Applied Thermal Engineering 65 (2014) 262–272

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Surface ignition behaviors of methane–air mixture in a gas oven burner

Jungwan Ryu [b], Jongseo Kwon [a], Ryanggyun Kim [a], Minseong Kim [a], Youngsoo Kim [b], Chunghwan Jeon [a], Juhun Song [a,*]

[a] *School of Mechanical Engineering, Pusan National University, Republic of Korea*
[b] *LG Electronics, Changwon, Kyungsangnamdo, Republic of Korea*

HIGHLIGHTS

- We revealed a surface ignition behavior of combustible mixture in gas oven burner.
- We employed a flame visualization technique with temperature measurement.
- We evaluated effects of parameters such as lifetime, mixture velocity and igniter distance.
- We recognized several abnormal modes leading to ignition failure.

ARTICLE INFO

Article history:
Received 26 October 2013
Accepted 4 January 2014
Available online 13 January 2014

Keywords:
Gas oven burner
Surface ignition
Methane–air mixture
Ignition temperature
Abnormal mode

ABSTRACT

In a gas oven burner, commonly used as a residential appliance, a surface igniter is a critical component for creating a pilot flame near the surface that can propagate safely back to the nozzle of the burner. The igniter should meet critical operating requirements: a lower surface temperature needed to ignite a methane–air mixture and a stable/safe ignition sustained. Otherwise, such failure would result in an instantaneous peak in carbon monoxide emission and a safety hazard inside a closed oven. Several theoretical correlations have been used to predict ignition temperature as well as the critical ignition/extinction limit for a stagnation flow ignition. However, there have only been a few studies on ignition modes or relevant stability analysis, and therefore a more detailed examination of the transient ignition process is required.

In this study, a high-speed flame visualization technique with temperature measurement was employed to reveal a surface ignition phenomenon and subsequent flame propagation of a cold combustible methane–air mixture in a gas oven burner. The operating parameters were the temperature–time history of the igniter surface, mixture velocity, and the distance of the igniter from the nozzle. The surface ignition temperatures were analyzed for such parameters under a safe ignition mode, while several abnormal modes leading to ignition failure were also recognized.

1. Introduction

There has been continuing interest in cleaner energy sources, such as the natural gas demanded by a gas oven burner, commonly used as a residential appliance. Compared to an electric oven range, the gas oven burner has demonstrated some benefits of a fast heating time and uniform temperature distribution, leading to better cooking. To advance such use of the gas oven burner, a thermal efficiency must be improved, and a significant reduction in carbon monoxide (CO) and hydrocarbon (HC) emission [1,2] must be achieved. Much research has been done on a steady stable flame in the gas oven burner [3,4], e.g., a study on the effect of flame height and orientation on the heat transfer and CO emission [5].

In the gas oven burner, a hot surface igniter is essential for creating an incipient pilot flame and transferring it to the entire fuel port. A similar ignition device, such as a glow plug, is used to initiate the combustion for other applications: either in a residential boiler or in a diesel engine [6]. However, the use of the igniter in those applications often resulted in unstable ignition behavior. For example, there were cases where the pilot flame did not immediately form near the igniter surface or where the flame was quenched right after its appearance. As a result, significant amount

---

* Corresponding author. Tel.: +82 51 510 7330; fax: +82 51 512 5236.
E-mail address: jxs704@pusan.ac.kr (J. Song).

1359-4311/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.applthermaleng.2014.01.006

Nomenclature

d	nozzle diameter [m]
r	nozzle radius [m]
x	distance along the surface from the stagnation point to the wall jet region
H	distance from the igniter to the nozzle [m]
h	convective heat transfer coefficient [W/m^2 K]
Nu	Nusselt number
Re	Reynolds number
Pr	Prandtl number
T	temperature [K]
S_u	flame propagation speed [m/sec]
R_u	universal gas constant [J/mol K]
V	combustible mixture velocity [m/sec]
$\dot{Q}$	heat transfer rate [W]
Da_I	first Damköhler number
Da_{II}	second Damköhler number
E_a	activation energy [J/mol]
E_a^*	dimensionless activation energy $(= E_a/R_uT_e)$
a	coefficient of the potential flow [1/s]
A	frequency factor [m^3/s mol]
C_p	specific heat at constant pressure [J/kg K]
q_c	heating value [J/kg]
Y_i	mass fraction of species i
MW	molecular weight [kg/kmol]
$\tilde{T}_w$	dimensionless ignition temperature
$\tilde{y}_i$	dimensionless mass fraction of species i $(= y_i/y_{i,e})$
m	exponent of Reynolds number
n	exponent of Prandtl number
l	distance the flame travels from the igniter surface to the nozzle [m]
t	time [s]

