

Experimental Determination of Leidenfrost and Minimum Temperature for Fuel Droplets Vapourizing on Hot Surfaces

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ABSTRACT: In all IC engines vapourization rates of fuel on various hot surfaces has an impact on unwanted exhaust emissions, particularly the oxides of nitrogen and also the combustion efficiency of engine. More the vapourization rate less is NO_x emission and higher is combustion efficiency. In this paper an attempt has been made to experimentally determine the Leidenfrost temperature and Minimum temperature for different fuels like gasoline, diesel and methanol on flat heated surfaces. Also comparison of Leidenfrost and Minimum temperature values has been made between Stainless steel and Zirconia.

KEYWORDS: Leidenfrost, temperature, minimum, zirconia, surface.

I. INTRODUCTION

It is well known fact that in all SI and CI engines atomization of fuel is prerequisite for combustion and the same is done before ignition of the fuel. In case of SI engines atomization of fuel is achieved before injecting it into the inlet manifold, while in CI engine the same is accomplished by injecting fuel into combustion chamber of the engine. In the former case some of the fuel droplets are bound to be deposited on the walls of the inlet manifold and the inlet port, on the back of inlet valve and on the various hot surfaces in the cylinder. In the later, fuel droplets invariably gets deposited on the walls of combustion chamber, faces of inlet and outlet valves and predominantly on piston crown. A fraction of mixture of fuel and air is result of fuel droplets vapourizing on various hot surfaces. Thus, the vapourization rate can be improved by altering the hot surface temperature, surface material, velocity of impact and surface conditions and the rate depends on Leidenfrost and Minimum temperature. The Leidenfrost Temperature is that temperature of hot surface at which evaporation lifetime of a single fuel droplet is maximum whereas the Minimum temperature is that temperature of hot surface at which evaporation lifetime of single fuel droplet is minimum. Factors that influence these both temperatures are surface material, pressure and surface conditions.

II. LITERATURE SURVEY

Recently, ceramic is identified as challenging material for IC engine construction. There are many ceramics like SiC, Si₃N₄&Al₂O₃ which can be used for IC engine parts. But on grounds of thermal conductivity and thermal expansion Zirconia best satisfies the requirements of IC engine construction material. The thermal conductivities of other ceramics have higher values at lower temperatures and at higher temperatures they reduce to lower values. But for Zirconia thermal conductivity is nearly constant at all temperatures and it's value is lowest in comparison to other ceramics. Partially stabilized Zirconia with MgO stabilizer is prone to change phase at elevated temperatures. Transformation changes can be avoided by using Yttrium Oxide (Al₂O₃) stabilizer. Thus, Yttrium stabilized zirconia is used here for experiment.

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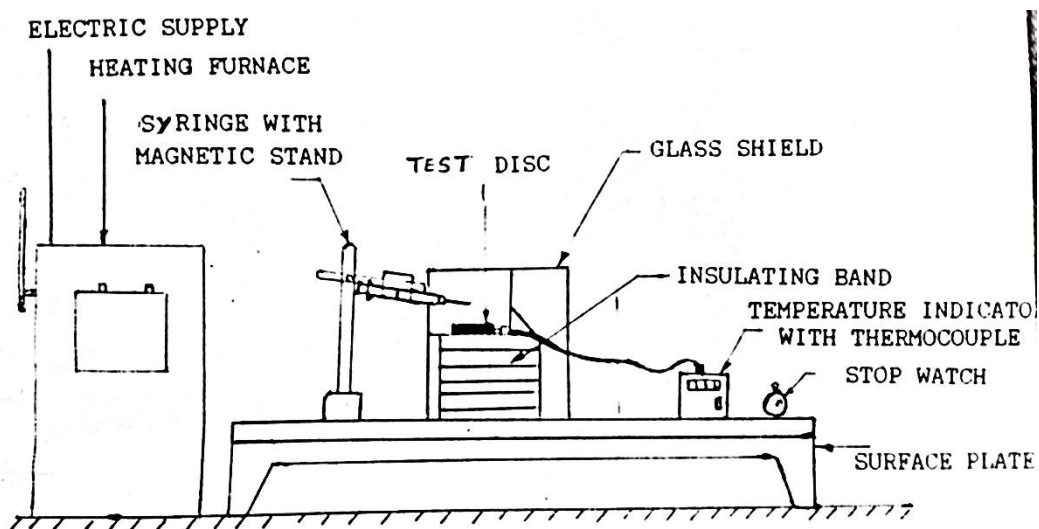
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Vol. 6, Issue 2, February 2017

