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DROPLET SIZE MEASUREMENT OF BIODIESEL AND ITS BLENDS USING DISPERSION TECHNIQUE AND IMAGE PROCESSING

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Abstract: In present investigation a twin-fluid external mixing atomizer was designed and developed for fuel atomization which is used in liquid fuel burner. The droplet sizes (SMD) in the spray which was produced through the atomizer was measured experimentally. The experiments have been performed for different liquid fuel types, as well as for air to liquid mass flow rates (ALR), to study the effects of these parameters on droplet size (SMD).The liquid fuels used during the tests are biodiesel and its blends (biodiesel-diesel Bx and biodiesel-kerosene Bkx) with three values of ALR (0.6, 0.8 and 1.0).The droplets sizes were investigated for the region near-nozzle by using imaging setup and using dispersion technique. The images viewing regions 366.6 mm^2, to determine the droplet size (SMD). Matlab cod software has been used for a number of image processing techniques to identify and improve the detection of small droplets.The results showed that the increasing of biodiesel ratio in blending with diesel and kerosene increases the (SMD), and the increasing of ALR reduces the (SMD) for all experiments fuels. Also the results showed that the agreement is good of this method of SMD measurement and calculations with published studies.

Keywords: *Biodiesel, Sauter Mean Diameter (SMD), Shutter Speed, Atomizer, Image Processing.*

قياس قطر القطيرة لوقود الديزل الحيوي وخلائطه باستخدام تقنية التشتت ومعالجة الصور

الخلاصة: في هذا البحث تم تصنيع مرذذ نوع (external twin fluid-atomizer) وتطويره لغرض ترذيذ الوقود المستخدم في مشعل الوقود السائل. حيث تم قياس قطر القطيرات (SMD) في مجال الترذيذ الناتج من خلال المرذذ تجريبيا. واجراء التجارب لمجموعة مختلفة من الوقود السائل، كذلك استخدمت نسب مختلفة لتدفق كتلة هواء الترذيذ الى كتلة الوقود (ALR) لدراسة تأثيرات هذه المتغيرات على قطر القطـــــيرات (SMD). إن أنواع الوقود السائل المستخدمة أثناء الاختبارات هي وقود biodiesel وخلائطـــــه (-biodiesel diesel Bx, biodiesel-kerosene Bkx) عند ثلاث نسب ترذيذ (ALR=0.6, 0.8 and 1.0). تم اخذ الصور للقطيرات باستخدام منظومة التصوير عند المنطقة القريبة من فتحة المرذذ بمساحة 366.6 mm^2 واستخدام (dispersion technique) لتحديد حجم القطيرة (SMD) وذلك باستخدام برنامج Matlab لمعالجة الصور باستخدام تقنيات معالجة الصور لتحديد وتحسين الكشف عن القطيرات الصغيرة .أظهرت النتائج أن زيادة نسبة وقود الديزل الحيوي عند مزجه مع الديزل والكيروسين يزيد من (SMD)، وزيادةALR يقلل من (SMD) لجميع أنواع الوقود المستخدم في التجارب. كما اظهرت النتائج أيضا أن هذه الطريقة تتفق مع نتائج البحوث السابقة وهي طريقة فعالة.

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1. Introduction

Air-blast atomizers are better than pressure atomizers, because of their operating at lower pressure to produce a finer spray, air-fuel mixing enhanced, higher efficiency of combustion and turndown ratio is higher [1].

The principle of twin fluid atomizer using an external air to shear the liquid jet into droplets. The properties of liquid and geometry on the spray qualities of air blast atomizer have been registrant by Lefebvre [2]. The factors affecting on air blast imminent atomization are the relative velocity of liquid-air U_R, air to liquid ratio flow rates of atomization (ALR), and the surface tension of liquid. At high air velocity, the atomization occurs quickly, liquid viscosity and density of air to have minimum effects on the mean size of droplet. The air to liquid ratio (ALR) is effects on the atomization regimes drastically. At 3 ALR, good atomization with fine droplets can obtain. An increase of the ALR out this value does not increase the degree of atomization more. So there are many previous studies concerned on ALR.

