Research Journal of Applied Sciences, Engineering and Technology 16(2): 56-66, 2019
DOI:10.19026/rjaset.16.6000
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: October 14, 2018 Accepted: January 24, 2019 Published: March 15, 2019

Research Article

Experimental Study of Heat Transfer Through the Protective Cloths of Cooks

[1, 2, 3]Patrice Changement, [1, 3]Jeanm'Boliguipa, [1, 3]Oumarou Sanda Abbo and [2]Ruben Mouangue
[1]Department of Physics, Faculty of Science, University of Bangui, RCA
[2]LACOTEV, Department of Energy Engineering, IUT, University of Ngaoundere, Cameroon
[3]Laboratory of Carnot Energy, University of Bangui, RCA

Abstract: The objective of this work is to study the transfer of heat through the apron used by cooks, when they are involved in food cooking processes, in order to determine the minimum distance they need to respect to insure their safety whenever they are close to a heat source. Experimental studies of heat transfer from the heat source to the material used to fabricate the apron are being carried out as a means to achieve this goal. The variation of the source, the distance separating the two systems and equally the height of the target are taken into account in the study. At the end of the study the distance and the maximum duration for the user to be exposed to burns is determined. At 0.48 m from the 1.5 kW radiant source, the duration is 3 min 58 sec. Maximum durations of 4 min 25 sec and 1 min 15 sec are equally obtained for distances of 0.48 m and 0.18 m from the 1 kW source respectively. These durations correspond to the average minimal temperature of 43°C which signifies the beginning in the loss of the physical capacity. Obtained results make it possible to properly evaluate the state of protection against thermal aggression of aprons used by cooks.

Keywords: Apron, cloths of cook, fire safety, heat transfer, minimum distance, thermal experimentation

INTRODUCTION

Presently the main preoccupations such as fire safety and thermal aggression live researchers with no other choice than to study and develop systems of protection against thermal attacks. Fire, characterized by the quantity of energy it gives out per unit time in watts, is the source of heat released which is the principal cause of thermal damage, a function of protein denaturation and the exposition time at a particular temperature (Domoino, 2012). This energy released from a fire source may be propagated in four ways; radiation, conduction, convection as well the release of small flames from the source (Anne, 2010; Batchelor, 1967). People that are exposed to heat for a long time are generally victims of hyperthermia malignancy provoked by dehydration and an increase in the bodily temperature of the person. This phenomenon can provoke confusion, delirious behavior, convulsion, a loss of consciousness which eventually leads to a comma and to death of vulnerable people (children, the old and people suffering from obesity). Putting on protection garments or aprons protect one from the thermal risks (Nathanaelle *et al*., 2012). This study requires proper understanding of heat transfer (Collina *et al.*, 2013) through the aprons won by different users in various places reserved for cooking. Literature review shows related works. A. Collin et al in their work had shown that first degree burns occur at the beginning of the seventh minute when the target is without a vest and at the twenty first minute when protected by a vest. These time units correspond to a temperature of 43°C (Collina *et al*., 2013). Domoina Ratovosonin his work presents different sources, flux and the target of danger of house fire on people and properties (Domoino, 2012). Anne Muller used a solar source of 45 kW in his studies. He showed that the lightest material at the target face leads to an increase of 24.6°C of temperature at the interface of the dermis/ hypoderm (Nathanaelle *et al*., 2012).

Unfortunately there is no work with attention drawn on the variation of the distance separating the target and the source. In this study, we have opted for experimental studies in order to determine the minimum distance of safety separating the target and the source. Two radiant sources with different powers (1 kW and 1.5 kW) are being used in this study and the distance between the two systems is varied.

MATERIALS AND METHODS

In this section, we present the material and the methods which help in our research work carried out in Cameroon in 2018.

Corresponding Author: Ruben Mouangue, LACOTEV, Department of Energy Engineering, IUT, University of Ngaoundere, Cameroon

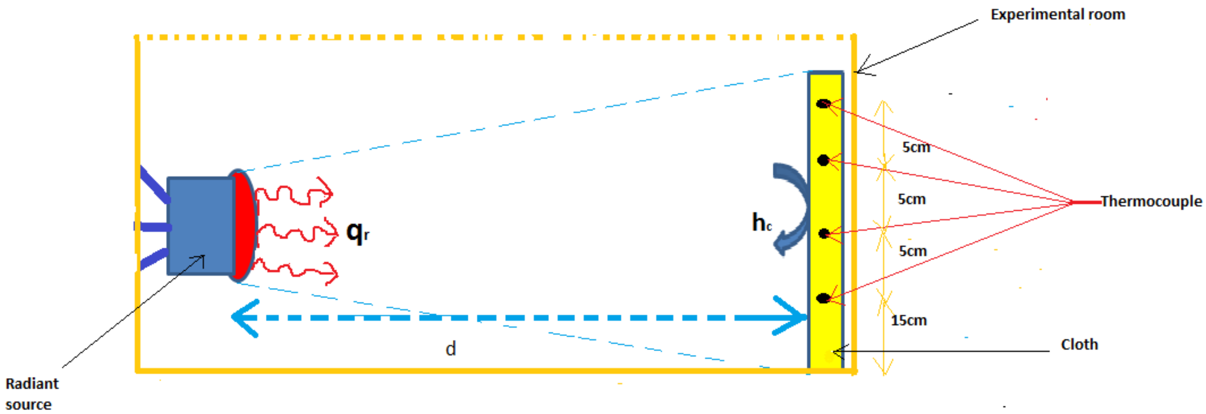


Fig. 1: The experimental room where investigations are made

Table 1: Description of the experimental room

Wall	Cardboard: 0.05 m Thickness
Length	0.65 m
Width	0.50 m
Height	0.50 m

Table 2: Characteristics of the source

	Diameter (m)	Power (kW)	Height (m)
Source (S1)	0.16	1	0.20
Source (S2)	0.18	1.5	0.20

Table 3: Position of the thermocouples

Thermocouples	Height (m)
T1 and T'1	0.15
T2 and T'2	0.20
T3 and T'3	0.25
T4 and T'4	0.30
TS	0.20

Experimental setup: For experimental investigations the room presented in Fig. 1 is used. The characteristics of this room are presented in Table 1 above.

The experimental room which was manufactured in our laboratory of combustion and green technology of the University of Ngaoundere is equipped with a circular radiant source placed at a height of h = 0.20 m from the floor of the room. The material used to fabricate the apron is attached to plywood of dimensions 0.50 m by 0.45 m. Convection of heat takes place in the layer of air found between the material and the plywood. Table 2 contains the characteristics of the sources used in this study.

The experimental room is equipped with nine thermocouples. Eight of the thermocouples are of type N and are positioned on the material such that four (T1, T2, T3, T4) are on the face exposed to radiation and the other four (T'1, T'2, T'3, T'4) on the face hidden from radiation. The ninth thermocouple is of type K and is fixed on the source. Table 3 shows the position of each thermocouple from the floor of the room.