III. EXPERIMENTAL SETUP

The principle of this experiment is based on the classic Leidenfrost method in which the droplet is levitated above a hot surface by rapid evaporation of liquid from bottom of the droplet. In the present work the test droplets consists of IC engine fuels like gasoline, diesel and methanol and the test material used is stainless steel and Zirconia(Al_2O_3). The test surfaces are heated to temperature of 500-600°C to which IC engine components like pistons, liners, manifold, valves are expected to be heated at maximum load conditions.

The schematic diagram of experimental setup is shown below.



The primary components used are

1. Heater furnace
2. Temperature indicating device
3. Glass shield and insulating materials
4. Droplet injector with magnetic stand.
5. The mounting platform
6. Stopwatch

The stainless steel test surface are in the form of circular discs of diameter 65mm & 15mm thick and Zirconia is small circular disk of diameter 10mm & thickness 8mm. They consist of small hole for placing thermocouple rod.

IV. PROCEDURE

The test disk is kept in the heater furnace and heated for some time so that heating of disk up to 650°C is achieved. It is then removed by tongs and placed on insulating band and immediately covered by glass shield. The thermocouple sensor is inserted in the hole of test disc & temperature indicated by indicator is watched. The temperature goes down slowly because of losses. The first droplet is deposited at 550°C by pressing the injector plunger until the droplet is detached by gravity from tip of the needle. The stopwatch is started exactly at the moment the droplet strikes the hot disc. The evaporation goes on and the moment when droplet gets completely evaporated, the stopwatch is stopped. Total evaporation time of the droplet is noted down.

Then the successive droplets are deposited at temperatures 525°C, 500°C, 475°C up to 100°C. The total evaporation times are noted down. The same procedure is repeated again by heating the disc in furnace and depositing droplets. The

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Vol. 6, Issue 2, February 2017

average of two evaporation times at each temperature is computed. Graph of Surface temperature vs Evaporation lifetime of single droplet are plotted.

V. READINGS AND RESULTS

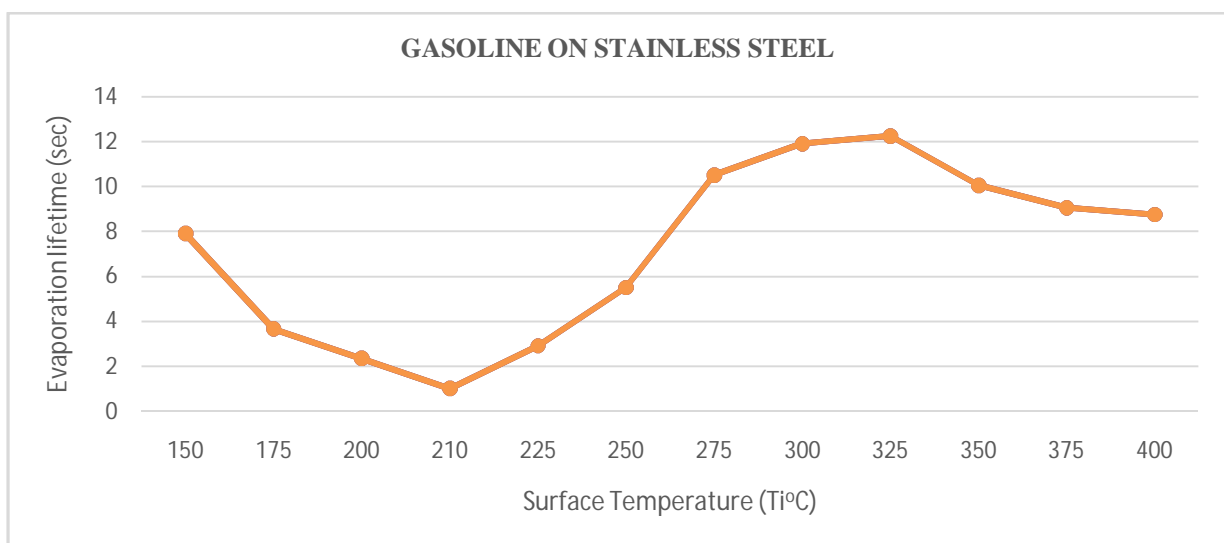
Graphs are plotted with evaporation life time in seconds on y-axis and initial surface temperature in °C on x-axis for different fuels on different surfaces. The nomenclatures used are as follows :

