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ATOMIZATION OF FUEL MIXTURES

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The combustion process of a coal/oil slurry begins by atomization of the slurry. This project is a presentation of experimental system and results on atomization of coal/oil(COM) and coal/methanol mixtures with a twin-fluid and a wheel atomizer. The slurries are consisted of coal/methanol and coal/oil mixtures with two different concentrations and two coal particile sizes. The volume median diameters of the coal particles were 45 and 130 microns. The oil was No. 2 diesel oil. The droplet size was determined by photographing the spray and the photographs were analyzed to determine droplet size and distribution. The results show that the inclusion of particles in the liquid(both methanol and diesel oil) does not appreciably affect the atomized droplet size. The tendency is for the slurry droplets to be somewhat smaller than the droplets atomized with the pure liquid.

Key Words : Atomization, Fuel Mixture, COM

1. INTRODUCTION

It is essential that energy resources be sued effectively and efficiently. Coal is one fossil fuel available is sufficient quantities which, if developed properly, could reduce dependence on petroleum. COM and CWM (coal/water mixtures) were initially intended for use in power plants, but additional ways of using COM and CWM now encompass their use as a replacement for diesel engin fuel(Annual Books of ASTM Standards, 1979)

Increased use of coal requires solutions to technical problems associated with mining, processing, transporting, uttilization and pollution control. Many directions for coal processing, including liquification and gasification, have been proposed. One other direction, the genesis of this project, is the direct mixing of solid coal particles with liquid fuels. This approach is attractive in the short run because it could replace a sizeable percentage of the petroleum used in oil-fired power plants with minium modification to the furnace. Before an assessment can be made of the types of retrofit modifications necessary, information is needed about the effect of the presence of coal particles on the fundamentals of atomization, vaporization, and combustion. Each of these processes may be affected by parameters such as loading rations, coal and droplet sizes and fluid properties.

Although the spraying of mixtures has been a routine process in the spray drying industry(Masters, 1976), there appears to be little data on the effect of mixture properties on droplet size. Fundamental studies performed at Brookhaven laboratory(Butcher, Pucci and Krishna, 1979), using a twin-fluid atomizer, have shown that the Sauter mean diameter for 20% COM was not significantly different than that for pure oil. The argument is made that the influence of coal should increase drop size as the concentration increases. The effects of coal particles size and atomizer type were not reported. The objective of this project was to obtain fundamental information concerning the atomization of coal -methanol mixture and COM.

2. MIXTURE PREPARATION AND IXTURE HANDLING SYSTEM

The pulverized coal was prepared by crushing the coal with a jaw crusher and a roll crusher and finally pulverizing the coal with a laboratory grinder. The coal particles were cut at 100 microns with a classifier. Coal smaller than 100 microns had a volume median diameter of 45 microns as easured by a Coulter counter (model TAII). The above 100 micron coal was further cut with a 200 micron sieve to yield a volume median diameter of 130 microns. The distributions are shown in Fig. 1.

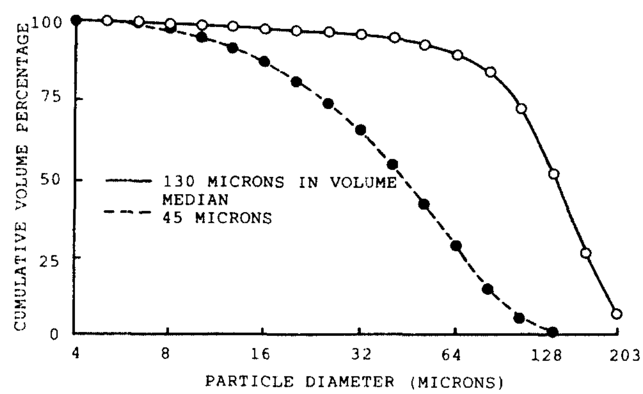

Fig. 1 Coal particle distribution

The degine of the mixture handling system was done following criteria(Crow, Eddie, 1981). (a) The photographic technique required steady state run times on the order of four minutes to allow approximately 20 exposures to be taken. (b) Steady state operation with constant flow conditions was necessary. These conditions include uniformity of mixture delivery to the atomizer(constant loading), symmetry of the hollow-cone spray in the test section, and constnt mixture supply pressure and air pressure. (c) The apparatus had to be convenient and easy to operate. These features included a straightforward method for mixture transfer to and from the apparatus, good acesss for maintenance and clean up, and ample room for set-up of the photographic apparatus.

