Characterization of Flow and Spray Behavior of Gelled Fuels with Regard to Air Blast and Impinging Jet Atomizers

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ABSTRACT

The spray behavior of different gelled fuels based on Jet A-1, has been investigated with two different atomizer types, i.e. an air blast atomizer with an annular coaxial air flow and a doublet like-on-like impinging jet atomizer. The characteristics of the jet breakup process of both injector types have been visualized by means of the shadowgraph technique. For the air blast atomizer different breakup regimes have been observed with increasing momentum flux ratio for the 3 investigated fuels. For the impinging jet atomizer the formation of a gel sheet has been observed, which is located at the intersection point of both gel jets and which is perpendicular oriented to the injector plane. Also the flow behavior in cylindrical and slightly conical tubes of gelled fuels, whose viscosity is shear rate dependent, has been described with analytical assumptions.

1.0 INTRODUCTION

Gelled fuels and propellants are today of increasing interest for propulsion systems, because of their safety and performance benefits [1,2]. Mission profiles of future missiles with variable thrust levels require engines with a high throttleability, eventually up to a complete engine shut down and subsequent reignition. Gelled fuels and propellants offer the possibility to build throttleable engines, which have similar simple handling characteristics like motors with solid fuels or propellants due to their shear-rate dependent non-Newtonian fluid flow behavior. The addition of gelling agents to conventional liquid fuels and the conduction of a gellation process changes the rheological properties significantly. These gelled fuels and propellants can be described as shear thinning or viscoelastic fluids, which show decreasing viscosity values with increasing shear rates. Without any applied shear they are more or less non-flowable with very high dynamic shear viscosity values and also often with a so called “yield stress” so that this state often is described as “semi-solid”. Therewith not only the leakage behavior is significantly decreased but also ignition can only occur at the interface between the gelled fuel and oxidizer in cases of accidental spillage of hypergolic systems or if an ignition source is present. Applying high shear rates during the injection process, however, it is possible to reach low viscosity values and even possibly liquefaction in the area near the injector exit plane. So these fluids can be fed to an injector and thrust variation can be realized by variation of the mass flow rate similar to engines with liquid fuels. Further advantages of engines with gelled fuels are summarized in Tab. 1 and are rated in comparison to engines with solid and liquid fuels, whereas the + sign marks advantage and the – sign disadvantage. Consequently can be said that gelled propellants combine many of the advantages of liquid and solid fuels and propellants.

Table 1: Comparison of Missile Propulsion Systems with Solid, Liquid and Gelled Fuels and Propellants

<table>
<thead>
<tr>
<th></th>
<th>Solid</th>
<th>Liquid</th>
<th>Gel</th>
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</thead>
<tbody>
<tr>
<td>Throttleability</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Defined engine shut down</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Re-ignitability</td>
<td>±</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Handling characteristics</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

The following characteristics should be pronounced as low as possible (+ = low):

<table>
<thead>
<tr>
<th></th>
<th>Solid</th>
<th>Liquid</th>
<th>Gel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidental ignition</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Leakage behavior</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Sensitivity to impact, friction, electrical discharge, etc.</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Sensitivity to cracks, etc.</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Sedimentation of particle additives</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Boil-off</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Fuel movement and slosh in tank</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

Due to the fact that there exist only few investigations on the flow behavior and especially on the spray visualization and characterization of gelled fuels with regard to propulsion applications, e.g. [3,4], the aim of the basic investigation presented here is to get a better insight in the flow behavior and the occurring processes of jet break-up and atomization of these non-newtonian fluids. For this task both a commercial available air assist atomizer and a basic set-up for impinging jet atomization have been chosen. The air blast atomizer with an annular coaxial air flow and integrated swirlers is useful for the atomization of viscous media according to the declaration of the manufacturer. The second injector type is a modular like-on-like doublet impinging jet atomizer set-up with two identical and “round” jets and commercial available nozzles. This second injector type has been chosen, because it is often used in liquid rocket engines due to its simplicity and its good atomization and mixing characteristics as has been described in earlier publications, see e.g. Refs. [5,6].

2.0 HISTORY OF GEL PROPULSION

It is reported, that already since ca. the 60’s efforts have been made continuously to use gelled propellant systems for missile propulsion in the United States [7]. In this early time period the US Air Force formulated hydrazine gels with aluminum and beryllium particles for liquid rocket and advanced propulsion systems, while the US Navy investigated hydrazine / nitric acid bi-propellants. In the 70’s US work was mainly focused on fuel/oxidizer combinations of gelled fuels based on hydrazine derivatives and gelled inhibited red fuming nitric acid (IRFNA), with and without metal additives. After a decline after the mid 70’s, due to the fact that no operable gel-based missile-system could be developed, gel fuels got again interesting in the 80’s. New demands for the development of future propulsion systems like thrust and energy management, Insensitive Munitions (IM) criteria, fuels with high energy density, low toxicity, improved handling and storage safety, low over-all life costs, etc gave a new focus on these fuels. The first reported successful flight demonstration of two test missiles with a hypergolic combination of carbon loaded MMH gel fuel and an unloaded IRFNA oxidizer gel have been conducted in 1999 and 2000 by TRW [8-10]. More information about these and other publications up to the year 2000 is given in the detailed survey in the invited lecture of Natan and Rahimi [2], presented at the ISICP conference in 2000 at Stresa, Italy.
Due to the further increased interest in gel propulsion in the last years, basic research activities are conducted today also at some universities and research organizations. At NASA Glen Research Center at Lewis field, PA, USA recent work has been done on organic and especially on cryogenic gels, see e.g. Ref. [11]. At Penn State University, PA, USA various investigations have been conducted using sub-micron particles, see e.g. Refs. [12,13]. At the Technion in Haifa, Israel various numerical and analytical investigations have been conducted on the flow behavior of power-law type fluids in tapered injectors and also experimental investigations concerning spray characterization and burning behavior of single gel droplets, see e.g. Refs. [14,15]. Since ca two years also at DLR Space Propulsion Institute research activities on the production of gels, rheological behavior, flow and spray characterization are conducted, see e.g. Refs. [16-19].

