THE EFFECT OF BUGAESTS PLASMA SPARK PLUG (BSP) ON FLAME KERNEL DEVELOPMENT

(BSP)

Experiment: Tawfik Badawy

Supervisor: Professor Hongming Xu

School of Mechanical Engineering

University of Birmingham

August 2014

UNIVERSITY OF BIRMINGHAM

Content

UNIVERSITY OF BIRMINGHAM

Executive summary

This report is commissioned to examine the effect of BUGAESTS PLASMA SPARK PLUG (BSP) on the flame kernel growth. The flame kernel growth and growth rate for two kind of spark plug (BUGAETS and NGK) were investigated using Iso-octane fuel at (1 bar, 373k) for different equivalence ratios. It is shown that the flame kernel growth with BUGAETS is faster than with NGK spark plug for all the equivalence ratios especially for lean mixtures. For equivalence ratio $\Phi = 1$ the flame kernel growth rate is higher compare to the other equivalence ratios.

UNIVERSITY OF BIRMINGHAM

BUGAESTS PLASMA SPARK PLUG (BSP)

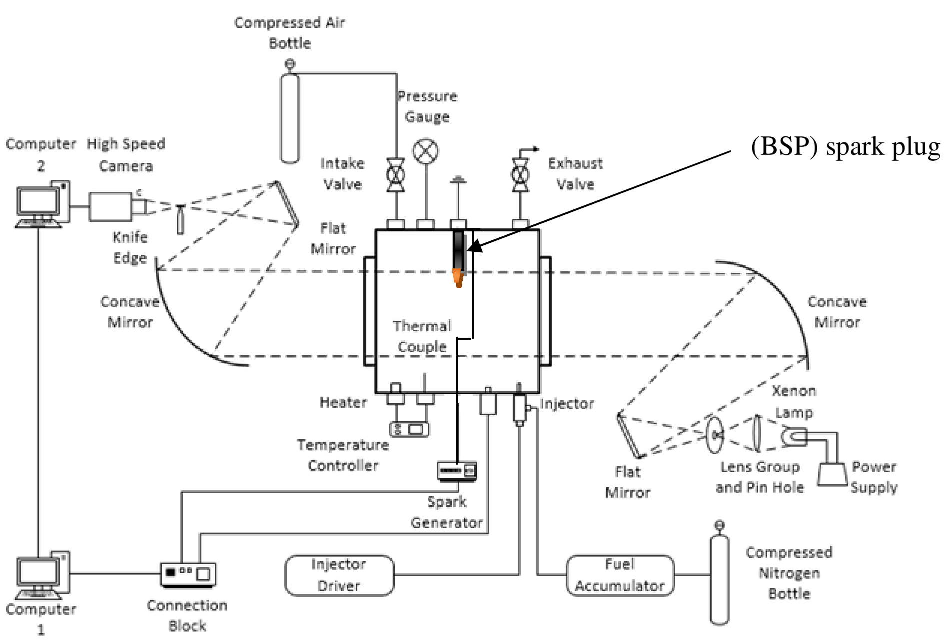
1-AIMS AND OBJECTIVES

Use high speed imaging to examine the flame kernel shape and the flame kernel growth rate of the (BSP) spark plug with a comparison to the NGK spark plug.

2-Methodology

The Schlieren system and technique of **[1]** is used for this test:

A 500W xenon lamp was coupled with a lens group and a pin hole was placed in front of them to generate a point light source for the test. The point light was then guided by the first concave mirror to produce parallel light which passed through the vessel and formed the test field. At the other side of the vessel, another concave mirror was used to integrate the parallel light. The light path was then cut by a knife edge at the focus for the schlieren effect. The images were recorded by a Phantom V710 high-speed camera at a sample rate of 10 kHz and a resolution of 800x800 pixels. The camera was synchronized with the spark timing.



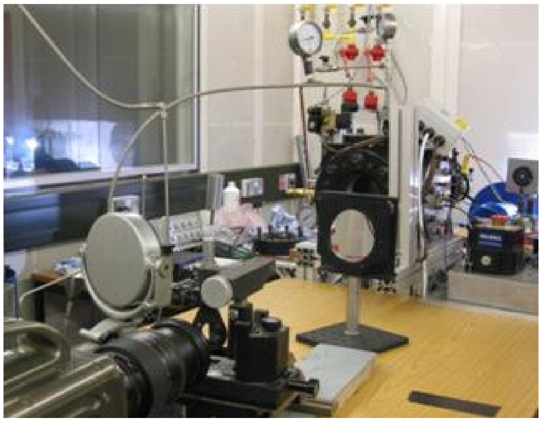


Figure 1 The Schlieren system schematic and photo

3-FUEL USED

The fuel used through the experiment is Iso-octane (2, 2, 4-Trimethylpentane 95% residue analysis Distol)

Fuel properties

C_8H_{18}

CAS: 540-84-1

MW: 114.23

Density at 20^{o}c:690 Kg/m^3

Boiling point: 98 to 99^{o}c

Melting point:-107 ^{o}c

Flash point:-12 ^{o}c

4-Experimental conditions

1-The vessel temperature: 100 ^{o}c

2-The vessel pressure: 1 bar

3-we will use equivalence ratio Φ :(0.8, 0.9, 1, 1.2)

5-TEST OPERATION PROCEDURES

1-Set up all the equipment for schlieren test, including the schlieren mirror system, the vessel, the air intake/exhaust system for the vessel and the septum

2-The vessel is heated to 100^{o}c to reach to the boiling point of the fuel

3- Inject the amount of fuel (Iso-octane) required according to the equivalence ratio to the vessel

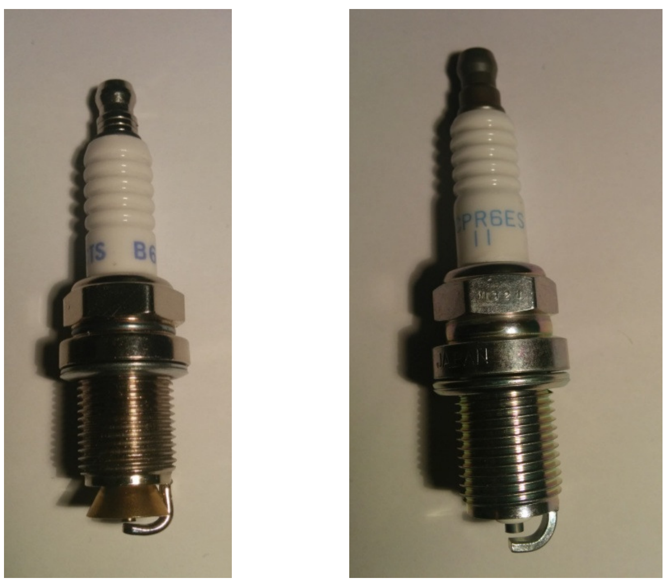
4- After an appropriate amount of time (5-10min), ignite the Iso-octane and air mixture in the vessel and record the images using high speed camera.

5-Turn on the air intake and air exhaust to purge the burnt gas out from the vessel

6-After this set of test, prepare the system for the next test.

SPARK PLUG

Through the experiments two spark plugs were used to investigate the laminar flame behavior of Iso-octane fuel as shown in figure (2);

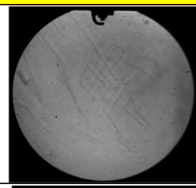
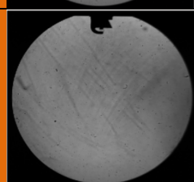
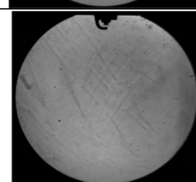
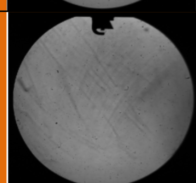
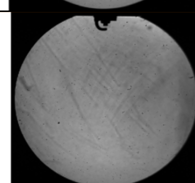
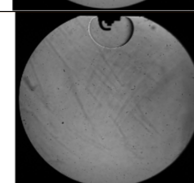
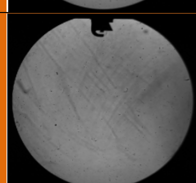
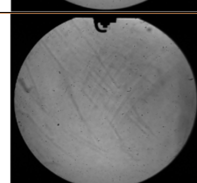
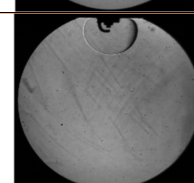
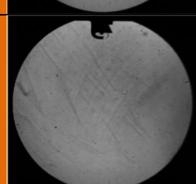
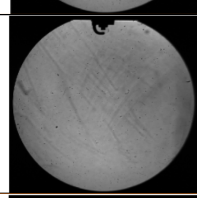
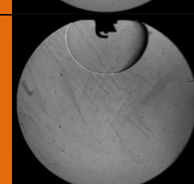
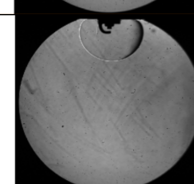
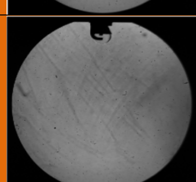
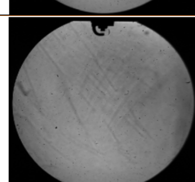
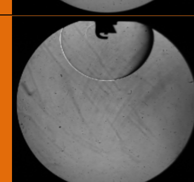
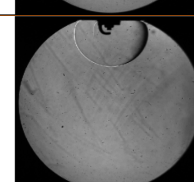
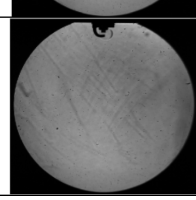
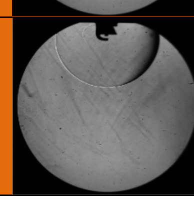
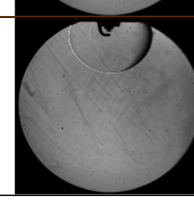