Figure 2 shows an Agilent 34970 connected to laptop. This setup is used in this research work to monitor and register temperature signal over extended period of time.

Mathematical modelling: The material is of a single layer. The modes of heat transfer in this study are represented in the following manner (Collina *et al*., 2013):

- Within the space between the radiant source and the material, there is heat transfer by radiation and by convection Eq. (1).
- Within the material itself there is heat transfer by conduction Eq. (2):

$$\lambda \frac{\partial T(x,t)}{\partial x} = h_c(T_{air} - T) + \sigma\alpha(T_{air}^4 - T^4) + \alpha q_r \qquad (1)$$

$$\frac{\partial T(x,t)}{\partial t} = \alpha \frac{\partial^2 T(x,t)}{\partial x^2} \qquad (2)$$

The surface density of radiative flux received by the material placed at a distanced from the radiant source is given by (Bernard, 1999):

$$q_r = \frac{Q_r}{4 \times \pi \times d^2} \qquad (3)$$

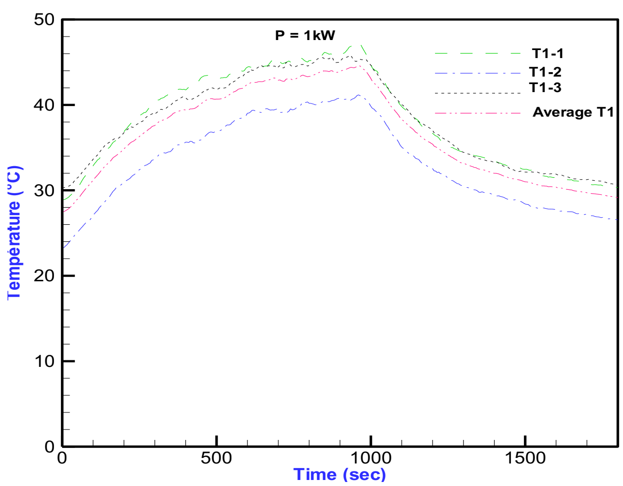
With λ as the thermal conductivity of the material ($W.m^{-1}.K^{-1}$), T(x,t) the temperature of the material at the point x and at an instant t (°K), h_c the coefficient convective exchange ($W.m^{-2}.K^{-1}$) with surrounding temperature T_{air}, the absorption coefficient of the material, the radiative surface density of the flux received by the material ($W.m^{-2}$) and originating from the source, total radiated power of the radiant source (W), d the distance separating the source and the target (m), Stefan-Boltzmann constant ($5.67.10^{-8} W.m^{-2}.K^{-4}$).

RESULTS AND DISCUSSION

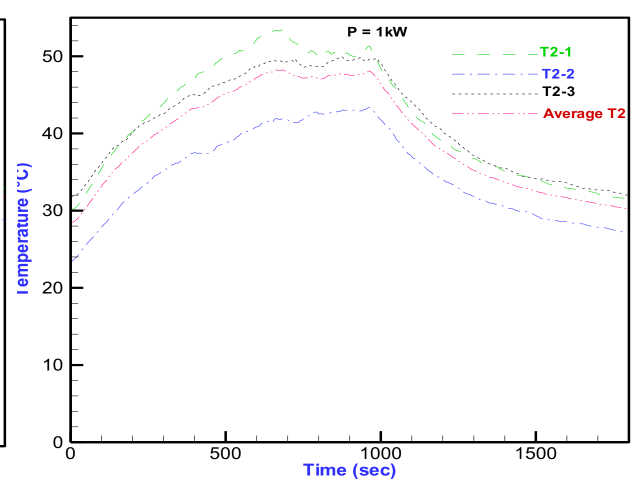
Detailed results of the experiment: Repeated experiment brings out values of temperatures which are reproducible for a given distance.

Figure 3a to 3d presents the time evolution of the temperature of the material during the experiment for

Fig. 2: The system for acquisition of data (N°34970)



(a)



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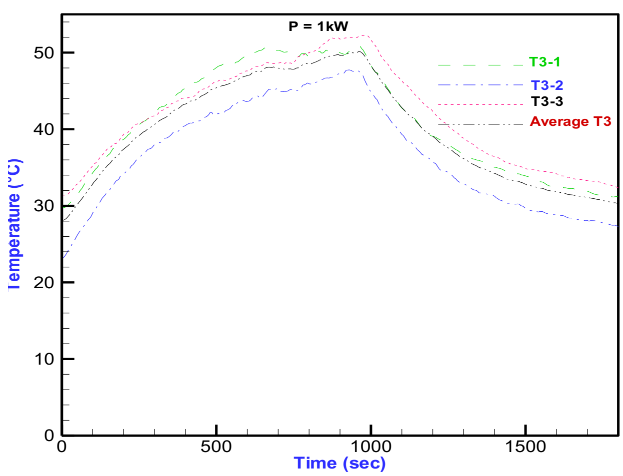