After considering several arrangements, it was decided to design the tank and pumping system as shown in Fig. 2. The tank was oriented vertically with an access port for cleaning located in the top. The rotaryt pump manufactured by Oberdorfer was selected. It had a pumping capability of about 30 gallon/min. To reduce pressure drop in the mixing lines, 4 in. pipes identical in size with the inlet and outlet sizes of pump were used.

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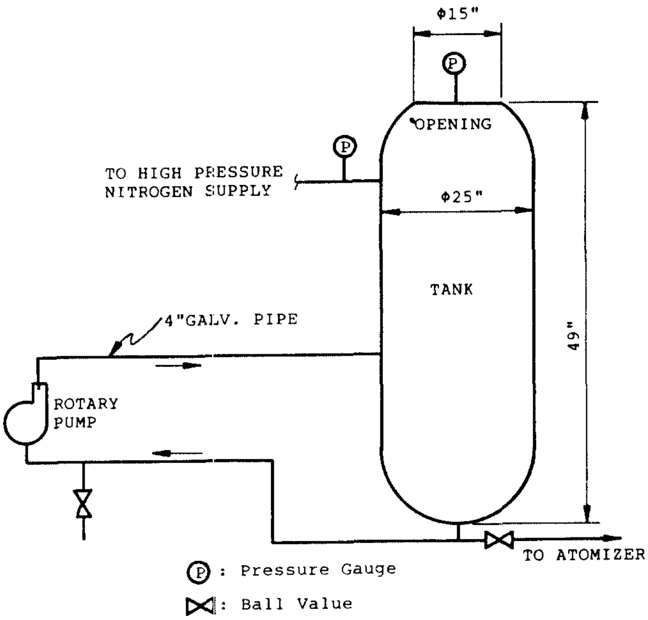


Fig. 2 Mixture handling system

3. TWIN-FLUID ATOMIZATION

The Delevan model 32668 in-line swirl air atomizing nozzle was selected based on the following features :

- Droplet size control provided by minor changes in air supply pressure
- Large fluid passages allowing flow of coal particles

The internal design of the nozzle is shown in Fig. 3. Air is introduced tangentially into the mixing chamber in a low pressure region of the swirling liquid creating high turbulence conditions and primary atomization. As the mixture leaves the orifice, it impinges against the pintle plate which serves a dual purpose ; fine control of spray angle and secondary air atomization causing even further break-up to finer droplets. The capacity of the nozzle was normally 4 gallon/min achievable with a maximum air supply pressure of 70 psig and mixture supply pressure of 106 psig. These values represent facotry calibrations using water only. The nozzle cap and pintle plate were made of wear-resistant 440 stainless steel, chosen for maximum survivability in this abrasive environment.

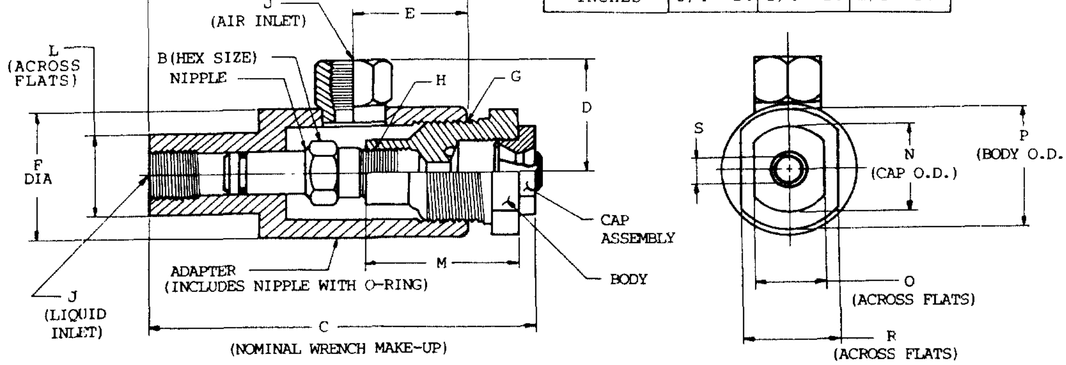
3.1 Photography Method for Twin-Fluid Atomization