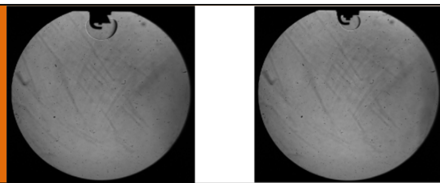
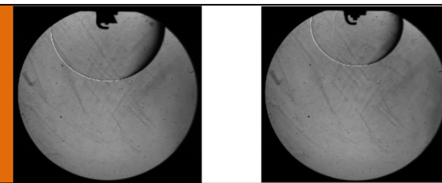
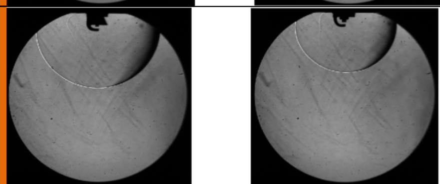
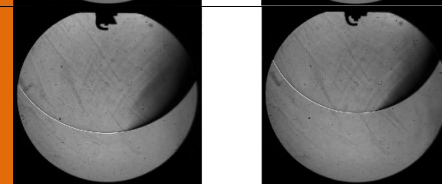
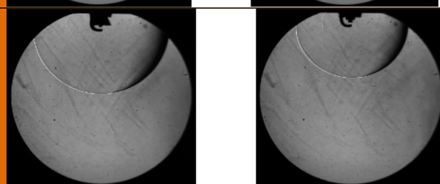
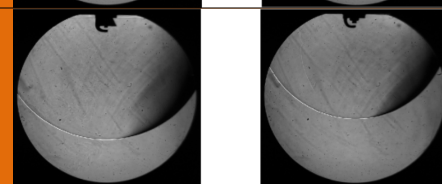
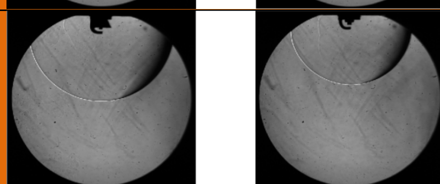
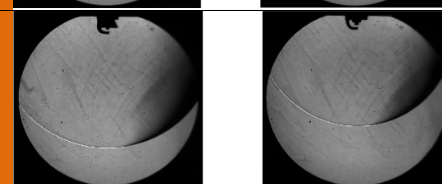
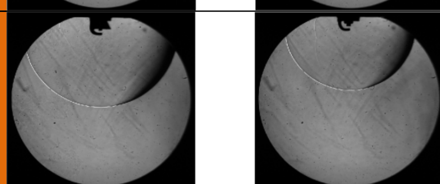
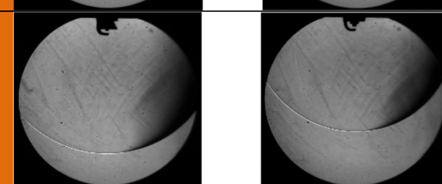
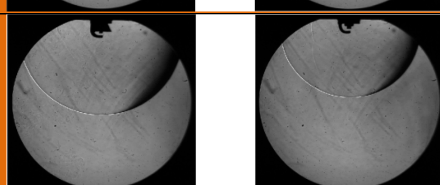
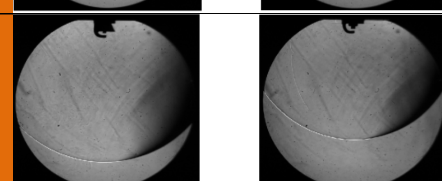
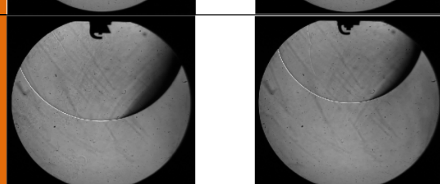
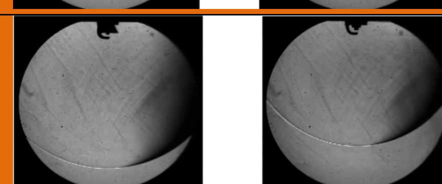
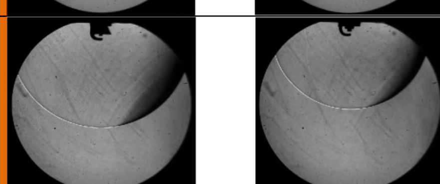
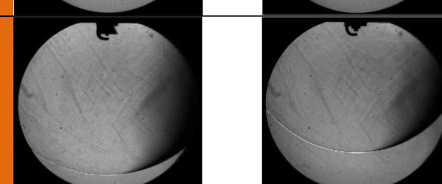
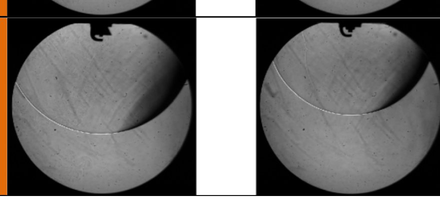
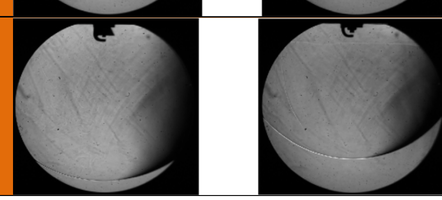
BUGAETS **NGK**

Figure 2 BUGAETS and NGK spark plug

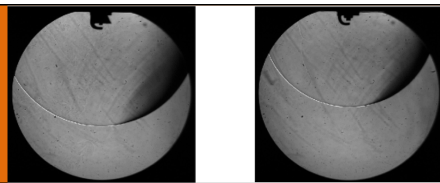
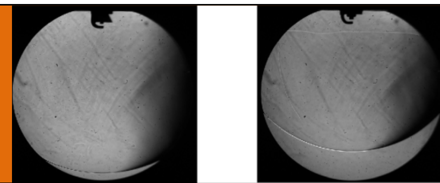
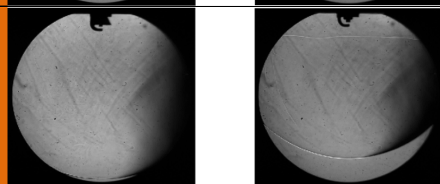
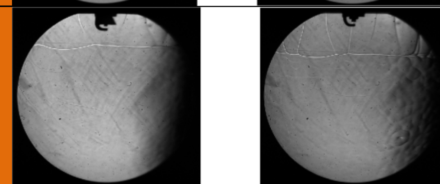
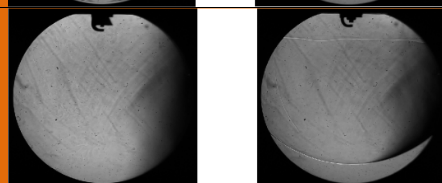
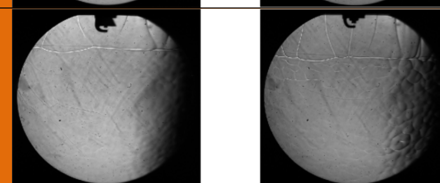
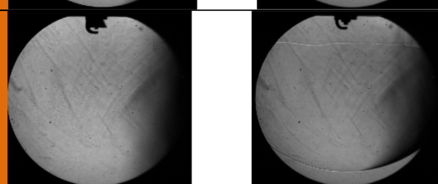
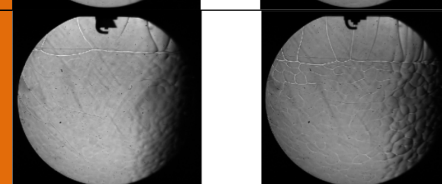
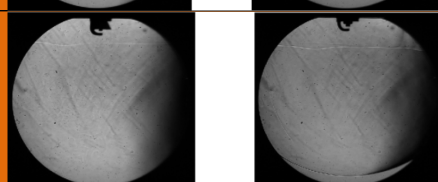
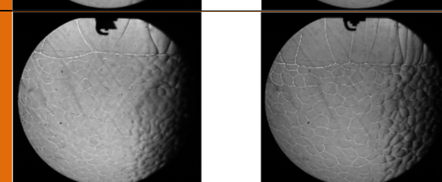
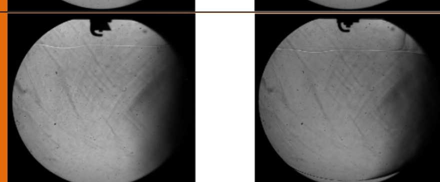
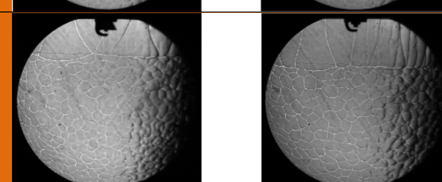
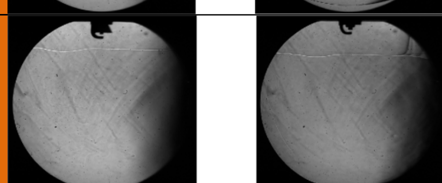
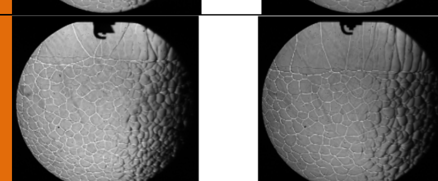
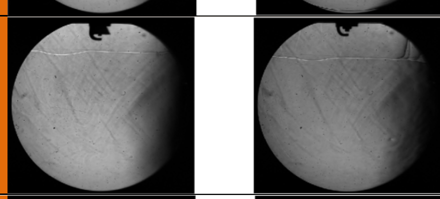
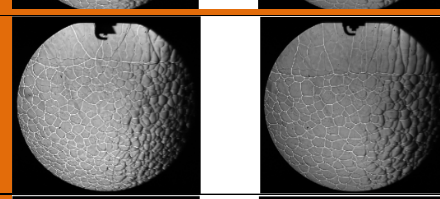
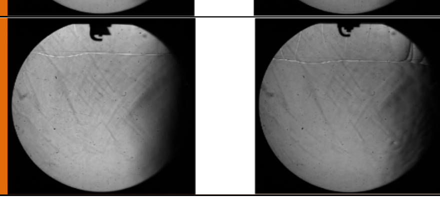
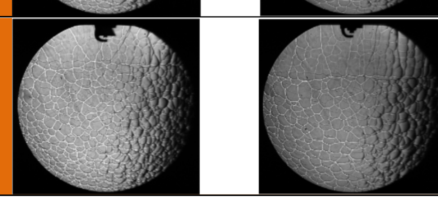
6-TEST RESULT