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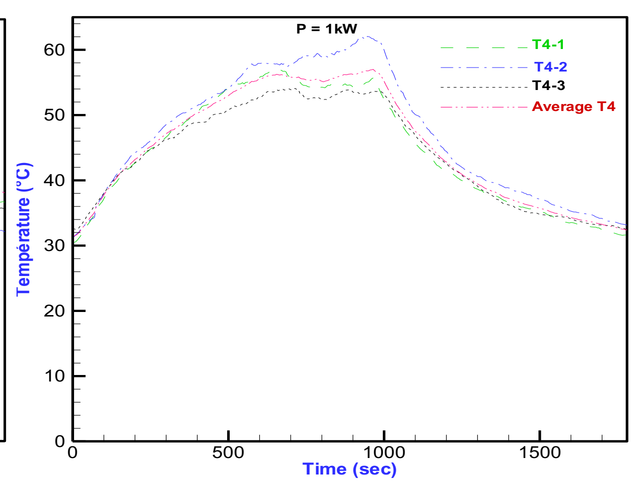
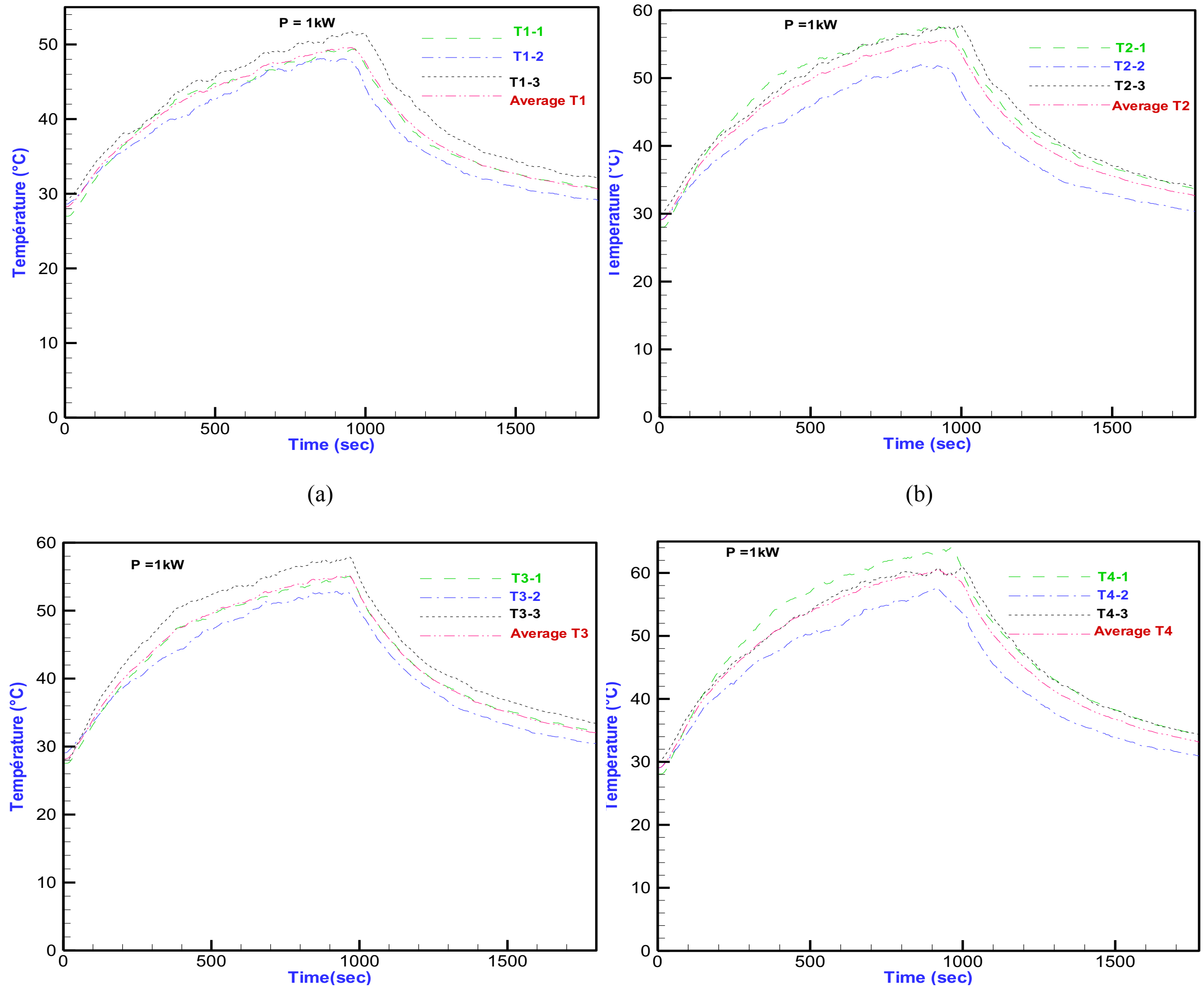


(d)

Fig. 3: Reoccurrence of the temperature of the material at a distance of 0.48



(c) (d)

Fig. 4: Reoccurrence of the temperature of the material at a distance of 0.38 m

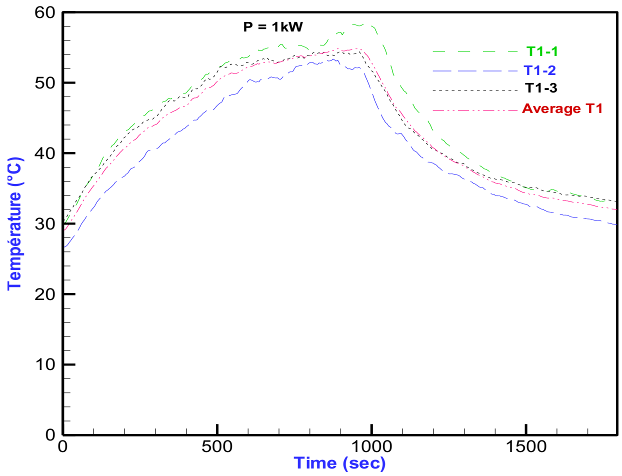
three repeated test carried out within three different days, when under the influence of a radiant source of 1 kW. These temperatures are measured with four thermocouples T1, T2, T3 and T4 placed at the exposed surface of the material. The average value of temperature of the material before the start of the experiment is 30°C. A rapid increase is recorded within the first 660 seconds of the experiment, after which there is a gradual slow down reaching minimal values of: 44°C, 47°C, 49°C et 58°C at 960 sec.

The variation in the values of the temperature recorded by a given thermocouple for different repeated experiment is explained by the fact that the experiment started with different initial temperatures of the material. There is equally a difference in the average minimal values of the thermocouples within the same experiment. This is due to the force of Archimedes; hot gasses rise up and cause circulation of air at the upper part of the room (Bernard, 1999). This explains high values recorded by T4 placed above the others at a distance of 0.30 m from the floor of the experimentation room.

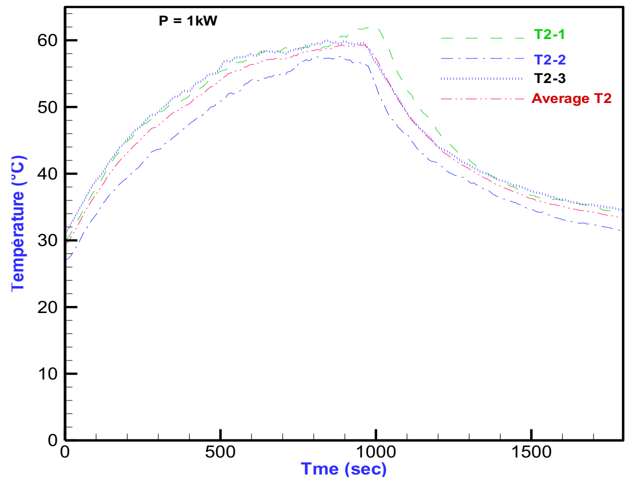
Figure 4 gives the temperature evolution profile of the material for various repeated experiment at a distance of 0.38 m from the 1 kW radiant power source. The temperatures increase relatively fast, then slowly to minimal values of 49°C, 55°C, 56°C and 59°C at an instant t = 960 seconds for the thermocouples T1, T2, T3 and T4 respectively. The ensemble cools down to the initial value when the source is switched off.

Figure 5a to 5d shows the temperature profile of the material for different repeated experiment placed at a distance of 0.28 m. the ensemble of temperature increases rapidly and is then stabilized at minimal values of 51°C, 58°C, 61°C and 64°C at 960 seconds for T1, T2, T3 and T4 respectively. Accommodation of heat is observed at the upper part of the room.