The Original photographic system consisted of a camera mounted on a microscope, a short duration, high-intensity light source, coupled with a condensing lens and a spray chamber(24 in. × 24 in. × 36 in.). Optical access to the chamber was provided by windows purged with a high velocity air stream issuing from a plannar nozzle at the top of the window. The film used for this photography was 24mm×36mm, which covered a spray field 2.4mm×3.6mm at a magnification ration of 40X. These large magnifications severely restrict the field of view. After many trials, the photography of the original system was abandoned. Another attempt at photography with a smaller spray chamber and a modified air cleaning system was done.

Redesign of the chamber was based on having a sufficient number of droplets in the sample volume for photography and analysis and ensuring a clean microscope lens. The spray from twin-fluid atomizers has a cone-type configuration so the number density of droplets increased rapidly as the sampling volume approached the nozzle, incomplete atomization occurs. The distance of 4 in. between nozzle and test section was chosen based on previous experience with the MgO method. The dimensions of the chamber shown in Fig. 4 were 4 in. × 8 in. and 20 in. high.

An air purging system which produced a cyclonic flow was designed to clean the two windows of the spray chamber. The air was directed toward the inside surface of the glass window. A cylinder was connected to the window to penetrate the spray and prevent excessive attenuation of the light by the dark spray. It was found, however, that this cylinder seriously affected the flow field in the chamber and created undesirable liquid flow patterns on the chamber wall. After many futile attempts, the cylinder and two windows were removed from the spray chamber, leaving two holes and an air-purge system on the microscope-camera side. The air -purge was directed toward the inside of the chamber. These modifications maintained a very clean microscope lens and a

DIMENSIONS	G	H	J
INCHES	3/4"-14	1/4"-18	1/2"-14



DIMENSIONS	A	B	C	D	E	F	L	M	N	O	P	R	S
INCHES	4.750	0.625	5.620	1.560	2.300	1.625	1.250	2.125	0.865	0.750	1.050	0.875	0.169

Fig. 3 Twin-fluid atomizer[Delavan Industrial Nozzles and Accessories, 1985(Catalog)]

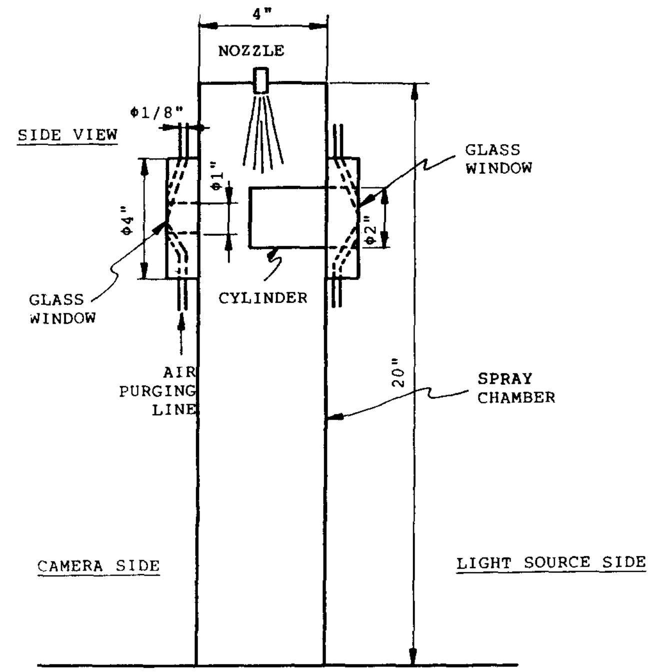


Fig. 4 Photographic system

sufficient intensity of the incident light. The diameter of the hole for the microscope was 1 in. and the hole for the light source was 2 in. The purge air flow rate was controlled by a ball valve at a rate which did not disturb the spray field inside the chamber and which maintained a microscope lens. The set-up of the photographic system is shown in Fig. 5.