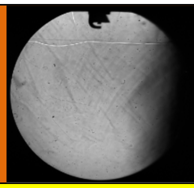
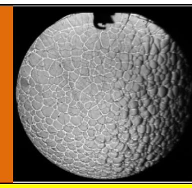
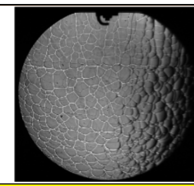
1- At equivalence ratio Φ=0.8 and spark duration 250 ms

Frame/Time	BUGAETS	NGK	Frame/Time	BUGAETS	NGK
17/ 1 ms before flame appear			97/8 ms		
27/ 1 ms			107/9 ms		
37/ 2 ms			117/10 ms		
47/3 ms			127/11 ms		
57/4 ms			137/12 ms		
67/5 ms			147/13 ms		
77/6 ms			157/14 ms		

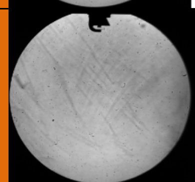
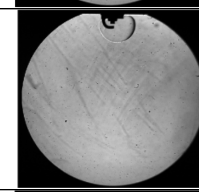
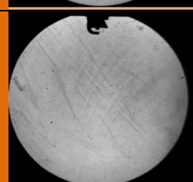
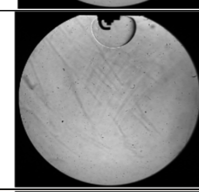
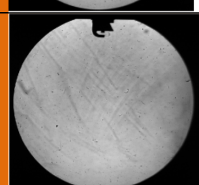
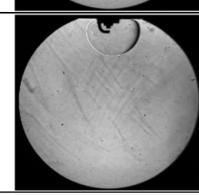
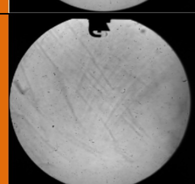
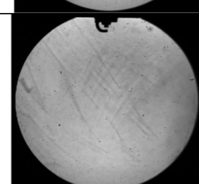
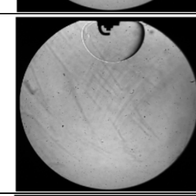
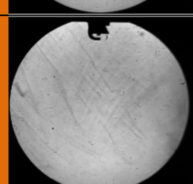
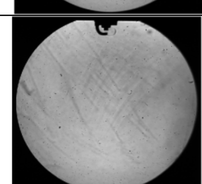
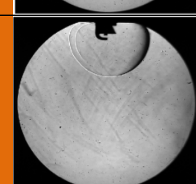
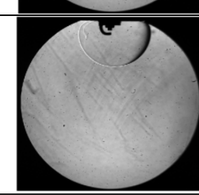
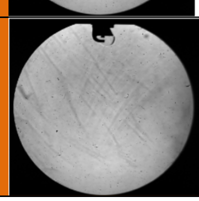
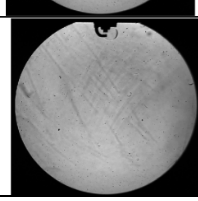
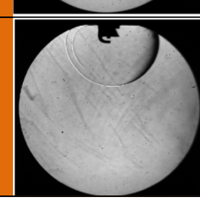
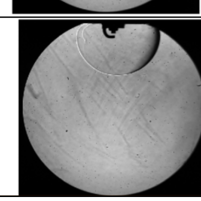
87/7 ms		167/15 ms	
177/16 ms		267/25 ms	
187/17 ms		277/26 ms	
197/18 ms		287/27 ms	
207/19 ms		297/28 ms	
217/20 ms		307/29 ms	
227/21 ms		317/30 ms	
237/22 ms		327/31 ms	
247/23 ms		337/32 ms	

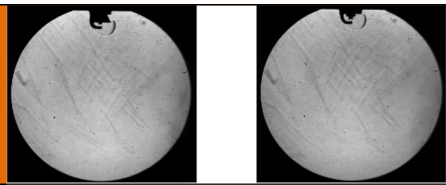
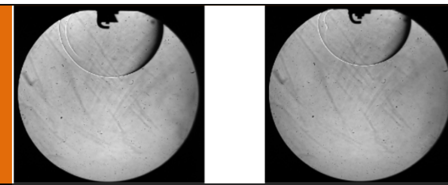
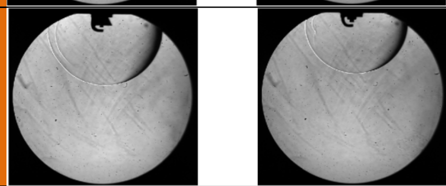
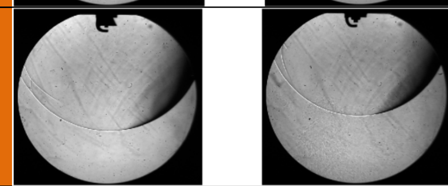
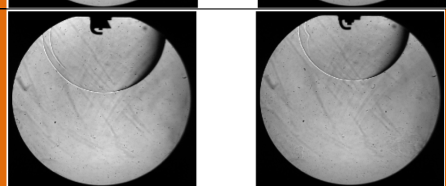
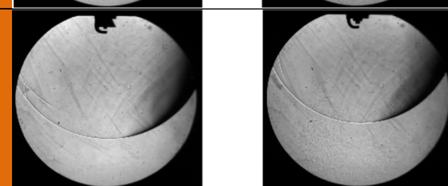
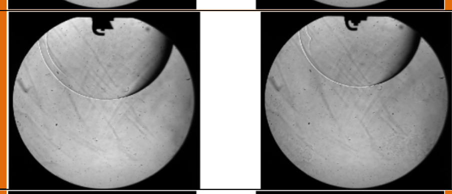
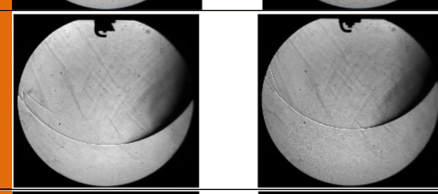
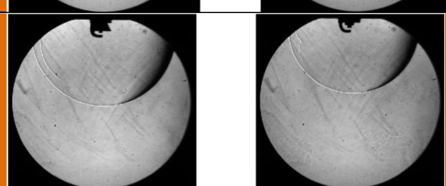
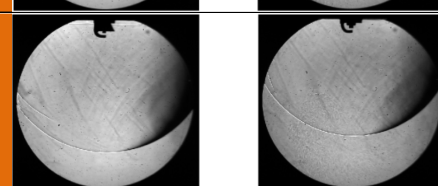
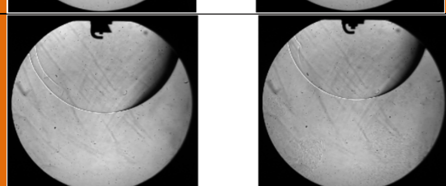
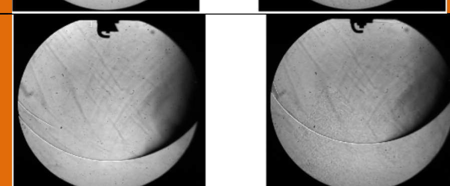
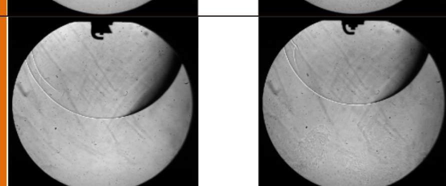
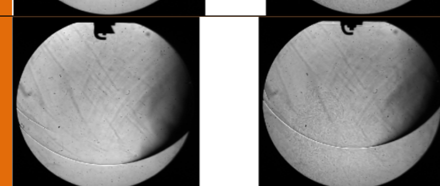
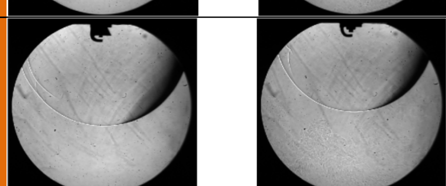
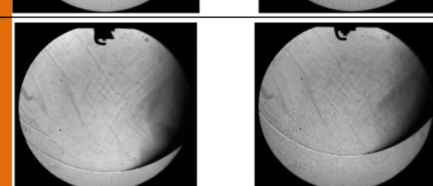
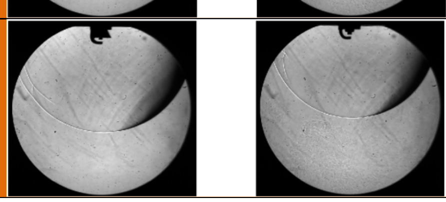
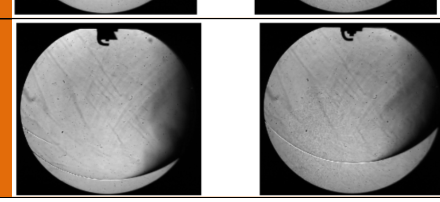
UNIVERSITY OF BIRMINGHAM