C.D. Bolsze and V. G. McDonell [3] studied experimentally the effect of ALR on the performance of 30kW gas turbine engine fueled by biodiesel. The result show, the values of SMD decrease with ALR increase, and the optimum SMD is 19μm at ALR=0.65. Also the results showed that, the optimum value of emissions reduction where ALR=0.85. Caio Pereira, et.al [4]. Investigated the effect of ALR on SMD and the NOx and CO_2 emissions from diesel and biodiesel fuel combustion, using laboratory burner equipped with air-blast atomizer. The results showed that, the CO emissions from combustion of biodiesel and diesel are similar, around 20ppm and no effected by the SMD change also showed that the NOx emission is increase with ALR increase for both fuel.

Christopher D. Bolszo [5] carried out experiment tests on micro turbine generator (MTGs) to investigate the influence of ALR in the range (0.2-0.7) on SMD from measured values and calculation values using empirical equation of (Rizk and Lefebrve, 1984). They showed that, the trends of both empirical and measured carves of relation between ALR & SMD are similar, and the values of SMD decreasing with ALR increasing. J.M. Legg, et al.[6] studied the atomization performance of five type of fuel (Algae diesel, biodiesel, ethanol, diesel and F-76). The breakup of fuel investigated is done by using high speed cinematography &laser diffraction technique for droplets size measurement. The results showed that all characteristics of fuel atomization are similar, due to the flow conditions and the geometry of atomizer. Also at best condition of tests the range of drops size (10-25μm) for all fuels except the biodiesel, due to the high viscosity of biodiesel.

Cheng Tung and Simone Hochgreb [7] carried out experimental tests to compare the characteristics of palm biodiesel with baseline Jet-A1 fuel. The sprays of both fuel were atomized by using an air-blast atomizer, the comparison of these fuel was done under same atomization air-to-liquid ratio (ALR) with non-reacting spray condition. The measurements of the droplets characteristics were performed using Phase Doppler Anemometry (PDA). The results the size of palm biodiesel droplets are larger than Jet-A1 droplets, due to the effect of lower volatility and higher viscosity of biodiesel, the range of drops size according to radial locations are (13-42μm), (10-38μm) and (13-47μm) for diesel, Jet-A1 and biodiesel respectively.

Abdullah Adam et al [8] investigated the effect of injection pressure and ambient temperature on distribution of number density and diameter of fuel droplet in diesel fuel spray by using shadow-graph photography technique. The large number of fuel droplets was statistically analyzed by newly developed algorithm. Their results showed that the larger-size particles exist closer to the spray tip. Higher injection pressure promotes atomization and high ambient temperature has great effect on formation of small-size droplet at early time of injection period, especially at up and midstream of the spray. C. Crua*et al.* [1] investigated the atomization of diesel and biodiesel fuels near the nozzle region using a long working distance microscope. The light source and imaging optics were optimized to produce blur-free shadow graphic images of sprays with a viewing region of 593x784 μm. A number of image processing techniques were explored and described to identify both small and large droplets. The measured diameters were compensated based on an analysis of the droplets' local contrast and size.

Pipatpong Watanawanyoo *et al.* [9] designed and developed a twin-fluid atomizer used to experimentally investigation. In their research, the test liquid supply pressure was kept constant and the air flow rate through the atomizer was varied over a range of air supply pressure to obtain the variation in air liquid mass flow ratio (ALR) from 0.2 to 2.7. The results revealed that the air assisted atomizer had a capability to inject the test liquid in the range of the rates of 0.0019-0.00426 kg/s, with the use of air pressure supplied from 68.9 to 689 kPa. The images of the spray were obtained with a shadowgraph technique and analyzed to obtain the particle size and its distribution. Droplet size from twin-fluid atomizer had various sizes in the range of about 17-200 μm. The atomizer can be applied for aerosol and combustion purposes.

Cheng Tung Chong and Simone Hochgreb [10] conducted an experimental study of characterize the spray droplets of the reacting flames using a one Dimension phase Doppler anemometer (PDA). The PDA allows the simultaneous measurement of droplet velocity and size, where the droplet size is determined based on the measured phase shift difference between two Doppler bursts whilst the droplet velocity is derived from the Doppler burst frequency. The PDA measurements were performed at the downstream axial locations of z = 30, 50 and 80 mm from the burner outlet (z = 0). At each axial plane, the measurement volume was traversed radially across the burner centerline to obtain the distributions of droplet size.