The time evolution of temperature of the material during three repeated experiment carried out within three different days when under the influence of the 1



(a)



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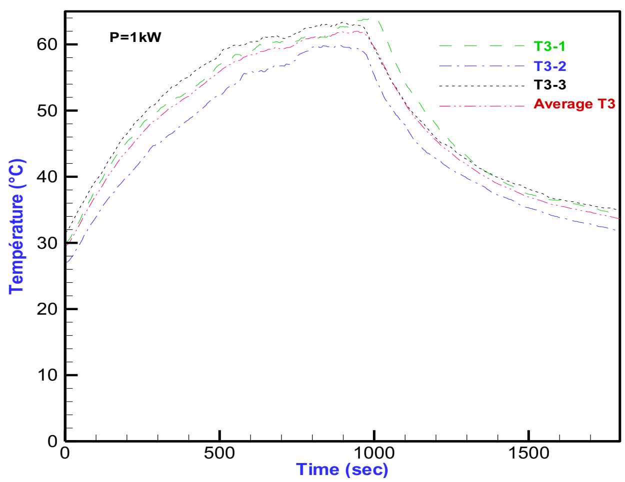

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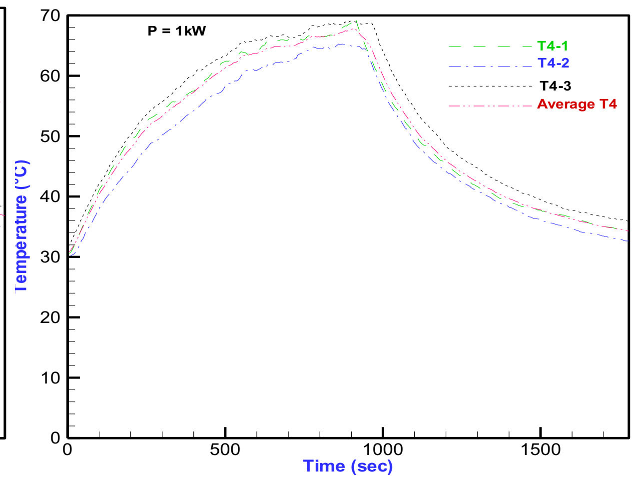
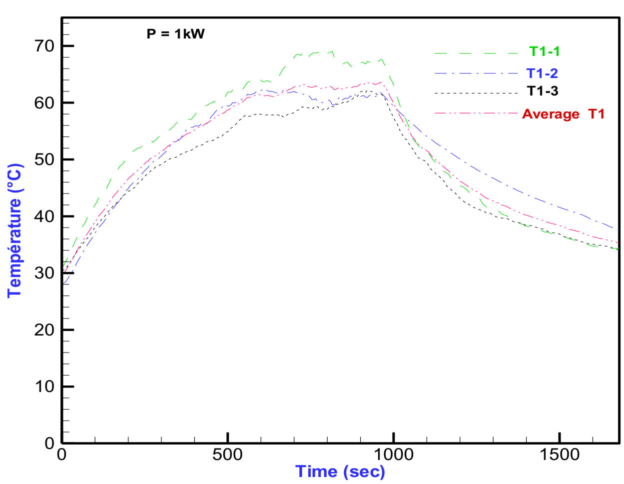
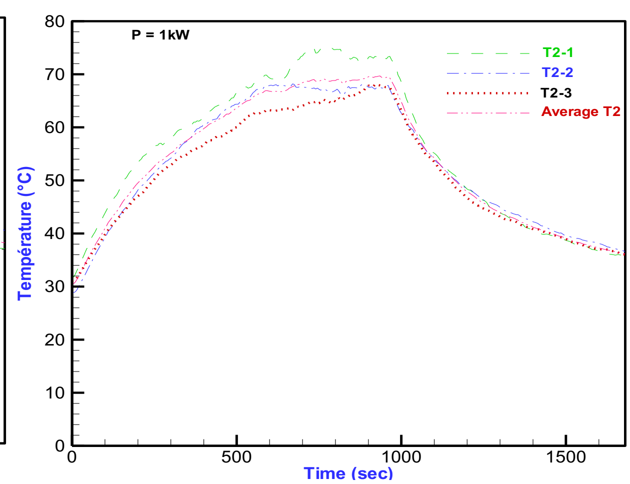


(d)

Fig. 5: Reoccurrence of the temperature of the material at a distance of 0.28 m

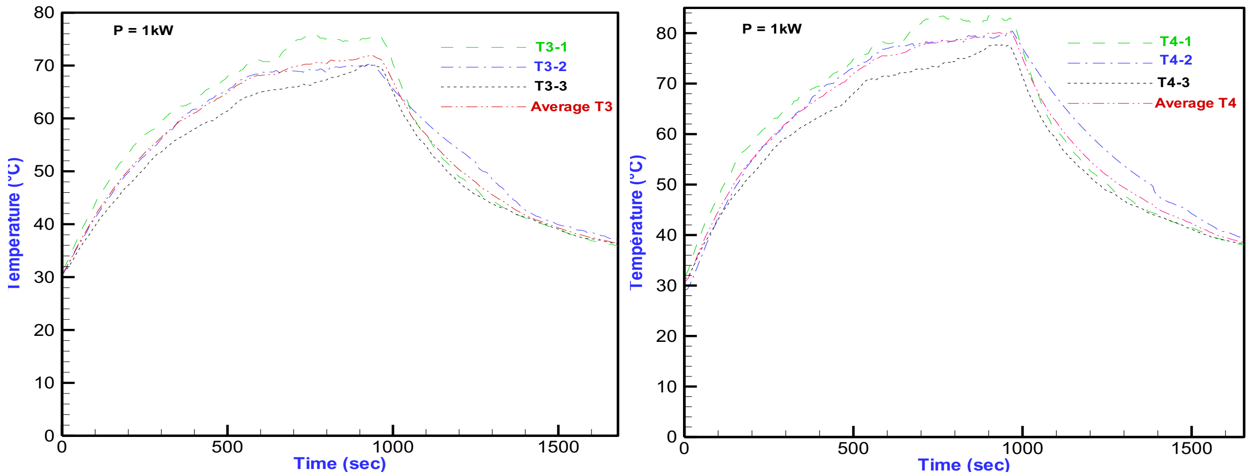


(a)



(b)

Fig. 6: Continue



(c) (d)

