Journal of Engineering and Technology Vol. 4 No. 1, 2005 *ISSN 1684-4114*

DROPLET COMBUSTION WITH LIQUID PARAFFIN AND OXYGENATED FUELS

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ABSTRACT

In this report single liquid fuel droplet combustion of neat diesel fuel, neat oxygenated fuels, blends of diesel-paraffin and diesel-oxygenated fuels have been investigated. The volumetric blending ratios of paraffin and oxygenated fuels to diesel fuel have been set to 0, 25, 50 and 100%. The result showed that the shapes and sizes of the flames of diesel-paraffin and diesel-oxygenate fuel blends were completely different from those of conventional diesel fuel. It has been interesting to note that the combustion with the blends of diesel-paraffin and diesel-oxygenate ended rapidly after the ignition started. Compared with neat diesel fuel, the combustion speed was found faster for low temperature paraffin fuels including normal nonane (NN) and normal decane (ND) as well as oxygenated fuels, such as, ethylene glycol mono n butyl ether (ENB) and diethyl succinate (DES). The rapid changes of combustion might result from the micro-explosion of the fuel droplet for their low boiling temperature.

1. INTRODUCTION

Combustion of a liquid fuel droplet cloud occurs in a wide range of industrial applications like internal combustion engines, the burners, etc. Several researches have been conducted regarding the fiber-supported fuel droplet combustion (FSDC) to obtain combustion mechanism of a fuel droplet cloud. In a joint program involving California University and Lewis microgravity research center (1), the combustion of liquid fuel droplets having initial diameters between about 1 mm and 6 mm was being studied. The objectives of the work were to improve fundamental knowledge of droplet combustion dynamics through experiments and theoretical analyses. Emphasis of the Princeton work were on the study of simple alcohols (methanol/ethanol), alcohol/water mixtures, and pure alkanes (n-heptane, n-decane) as fuels, with time dependent measurements of drop size, flame stand-off, liquid phase composition and finally, extinction (2-3).

The results from methanol/water droplet combustion experiments conducted FSDC-1 and FSDC-2 were analyzed and compared against the predictions of a detailed numerical model (4). The model used was fully time dependent, with consideration of detailed methanol oxidation chemistry, non-luminous radiative coupling, and water dissolution and vaporization from the liquid phase.

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Ethanol was also used as one of the primary fuels studied in the shuttle mission program (5). In this study, the burning rate, flame diameter measurements, and extinction behavior for droplets ranging from 2.5 to 6 mm were investigated. In the above study, experiment was performed for ethanol droplets burning in atmospheric pressure.

In an effort to gain better understanding of ethanol combustion, isolated droplet experiments were performed by varying initial droplet diameter, oxygen concentration and ambient pressure. Experiments were performed at the NASA Glenn 2.2 sec. Drop tower and the JAMIC 10 sec. dropshaft. These experiments revealed that while ethanol droplets burned in 1 atmosphere air without soot formation, luminous radiation from soot particles at higher pressures, with increased sooting at higher oxygen indices were observed. The measurement of the burning rate, soot standoff ratio and soot volume fractions are described. These experiments provide the first measurements of the soot volume fraction for ethanol droplets burning under microgravity conditions (6).

When alkane fuels have to stay partially or fully premixed in an oxidizing atmosphere at elevated temperatures and pressures, ignition can occur in a multistage mode. The ignition process can follow completely different schemes of oxidation and is controlled by two different chain-branching reaction mechanisms: the low temperature reaction path, where the fuel is oxidized by O_2 in degenerated branched chains, and the high temperature path, where the fuel is rapidly oxidized into C_2 and C_1 hydrocarbons and subsequently consumed (7).

Several researches have been conducted regarding the fiber-supported fuel droplet combustion to obtain combustion mechanism of a fuel droplet cloud (8-9). However, the mechanism of fuel droplet combustion has not yet been completely clarified because it is necessary to consider the interaction of many factors, such as, droplet composition, droplet size distribution, velocities, oscillations and distributions. The combustion phenomenon is naturally associated with the evaporation behavior of droplets. Extensive literatures concerning both experimental and theoretical research are available on the subject of single droplet evaporation in a stagnant environment or under forced convective conditions at atmospheric or near atmospheric pressures.