Tanasawa and Nukiyama [11] studied the rendering of a plain-jet type air-blast atomizer and derived an empirical equation of Sauter mean diameter (SMD). They found that the orifice diameter has no impact on mean drop size. Lefebvre and Lorenzetto [12] found that the plain-jet air-blast atomizer produces for low liquids viscosity have inverse relation of relative velocity with air. Also noted that the liquid orifice size has few impacts on the mean drop size for low viscosity liquids according to their empirical equation (1).

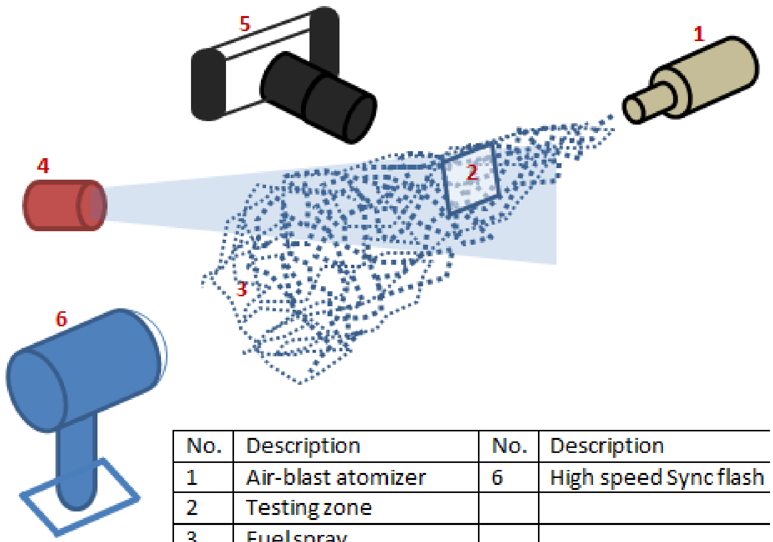
The previous studies have been conducted to investigate the atomization of conventional liquid fuels, biodiesel and some blends. Different methods were used to measure the droplet size (SMD). It can be seen from the available literatures that there are a shortage in dealing with two types of blending and the values range of blending.

The objective of this work to fill part of this research gap by study the effect of fuel type (diesel, kerosene, biodiesel, and their blending) and ALR on atomization quality (SMD) by using dispersion technique and image processing. The results of this study are expected to provide some insights into understanding the correlation between biodiesel blends (Bx and Bkx) and ALR and atomization quality (SMD).

2. Experimental Setup and Procedure

2.1. Droplet size Measurement System

In this study, the drop sizes were measured with a system arranged for this purpose with a new configuration as shown in Fig.1 and Fig. 2 , the system consists of high power led light, external high speed Sync 1/8000s TTL flash with auto trigger to ensure the image capture at high shutter speed and high speed camera Nikon 7100 with 1/8000s shutter speed 24Mbixel equipped with macro lens sigma 105mm and extension tubes, to great the view of the image that help to measure the droplet diameter Fig. 1. To determine the droplet size and sauter mean diameter (SMD), (Matlab cod) software has been used as image processing program.



No.	Description	No.	Description
1	Air-blast atomizer	6	High speed Sync flash
2	Testing zone		
3	Fuel spray		
4	High power led light		
5	High speed camera		

Fig.1:3D Schematic diagram of Droplet imaging system.

Fig.2: Photo of droplet imaging system

2.2 Air Blast Atomizer

A non-reacting and reacting atomization facility is utilized to investigate biodiesel and it's blending with kerosene and diesel. Sprays established via modified an external mix air blast atomizer. The air and fuel orifice diameter are (da=2.5mm) and (df =1.5mm) respectively, the details of the atomizer geometry shown in Fig. 3.

To determine ALR through the airblast atomizer, using calibrated air and fuel flow meter Fig. 4.

2.3 Preparation of Biodiesel Blending

The biodiesel blends prepared for the experiments by mixing the two fuels volumetrically. Biodiesel is mixing with diesel and kerosene with no layer separation or emulsions was observed. The physicochemical properties of the blends tested in fuel laboratory, mechanical engineering department, University of Technology, Table 1and 2.