T_i – Initial surface temperature in °C, T_L – Leidenfrost temperature in °C, T_{min} – Minimum temperature in °C

E_{max} – Maximum evaporation lifetime in sec, E_{min} – Minimum evaporation lifetime in sec

- 1.) Gasoline with stainless steel
- 2.)

Reading No.	Ti	Evaporation Time(sec)		Average Evaporation time(sec)
		I	II	
1	400	10.2	7.3	8.75
2	375	10.0	8.1	9.05
3	350	10.3	9.8	10.05
4	325-T _L	13.3	11.2	12.25-E _{max}
5	300	11.3	12.5	11.9
6	275	11.1	9.9	10.5
7	250	6.8	4.2	5.5
8	225	3.7	2.1	2.9
9	210-T _{min}	0.9	1.1	1.0-E _{min}
10	200	2.7	2.0	2.35
11	175	4.1	3.2	3.65
12	150	8.8	7.0	7.9



In the wetting region, evaporation time reduces sharply from 7.9 sec(at Ti=150°C) to 1 sec(at Ti=210°C) indicating high heat transfer rates in this region. The transition boiling region is comparatively short(T_L-T_{min}=150°C) indicating speedy formation of insulating film beneath the droplet.

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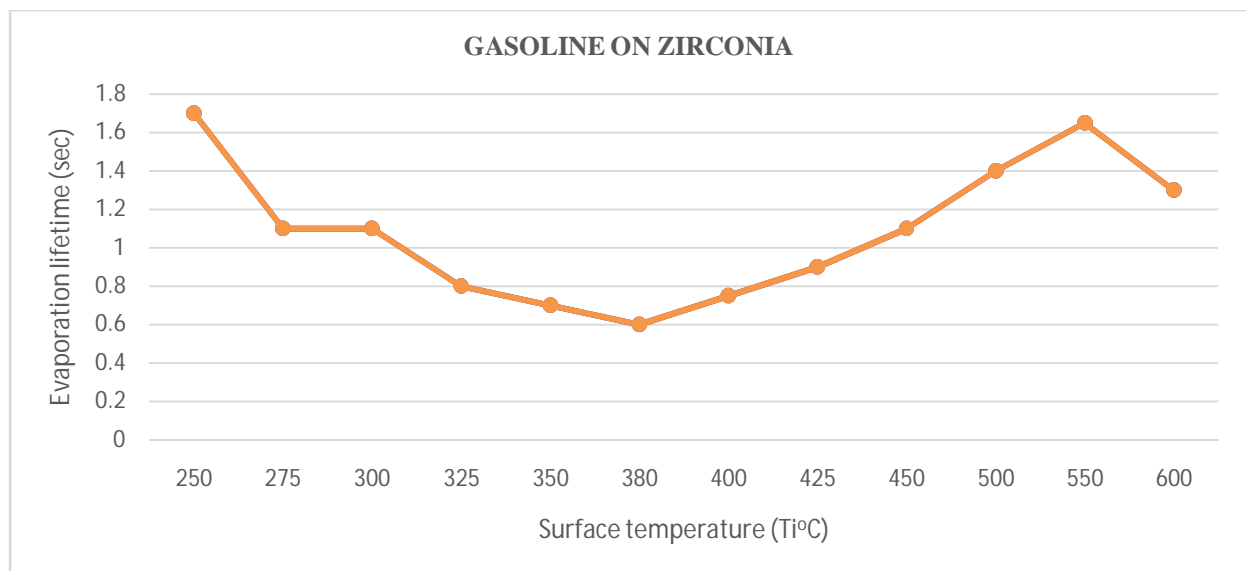
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Vol. 6, Issue 2, February 2017