This report investigates the single liquid fuel droplet combustion of neat diesel fuel, neat paraffin fuels, diesel-paraffin fuel blends, neat oxygenated fuels and diesel-oxygenated fuel blends under atmospheric pressure and high ambient temperature.

2. EXPERIMENTAL SET-UP

To make a clear conception for the combustion behavior of neat diesel fuel and blends of diesel- oxygenates and diesel-paraffin fuels an apparatus for fiber-supported droplet combustion was used in this experiment. Figure 1 shows its schematic diagram. An electric furnace shown in the set up has an inside volume of 6300 cm^3 and is designed to burn a liquid fuel droplet. An electric heater is placed inside the furnace wall. The operating temperatures of the furnace can be controlled from 600 to 1000 °C. Two thermocouples (Ni-Cr) of 120 μm in diameter are installed in the quartz fiber to measure the liquid and ambient temperatures respectively. To visualize the combustion behavior of the fuel droplet with elapsed time, two windows with quartz glasses are equipped in the chamber. A high-speed camera (NAC MemrecamC) with 500 frames per second is used to take the flame photographs through the window. After raising the temperature to 800 °C, the electric heater is automatically off with the action of a thermostat. When the temperature is reached to 800 °C, the furnace is dropped to the table and it covers the fuel droplet, which is supported in the thermocouple. Dropping the electric furnace to the table, the fuel droplet is started to burn and the combustion flame photographs are taken by the high-speed video camera at a preset timing. The furnace inside temperature and the inside droplet temperature data is recorded in the computer simultaneously. The combustion photographs recorded by the high-speed video camera are then analyzed with the help of a television (TV). The video film is run in the TV. Initially the droplet diameter (D_0) was set at 1 mm before combustion was started. When combustion was started, the liquid droplet diameter (D) was reduced with elapsed time and the D was measured by viewing the TV monitor.

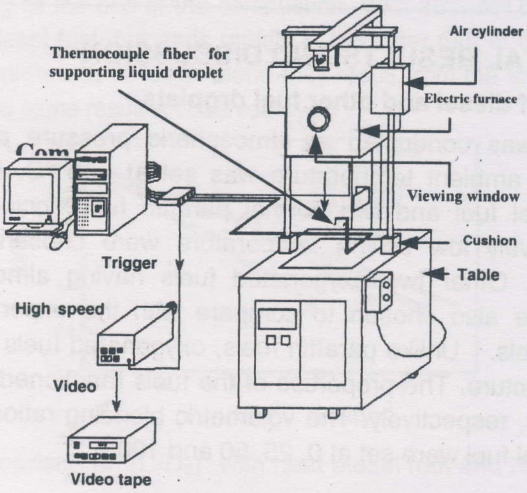

Fig. 1. Schematic diagram for droplet combustion

Table 1. Properties of tested paraffin fuels

Paraffin fuels	Abbrevi-ation	Mole-cular formula	Dist. temp. 90% (°C)	Self - ignition temp. (°C)	Cal. Value (MJ/kg)	Density (g/cc)	Cetane no.
Normal nonane	NN	C_9H_{20}	153	205	46.50	0.712	72
Normal decane	ND	$C_{10}H_{22}$	174	210	45.90	0.730	76
Diesel fuel	GO	----	336	350	42.74	0.830	50

Table 2. Properties of tested oxygenated fuels

Oxygenated fuels	Abbre-viation	Molecular Formula	Oxygen content (wt-%)	Density (g/cc)	Boiling point (°C)	Self - ignition temp. (°C)	Cal. Value (MJ/kg)	Cetane no.
Ethylene glycol mono-n-butyl ether	ENB	$C_6H_{14}O_2$	27.10	0.905	171	228	32.40	24
Diethyl succinate	DES	$C_8H_{14}O_4$	36.80	1.047	218	241	22.90	20

3. EXPERIMENTAL RESULTS AND DISCUSSION

Flame behavior of diesel and other fuel droplets

The experiment was conducted at atmospheric pressure and high ambient temperature. The ambient temperature was set at 800 °C. In the experiment conventional diesel fuel and two normal paraffin fuels including NN and ND having comparatively low boiling temperature were chosen for their almost similar properties. Other two oxygenated fuels having almost similar boiling temperatures were also chosen to compare with the experimental results of normal paraffin fuels. Unlike paraffin fuels, oxygenated fuels contain oxygen in the molecular structure. The properties of the fuels mentioned above are shown in Tables 1 and 2, respectively. The volumetric blending ratios of these fuels to conventional diesel fuel were set at 0, 25, 50 and 100%.