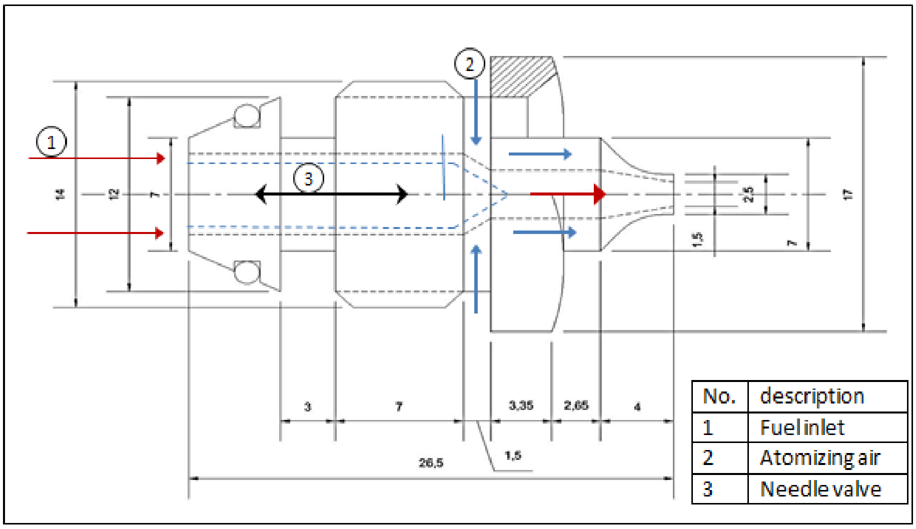


Fig.3: The atomizer geometry

Fig.4: Photo of atomization air flow meter, Photo of fuel flow meter.

Table 1: The physicochemical properties of the biodiesel, diesel and it's blends

Properties	Blending range					Limits
	0:100	20:80	35:65	50:50	100:0	
	B100	B20	B35	B50	D100	
Density kg/m^3	875	855	859	862	850	815-870
Viscosity cSt (40 ^{0}C)	4.92	3.22	3.54	3.86	2.8	2-5
Flash point ^{o}C	176	89	105	121	67	Min60 diesel Min100 biodiesel
Cloud point ^{o}C	4	-1	0	2	-	Max 18
Pour point	2	-3	-2	-1	-7	Max 18
Cetane index	67.4	57.4	59	60.3	53	48-67

Table 2: The physicochemical properties of the biodiesel, kerosene and it's blends

Proper.	Blending range					Limits
	0:100	20:80	35:65	50:50	100:0	
	Bk100	Bk20	Bk35	Bk50	K100	
Density kg/m^3	875	820	830	841	807	815-870
Viscosity cSt (40 ^{0}C)	4.92	2.1	2.6	3.15	1.38	2-5
Flash point ^{o}C	176	71.2	91	110.5	45	Min60 diesel Min100 biodiesel
Cloud point^{o}C	4	-2	0	2	-	Max 18
Pour point	2	-4	-3	-1	-7	Max 18
Cetane index	67.4	50.2	51.3	52.5	-	48-67

2.4 The Experiments Data Sheet

Table 3 show data sheet of each test conditions of fuels and blending including $\dot{m}_{\text{atomiz-air}}$, $\dot{m}_{\text{fuel}}$, ALR and blending ratio for heating load=12.2kW.

Table 3: atomization-air to fuel mass flow rate ratio (ALR) according to the values of mass flow rate of each fuel =12.2kW as heat load.

	ALR=0.6		ALR=0.8		ALR=1.0	
Fuel type	$\dot{m}_{air}$ g/s	$\dot{m}_{fuel}$ g/s	$\dot{m}_{air}$ g/s	$\dot{m}_{fuel}$ g/s	$\dot{m}_{air}$ g/s	$\dot{m}_{fuel}$ g/s
B100	0.198	0.330	0.226	0.330	0.330	0.330
B20	0.175	0.292	0.233	0.292	0.292	0.292
B35	0.179	0.980	0.238	0.980	0.980	0.980
B50	0.183	0.305	0.245	0.305	0.305	0.305
D100	0.170	0.283	0.260	0.283	0.283	0.283
Bk20	0.175	0.290	0.237	0.290	0.290	0.290
Bk35	0.179	0.298	0.238	0.298	0.298	0.298
Bk50	0.183	0.300	0.244	0.300	0.300	0.300
K100	0.169	0.282	0.220	0.282	0.282	0.282

2.5 Droplet size Measurements

The ALR effect on droplet size was examined. SMD is defined as the diameter of a sphere that has the same volume/surface are a ratio as a particle of interest, SMD= $\Sigma N_i D^3{}_i / \Sigma N_i D^2 i$, where Ni is the number of drops and Di is middle diameter of size range i. This notation is the distributions of droplet SMD profiles on one side of the centerline at downstream locations of x = 180 mm.