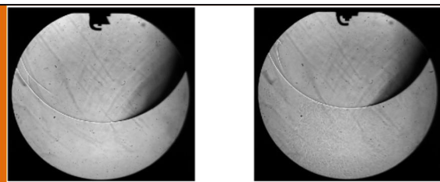
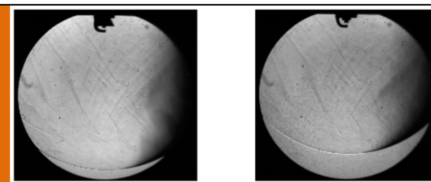
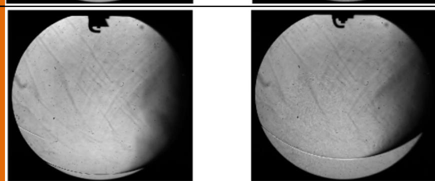
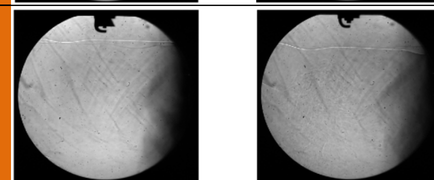
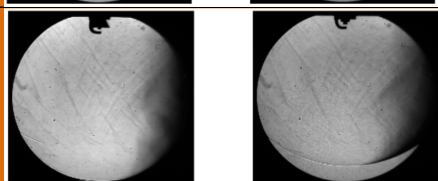
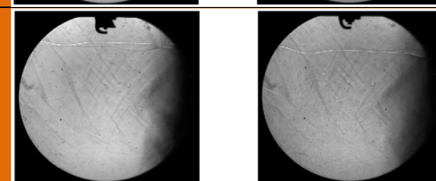
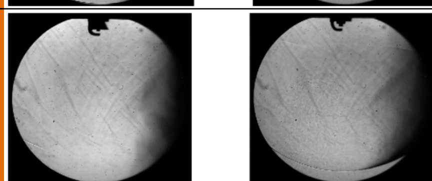
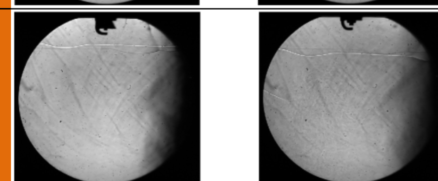
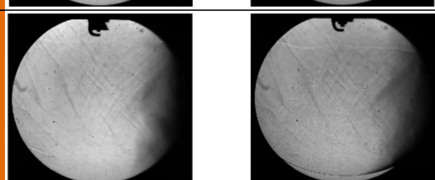
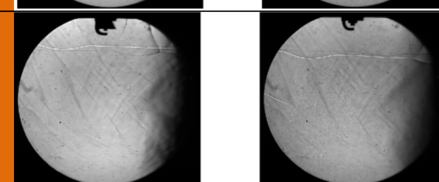
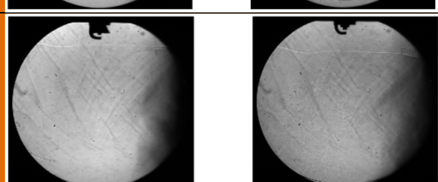
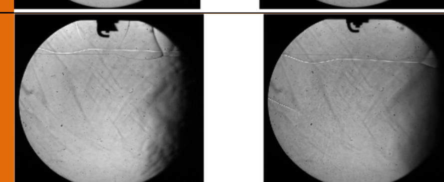
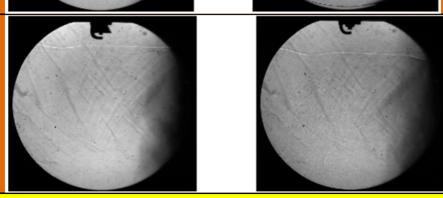
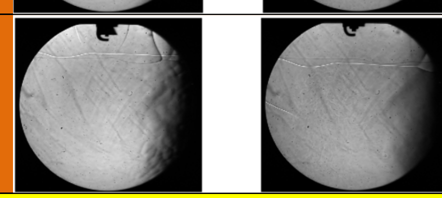
257/24 ms		347/33 ms	
357/34 ms		447/43 ms	
367/35 ms		457/44 ms	
377/36 ms		467/45 ms	
387/37 ms		477/46 ms	
397/38 ms		487/47 ms	
407/39 ms		497/48 ms	
417/40 ms		507/49 ms	
427/41 ms		517/50 ms	

437/42 ms			527/51 ms		

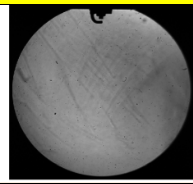
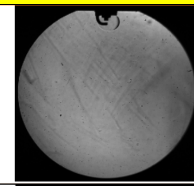
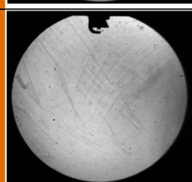
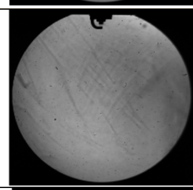
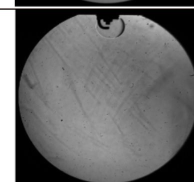
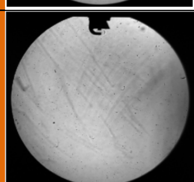
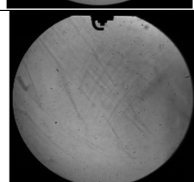
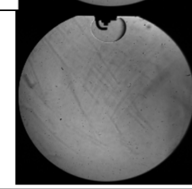
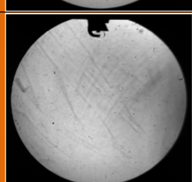
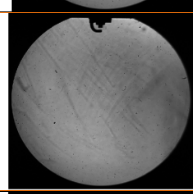
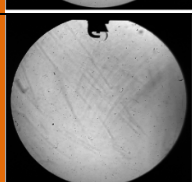
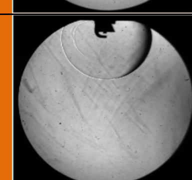
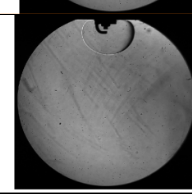
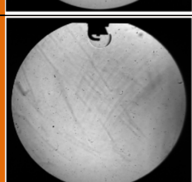
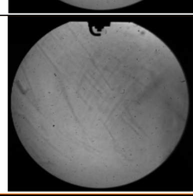
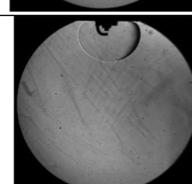
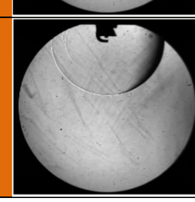
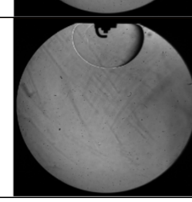
2- At equivalence ratio Φ=0.9 and spark duration 250 ms

