The Effect of Using Castor Oil on the Pollutants Emission in a Continuous Combustion Chamber

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Abstract

This study investigates the effect of Castor oil on the pollutants emissions in the continuous combustion chamber. The bio-blend fuels used are mixtures of Castor oil with two types of hydrocarbon fuels (gas oil and kerosene). The pollutants measured include carbon monoxide CO, unburned hydrocarbon UHC, soot and nitrogen oxide NO_x . It is found that all pollutants have less emissions when using Castor oil blended in different percentages of 5% , 7%, and 10% . The lower emission with Castor oil blends due to the existence of oxygen O_2 in the chemical structure of the Castor oil which is sufficient to seek the complete combustion. The test were conducted through the range of equivalence ratio between (0.85-1.7) . Results showed that Castor oil blends with gas oil brings a reduction of about 71.2% in CO, 22.1% in UHC, 37.8% in NO_x and 29.6% in soot emissions from that of pure gas oil. But, blends with kerosene, showed a reduction of about 70.6% in CO, 20% in UHC, 35.8% in NO_x and 29% in soot emissions compared with those of pure kerosene.

Keywords: Castor oil, vegetable oils , Pollution, Emissions, continuous combustion chamber,.

1 Introduction

Recently a strong efforts have been done to reduce the impact of combustion pollutants and their harmful effects on the environment due to their role in ozone depletion and the creation of global warming. Much works have been done to reduce the the production of NO_x and photochemical smog **[1]**. The major disadvantage of the use of various petroleum products results from their pollutants emissions, such as carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO), unburned hydrocarbons (UHC), particulate matter (PM) and other harmful compounds. The above furnishes some of the reasons why alternative fuels are required. The "right" alternative fuels must be inexpensive, abundant, and their combustion product must be environmentally friendly . Also, they must be used in existing engines without any or with minor modifications replacing fossil fuels with bio fuels could reduce the world dependence of fossil fuel**[2,3]**.

Bio-diesel and fatty acid ethyl or methyl ester made from virgin or used vegetable oils are environmental friendly. Both edible oils and Bio-diesel are considered clean fuel since it has almost no sulfur content (typically it is less than 15 ppm), no aromatics and has about 10% built-in oxygen. Blending with diesel fuel can be utilized to increase Flash point of diesel particularly where flash point is 44°C well below the world average of 55°C. This is important from the safety point of view .Cetane number (CN) of the bio-diesel is in the range of 48–60. Higher Cetane number of bio-diesel improves the ignition quality even when blended in the petroleum diesel. Ethyl and methyl esters contain 10–11% oxygen by weight, which may encourage lower volumetric heating values (about 12%) than diesel fuel, they have slower volatility characteristics. In addition, they are biodegradable, non-toxic, and have a potential to significantly reduce pollution. **[4]**

John Britt **[5]** explored the most important reason behind using vegetable oil and that the tests showed that bio-blend diesel emissions are substantially lower in carbon dioxide, carbon monoxide, sulfur dioxide, and a host of other emissions than petroleum diesel emissions. In fact , the amount of carbon dioxide emitted into the air equals theoretically its amount that absorbed by the growing crop of soybeans or corn**.**

Gupta et .al **[4]** studied the viscosity effect ,flash point, Cetane - number and density of bio-blend diesel. They found that using vegetable oil leads to reduce the emission of sulfur oxides, carbon monoxide (CO), poly aromatic hydrocarbons (PAH), unburned hydrocarbons (UHC) , and particulate matter (PM).

Tunio et al **[6]** concluded that the Castor oil blends with diesel fuel in proportions of 10 to 30% achieve the ASTM permissible limits. Less emissions of CO, CO_2 and NO_x were recorded when tested and compared to pure diesel fuel in CI engines at various ratios.

Sreenivas ,et al **[7]** presented method of producing biodiesel from castor oil (treated with mineral turpentine oil) by transesterification of the crude oil with methanol in the presence of NaOH as catalyst. The study supports the production of biodiesel from castor oil as a viable alternative to the diesel fuel. It is nontoxic, biodegradable, renewable fuel. The use of biodiesel in conventional combustion systems results in substantial reduction of UHC & CO. Researchers have concluded that biodiesel is clean fuel, since it has almost no sulfur, no aromatics and has 10% built in oxygen, which helps it to burn completely.