All droplets images were taken at same location at exit nozzle of atomizer with images viewing regions 366.6 mm^2, using the 1/8000s shutter speed, 1:1 magnification, 24Mb, 200kW led light and 1/64 high speed flash light. The images were transferred to PC and calculated SMD used image processing program (Matlab) code Fig.5.

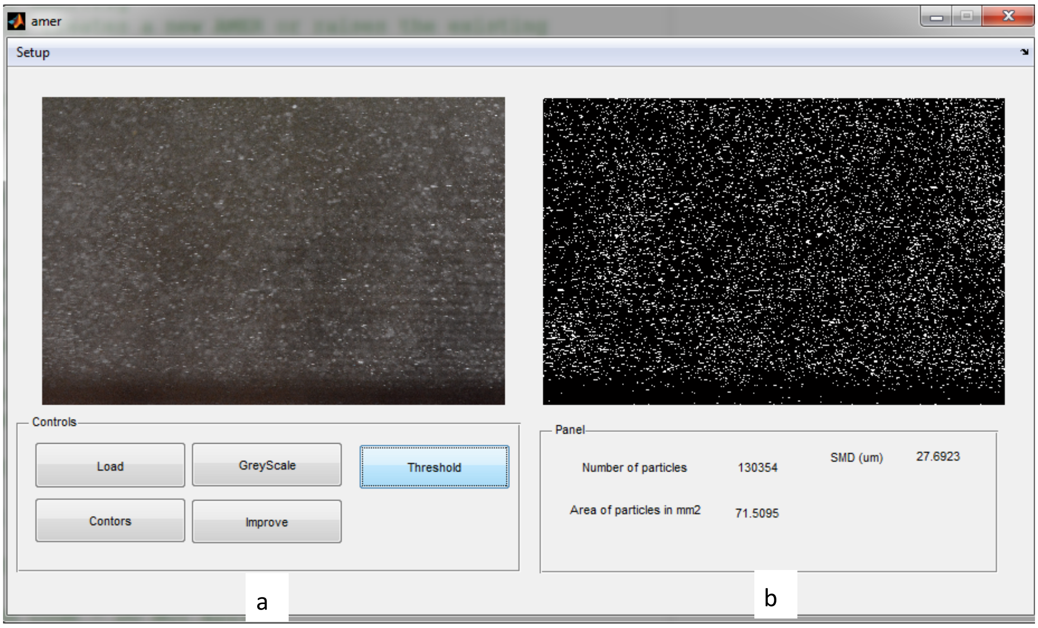


Fig.5: Photo of a. droplets image before processing, b. after processing

3. Results and Discussion

3.1 Effect of ALR upon Droplet Size (SMD)

Fig. 6 and 7 shows set of results from the experimental work which summarizes the effect of ALR on the (SMD) for experiments fuels, where the marks on the figures represent the experimental results. It can be observed that the SMD decreases with ALR increases for all types of fuel and their blending, due to the high velocity of atomizing air which provide high concentration shear force to break up the liquid jet to fine droplets. The percent of SMD decreases for all fuel types about 20% and 35% for ALR 0.8 and 1.0 respectively.

3.2 Effect of Fuel Type and Blending on Droplet Size (SMD)

The effect of fuel type on droplet size (SMD) are demonstrated in Fig. 6 and 7 respectively. It can be observed that the kerosene droplet (SMD) is 22% lower than diesel droplet and lower than biodiesel SMD about 31%. This is because kerosene has lower surface tension and kinematic viscosity values compared to diesel and biodiesel, which has higher breakup and disintegration compared to diesel and biodiesel, therefore the increases of biodiesel percent in blending are increases the SMD values, due to the higher viscosity of biodiesel compared to other fuels for all ratios of atomization air to fuel (ALR).