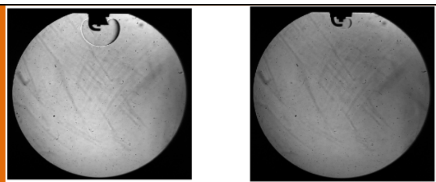
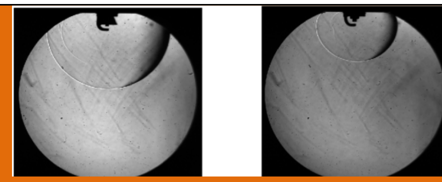
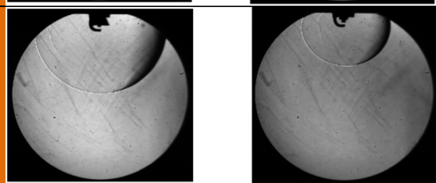
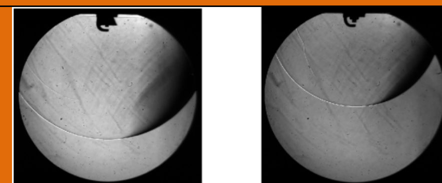
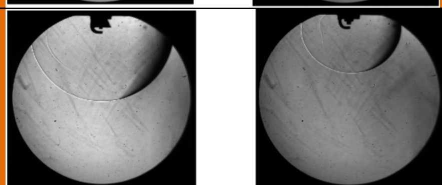
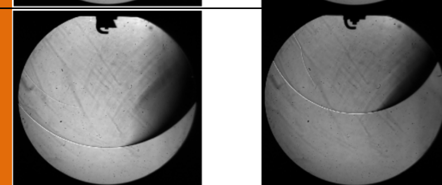
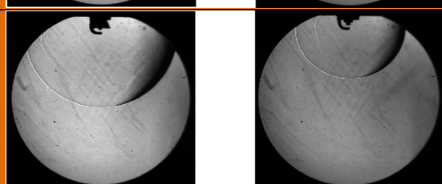
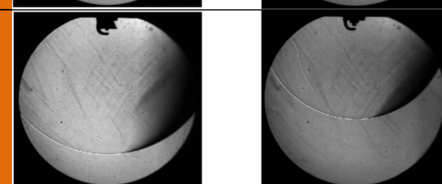
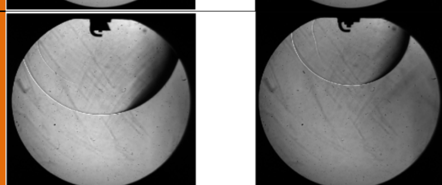
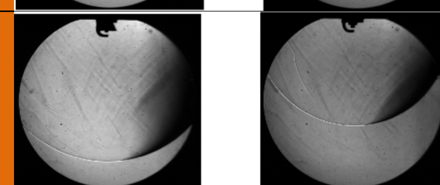
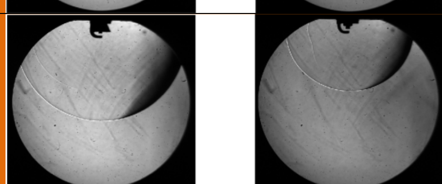
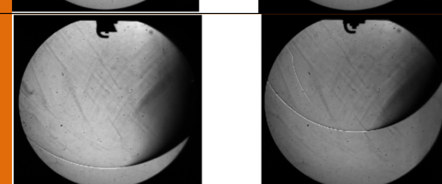
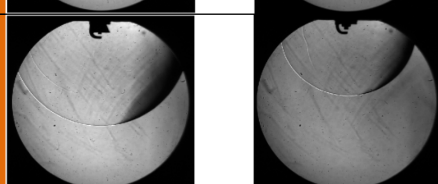
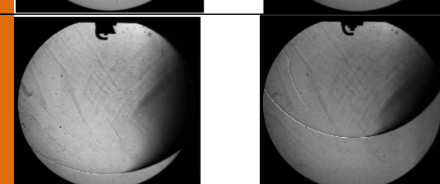
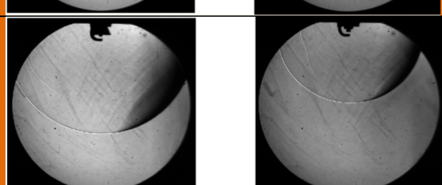
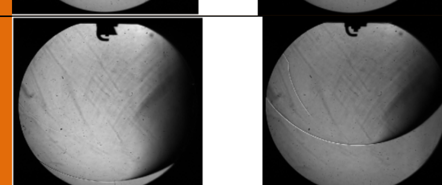
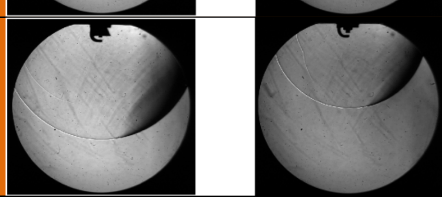
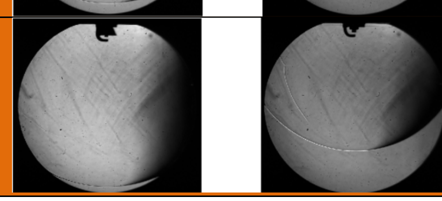
Frame/Time	BUGAETS	NGK	Frame/Time	BUGAETS	NGK
3/ 1 ms before flame appear			83/8 ms		
13/1 ms			93/9 ms		
23/2 ms			103/10 ms		
33/3 ms			113/11 ms		
43//4 ms			123/12 ms		
53/5 ms			133/13 ms		
63/6 ms			143/14 ms		

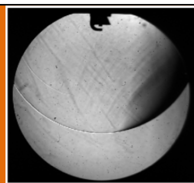
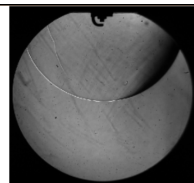
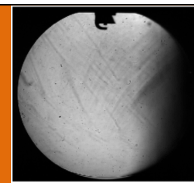
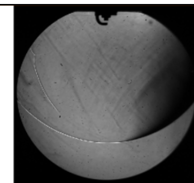
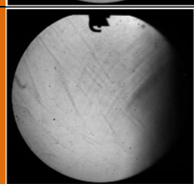
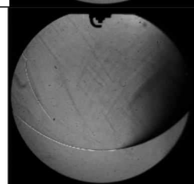
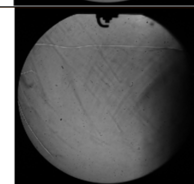
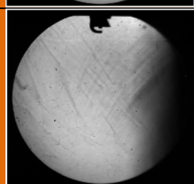
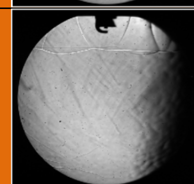
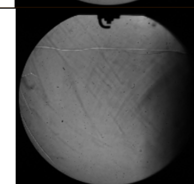
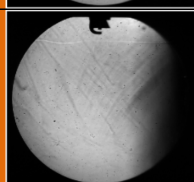
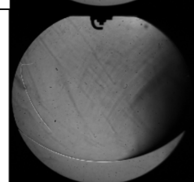
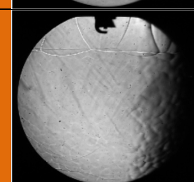
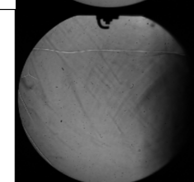
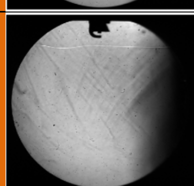
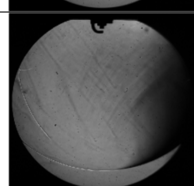
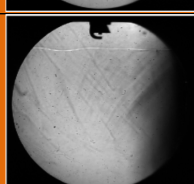
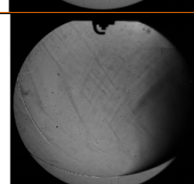
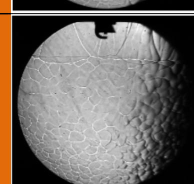
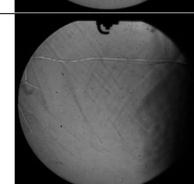
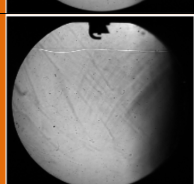
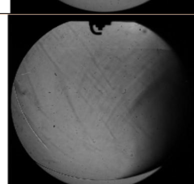
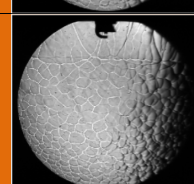
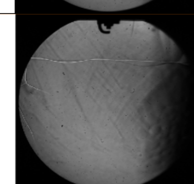
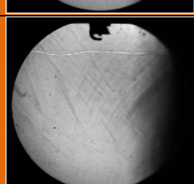
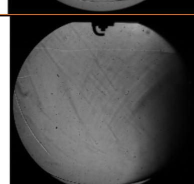
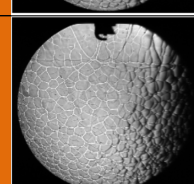
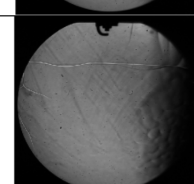
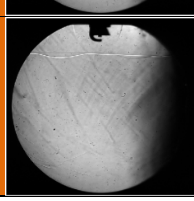
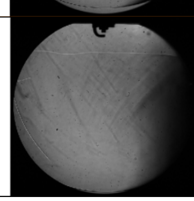
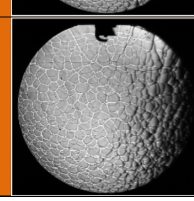
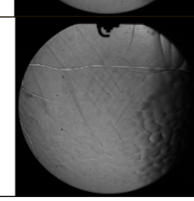
73/7 ms		153/15 ms	
163/16 ms		253/24 ms	
173/17 ms		263/25 ms	
183/18 ms		273/26 ms	
193/19 ms		283/27 ms	
203/3 ms		293/28 ms	
213/20 ms		303/29 ms	
223/21 ms		313/30 ms	
233/22 ms		323/31 ms	

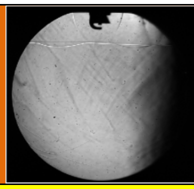
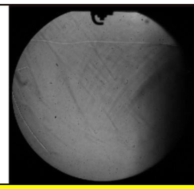
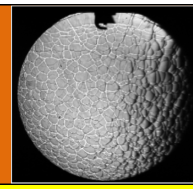
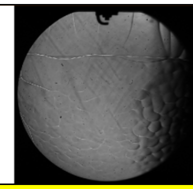
243/23 ms		333/32 ms	
343/33 ms		403/39 ms	
353/34 ms		413/40 ms	
363/35 ms		423/41 ms	
373/36 ms		433/42 ms	
383/37 ms		443/43 ms	
393/38 ms		447/43.4 ms	