Bajpai and Das **[8]** were investigating the preparation of biodiesel from methanol, ethanol and butanol in formation of alkyl esters of Castor. The physico-chemical properties similar to methyl esters, but deviation become larger for higher blending ratio. Therefore, restoring the conventional engine performance need the blending ratio to be less than methyl esters.

Jafarmadar et al **[9]** tested a heavy duty MT4.244 agricultural engine at various loads in order to evaluate performance and emissions of DI diesel engine using the blends of neat diesel fuel with 5,10,15,20 and 30% by volume Castor oil. The results show that the maximum decrease in PM emission is 64% and NO_x is 6% compared to pure diesel observed in 15% blend at 25% load.

Mohapatra et al **[10]** conclude that castor oil methyl ester (COME) poses lower hazardous emissions than castor oil ethyl ester (COEE). Both additives can be used in 20% package to petroleum diesel in agricultural CI engines without any modifications. However, these additives need the engine hardware to be changed to facilitate preheat up to 100°C in overcoming cold weather operability.

The present work investigates the effect of adding Castor oil to gas oil and kerosene fuels on the emissions of a locally fabricated industrial burner. The burner will be examined under various operational conditions in order to promote design and specify the best mixing proportion of Castor oil in hydrocarbon fuels comply with it.

2 Experimental Work

Figure 1 shows the test rig that is completely constructed and used in this study. The liquid fuel is stored in a fuel tank and forced in fuel injection system by compressed air produced by a reciprocating compressor. The compressed air is also used to atomize the liquid fuel in order to generate very small size droplets. The liquid fuel is directly sprayed into a (14×14) cm combustion chamber via the four-point air blast atomizer and measured by using liquid flow meter, as illustrated in figure 2. The main air flow from the blower is forced through nine holes surround the atomizer as shown in figure 2 and measured by using an orifice plate.

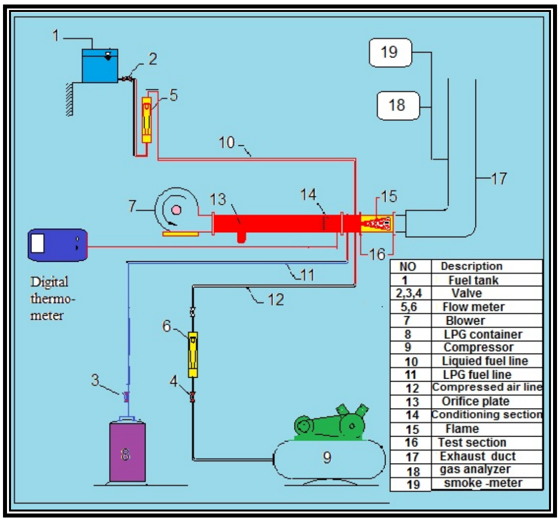
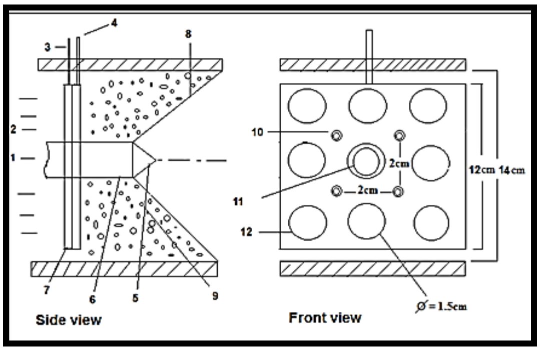


Figure 1: The test rig.



1	LPG and Air	2	Main air
3	Liquid fuel supply	4	Air blast air supply
5	Pilot flame	6,11	Pilot flame tube
7	Atomizer	8	Main flame
9	Fuel spray	10	Individual atomizer
12	Main air ports		

Figure 2: Schematic diagram of flame holder**.**

In this study, the measurement of pollutants is done by Smoke-meter PRODIT ST1006/S06/004 used to measuring soot emission, while CO, UHC, NO_x were measured by the gas analyzer AIRREX HG-540/550 shown in figure 3. The droplets size was measured with a camera system arranged for this purpose **[11]**.

As shown in figure 4, the camera system consists of light source, lenses, and camera. The measuring of the droplets size (Sauter mean diameter, SMD) was achieved by rapid photographing of group droplets. A high speed camera type G_5 Canon Digital Camera was used for this purpose. The image of the droplets magnified by using lenses fixed to the camera. The group of the droplets was lighted by the high intensity light source. The diameters of the droplets were measured by comparing them to the diameter of a standard wire shown in the same picture. The average SMD is calculated by dividing the total volume of all droplets, by the total surface area of all the droplets. Thus, the dimension obtained represents the average diameter of the group of droplets shown in the picture taken by the camera. One example of such pictures is that shown in figure 5.