A simplified flame and fuel droplet diagram is shown in Figure 2. During combustion the droplet diameter D with elapsed time can be represented by the following relation (10).

$D^2 = D_0^2 - kt$

where,

D_0 is initial droplet diameter and

k is evaporation coefficient.

The foregoing equation can be rearranged as follows:

$(D/D_0)^2 = 1 - k(t/D_0^2)$

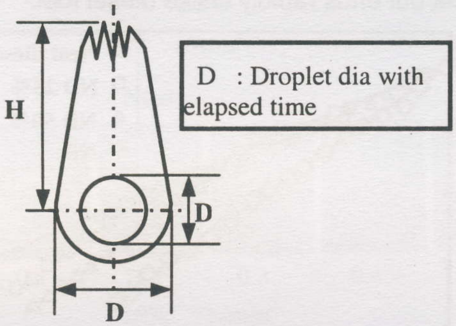

Fig. 2. Simplified flame and fuel droplet diagram

Figure 3 shows the $(D/D_0)^2$ with respect to (t/D_0^2) for neat diesel fuel, neat NN and their blends. To minimize error, the ordinate is made dimensionless by dividing the droplet diameter D with the initial droplet diameter D_0. It is clearly seen from the figure that with the increase of elapsed time, the combustion speed of neat diesel fuel or neat NN is linearly decreasing till the end of the combustion. With 25% NN blend, the combustion starts like neat diesel fuel, but ends rapidly in the latter part of combustion. The rapid ending of combustion with 25% NN blend may result from the low boiling temperature of NN. Almost the same result is observed

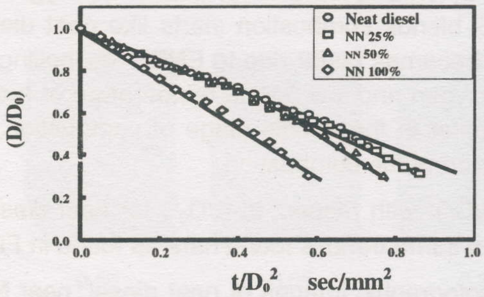

Fig. 3. Comparison of $(D/D_0)^2$ with neat diesel fuel and diesel-NN blends

For the combustion of 50% NN blend. Compared with neat diesel fuel, the combustion speed with neat nn is much faster than that of neat diesel fuel. The faster burning of neat nn results from its low boiling temperature.

Figure 4 shows the $(D/D_0)^2$ with respect to (t/D_0^2) for neat diesel fuel, neat ND and their blends. The boiling temperature of nd is slightly higher than that of NN but lower than that of neat diesel fuel. ND is taken here for comparison to observe the effect of low boiling temperature on combustion as found in NN. It is seen from the figure that combustion speed with neat nd is gradually decreasing with the increase in elapsed time and then becomes faster throughout the combustion as observed in neat NN. Combustion with 25% and 50% ND blends starts like diesel fuel but ends rapidly unlike diesel fuel.