3- At equivalence ratio Φ=1 and spark duration 250 ms

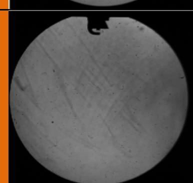
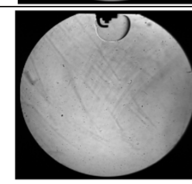
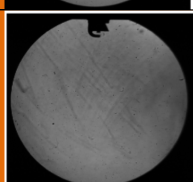
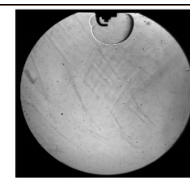
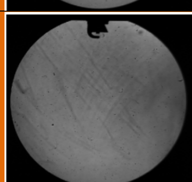
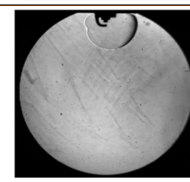
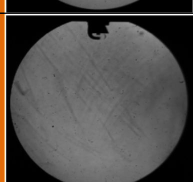
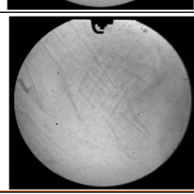
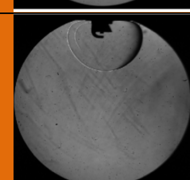
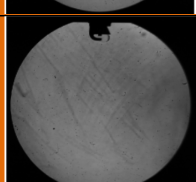
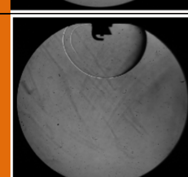
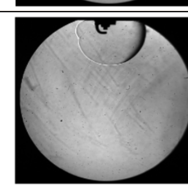
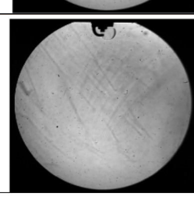
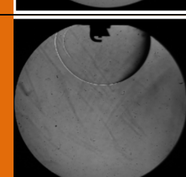
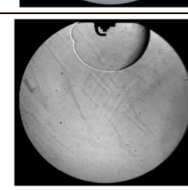
Frame/Time	BUGAETS	NGK	Frame/Time	BUGAETS	NGK
8/ 1 ms before flame appear			88/8 ms		
18/1 ms			98/9 ms		
28/2 ms			108/10 ms		
38/3 ms			118/11 ms		
48/4 ms			128/12 ms		
58/5 ms			138/13 ms		
68/6 ms			148/14 ms		

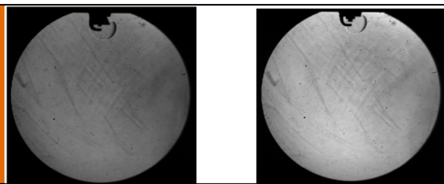
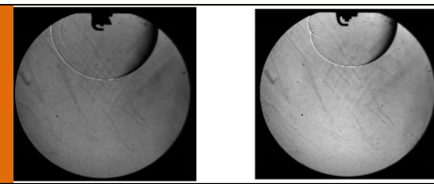
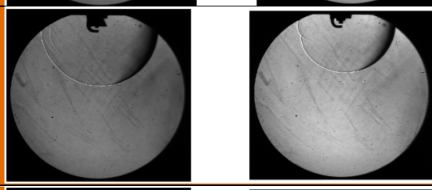
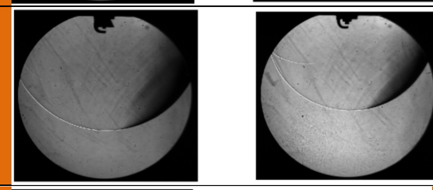
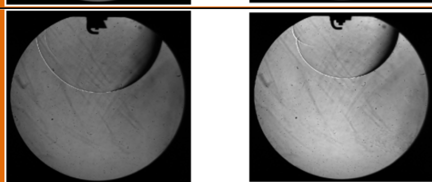
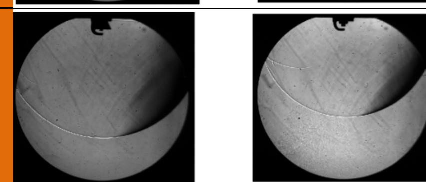
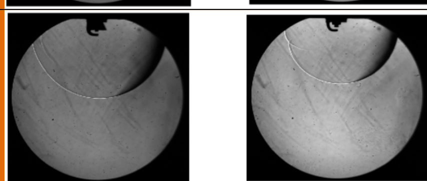
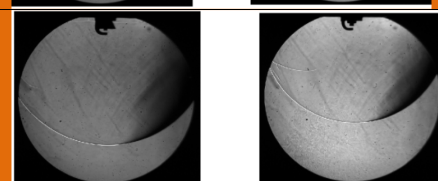
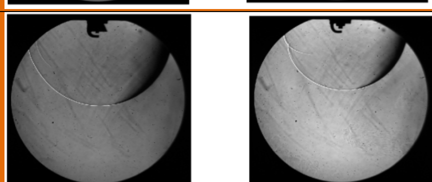
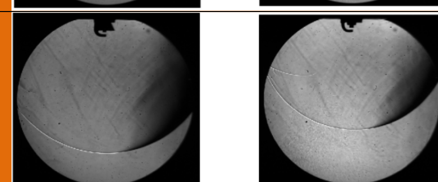
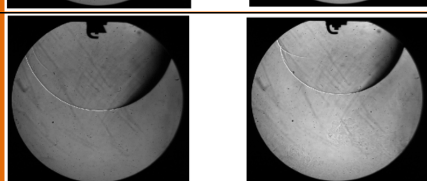
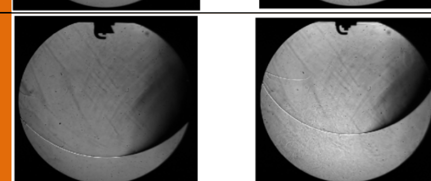
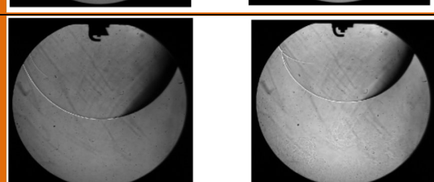
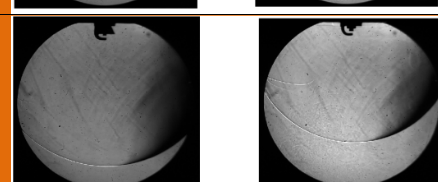
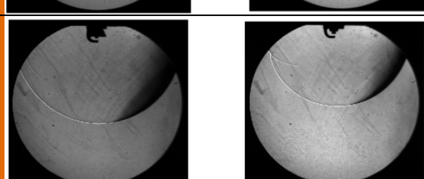
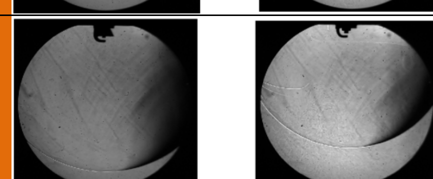
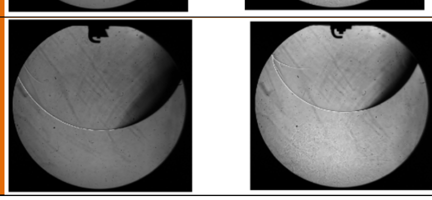
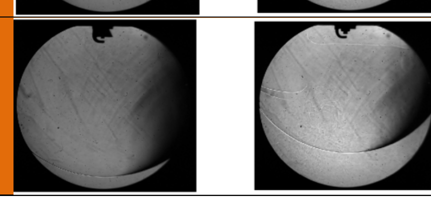
78/7 ms		158/15 ms	
168/16 ms		258/25 ms	
178/17 ms		268/26ms	
188/18 ms		278/27 ms	
198 /19 ms		288/28 ms	
208/20 ms		298/29 ms	
218/21 ms		308/30 ms	
228/22 ms		318/31 ms	
238/23 ms		328/32 ms	