(a)

(b)

Figure 3: Emission detecting devices (a) Gas analyser (b) Smoke meter

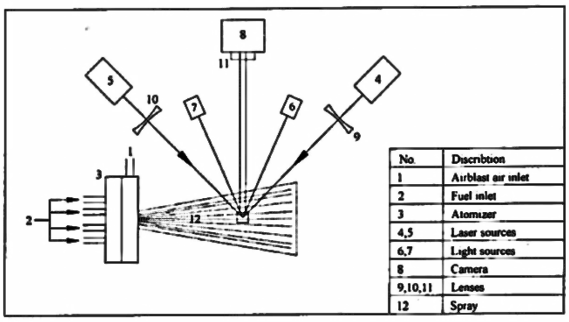


Figure 4: Droplet size measurement system [7].

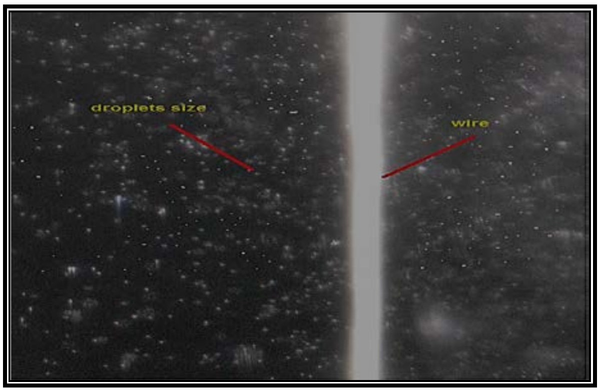


Figure 5: Photograph of the spray captured by the camera for comparison between wire and droplets (SMD = 100 μm) .

The measured pollutants resulted from the use of Castor blended fuel were compared with those emitted when using pure gasoil and pure kerosene. The blends are formed by mixing Castor oil in percentages of 5%, 7 %, and 10% with neat gas oil and kerosene fuels. The test will cover the range of equivalence ratio ($\phi = F_{act}/F_{st}$) between (0.85-1.7), as F is the fuel/air ratio.

3 Results and Discussion

Tests were conducted on bio-fuel mixtures prepared by blending castor oil with two conventional hydrocarbon fuels namely gasoil and kerosene. The pollutants detected were CO, UHC, NO_x, and soot. The burner was operated in a range of equivalence ratio between 0.85 and 1.7 corresponding to the flammability limits while using blends of castor oil with ratios of 5%, 7%, and 10%.

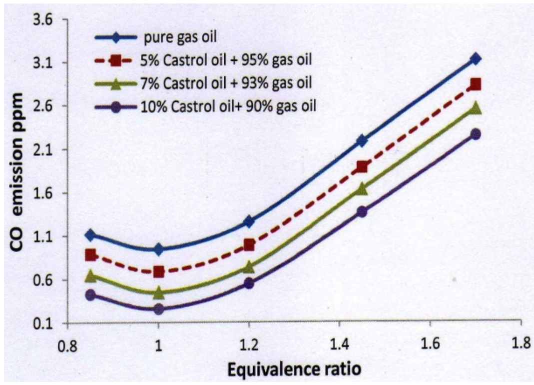


Figure 6: CO emission from gasoil bio-blend vs. equivalence ratio with SMD=100 μm.

The equivalence ratio refers to the mixture strength, and when it is decreased, the mixture becomes leaner with sufficient oxygen for the oxidation process.

Figure 6 and figure 7 depict clearly the effect of the equivalence ratio on the CO emission at SMD = 100 μm for bio-blend of Castor oil with gas oil and with kerosene respectively. With 10% bio-blend, when the equivalence ratio decreased from 1.7 to 0.85, the overall CO emission is decreased about (85.5%) for gas oil blend, but for kerosene blend it reaches (86.4%). The minimum emission is recorded at chemically correct mixture, i.e., an equivalence ratio (ϕ =1) for both fuels as it gives a maximum reduction of (93.5%) for gas oil blend, while it gives (95.8%) maximum reduction for kerosene blend respectively. However, compared with pure petroleum gas oil and kerosene, the decrease in CO is (71.2%) and (70.6%) respectively.