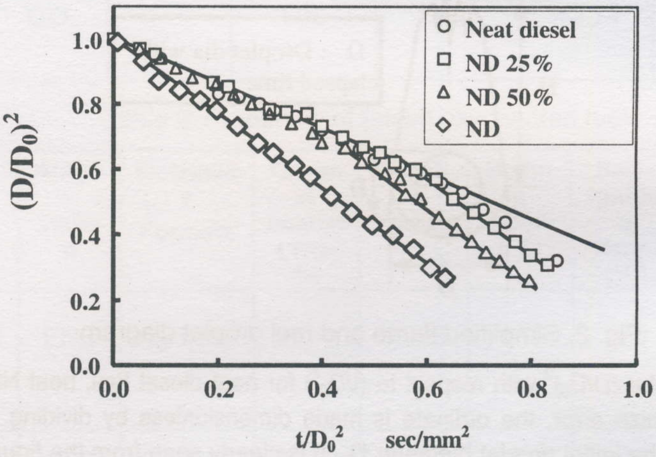

Fig. 4. Comparison of $(D/D_0)^2$ with neat diesel fuel and diesel-ND blends

Figure 5 shows the $(D/D_0)^2$ with respect to (t/D_0^2) for neat diesel fuel, neat ENB and their blends. It is interesting to see that like low boiling temperature paraffin fuel, neat ENB shows very faster combustion. Blends with diesel-ENB show similar trends as found in NN and ND blends. ENB is an oxygenated fuel and that is why with diesel-ENB blends combustion starts like neat diesel fuel and then the combustion speed becomes faster due to ENB's low boiling temperature and oxygen content. This oxygen and low boiling temperature of fuel promotes faster combustion. Burning faster in the middle stage of combustion, it ends like neat diesel fuel in the latter part of the combustion.

Figure 6 shows the $(D/D_0)^2$ with respect to (t/D_0^2) for neat diesel fuel, neat DES and their blends. Almost same trend is found here as found in Fig. 5.

Figure 7 shows the photographic images of neat diesel, neat NN and neat ENB fuels.

These photographs have been taken by a high-speed camera at 500 frames per second. The diameter D is calculated with the help of these images. It is clearly evident from these Figures that t/D_0^2 is