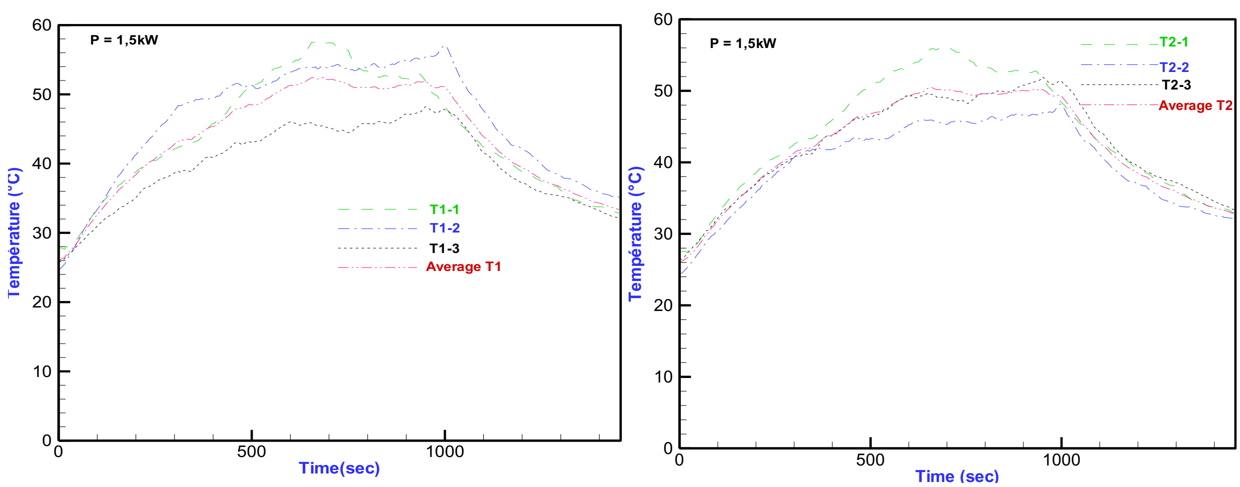
Fig. 6: Reoccurrence of the temperature of the material at a distance of 0.18 m

kW source placed at a distance of 0.18 m is represented in Fig. 6. These temperatures are measured with four thermocouplesT1, T2, T3 and T4 placed at the exposed surface of the material. The average temperature of the material before the start of the experiment is 30°C. There is a noticeable rapid increase in ensemble within the 660 sec after which evolution become slowed down and stabilizes at minimal values of 63°C, 69°C, 71°C and 80°C at 960 sec. At the moment the source is switched off the ensemble takes 1800 sec to reach (30°C).

Figure 7 to 10 shows the temperature profile for different experiment carried out on the material placed at different distances and under the influence of a 1.5 kW source. There is a remarkable evolution of temperature of the ensemble within the first 660 sec of the experiment after which there is a slowdown arriving average minimal values of: 51°C, 52°C, 53°C and 58°C (Fig. 7a to 7d), 57°C, 58°C, 59°C and 63°C (Fig. 8a to 8d), 65°C, 67°C, 69°C, 78°C (Fig. 9a to 9d) and 79°C, 82°C, 89°C and 91°C (Fig. 10a to 10d) at 960 sec. Values decreases after the source is switched off at the 960 sec until the end of the1500th sec. This phase corresponds to natural convection.

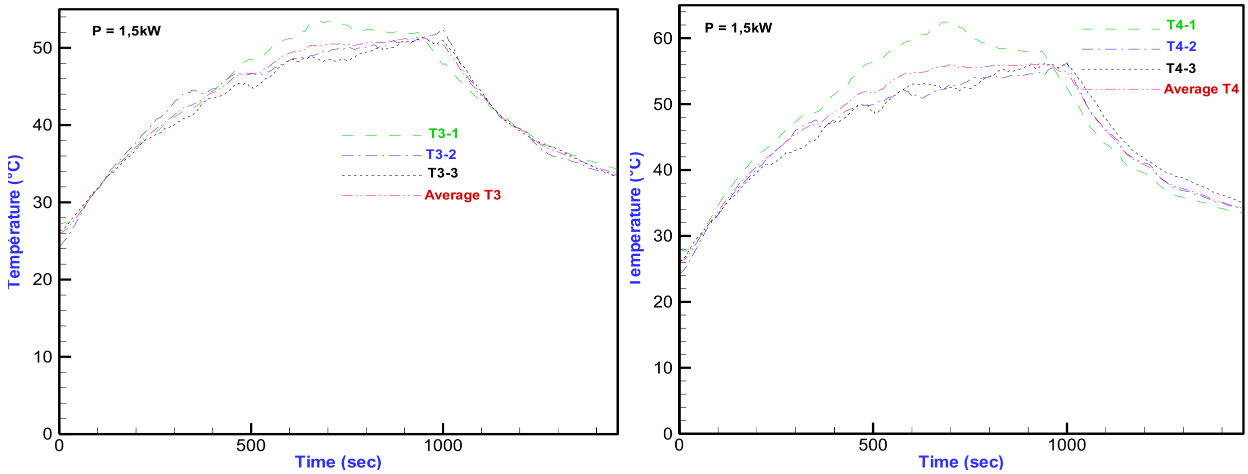
It is clear from the previous graphs (1 kW and 1.5 kW) that the temperatures do not suffer much fluctuation within the three experiment (Alexandre, 2013). The average values of the temperature is considered in the preceding sections.

Analysis: The evolution profile of the average temperature of the material (expose surface) deduced as