Figure 8 and figure 9 depict the effect of the equivalence ratio on the UHC emission at SMD = 100 μm for bio-blend of Castor oil with gas oil and with kerosene respectively. With 10% bio-blend, when the equivalence ratio decreased from 1.7 to 0.85, the overall UHC emission is decreased about (30.4%) for gas oil blend, but for kerosene blend it reaches (31.9%). The minimum emission is recorded at chemically correct mixture, i.e., an equivalence ratio (ϕ =1) for both fuels as it gives a maximum reduction of (36.3%) for gas oil blend, while it gives (36.6%) maximum reduction for kerosene blend respectively. However, compared with pure petroleum gas oil and kerosene, the decrease in UHC is (22.1%) and (20%) respectively.

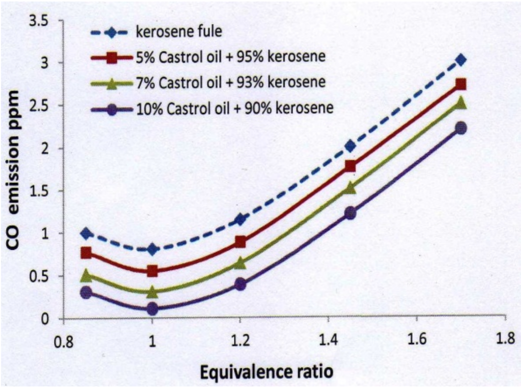


Figure 7: CO emission from kerosene bio-blend vs. equivalence ratio with SMD=100 μm

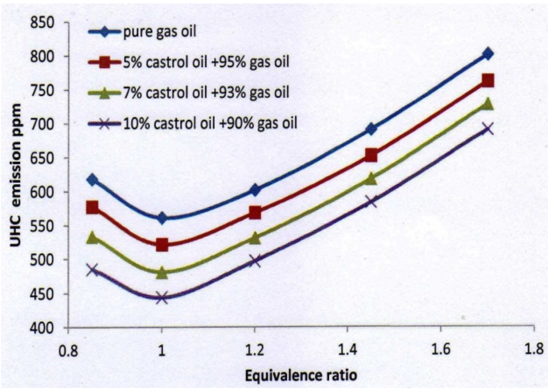


Figure 8: UHC emission from gasoil bio-blend vs. equivalence ratio with SMD=100 μm.

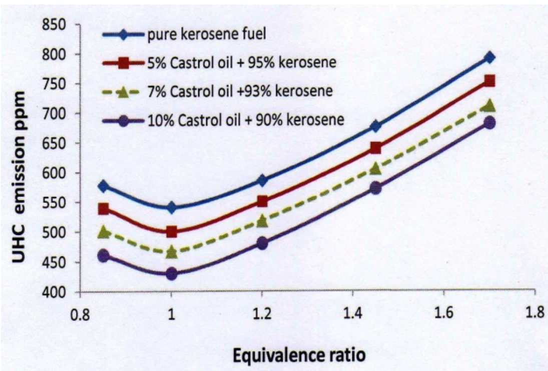


Figure 9: UHC emission from kerosene bio-blend vs. equivalence ratio with SMD=100 μm

Figure 10 indicates the NO_xemission against the equivalence ratio with SMD = 100 μm for bio-blend of Castor oil and gas oil. With 10% bio-blend, when the equivalence ratio is increased from 0.85 to 1.7, the overall NO_x emission is decreased by (50%). But, compared to pure gas oil, the decrease in NO_x is (37.8%). Nevertheless, at (ϕ =1), the NO_x records its higher level such that the corresponding maximum reduction is about (58.5%) when reaching (ϕ = 1.7).

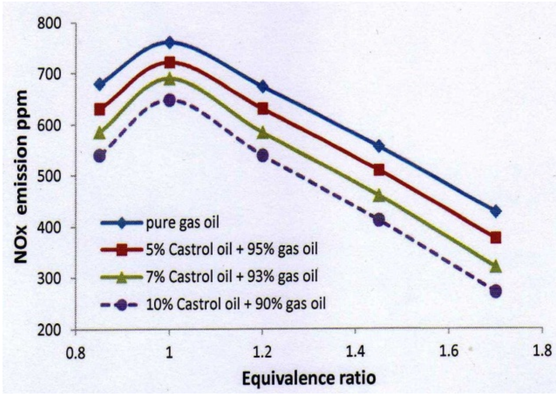


Figure 10: NO_x emission from gasoil bio-blend vs. equivalence ratio with SMD=100 mm.