Greek characters

Φ	equivalence ratio
τ	flow residence time [s]
β	flow factor
ρ	density [kg/m^3]

Subscripts

u	unburned
s	stoichiometric
w	wall surface
e	nozzle exit
m	mixture
i	species i
∞	ambient condition
F	fuel
o	oxygen
f	flow
d	delay

of a fuel–air mixture would escape without complete conversion to the appropriate products. This thus could lead to unintended CO emission and, in the worst case, to an explosion. In the case of "normal ignition," a combustible mixture is injected from the fuel port and then impinges on the hot surface igniter. Once the ignition criterion is met, i.e., heat generation is balanced by heat loss, the incipient flame forms quite near the stagnation region of the igniter surface. This flame then travels from the igniter surface back to the fuel port. At the end of the ignition process, it is anchored properly and is stabilized at the tip of the fuel port.

However, certain circumstances may block one occurrence of a normal ignition process, which consists of the formation of the incipient pilot flame, its propagation, and a final attachment of the flame to the nozzle and its subsequent sustainment. A failure in one of these steps would eventually lead to an abnormal ignition [7,8]. As a first example, under some conditions, there is no ignition. In such case, no initial flame forms at the surface, and this is referred to here as "no ignition". Even if a pilot flame forms at the surface, the flame may be suspended between the surface and the nozzle. This mode is denoted here as "floating". The oscillatory presence of the pilot flame is often observed where an ignition followed an extinction repeated at some interval. This mode is referred to as "periodic ignition" [9,10].

In previous work on the stagnation region ignition that was reviewed by Laurendeau [11], data on normal ignition behavior has been primarily analyzed. The determination of the surface temperature that causes ignition was of fundamental interest. In addition, the effects of various parameters on the ignition temperature were explored: They included igniter size, surface configuration relative to the nozzle, and mixture flow rate. Those effects were further supported by a theoretical correlation called the surface ignition criterion [12]. This correlation relates the ignition temperature to other operating parameters such as igniter size, flow rate, and stoichiometry. This criterion also predicted a critical ignition/extinction limit under particular conditions.

However, complete descriptions of different modes leading to abnormal ignition have not been fully analyzed. Few studies have developed a stability diagram indicating safe and unsafe ignition regions; the stability diagram for the operation window of an industrial burner has been particularly neglected. In addition, only one measurement of temperature is insufficient to reveal the stability diagram, but it may require the direct visualization of ignition phenomena. However, natural emission from igniter surfaces often prevented detection of relatively weak emission from the incipient flame at the moment of the ignition. A special imaging technique such as the Schlieren technique should be considered to eliminate the stronger background emission from the surfaces [13]. This technique would also be useful for identifying where the pilot flame is developed around the surface and to clarify any differences in subsequent flame propagation.

In this study, a conventional high-speed Schlieren photography with the temperature measurement was employed to describe the detailed time-dependent process of surface ignition including flame initiation, propagation, and extinction. A lab-scale burner with the same nozzle diameter and velocity as used in commercial gas oven burners was developed. The effects of operating parameters such as temperature–time history, velocity, and distance from the igniter surface were evaluated in terms of the surface temperature for ignition. From those data sets, several unstable modes leading to ignition failure were identified.

2. Experimental

2.1. Burner system

A lab-scale burner was developed to simulate the ignition or extinction performance of a commercial gas oven burner. As the commercial burner was scaled down to the lab-scale burner, the diameter of the fuel nozzle was not changed. However, the number of fuel nozzles was reduced to seven while maintaining a constant flow rate per nozzle. The volume of the oven chamber