3.3 Comparison with the Other Works

In order to verify the validity of the experimental results, the results of the present work plotted together with the published data. Fig. 8 illustrates a comparison between the present results of SMD values of B100, B20, and Bk20, with the published experimental and empirical results of some investigators. The present results of SMD at B100 show that they have same curves trends according to ALR and fuel type especially with J. M. Legg [6] and Lorenzetto and Lefebvre [12].The Caio et al results [4] showed lower SMD values than present work, due to the geometry differences in atomizer and the conditions of experiments.

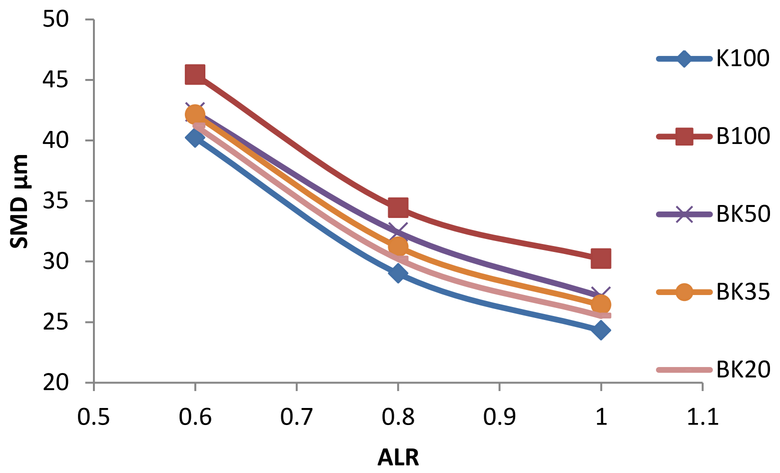


Fig. 6: Variation of Sauter mean diameter (SMD) with atomization ratio (ALR) of BK blends.

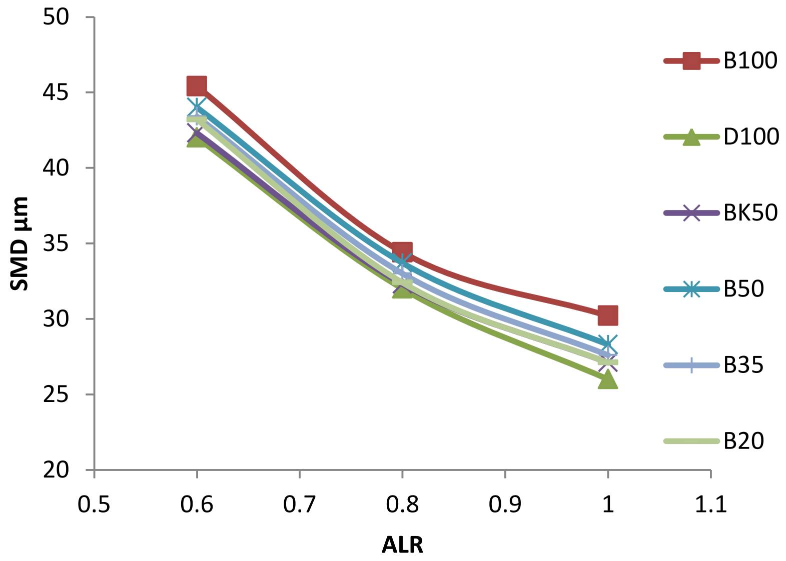


Fig. 7: Variation of Sauter mean diameter (SMD) with atomization ratio (ALR) of B blends.