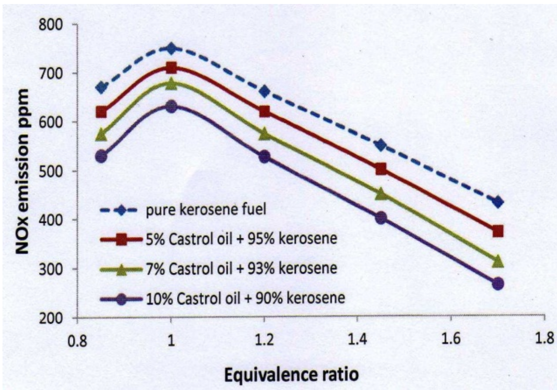


Figure 11: NO_x emission from kerosene bio-blend vs. equivalence ratio with SMD=100 μm

Figure 11 exhibits clearly the NO_x emission against the equivalence ratio with value of SMD = 100 μm for bio-blend of Castor oil and kerosene. With 10% bio-blend, when the equivalence ratio is increased from 0.85 to 1.7, the overall NO_x emission is decreased by (47.5%). But, compared to pure kerosene, the decrease in NO_x is (35.8%). Nevertheless, at (ϕ =1), the NO_x records its higher level such that the corresponding maximum reduction is about (55.6%) when reaching (ϕ = 1.7).

This behavior of NO_x is attributed to increasing equivalence ratio that causes a reduction in combustion temperature due to low oxygen levels in rich mixture. This situation causes the fuel droplets not to find the suitable amount of oxygen to complete the combustion and release the largest amount of heat. Hence, the NO_x level will be reduced.

Figure 12 and figure 13 depict the effect of the equivalence ratio on the soot emission at SMD = 100 μm for bio-blend of Castor oil with gas oil and with kerosene respectively. With 10%

bio-blend, when the equivalence ratio decreased from 1.7 to 0.85, the overall soot emission is decreased about (41.1%) for gas oil blend, but for kerosene blend it reaches (42.6%). The minimum emission is recorded at chemically correct mixture, i.e., an equivalence ratio (ϕ =1) for both fuels as it gives a maximum reduction of (46.2%) for gas oil blend, while it gives (46.4%) maximum reduction for kerosene blend respectively. However, compared with pure petroleum gas oil and kerosene, the decrease in soot is (29.6%) and (29%) respectively.

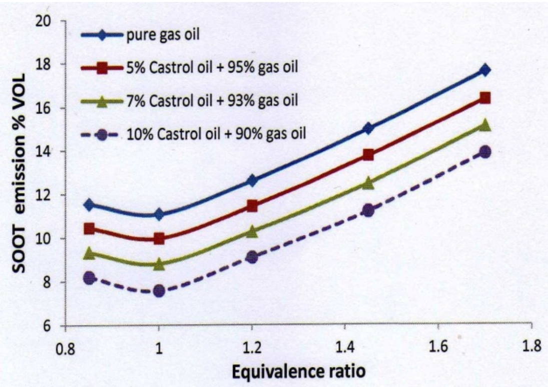


Figure 12: Soot emission from gasoil bio-blend vs. equivalence ratio with SMD=100 μm.

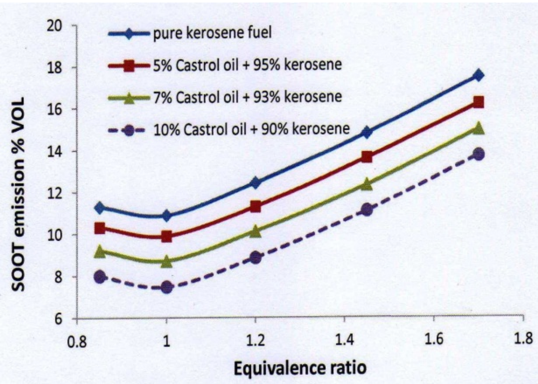


Figure 13: Soot emission from kerosene bio-blend vs. equivalence ratio with SMD=100 μm.