A twin-fluid atomizer, attached with moveable holder, was positioned at the mid-point of the top cover of the spray chamber. This atomizer was connected directly to the mixture delivery line. The same camera-microscope combination as was used previously was used. This microscope had five magnification ratios of which 30X was used most frequently. Two film types were used. ASA 30 film was used for the pure liquid spray and ASA 400 for mixtures because the dark mixture attenuates the incident light significantly. A microscope, a light and two holes were carefully aligned. The distance from the axis of spray cone to the lens of microscope has to be greater than 4 in. owing to 4 in. focal length of microscope and a hollow cone type of spray. The

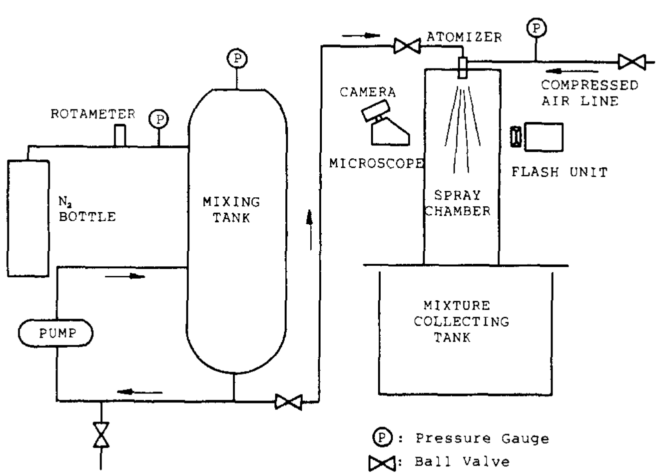


Fig. 5 Photographic system

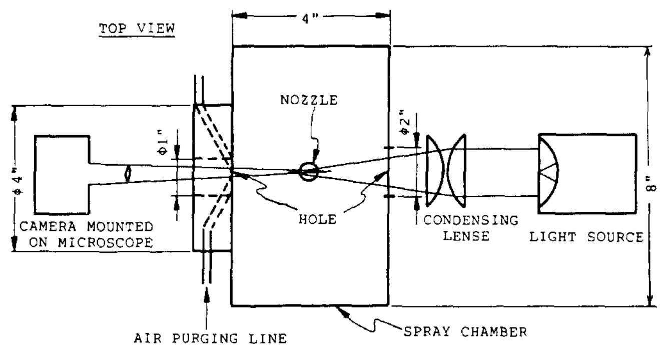


Fig. 6 Layout of experimental system

light source is a half microsecond duration, high intensity EGG type light with a condensing lens. It is located at about 8 in. from the axis of the spray cone. But this distance is not a critical factor for good droplet images. Fig. 6 shows the overall layout of the experimental system.

3.2 Data Analysis and Results

With this arrangement of the system, about 100 pictures on each operational condition shown in Table 1 and Table 2 are taken directly from the fuel spray at a point, 4 inches in distance from a nozzle exit. The lens was opened so the