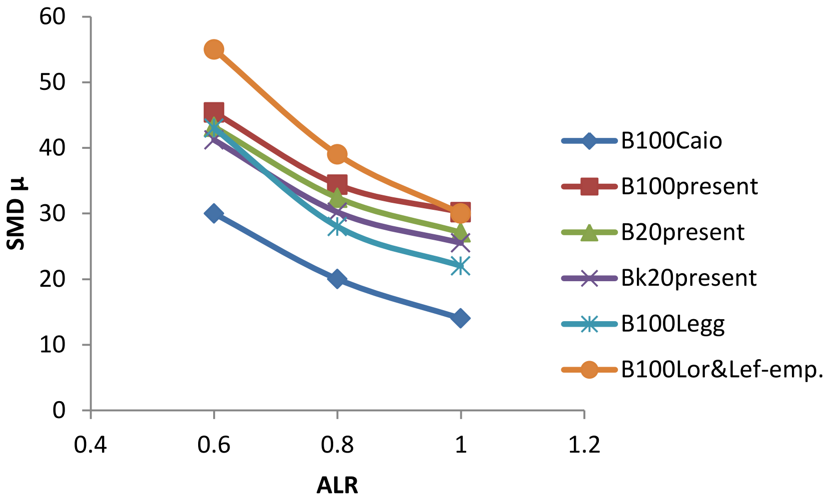


Fig. 8: Comparison of present results (exp.) of SMD with the published results.

4. Conclusions

The properties of spray and atomization of air-blast atomizer were examined by using high-speed flash light dispersion technique. The effect of ALR and fuel type on the properties of droplets was studied.

The following conclusions can be drawn from the present study:

1. The differences of SMD values between all fuels and blends are reduced when ALR is increased. This trend is well consistent with experimental and empirical formulas developed by previous researchers using similar spray configuration.
2. The test method of SMD in present work is in good agreement with other methods.
3. The variation of the ALR as a control parameter can be used to improve the SMD values in the burner causing more efficient combustion.
4. The results of SMD show dependence on the specifications of liquid fuels.
5. For both blends (Bx and Bks) the SMD value increases with the increasing of biodiesel percent in the blend.
6. The physical specifications of the fuel, surface tension and viscosity in particular, have direct impact on the SMD values.

5. References

1. C. Crua*, G. de Sercey, M. R. Heikal, (2012)." *Dropsizing of Near-Nozzle Diesel and RME Sprays by Microscopic Imaging*".*12th Triennial International Conference on Liquid Atomization and Spray Systems, Heidelberg, Germany.*
2. A. H. Lefebvre, (1980). "*Airblast atomization*". *Prog. Energy Combust. Sci.*, vol. 6, pp. 233-261.
3. C.D. Bolszo, V.G. McDonell, (2009). " *Emissions optimization of a biodiesel fired gas turbine*". Proceedings of the Combustion Institute 32 ,pp. 2949–2956.

4. Caio Pereira, Gongliang Wang, M_ario Costa, (2014). "Combustion *of biodiesel in a large-scale laboratory furnace*". Energy 74,pp. 950-955.
5. Christopher D. Bolszo,(2005)."*Investigation of Atomization, Mixing and Pollutant Emissions for a Microturbine Engine*". The U C I research journal, pp. 13-22.
6. J. M. Legg, A. A. Narvaez, V. G. McDonell, (2012)." *Performance of Algae-Derived Renewable Diesel in a Twin-Fluid Airblast Atomizer*". *Triennial International Conference on Liquid Atomization and Spray Systems, Heidelberg, Germany, September 2-6.*
7. Cheng Tung Chong, Simone Hochgreb, (2015)."*Spray and combustion characteristics of biodiesel: Non-reacting and reacting*". International Bio-deterioration & Bio-degradation, 102, pp. 353-360.
8. Abdullah Adam, Mamat Rizalman, and TomoakiYatsufusa, (2015)." *Analysis of Diesel Spray Droplets Behavior Using Shadowgraph Technique Images*". International Journal of Materials, Mechanics and Manufacturing, *Vol. 3, No. 1, February.*
9. Pipatpong Watanawanyooa* , Hiroyuki Hiraharab Hirofumi Mochidac, Teruyuki Furukawad, Masanori Nakamurae and Sumpun Chaitepf, (2011)." *Experimental Investigations on Spray Characteristics in Twin-Fluid Atomizer*". International Conference On Advances In Engineering.
10. Cheng Tung Chong and Simone Hochgreb b,(2014)." *Spray flame structure of rapeseed biodiesel and Jet-A1 fuel*". Science Direct, Fuel 115, pp. 551–558
11. S. Nukiyama and Y. Tanasawa, (1939). "*Experiments on the atomization of liquid in an airstream".* Trans.Soc, Mech. Engrs. Japan, vol. 5, pp. 68-75.
12. G. E. Lorenzetto and A. H. Lefebvre, (1977). "*Measurements of drop size on a plain jet airblast atomization*". *AIAA J.*, vol. 15, pp. 1006-1010.