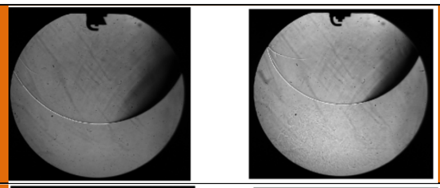
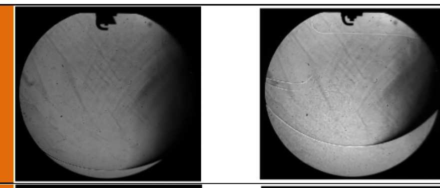
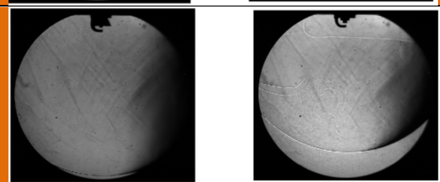
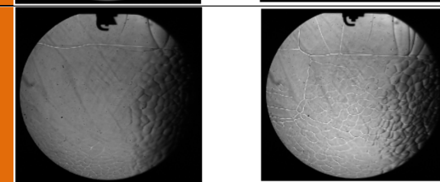
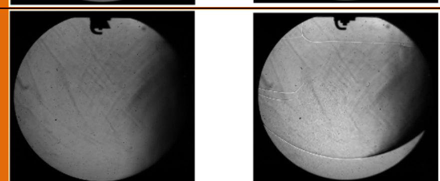
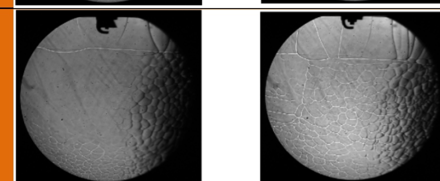
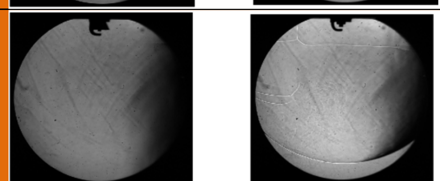
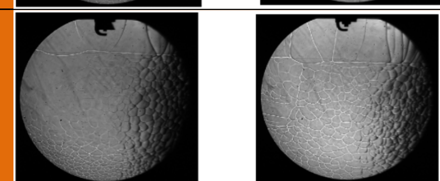
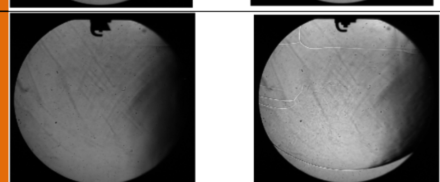
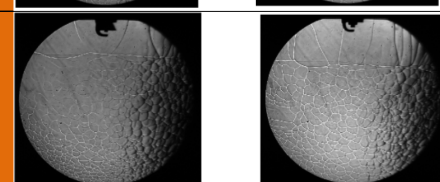
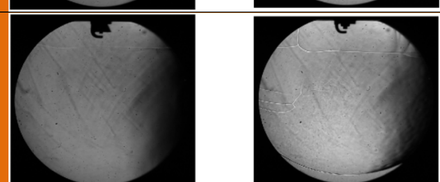
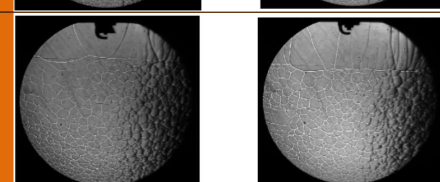
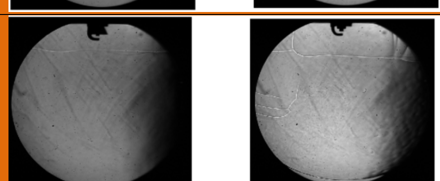
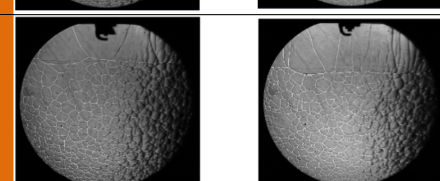
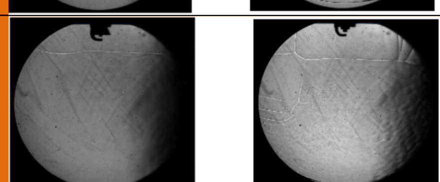
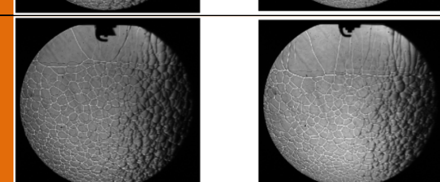
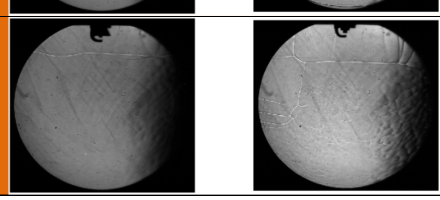
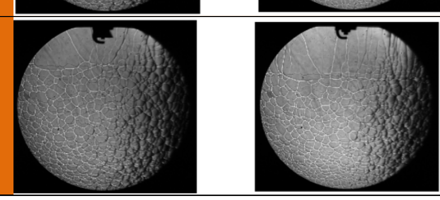
248/24 ms			338/33 ms		
348/34 ms			438/43 ms		
358/35 ms			448/44 ms		
368/36 ms			458/45 ms		
378/37 ms			468/46 ms		
388/38 ms			478/47 ms		
398/39 ms			488/48 ms		
408/40 ms			498/49 ms		
418/41 ms			508/50 ms		

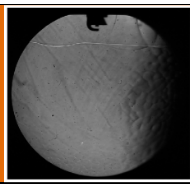
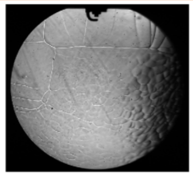
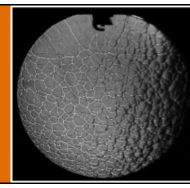
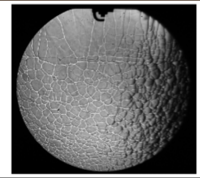
428/42 ms			518/51 ms		

4- At equivalence ratio Φ=1.2 and spark duration 250 ms

Frame/Time	BUGAETS	NGK	Frame/Time	BUGAETS	NGK
3/ 1 ms before flame appear			83/9 ms		
13/2 ms			93/10 ms		
23/3 ms			103/11 ms		
33/4 ms			113/12 ms		
43/5 ms			123/13 ms		
53/6 ms			133/14 ms		
63/7 ms			143/15 ms		

73/8 ms		153/16 ms	
163/17 ms		253/26 ms	
173/18 ms		263/27 ms	
183/19 ms		273/28 ms	
193/20 ms		283/29 ms	
203/21 ms		293/30 ms	
213/22 ms		303/31 ms	
223/23 ms		313/32 ms	
233/24 ms		323/33 ms	

243/25 ms		333/34 ms	
343/35 ms		433/44 ms	
353/36 ms		443/45 ms	
363/37 ms		453/46 ms	
373/38 ms		463/47 ms	
383/39 ms		473/48 ms	
393/40 ms		483/49 ms	
403/41 ms		493/50 ms	
413/42 ms		503/51 ms	

423/43 ms			513/52 ms		

Flame kernel growth

Figure (3) shows a sample for the flame kernel growth at Φ=0.9 to study the flame kernel propagation up to ~10 mm

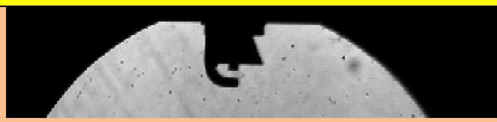
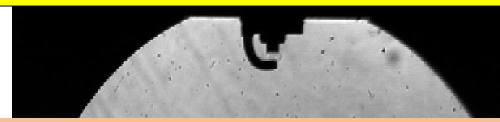
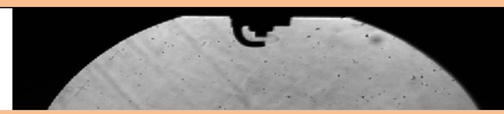
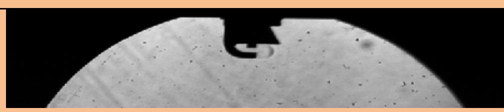
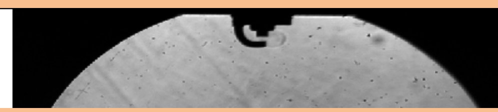
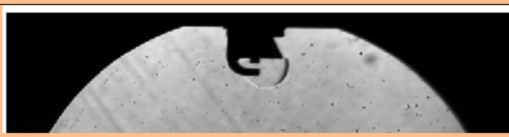
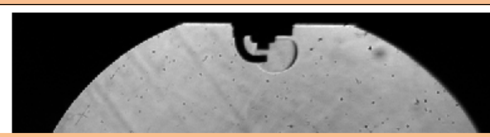
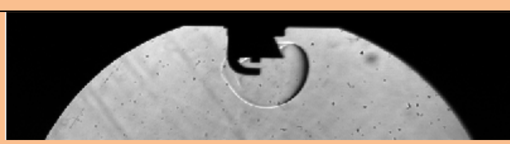
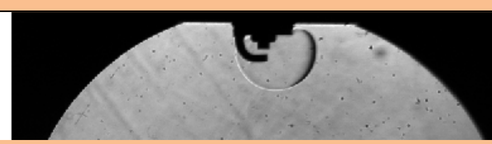
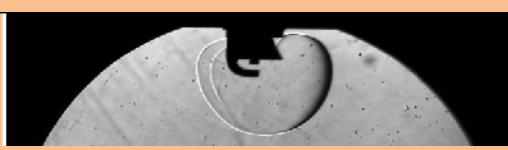
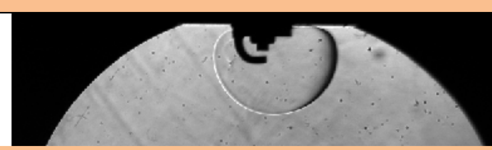
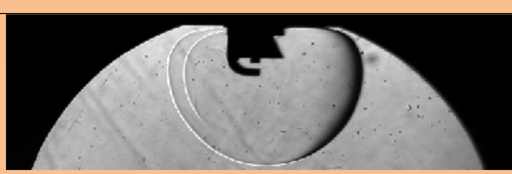
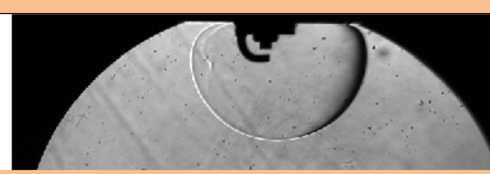
Time (ms)	BUGAETS	NGK
0.1 ms		
2.1ms		
4.1ms		
6.1ms		
8.1ms		
10.1ms		
12.1ms		

Figure 3 Flame kernel growth until radius ~ 10 mm for Φ = 0.9

The characteristics of the igniter like (spark energy, spark duration, gap between the electrodes and spark shape) can affect the measured value of burning velocity.