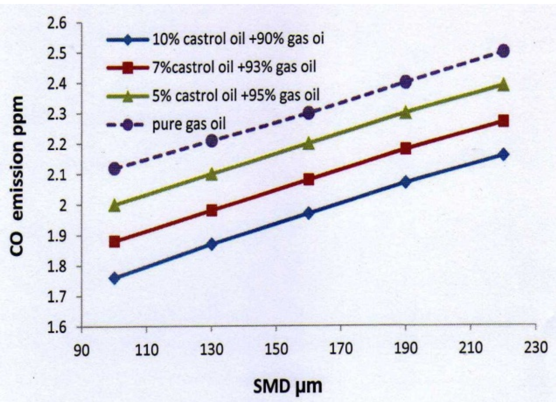


Figure 14: CO emission from gasoil bio-blend vs. SMD at ϕ = 1

The following section dedicated for the variation of pollutants emissions with varying the SMD of the fuel injected. Generally, at any proportion in bio-blend when SMD is decreased, the pollutants emissions are improved. Also, increasing the mixing proportion will improve the emission as well.

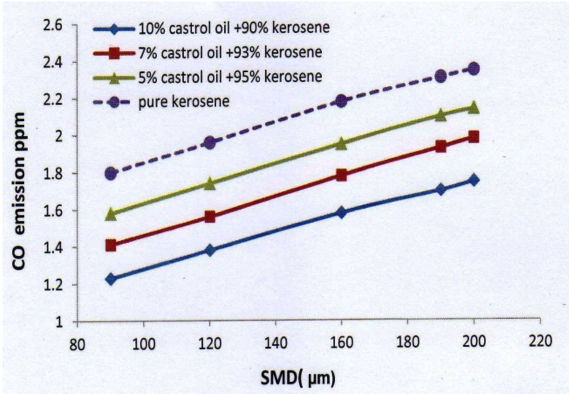


Figure 15: CO emission from kerosene bio-blend vs. SMD at ϕ = 1

Figure16 and Figure 17 illustrate the effect of SMD on UHC emissions when using a chemically correct equivalence ratio (ϕ = 1) for bio-blends of Castor oil with gas oil and with kerosene respectively. Figure 16 shows that with 10% bio-blend, when SMD has decreased from 220 μm to 100 μm, the corresponding decrease in UHC emission is (23.6%). But, compared with pure gas oil, the decrease in UHC concentration is about (16.7%). Nevertheless, figure 17 shows that when SMD is decreased from 200 μm to 90 μm, the decrease in UHC emission is (18.4%) using 10% bio-blend. But, when compared with pure kerosene, the decrease in UHC concentration is about (30.7%).

This behavior attributed to increasing the droplets surface area and the exposure time to air which reducing the droplets size and result in mixing improvement which produces more homogeneous mixture, as well as increasing burning rates.

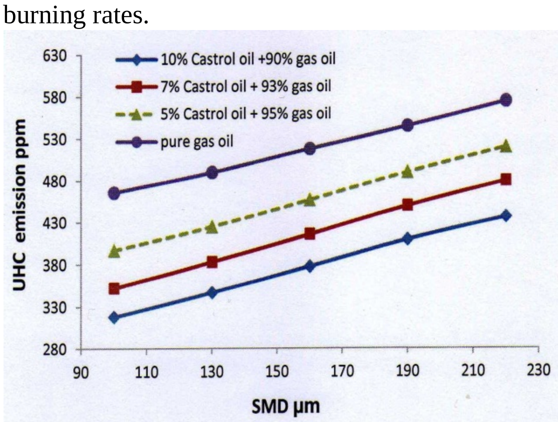


Figure 16: UHC emission from gasoil bio-blend vs. SMD at ϕ = 1

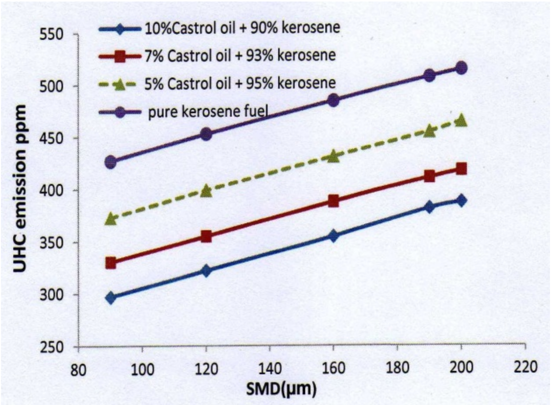


Figure 17: UHC emission from kerosene bio-blend vs. SMD at $\phi = 1$

Figure 18 and Figure 19 illustrate the effect of SMD on NO_x emissions when using a chemically correct equivalence ratio ($\phi = 1$) for bio-blends of Castor oil with gas oil and with kerosene respectively. Figure 18 shows that with 10% bio-blend, when SMD has decreased from 220 µm to 100 µm, the corresponding decrease in NO_x emission is (18.3%). But, compared with pure gas oil, the decrease in NO_x concentration is about (21.2%). Nevertheless, figure 19 shows that when SMD is decreased from 200 µm to 90 µm, the decrease in NO_x emission is (25.4%) using 10% bio-blend. But, when compared with pure kerosene, the decrease in NO_x concentration is about (40.6%).