- 3.) Gasoline with Yttrium stabilized Zirconia
4.)

Reading No.	Ti	Evaporation Time(sec)		Average Evaporation time(sec)
		I	II	
1	600	1.5	1.1	1.3
2	550-T _L	1.7	1.6	1.65-E _{max}
3	500	1.4	1.2	1.4
4	450	1.3	0.9	1.1
5	425	0.9	0.9	0.9
6	400	0.8	0.7	0.75
7	380-T _{min}	0.6	0.6	0.6-E _{min}
8	350	0.9	0.5	0.7
9	325	1.0	0.6	0.8
10	300	1.5	0.6	1.1
11	275	1.5	0.6	1.1
12	250	1.7	1.7	1.7



The wetting region is characterized by low evaporation time and curve descends from 1.7 sec(at Ti=250°C) to 0.6 sec(at Ti=T_{min}=380°C) rendering a very long contact evaporation range. The reason behind this is due to porosity of ceramic material. The vapour film beneath the droplet percolates into the porous surface, facilitating direct contact of droplet with surface for a higher range of temperature. This results in comparatively higher T_{min} and lower evaporation time in wetting region.

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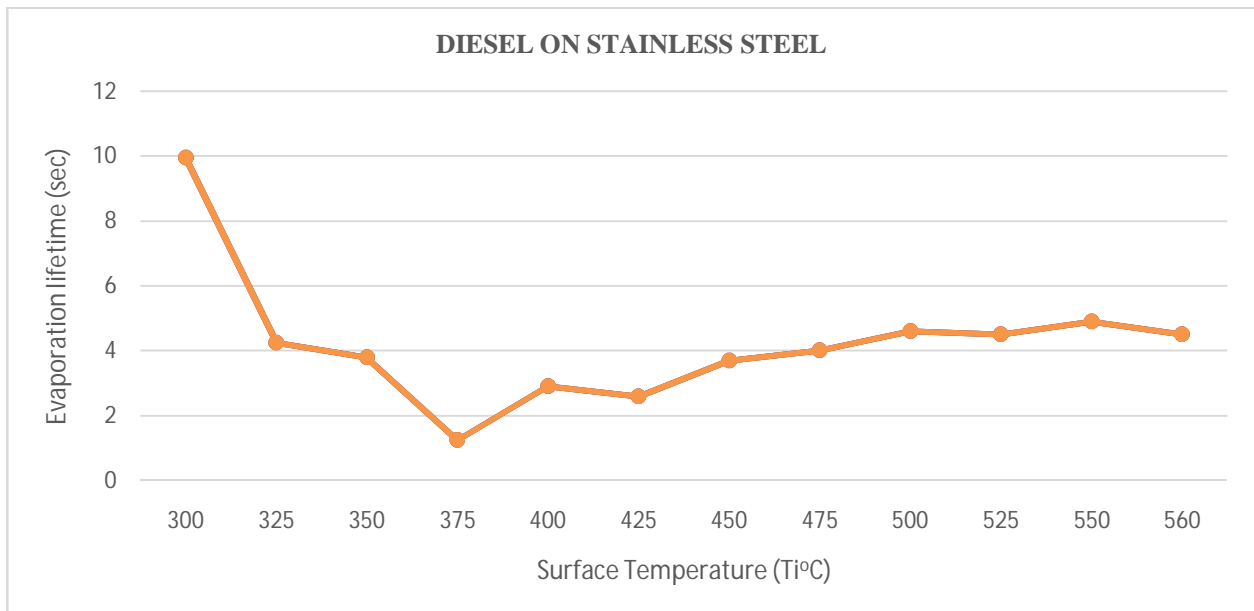
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Vol. 6, Issue 2, February 2017