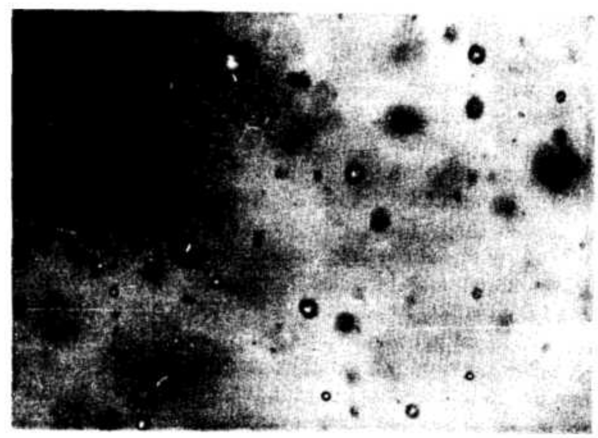


Fig. 7 Picture of droplets

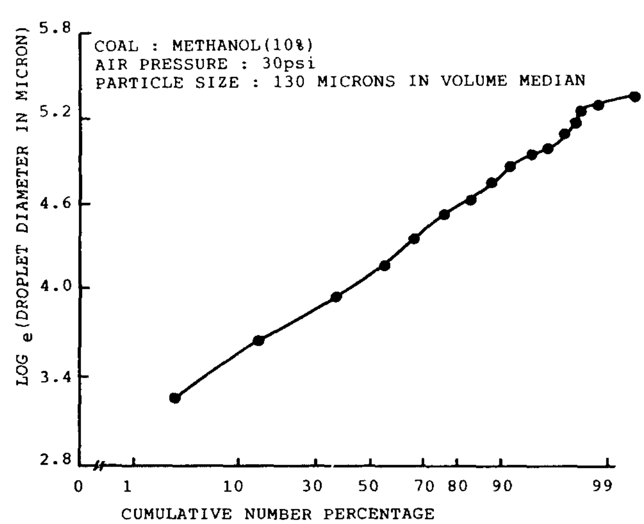


Fig. 8 Probability graph

exposure time was determined by the duration of the flash. These pictures are developed and the negative films shown in Fig. 7 are enlarged 10 times on white papers. The sizes of droplets are measured directly from the enlarged images of droplets on the papers. Each negative film has 10 to 20 clear droplet images. 1500 to 2000 droplet images are measureed and data is accumlated. This accumulated is plotted on the probability graph as shown in Fig. 8 from which the number median diameter of droplet distribution is found at a 50 percent point.

The following table summarizes the experimental results. The moninal liquid flow rate was 4 gallons per minute.

4. WHEEL ATOMIZATION

Wheel atomization is a rotary atomization in which the liquid is disintegrated into many droplets by accelerating centrifugally the feed liquid to a high velocity before discharge. The ligaments of liquid are equally distributied along the wheel and these ligaments disintegrate into many droplets due to the kinetic energy of the liquid. The degree of atomization depends on wheel speed, feed rate, liquid properties and atomizer design.

Table 1 Experimental results for the twin-fluid atomizer

Number median diameter of droplets in microns					
Coal particle size in volume median		45 microns		130 microns	
Air-atomizing pressure		30 psi	60 psi	30 psi	60 psi
Fluid	Methanol	76	60	76	60
	10% coal-methanol	66	49	66	60
	20% coal-methanol	63	46	60	52
	D-2 diesel oil	87	69	87	69
	10% coal-oil	84	59	82	64
	20% coal-oil	84	60	83	62

The wheel atomizer unit is shown in Fig. 9. The wheel, fabricated from aluminum, was 4 in. in diameter and had forty 3/22 inch holes. The veriable speed motor had a maximum rotational rate of 1450 rpm. The mixture was supplied through a stationalry tube to the inner part of the rotating wheel and expanded radially towards the rim. In the central portion of a wheel, friction between the mixture and the inner surfaces of the wheel cause the mixture to rotate. The mixture ultimately rotates at the wheel speed when it escapes through the holes.