This NO_x behavior is associated with droplet interaction and the transitions from diffusive type of spray burning. Decreasing SMD results in increasing the droplet interactions, this suppressed the temperatures and reduced NOx emission.

Figure 20 and Figure 21 illustrate the effect of SMD on soot emissions when using a chemically correct equivalence ratio ($\phi = 1$) for bio-blends of Castor oil with gas oil and with kerosene respectively. Figure 20 shows that with 10% bio-blend, when SMD has decreased from 220 µm to 100 µm, the corresponding decrease in soot emission is (48.3%). But, compared with pure gas oil, the decrease in NO_x concentration is about (38.6%). Nevertheless, figure 21 shows that when SMD is decreased from 200 µm to 90 µm, the decrease in soot emission is (47.2%) using 10% bio-blend. But, when compared with pure kerosene, the decrease in NO_x concentration is about (45.6%).

This behavior may be attributed to the fact that at low atomization pressure, the droplet size of the fuel is large, and the total surface of droplet exposed to the hot air is small, that produced lower evaporation rate so that a large portion of fuel will burn in fuel-rich region therefore the soot emission will increase. Increasing the atomization pressure results in formation of a small droplet size with higher evaporation rate due to larger surface area of droplet exposed to hot air. These droplets after evaporating and mixing with air will form more homogenous mixture flame. This type of flame has sufficient oxygen available for oxidation of soot, thus decreases soot emission.