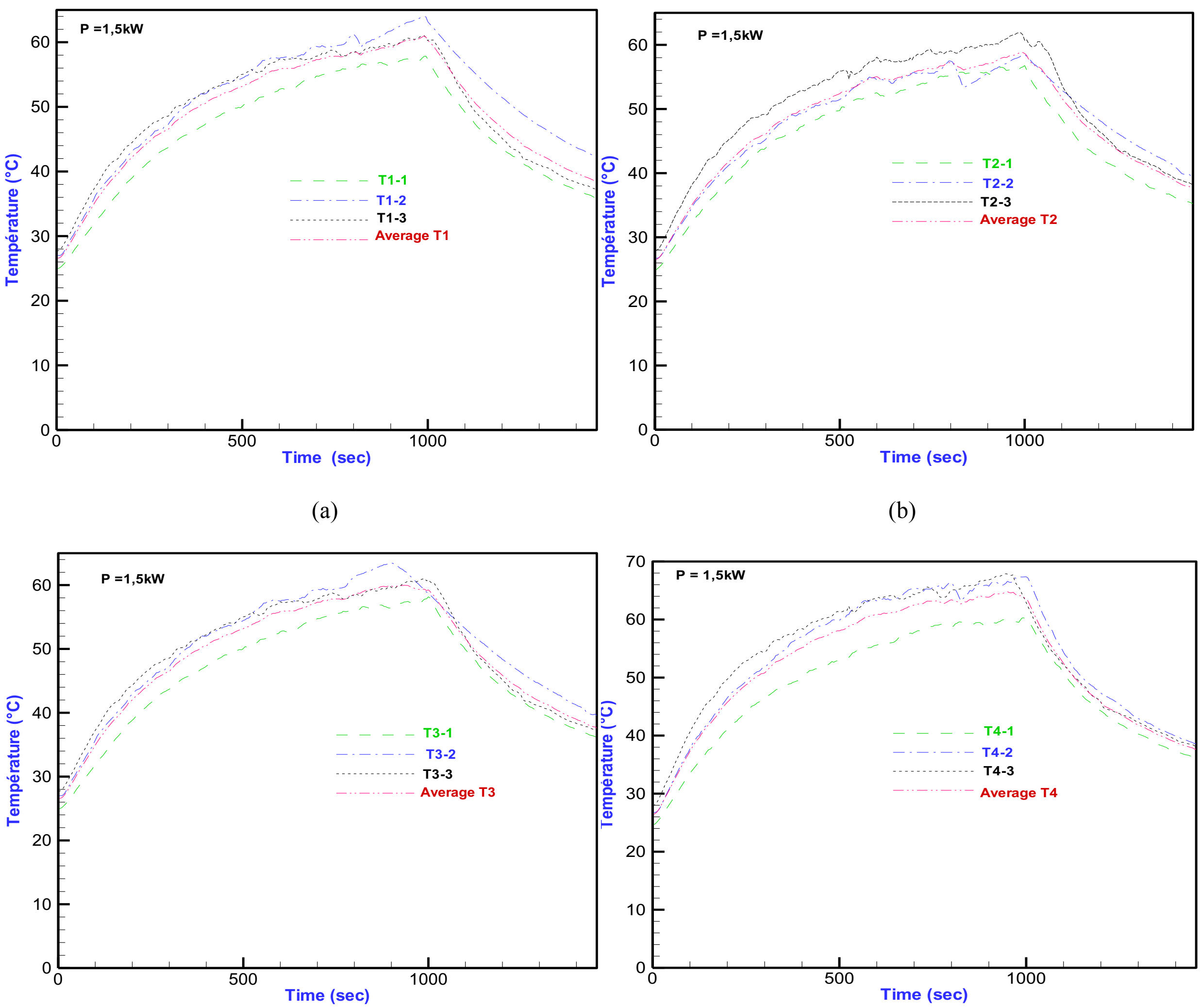
(a) (b)

Fig. 7: Continue



(c) (d)

Fig. 7: Reoccurrence of the temperature of the material at a distance of 0.48m



(a) (b)

(c) (d)