The ignition energy, well above the minimum ignition energy, can lead to very high apparent flame propagation, due to the expansion of the spark plasma and the conductive energy transfer from it. As we know, the role of spark is to initialize a flame, which can overcome the tendency for the flame to quench because of the high curvature stretch rate, during the early stages of flame propagation.

In the present work, the measurements of initial flame development are made for two spark plugs with different shapes to ascertain their subsequent effects on the flame development. Figure (4) shows the flame kernel (growth and growth rate) with respect to time for BUGAETS and NGK spark plug at different equivalence ratio

The flame kernel (growth and growth rate) for Iso-octane & air mixture at different equivalence ratios for the two spark plugs was quantitatively analyzed within flame kernel radius up to 10 mm.

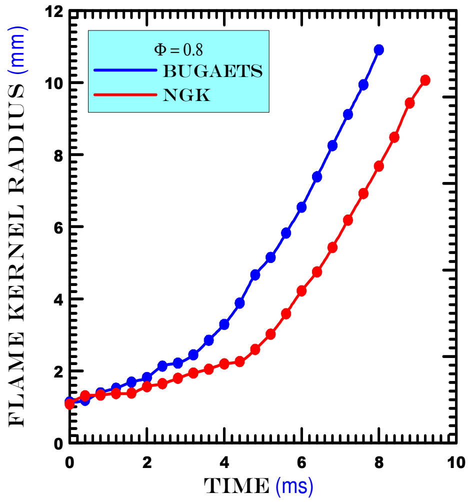
It is obvious that the flame kernel growth for BUGAETS is faster than NGK spark plug for all the equivalence ratio specially for lean mixture where the kernel growth reach to 10 mm after time 7.7 ms for BUGAETS while take time 9.2 ms for NGK.

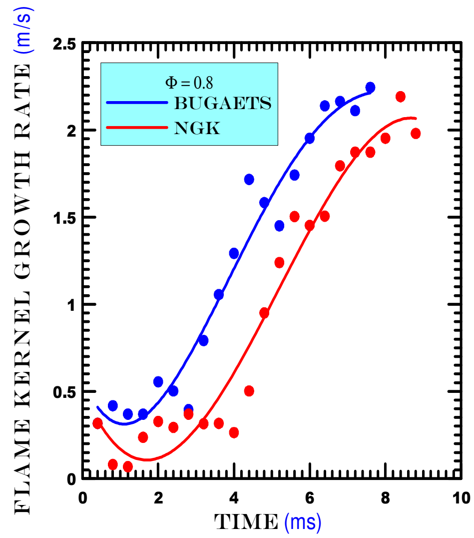
For equivalence ratio Φ = 1 the flame kernel growth rate is higher compare to the other equivalence ratio **[2]**.

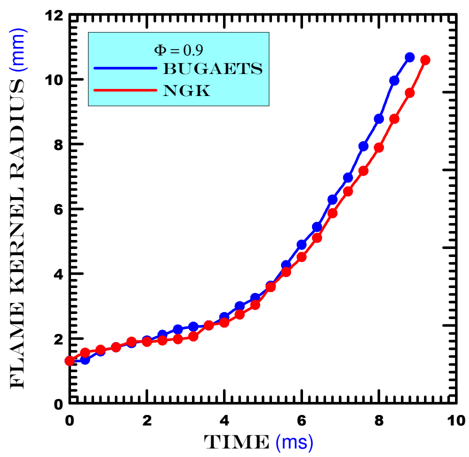
The flame kernel growth rate illustrate a decrease initially, and then increase gradually with the radius **[3]**.

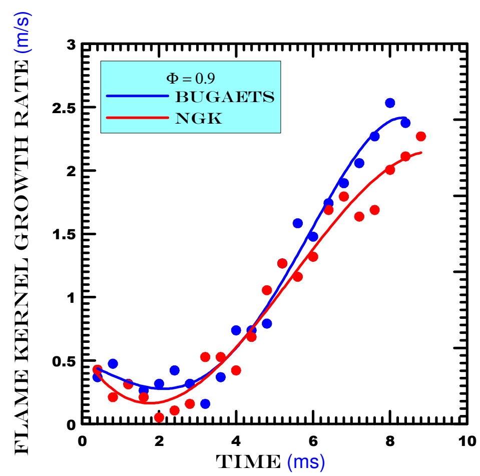
The flame kernel growth rate for BUGAETS is higher than NGK that mean that BUGAETS has higher spark energy.

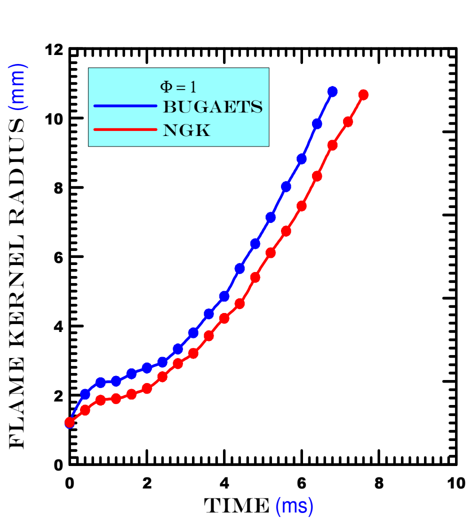
UNIVERSITY OF BIRMINGHAM

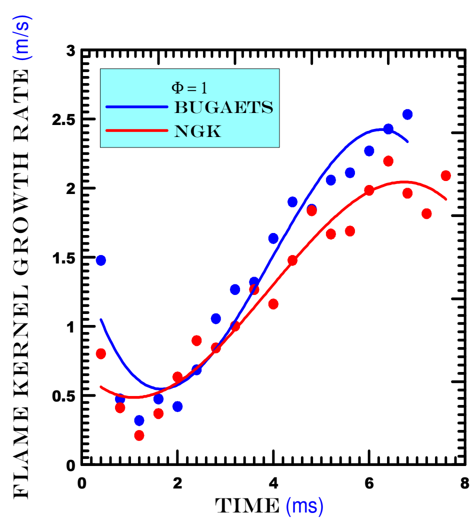












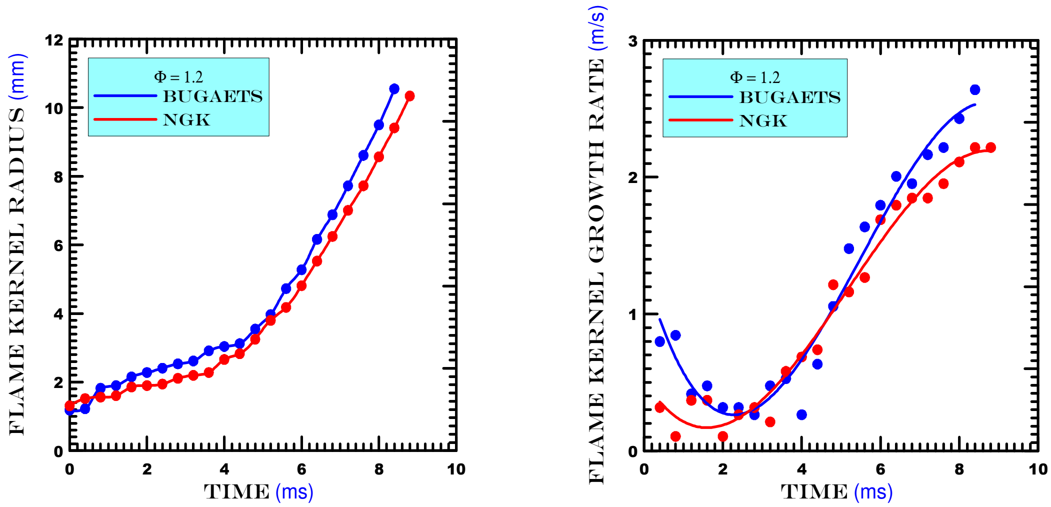


Figure (4) The flame kernel (growth and growth rate) with respect to time for BUGAETS and NGK spark plug at different equivalence ratios

7-Conclusions

1-The flame kernel growth with BUGAETS is faster than NGK spark plug for all the equivalence ratio specially for lean mixtures where the kernel growth reached to 10 mm after 7.7 ms time with BUGAETS while it took 9.2 ms with NGK.

2-For equivalence ratio Φ = 1 the flame kernel growth rate is higher compare to the other equivalence ratio.

3-The flame kernel growth rate illustrates a decrease initially, and then increase gradually with the radius.

References:

[1] G Tian, R Daniel, H Li, H.M.Xu*, S. Shuai, P. Richards, “Laminar Burning Velocities of 2,5-Dimethylfuran Compared with Ethanol and Gasoline,” Energy Fuels, 2010, 24 (7), pp 3898–3905.

[2] Alger, T., Mangold, B., Mehta, D., and Roberts, C., "The Effect of Sparkplug Design on Initial Flame Kernel Development and Sparkplug Performance," SAE Technical Paper 2006-01-0224, 2006, doi:10.4271/2006-01-0224.

[3] S.Y. Liao, D.M. Jiang, J. Gao, Z.H. Huang. Measurements of Markstein numbers and laminar burning velocities for liquefied petroleum gas–air mixtures. Journal of Fuel 83 (2004) 1281–1288