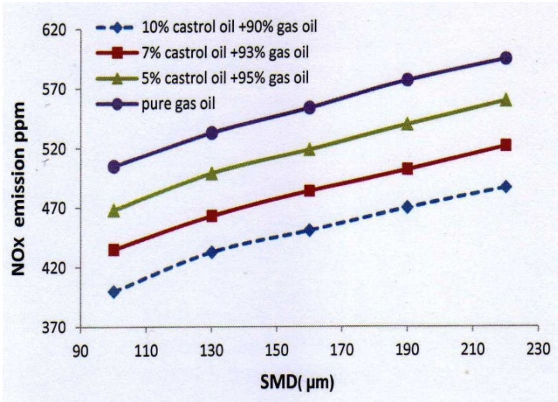


Figure 18: NO_x emission from gasoil bio-blend vs. SMD at $\phi = 1$

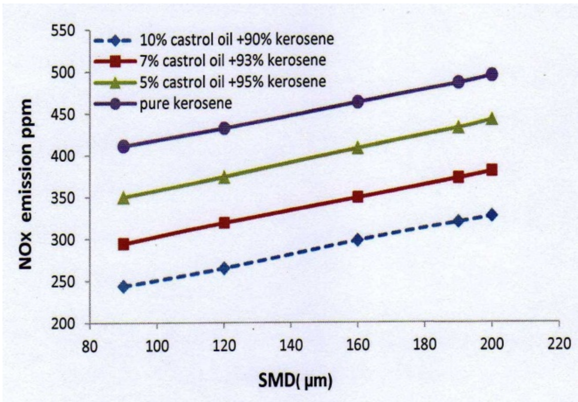


Figure 19: NO_x emission from kerosene bio-blend vs. SMD at $\phi = 1$

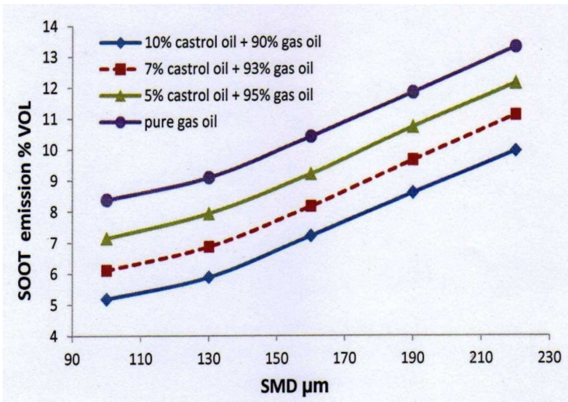


Figure 20: Soot emission from gasoil bio-blend vs. SMD at $\phi = 1$

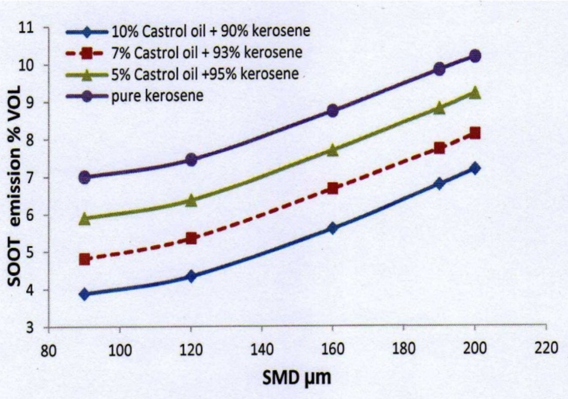


Figure 21: Soot emission from kerosene bio-blend vs. SMD at $\phi = 1$

4 Conclusions

- Decreasing the equivalence ratio leads to improve all pollutants levels except for NO_x which is deteriorate with decreasing the equivalence ratio. The improvement in emission levels for all pollutants is preferable when using Castor oil bio-blend with kerosene fuel rather than those with gas oil fuel. However, NO_x levels are better with gas oil bio-blend.
- In comparison to the conventional petroleum fuels, the average improvement in emission levels is better in case of using gas oil bio-blend with varying equivalence ratio.
- Reducing the SMD of bio-blend fuel droplets brings lower emission levels for all the pollutants. When using Castor oil mixed with gas oil fuel, the emission levels recorded are lower for all pollutants except NO_x which has its preferable value with kerosene bio-blend.
- In comparison to the conventional petroleum fuels, all pollutants having better improvement with kerosene bio-blend rather than with gas oil bio-blend as SMD is reduced.

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APPENDIX

Table A-1 Specifications of gas analyzer HG-540/550

		Measuring Range
Item	UHC	0 – 10000 ppm
	CO	0 – 100000 ppm
	NO_X	0 – 5000 ppm
Response Time		Within 10 sec
Flow Rate		2 – 4 *l* / min
Power Supply		AC 90 – 240 V, 50/60 Hz

Table A-2 Specifications of Smoke meter ST1006/S06/400

Response Time	2 - 3 sec
Measuring Range	0 – 65%
Power Supply	AC 220 V, 50 Hz /or DC 12 V
Transmitter	Halogen bulb 3000K

تاثير استخدام زيت الخروع على انبعاث الملوثات في غرفة احتراق مستمر

عبدالستار جواد محمد
قسم الهندسة الميكانيكية \ الجامعة
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التكنولوجية \ بغداد – العراق

الخلاصة

تقدم هذه الدراسة استقصاء لتاثير زيت الخروع على انبعاث الملوثات من غرفة احتراق مستمر. الوقود العضوي المستخدم هو عبارة عن خليط من زيت الخروع مع نوعين من الوقود الهيدروكربوني (زيت الغاز والكيروسين). الملوثات المقاسة تتضمن (اول اوكسيد الكربون , الهيدروكربونات غير المحترقة , السخام واكاسيد النتروجين). لقد وجد ان كل الملوثات قد انخفضت انبعاثاتها مع استخدام زيت الخروع مخلوطا بنسب مختلفة وهي 5% , 7% , و 10% . الانبعاث الاوطئ مع خلائط زيت الخروع تعود الى وجود الاوكسجين في البنية الكيمياوية لزيت الخروع وبكمية كافية سعيا الى الاحتراق التام. تم اجراء الاختبارات ضمن حدود نسبة مكافئة تتراوح بين 0.85 الى 1.7 . اظهرت النتائج ان خلط زيت الخروع مع زيت الغاز يحقق خفضا بالانبعاث بحدود 71.2% لأول أوكسيد الكربون ، 22.1% للهيدروكربون غير المحترق ، 37.8% لأكاسيد النتروجين و 29.6% للسخام مقارنة مع انبعاث زيت الغاز النقي . لكن الخلائط مع الكيروسين تظهر خفضا بالانبعاث بحدود 70.6% لأول أوكسيد الكربون ، 20% للهيدروكربون غير المحترق ، 35.8% لأكاسيد النتروجين و 29% للسخام مقارنة مع انبعاث الكيروسين النقي.

الكلمات المرشدة: زيت الخروع ، الزيوت النباتية ، التلوث ، الأنبعاثات ، غرف الأحتراق المستمر