國立交通大學

機械工程學系

碩士論文

多孔性圓柱燃燒器逆流擴散火焰實驗分析-氮氣稀釋甲烷效應研究

The Experimental Analyses of Counter-Flow Diffusion Flame over Tsuji Burner – The Effects of Methane Diluted with Nitrogen

研 究 生：蔡耀慶

指導教授：陳俊勳 教授

中華民國九十四年六月

多孔性圓柱燃燒器逆流擴散火焰實驗分析

－氮氣稀釋甲烷效

The Experimental Analyses of Counter-Flow Diffusion Flame over Tsuji Burner – The Effects of Methane Diluted with Nitrogen

研 究 生：蔡 耀 慶　　Student：Yao-Ching Tsai

指導教授：陳 俊 勳　　Advisor：Chiun-Hsun Chen

國立交通大學

機械工程學系

碩士論文

Submitted to Institute of Mechanical Engineering

Collage of Engineering

National Chiao Tung University

In Partial Fulfillment of the Requirements

For the degree of

Master of Science

In

Mechanical Engineering

June 2005

Hsinchu, Taiwan, Republic of China

中 華 民 國 九 十 四 年 六 月

多孔圓柱燃燒器逆流擴散火焰實驗分析

-氮氣稀釋甲烷效應研究

學生：蔡耀慶　　　　　　　　　　指導教授：陳俊勳

國立交通大學機械工程學系

摘要

本實驗是研究進氣速度(U_{in})與甲烷-氮氣質量比(α)，固定噴油速度(0.05 m/sec)在風洞中單多孔性圓柱燃燒器對火焰轉換現象。實驗過程中先固定燃料之甲烷-氮氣質量比再改變進速度 0.41 至 2.63 m/sec 來觀察相關的火焰結構變化。在實驗中發現在甲烷-氮氣質量比例在高於$\alpha > 60\%$，當進氣速度增加時火焰結構變化由包封火焰、轉換火焰、尾焰依序出現。轉換區存在於包封火焰與尾焰之間。在此區域火焰呈現一來回擺動的特徵且只存在 5~8 秒。在此區域火焰為高度不穩定它可以是一個昇離火焰、尾焰或是熄滅。在另一方面當甲烷-氮氣質量比例在低於 60%，當進氣速度逐漸增加至極限值時火焰由包封焰直接轉變為尾焰並且沒有轉換火焰存在於此區域。除此之外研究發現當燃料混合物中甲烷質量變低時，火焰轉換極限速度也會變低，此外透過圖片來表示火焰跳距距離(stand-off distance)、火焰厚度(flame thickness)、方位角(attached angle)的變化來了解相關火焰的物理機制。在包封焰與尾焰中量測沿多孔圓柱燃燒器垂直中心線的火焰

溫度分佈來了解相關的火焰變化趨勢。最後將觀測的實驗結果與相關的數值模擬比較來驗證實驗的正確性。比較數值與實驗結果發現有相同的趨勢。在甲烷-氮氣質量比 $\alpha \leq$ **60%** 由包封火焰轉變成尾焰與 $\alpha > 60\%$ 由包封火焰變為轉換火焰再轉變為穩定尾焰的火焰轉換速度發現由實驗得到的結果高於數值預測。由實驗得到的包封火焰厚度(flame thickness)與火焰跳距距離(stand-off distance)發現低於數值模擬，至於由實驗得到的尾焰方位角(attached angle)是高於數值模擬。

The Experimental Analyses of Counter-Flow Diffusion Flame over Tsuji Burner

-The Effects of Methane Diluted with Nitrogen

Student: Yao-Ching Tsai Advisor: Prof. Chiun-Hsun Chen

Institute of Mechanical Engineering

National Chiao Tung University

ABSTRACT

This experimental study investigates the flame transition phenomena over a single Tsuji burner as functions of the incoming flow velocity (U_{in}) and methane to nitrogen mass ratio (α) under a fixed fuel blowing velocity (0.05m/sec) in a wind tunnel. The experimental process is that it fixes the assigned composition of fuel firstly, then, changes the incoming velocity from 0.41 to 2.63 m/sec to observe the corresponding flame configuration. From the experimental observation, in the higher methane mass fraction regime, ($\alpha > 60\%$), the envelope, transition and wake flames appear in order as the incoming flow velocity increases. A transition zone between envelop and wake flame regions is identified in this regime. In such zone, the flame shows an oscillatory feature and can only be survived for 5~8 seconds. It is highly unstable that it might appear as a lift-off flame, wake flame or extinction. On the other hand, when $\alpha \leq \mathbf{60\%}$, the envelope flame is directly transformed into wake one as incoming velocity gradually increases up to the transition velocity, and no transition flame is identified in this regime. This study also finds that the flame

transition velocity is reduced as the mass fraction of methane in fuel mixture is lowered. The variations of envelope flame stand-off distance, flame thickness and wake flame attached angle are demonstrated graphically to interpolate the corresponding physical mechanisms. The flame temperature distributions along the vertical centerline of a single cylinder burner for the envelope flame and wake flame are measured to understand the flame varying trend. Finally, the visualized results from this experiment are compared with the corresponding numerical simulations to confirm the experimental credibility. The comparison shows that both numerical and experimental results have the same qualitative trend. The transition velocities from envelop to wake flames in the regime of $\alpha \leq \mathbf{60\%}$ and from envelop to transition flames and transition to stable wake flames in the regime of $\alpha > 60\%$ obtained from experiments appear to be higher than the predicted ones. The envelope flame thickness and stand-off distance obtained from experiments are smaller than those from simulations. As to wake flame attached angles, they are higher in the experiments.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

a	Length of the cross-section area of test section
A	Cross-section area of test section
A_s	Cross-section area of exhaust duct
A_{Burner}	Surface area of sphere
b	Width of the cross-section area of test section
b_s	Width of exhaust duct
D	Diameter of the cylinder
D_w	Thermocouple wire diameter
D_i	Inner diameter of the sphere
D_o	Outer diameter of the sphere
$-f_w$	Nondimensional fuel ejection rate
h	Convection heat transfer coefficient at thermocouple wire surface
M_i	Molecular mass of species i
$\dot{m}_i$	Mass flow rate of species i
X_i	Mole fraction of species i
Y_i	Mass fraction of species i
$\overline{P}$	Pressure
Q_{fuel}	Flux of fuel
R	Radius of the cylinder
Re	Reynold number
T	Temperature
T_g	True gas temperature
T_t	Temperature measured by thermocouple probe
U_{in}	Airflow velocity

V_C Transition velocity

V_w Fuel ejection velocity

α Methane to nitrogen mass ratio

Greek Symbol

μ Viscosity

ε Emissivity of the thermocouple

σ Stefan-Boltzman constant ($\sigma = 5.67 \times 10^{-8} \, W/m^2 \, K^4$)

φ Absorptivity of wire

ν Kinematic viscosity

α Methane to nitrogen mass ratio

ρ_{CH_4} Methane density