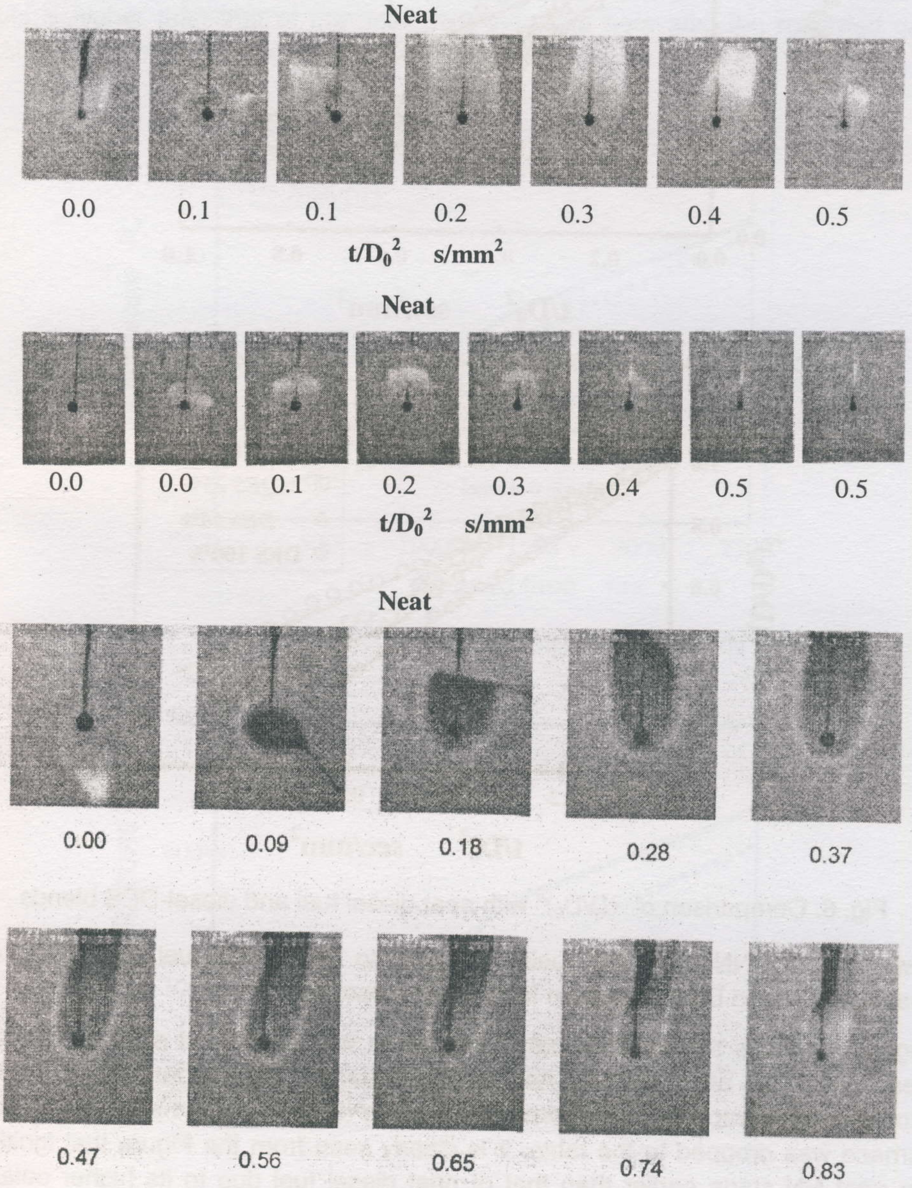

Fig. 7. Photographic images of neat NN neat ENB and neat diesel fuels.

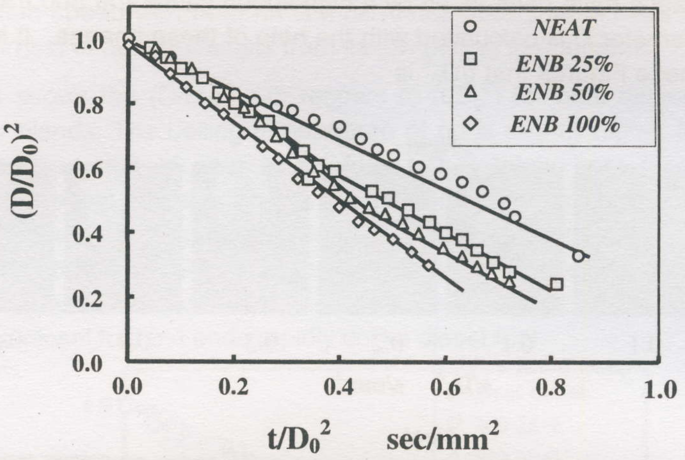

Fig. 5. Comparison of $(D/D_0)^2$ with neat diesel fuel and diesel-ENB blends

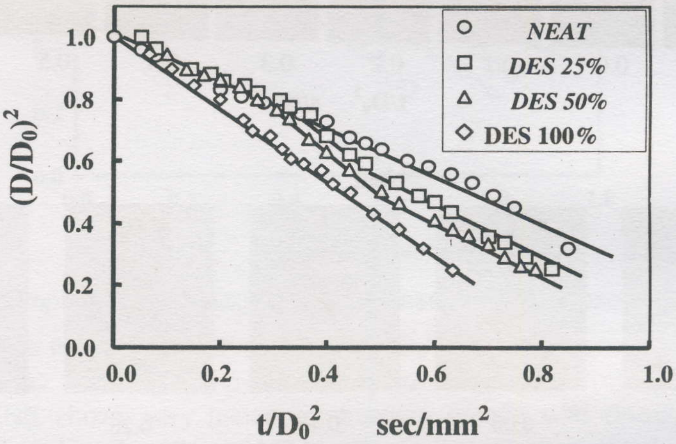

Fig. 6. Comparison of $(D/D_0)^2$ with neat diesel fuel and diesel-DES blends

lower for neat NN, and ENB fuels compared to neat diesel fuel. This indicates that neat NN and ENB fuels burn faster than diesel fuel.

Figure 8 depicts the liquid droplet temperature with respect to elapsed time for neat diesel fuel and neat NN. As mentioned earlier, the temperature data was stored in the computer via a thermocouple. The data was taken after the electric furnace was dropped to the table. It is clearly seen from the Figure that ignition for neat NN starts earlier than that of neat diesel fuel due to its higher cetane number. Also it is evident that as the self-ignition temperature of neat diesel fuel is higher than that of the neat NN, therefore the recorded data satisfies the fuel property.

Figure 9 displays the liquid droplet temperature with respect to elapsed time for neat diesel fuel and neat ENB. It is clearly seen from the Figure that ignition for neat diesel fuel starts earlier than that of ENB due to higher cetane number of diesel fuel. Also it is evident that as the self-ignition temperature of neat diesel fuel is higher than that of the neat ENB therefore here also the recorded data satisfied the property of ENB.