3.) Diesel with stainless steel

Reading No.	Ti	Evaporation Time(sec)		Average Evaporation time(sec)
		I	II	
1	560	4.8	4.2	4.5
2	550-T _L	4.6	5.2	4.9-E _{max}
3	525	4.5	4.5	4.5
4	500	5.0	4.2	4.6
5	475	4.2	3.9	4.02
6	450	3.4	4.0	3.7
7	425	2.7	2.5	2.6
8	400	2.8	2.9	2.9
9	375-T _{min}	1.2	1.3	1.25-E _{min}
10	350	3.8	3.8	3.8
11	325	4.2	4.3	4.25
12	300	11	8.9	9.95



In contact evaporation region, the curve drops down moderately from 9.95sec(at Ti=300°C) to 1.25 sec (Ti=T_{min}=375°C) indicating high evaporation and heat transfer rates. The transition region is characterized by initially fast and then slow heat transfer rates with T_L=550°C.

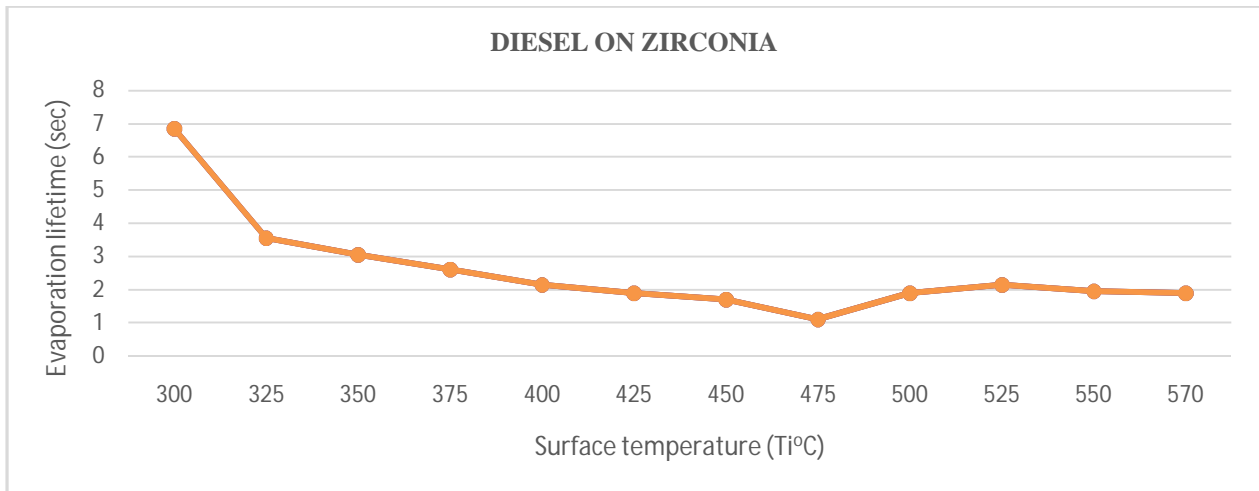
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Vol. 6, Issue 2, February 2017

4.) Diesel with Yttrium stabilized Zirconia



Reading No.	Ti	Evaporation Time(sec)		Average Evaporation time(sec)
		I	II	
1	570	1.8	2.0	1.9
2	550	1.8	2.1	1.95
3	525-T _L	2.2	2.1	2.15-E _{max}
4	500	2.1	1.7	1.9
5	475-T _{min}	1.2	1.0	1.1-E _{min}
6	450	1.3	1.2	1.7
7	425	2.0	1.8	1.9
8	400	2.4	1.9	2.15
9	375	2.8	2.4	2.6
10	350	2.9	3.2	3.05
11	325	3.7	3.4	3.55
12	300	6.9	6.8	6.85

In the transition film boiling region due to percolation of vapour film into the porous matrix, the evaporation times are less.