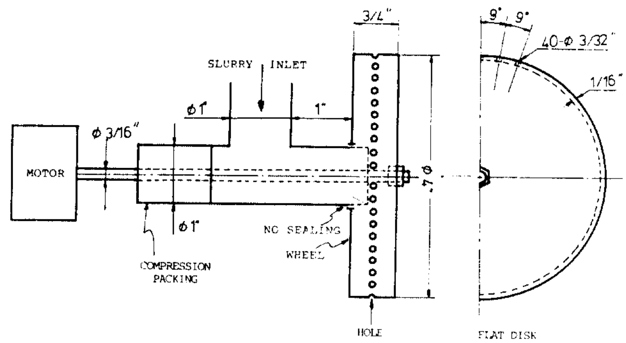


Fig. 9 Wheel atomizer

4.1 Photography Method for Wheel Atomization

The pattern of spray produced by a wheel atomizer is a very flat circular sheet. The problem in the spray chamber design was how to confine whole spray to a limited space in such a way as to not disturb the spray at the test section. The resulting design is shown in Fig. 10. The chamber had two holes for photography without any purge air. An adjustable mounting for the atomizer permitted positioning the atomizer an adequate distance from the test section. The chamber design inhibited the splashing of the droplets and allowed the liquid to flow smoothly down the side opposite the camera. This design prevented droplets, other than those issued directly by the wheel, from entering the sample volume.

The distance between the periphery of the wheel and the test section was 5 in., which was found, through several trial positions, to be optimum. If an atomizer is located too close to the test section, only ligaments appear at the test section. On the other hand, if it is too far from the atomizer, too few droplets appear in the field of vision to yield sufficient data

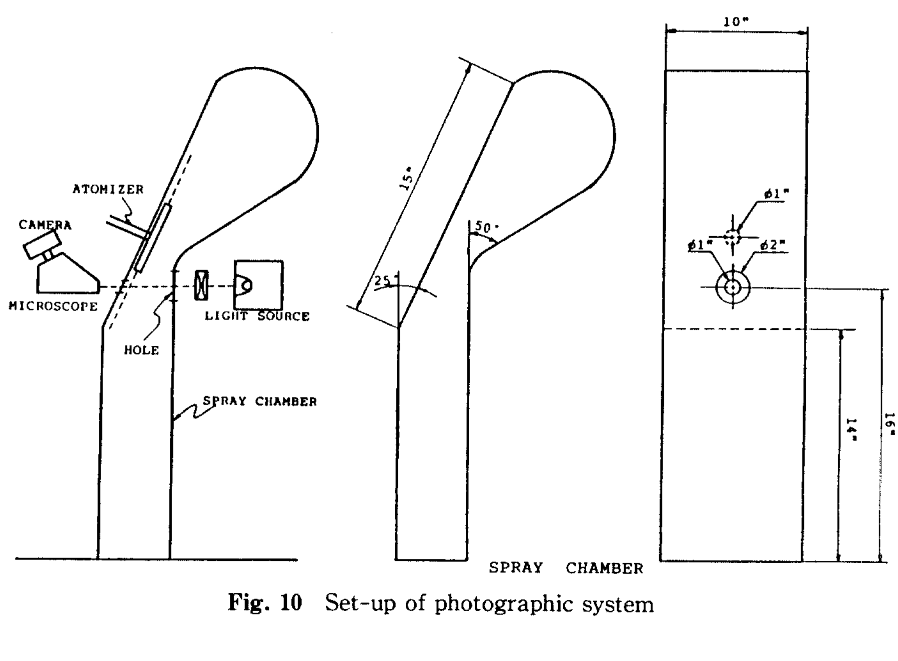


Fig. 10 Set-up of photographic system

per frame. The set-up of the photographic system is shown in Fig. 10. The same overall layout of the experimental system as in Fig. 6 is used even if a spray chamber is replaced by a new spray chamber in Fig. 10 and an atomizing air line is cut.

4.2 Data Analysis and Results

The data reduction procedure is the same as described for the twin-fluid atomizer. An interesting trend in the data was the appearance of a bimodal distribution of droplet size. This trend became more predominant as the wheel speed was reduced. Pictures of droplets are shown in Fig. 11 and a typical distribution is shown in Fig. 12.

The experimental results are shown in Table 2. The nominal liquid flow rate was 4 gallons per minute.