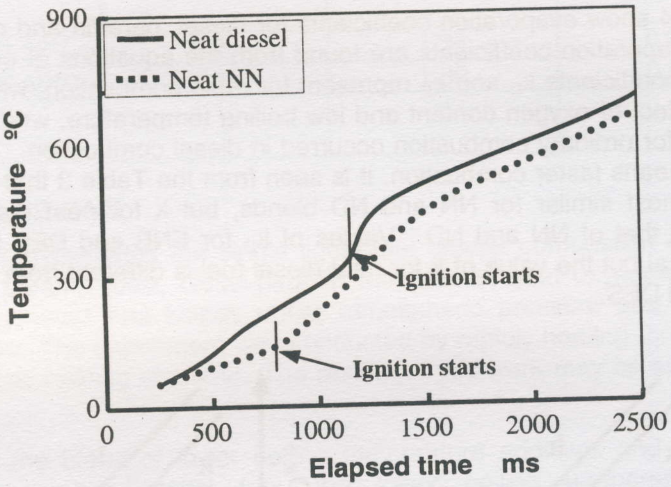

Fig. 8. Temperature history of neat diesel and neat NN fuels

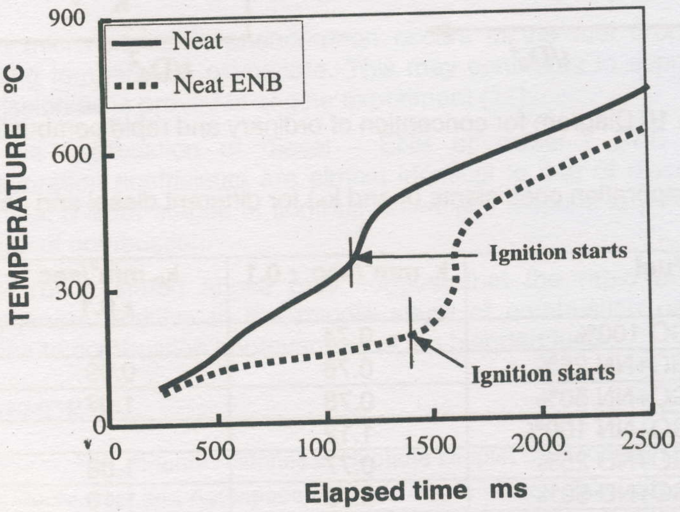

Fig. 9. Temperature history of neat diesel and neat ENB fuels

Figure 10 shows the diagram for evaporation coefficients k, k_P, k_D and k_A. Here k that represents the evaporation coefficient for ordinary combustion occurred in neat diesel, NN, ND, ENB and DES. k_P represents the evaporation coefficient for rapid combustion, which occurs in the bends of NN, ND at the latter part of the combustion. k_D demonstrates the evaporation coefficient for rapid combustion as found in the blends of ENB and DES at the middle stage of the combustion and k_A representing the evaporation coefficient for ordinary combustion occurred in the blends of ENB and DES at the final part of the combustion.

Table 3 and 4 show evaporation coefficients for diesel, paraffin and oxygenated fuels. The evaporation coefficients are found from the equations of curve fitting. Evaporation coefficients k_D and k_P represent for rapid combustion, which occurs due to the effect of oxygen content and low boiling temperature, whereas k and k_A represent for ordinary combustion occurred in diesel combustion. The higher values of k means faster combustion. It is seen from the Table 3 that the values of k_P are almost similar for NN and ND blends, but k for neat diesel fuel is different from that of NN and ND. Values of k_D for ENB and DES blends are almost identical but the value of k for neat diesel fuel is different from that of the neat ENB and DES.

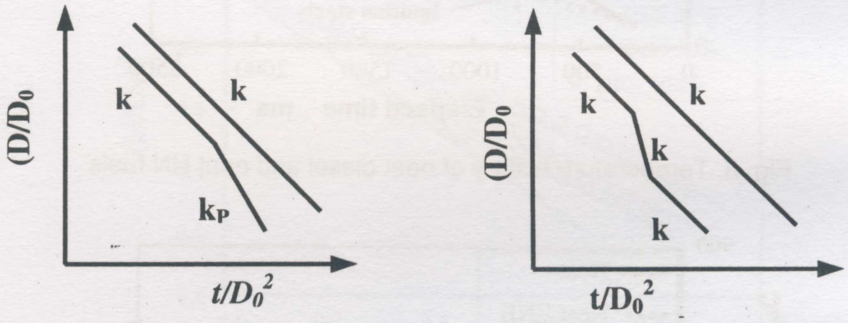

Fig. 10 Diagram for conception of ordinary and rapid combustion

Table 3. Evaporation coefficients (k and k_P) for different diesel and paraffin fuels