5.) Methanol with stainless steel

Reading No.	Ti	Evaporation Time(sec)		Average Evaporation time(sec)
		I	II	
1	400	18.9	18.6	18.75
2	375	19.8	19.2	19.5
3	325	18.5	187.4	18.45
4	275	26.7	26.5	26.6
5	250	26.5	22.4	24.45
6	225-T _L	29.6	25.6	27.6-E _{max}
7	200	23.2	19.4	21.3
8	175	15.3	11.6	13.45

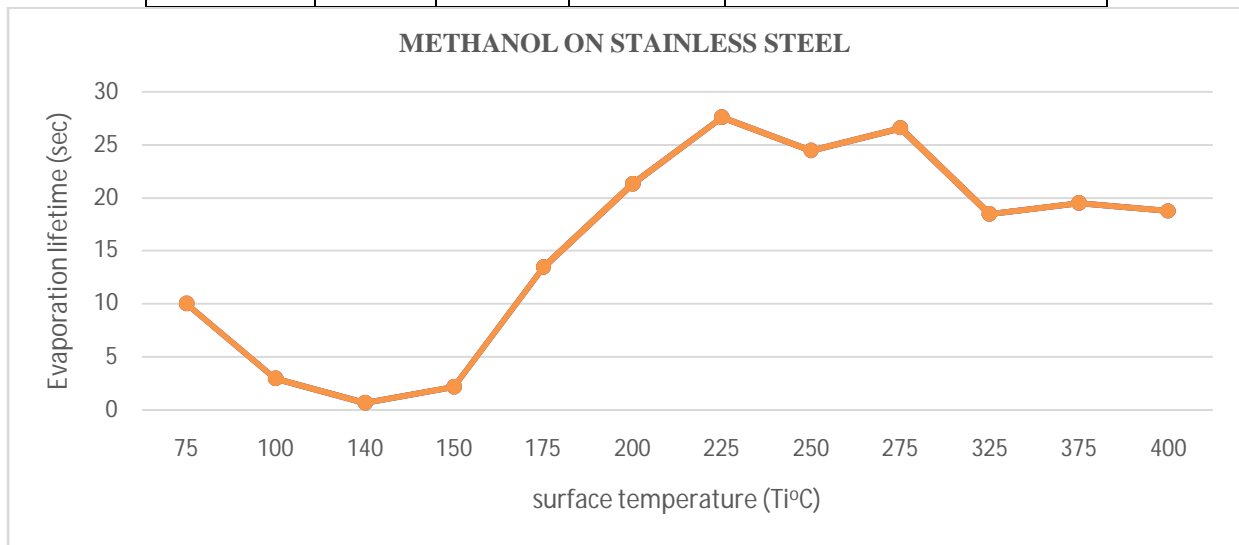
International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 2, February 2017

9	150	2.8	1.5	2.15
10	140-T _{min}	0.5	0.8	0.65-E _{min}
11	100	2.4	3.5	2.95
12	75	12.0	8.0	10



The curve in transition boiling rises steeply upto 225°C and it descends slowly in film boiling region indicating formation of vapour layer and radiation heat transfer from hot surface to droplet.