Fig. 8: Reoccurrence of the temperature of the material at a distance of 0.38 m

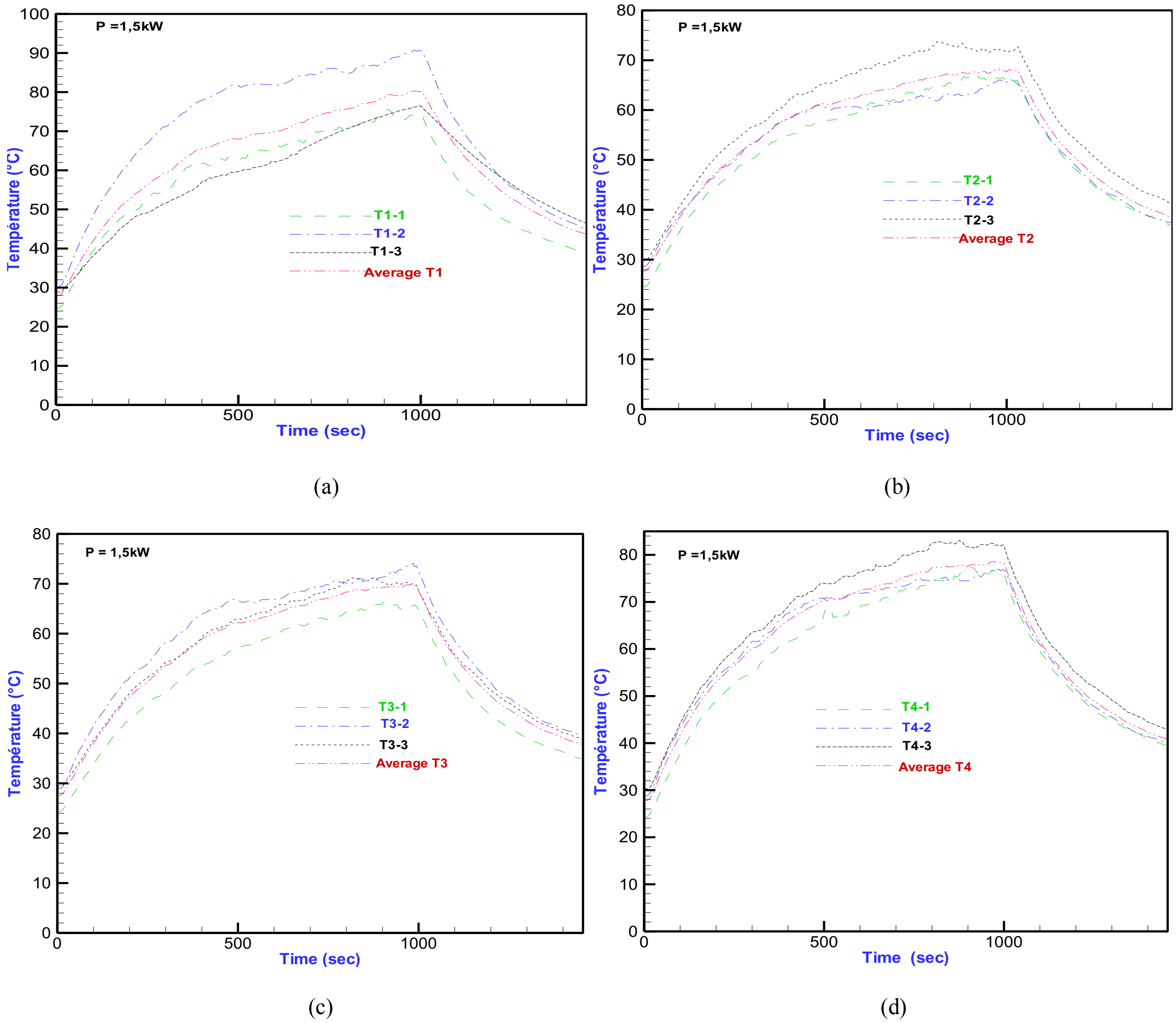


Fig. 9: Reoccurrence of the temperature of the material at a distance of 0.28 m

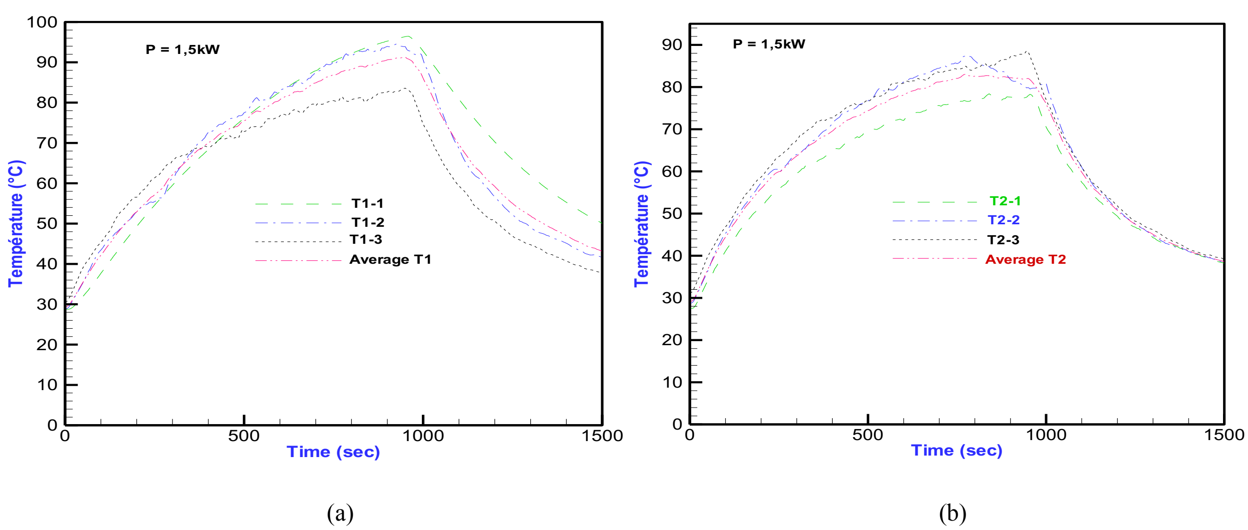
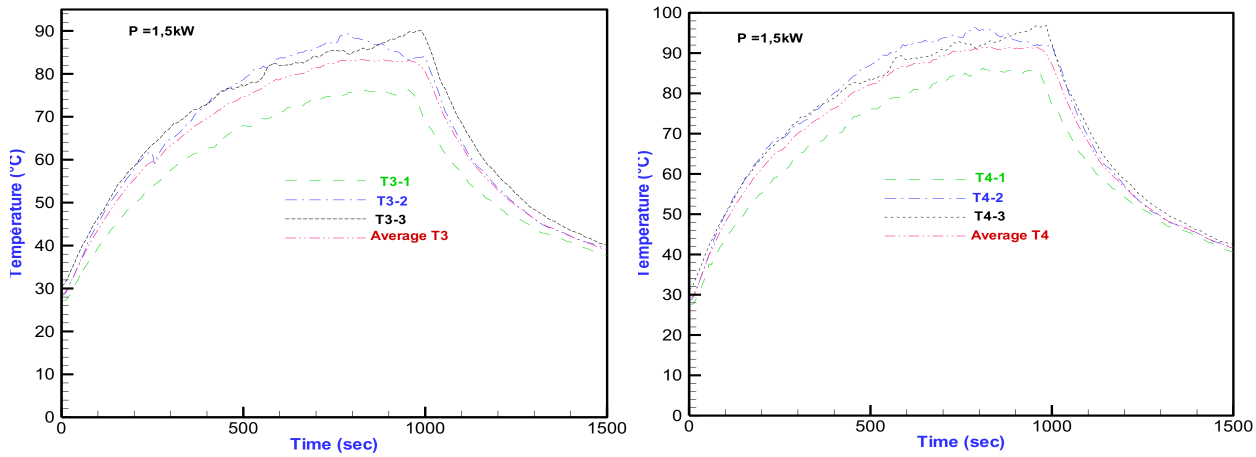
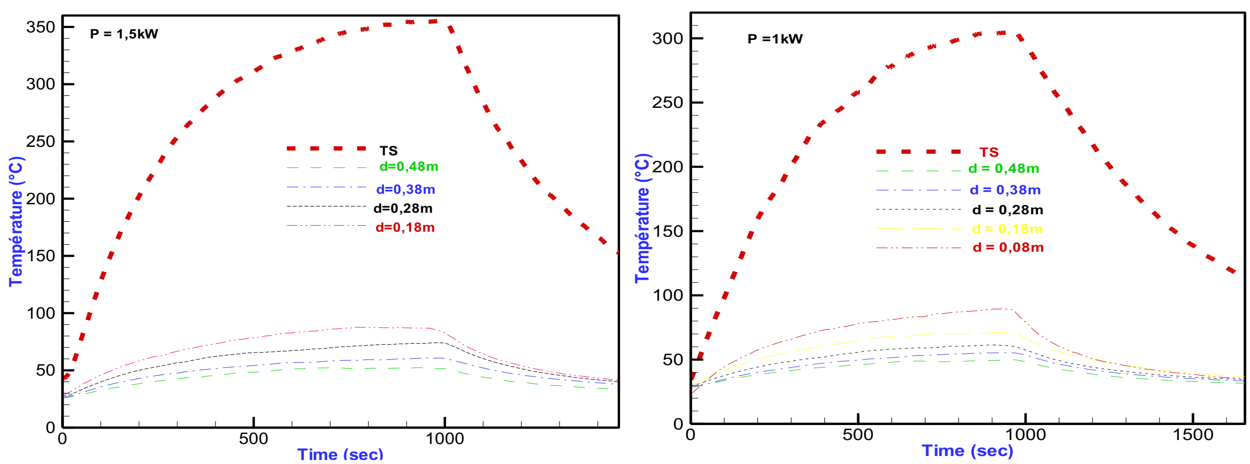


Fig. 10: Continue



(c) (d)

Fig. 10: Reoccurrence of the temperature of the material at a distance of 0.18 m



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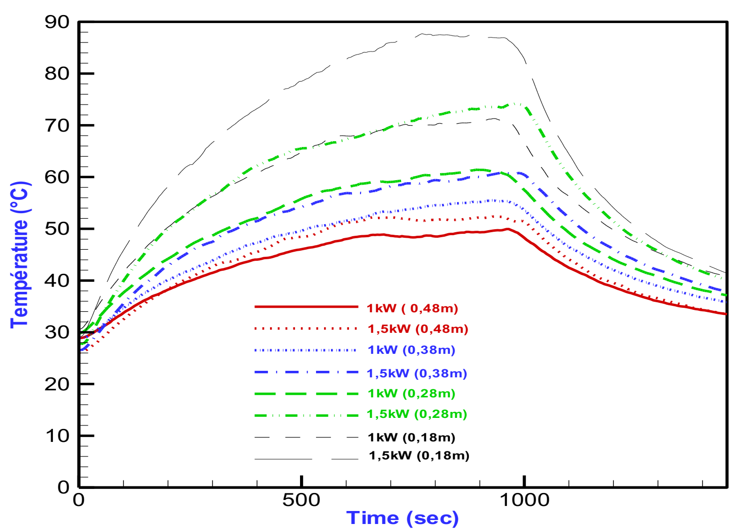