Fuel	**k mm^2/sec ± 0.1**	**k_P mm^2/sec ± 0.1**
GO 100%	0.74	-
GO+NN 25%	0.76	0.99
GO+NN 50%	0.78	1.07
GO+NN 100%	1.12	-
GO+ND 25%	0.77	1.08
GO+ND 50%	0.79	1.10
GO+ND 100%	1.16	-

Table 4. Evaporation coefficients (k, k_D, and k_A) for diesel and oxygenated fuels

Fuel	**k mm^2/sec ± 0.1**	**k_D mm^2/sec ± 0.1**	**k_A mm^2/sec ± 0.1**
GO 100%	0.74	-	-
GO+ENB 25%	0.81	1.18	0.84
GO+ENB 50%	0.88	1.36	0.89
GO+ENB 100%	1.24	-	-
GO+DES 25%	0.80	1.36	0.83
GO+DES 50%	0.86	1.30	0.83
GO+DES 100%	1.15	-	-

4. CONCLUSIONS

This report investigates the single liquid fuel droplet combustion of neat diesel fuel, neat paraffin fuels, diesel-paraffin fuel blends, neat oxygenated fuels and diesel-oxygenated fuel blends under atmospheric pressure and high ambient temperature. The experiment was conducted by rapidly heating the liquid droplet in an electric heating chamber. The results of this work may be summarized as follows:

1. In the blend of lower boiling temperature additives and higher boiling temperature diesel fuel, the lower boiling temperature additives evaporate and burn faster than conventional diesel fuel. The rapid burning may result from the so-called micro-explosion during burning of fuel.
2. The micro-explosion phenomenon occurs in the fuel droplet with low boiling temperature oxygenate. This may contribute to suppress smoke emission as is proved in engine experiment (11).
3. In the combustion of diesel - ENB or diesel - DES blends, the evaporation coefficients are almost identical to that of diesel fuel in the early and latter stages of combustion while it is found large in the middle stage of combustion.
4. The result stated above may suggest that the rapid evaporation of oxygenate additive in the middle stage of combustion can contribute much to combustion improvement of the blended fuels.

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Journal of Engineering and Technology Vol. 4 No. 1, 2005 *ISSN 1684-4114*

TECHNICAL & VOCATIONAL EDUCATION AND HUMAN RESOURCE DEVELOPMENT: TRENDS TOWARD A CLOSER INTEGRATION

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Abstract

The new work environments require broader skills than ever before and place intense pressures on all providers of workforce preparation to enhance the competitiveness of today's workforce. Technical & vocational education (TVE) and human resource development (HRD) are in the forefront in seeking new approaches to preparing the workforce of the future. This paper presents arguments that trends toward a closer integration of the two fields are appropriate responses to meet the challenges and should be pursued more vigorously. Historical, philosophical and practical contributions of both fields are examined as foundations of commonality upon which to build cooperative efforts. Analyses revealed substantial basis for cooperation that is largely overlooked. Integrative mechanisms and initiatives are discussed.

1. Introduction

The economy of most developing countries today is faced with the effects of competitive global markets that have fundamentally reshaped many elements of industry practice. Persistent waves of restructuring and constructive initiatives are testimony to the struggles that industries face to remain economically competitive. The fast waves of change, demands for higher quality, and ever changing technology are making jobs and skills obsolete overnight. Unfortunately, many industries have discovered that workers are not well prepared and lack basic skills.

Work places today require new and broader skills than ever before. Organizations have realized that they must have better trained workers if they are to survive. In response, many are increasing their training and demanding higher levels of entry level skills for all jobs. The 1996 training industry survey (Enzali, 1996) showed that organizations in most developing countries increased their training budgets from 5% to 7% in 1996 and trained 13% to 15% more people. As a consequence, all providers of workforce preparation are facing intense pressures and challenges to enhance the competitiveness of their workforce. Technical & vocational education and human resource development, two of the leaders in workforce development, are in the forefront in seeking the best approaches to preparing the workforce of the future.

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