6.) Methanol with Yttrium stabilized Zirconia

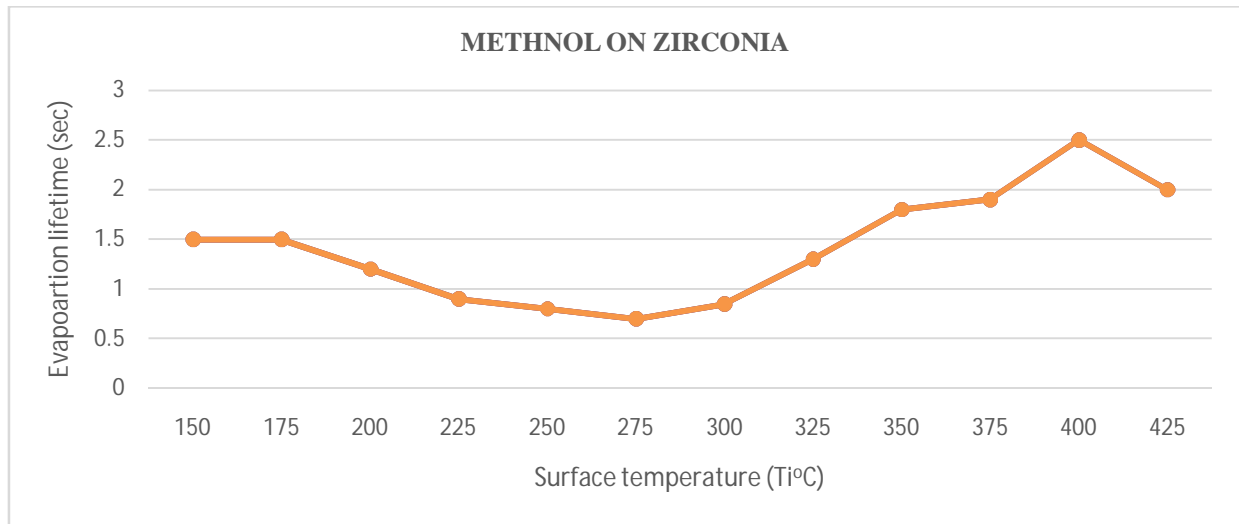
Reading No.	Ti	Evaporation Time(sec)		Average Evaporation time(sec)
		I	II	
1	425	2.2	1.8	2.0
2	400-T _L	2.4	2.6	2.5-E _{max}
3	375	1.9	1.9	1.9
4	350	1.6	2.0	1.8
5	325	1.3	1.3	1.3
6	300	0.9	0.8	0.85
7	275-T _{min}	0.7	0.7	0.7-E _{min}
8	250	0.9	0.7	0.8
9	225	0.7	1.1	0.9
10	200	1.1	1.3	1.2
11	175	1.2	1.8	1.5
12	150	1.8	1.8	1.5

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Vol. 6, Issue 2, February 2017



VI. CONCLUSION

The final determined values of T_L , T_{min} , E_{max} and E_{min} for different fuels are given below and are compared between Stainless steel and Zirconia.

FUEL	T_L (°C)		T_{MIN} (°C)		E_{MAX} (sec)		E_{MIN} (sec)	
	Stainless steel	Zirconia	Stainless steel	Zirconia	Stainless steel	Zirconia	Stainless steel	Zirconia
Gasoline	325	550	210	380	12.25	1.65	1.0	0.6
Diesel	550	525	375	475	4.9	2.15	1.25	1.1
Methanol	225	400	140	275	27.6	2.5	0.65	0.7

The following broad conclusions can be drawn by critically analyzing the results :

1. The Leidenfrost and Minimum temperature values are highest for diesel followed by gasoline & methanol on the surface of stainless steel whereas on Zirconia, Leidenfrost temperature is highest for gasoline followed by diesel & methanol and Minimum temperature is highest for diesel followed by gasoline & methanol.
2. The evaporation time of all fuels droplets on Yttrium stabilized Zirconia are substantially less than Stainless steel. This suggests that the use of such materials in various surfaces inside IC engine, where the fuel droplets are likely to fall would decrease the time needed for evaporation, hence improving the combustion efficiency and reducing NO_x emissions.

The main limitation of this experimental setup is that the size of the droplets are substantially larger than those in realistic fuel sprays. Thus the results reported herein should be viewed qualitatively instead of quantitative.

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