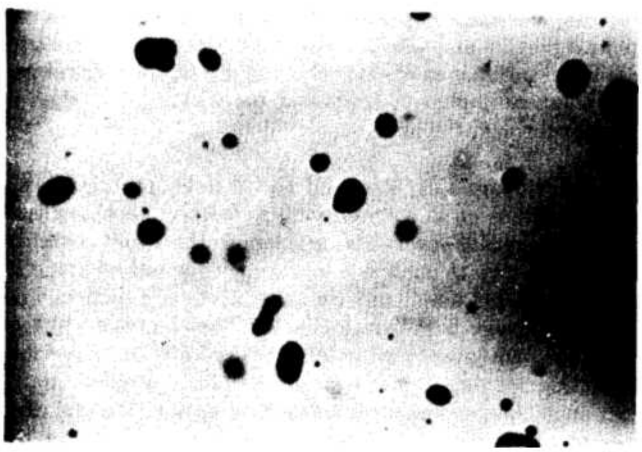


Fig. 11 Picture of droplets

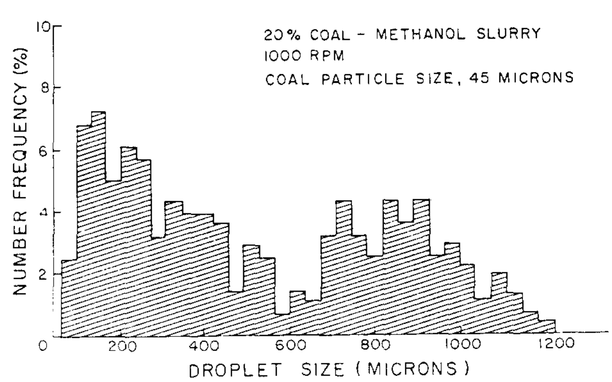


Fig. 12 Distribution of droplets

Table 2 Experimental results for wheel atomizer

	Number median diameter of droplets in microns				
	Coal particle size in volume median	45 microns		130 microns	
	Wheel speed	1000 rpm	1400 rpm	1000 rpm	1400 rpm
Fluid	Methanol	472	360	472	360
	10% coal-methanol	436	290	345	254
	20% coal-methanol	418	327	418	298
	D-2 diesel oil	509	436	509	436
	10% coal-oil	494	404	356	323
	20% coal-oil	500	389	429	362

5. EVALUATION OF EXPERIMENTAL RESULTS

5.1 Twin-Fluid Atomization

The expected decrease in droplet size with increased atomizing air pressure is evident. Pure diesel oil produced droplets somewhat larger than pure methanol. This is likely due to the larger viscosity of the diesel oil as shown in Table 3. The data suggests that the presence of the coal particles tends to reduce the atomized droplet size but the effect is minimal. This observation is consistent with the experimental data reported in reference (Butcher et al., 1979). An analysis of the coal particles with a volume median diameter of 130 microns showed many fine particles which shifted the number median diameter as low as 10 microns. Thus, there were very few particles larger than the observed number mean diameter of the droplets so the effect of the big particles should not be significant.

Table 3 Comparison of prosperties of methanol and diesel oil

Liguids	Specific qravity	Kinematic viscosity	Surface tension
Methanol	0.76	$0.78mm^2/s$	22.6 dyne/m
D-2 diesel oil	0.76-0.953	$1.9\text{-}4.1mm^2/s$	26 dyne/m

5.2 Wheel Atomization

Increasing the rotational speed of the wheel produces smaller droplets of pure liquid and mixture. The droplets produced by the wheel atomizer are an order of magnitude larger than those generated by the twin-fluid atomizer. Commercial wheel atomizers produce smaller droplets because of the higher wheel speeds achievable. The data show, as expected, that increasing the wheel speed leads to a smaller droplet. The presence of coal in the mixtures appears to reduce the droplet size but the trend is not significant. The effect of coal on the droplet size of the COM follows a similar trend but, once again, is not significant.

6. CONCLUSION

The presence of coal in coal/methanol mixtures and COM at concentrations up to 20 percent does not appreciably affect the droplet size generated by twin-fluid and wheel atomizers. The trend is a reduction in droplet size due to the presence of coal.

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