(c)

Fig. 11: Evolution profile of the average temperature of the material (expose surface) as a function of distance and power

Table 4: Temperature of the exposed surface as a function of distance and power

Power (kW)	Minimal average temperature (°C) at 0.48 m	Minimal average temperature (°C) at 0.38 m	Minimal average temperature (°C) at 0.28 m	Minimal average temperature (°C) at 0.18 m
1	49.5	54.75	58.5	70.75
1,5	53.5	59.75	69.75	85.25

Table 5: Minimum exposure time to a 1.5 kW source

Distance (m)	0.48	0.38	0.28	0.18
Duration (s)	238	144	94	60

Table 6: Minimum exposure time to a 1 kW source

Distance (m)	0.48	0.38	0.28	0.18
Duration (s)	265	180	130	75

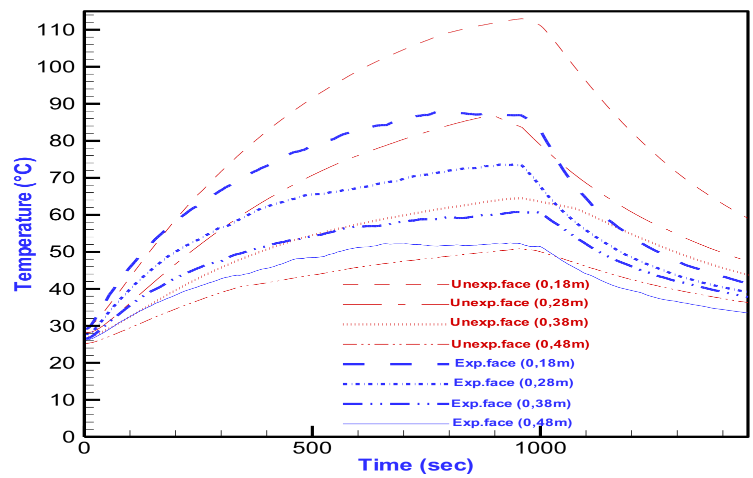

Fig. 12: Temperature profile for exposed and non-exposed surfaces for a 1.5 kW source

a function of distance and the source is presented in Fig. 11a and 11b. It is noticed that the temperature of the target increases as it gets closer to the source (Fig. 11a and 11b). With the distance kept constant, the quantity of heat received also depends on the power of the source used. The temperature of the target increases proportionally with that of the source. Table 4 presents the minimal average temperature of the expose surface as a function of distance (Fig. 11c):

At a distance of 8 cm, for a 1.5 kW source, fire set up on the material after 2 min15 s when at a temperature of 150°C. On the other hand this phenomenon does not occur for a 1 kW and the average minimal temperature is 89°C after the first 960 sec (Fig. 11b). The 39°C limit of the bodily temperature marks the beginning in loss of the physical capacity (Collina *et al.*, 2013) and becomes deadly at a temperature of 43°C, this is of help for the present work to bring out the distance and the minimal duration of exposure to a 1 kW and 1.5 kW source. Results are presented in Table 5 and 6.

Figure 12 presents temperature profiles for exposed and non-exposed surfaces at different experimental distances for a 1.5 kW source. It is noticed that the temperature of the non-exposed surface exceeds that of the exposed surface which was supposed greater at the beginning; at different instances as a function of the distance separating the source and the material (195 s for a distance d = 0.18 m; 315 s for d = 0.28 m; 470 s for d = 0.38 m and 1030 s for d = 0.48 m). The loss of heat by convection at the exposed surface and accumulation of heat at the interior (non-exposed surface) are at the origin heat increase at the interior. It is also observed that temperature fall at the interior is slow with respect to the exterior.

Figure 13 indicates that radiative flux received decreases when the target gets further away from the source and equally depends on the power of the source. The threshold of the irreversible effects delimiting the danger zone for human life is at 0.2 m for the 1.5 kW (3 kW/m^2) power (INERIS, 2014) and 0.16 m for 1 kW power source. The flux of 5000 W/m^2 corresponds to a severe danger zone for human life. This zone is situated at 0.13 m for 1 kW and 0.156 m for a power of 1.5 W. These theoretical results are in conformity with experimental results. The closer the target is to the source the more significant is the flux density received.

Experimental results obtained are in accord with theoretical results. It is noticed that the temperature or the flux received by the target increases as it gets closer to the source. The temperature of 44°C at 3 mn 58 s for a distance of 0.48 m and 1mn for distance of 0.18 m (P = 1.5 kW). This temperature corresponds to a flux of (3 kW/m^2).

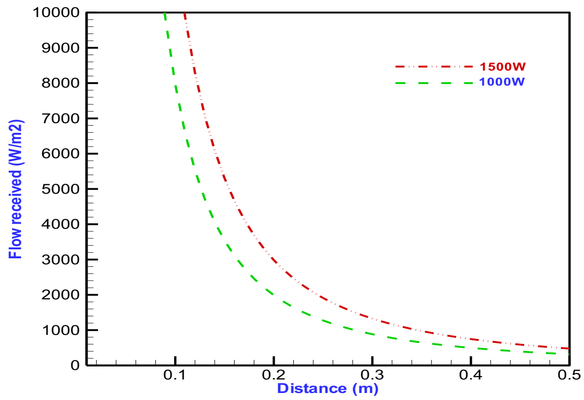

Fig. 13: Radiative flux density received by the material as a function of the distance separating the material and the source

CONCLUSION

This study has permitted us to stratify the increase in the temperature of a person (target) placed at the proximity of a given heat source. First of all, we have described the various mode of heat transfer taking place between the heat source and the target. The foundation of this study resides on taking into account the variation of the distance separating the source and the target and the other hand being able to reproduce the repartition of the temperature field as a function of the height of each point of the target. Obtained results shows the impact of the distance, the power of the source and the height on the temperature of the target. The minimum temperature of 43°C which marks the beginning in the loss of the physical ability of man has a distance of 48 cm within a duration of 3 mn 58 sec for a power 1.5 kW and 4 mn 25 sec for a power of 1 kW.

Preceding work will be directed towards experimentation of protective jackets of fire fighters and making comparison with numerical simulation at the end of it all.

CONFLICT OF INTEREST

Authors of this study declare no conflict of interest concerning the publication of this study.

ACKNOWLEDGMENT

The authors use this opportunity to express their sincere gratitude to the personnel of the laboratory of combustion and green energy of the University Institute of Technology Ngaoundere for having permitted us to write down this study. They equally thank the French Cooperation through the Services of Cultural Action Cooperation (SCAC) of Central Africa Republic for funding the project.

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