3.0 RHEOLOGICAL AND FLOW BEHAVIOR

Gels can be described as “... a substance, that contains a continuous solid skeleton enclosing a continuous liquid phase. The continuity of the solid structure gives elasticity to the gel.” as has been done by Brinker and Scherer [20] or “A liquid containing a colloidal structural network that forms a continuous matrix and completely pervades the liquid phase.” as has been determined by the ASTM group [21]. The rheological behavior of gels, which can generally be described as shear-thinning as has been mentioned above, makes them interesting for propulsion applications. The dependence of the dynamic shear viscosity $\eta$ upon the shear rate $\dot{\gamma} = -\partial\dot{u}/\partial\tau$ is commonly expressed by an empirical power-law-model (Eq. 1), which is also known as the Ostwald-de Waele model, see e.g. Ref. [22].

$$\eta = K\dot{\gamma}^{n-1}$$

(1)

Figure 1 presents the dynamic shear viscosity against the shear rate $\dot{\gamma}$ of two Jet A-1 based gels at ambient temperature conditions. It can be seen that at medium shear rates the dependence can be expressed by this power-law-equation, whereas the exponential factor $n$ is significantly below 1. The viscosity of pure Jet A-1, which is a newtonian fluid, is constant at ambient conditions and orders of magnitude lower than these of both gelled fuels up to medium shear rates as can be seen also in this diagram.

![Figure 1: Dynamic Shear Viscosity $\eta$ of Pure Jet A-1 and Jet A-1 based Gels against the Shear Rate $\dot{\gamma}$ at Ambient Temperature, Refs. [16,19].](image)
Newer rheological measurements show for some investigated gels the existence of a distinct “yield stress” \( \tau_0 \) so that under an applied shear stress below this value the gel is deformed due to its elasticity but does not flow. The flow behavior can be described by modified power-law equations, e.g. by the Herschel-Bulkley equation [16]

\[
\tau = \tau_0 + \eta^* \dot{\gamma}^n
\]  

(2)

whereas \( \eta \) can be determined as the ratio of the shear stress \( \tau \) to the shear rate

\[
\eta = \frac{\tau}{\dot{\gamma}}
\]

(3)

The occurrence of a yield stress changes the fluid flow field in the feeding line and the injector. The left sketch of Fig. 2 shows the flow field of a power-law fluid, which velocity profile can be described by Eq. (4)

\[
\frac{u}{u_0} = 3n + 1
\]

(4)

\[
\left( 1 + \frac{r}{R} \frac{n+1}{n} \right)
\]

The flow field of the Herschel-Bulkley fluid must be divided in two regions [16] as can be seen on the right sketch of Fig. 2. The inner core at \( r<R_0/\tau_0=2L\tau_0/\Delta p \) can be described as a plug flow with a constant velocity \( u_{pl} \)

\[
\frac{u}{u} = \frac{u_{pl}}{u} = \left[ 1 - \frac{2n}{2n+1} S_R + \frac{2n^2}{(2n+1)(3n+1)} S_R^2 \right]^{-1}
\]

(5)

The outer flow field at \( r>R_0 \) can be described with the following equation

\[
\frac{u}{u} = \frac{u_{pl}}{u} \left[ 1 - \left( \frac{r}{R} \frac{\tau_0}{\tau_w} \right) \frac{u_{pl}}{u} \right]
\]

(6)

with

\[
S_R = 1 - \frac{\tau_0}{\tau_w}
\]

(7)
which is proportional to the ratio of the yield stress $\tau_0$ and the shear stress at the wall $\tau_w$ and which depends upon the pressure loss $\Delta p$ along the tube length $L$

$$\tau_w = \frac{R \Delta p}{2 L} \quad (8)$$

Figure 3 shows the dimensionless velocity profile of a Herschel-Bulkley fluid, which has a similar exponential factor $\alpha=0.1$ as a Jet A-1/6%Aerosil-gel (Test fuel 1 in Tab. 2). It can be seen, that with increasing $\tau_0/\tau_w$ decreasing $u/\bar{u}$ occur in the core region together with broader velocity profiles and stronger velocity gradients near the wall. Also can be seen, that the plug flow region is enlarged with the same increasing parameter $\tau_0/\tau_w$.

![Figure 3: Dimensionless Velocity $u/\bar{u}$ against the Dimensionless Tube Radius $r/R$ for various $\tau_0/\tau_w$. Jet A-1/Aerosil-Gel with $\alpha=0.1$, Herschel-Bulkley Fluid, Ref. [16].](image)

### 4.0 EXPERIMENTAL APPARATUS

Figure 4 shows the sketch of the experimental set-up for the investigation of the jet breakup and atomization behavior. The feeding system consists of a cartridge in which the gelled fuels are stored and a hydraulic cylinder, which moves the piston inside the cartridge forward to press the fuel into the feeding line. The piston velocity can be varied in a wide range to allow volume flow variation. At the end of the feeding line the set-up allows to mount different injector types in a modular way. The pressure inside the cartridge is monitored by a pressure transducer. The shadowgraph technique with a slightly diverging light path through the measuring object has been chosen to visualize the spray behavior. A Nanolite spark light source from the High-Speed Photo-Systeme company with a flash duration of 18 ns (FWHM) has been used together with a Contax RTS III camera.
Two different types of injectors have been used for the investigation presented in this paper. For these first basic experiments a commercial available air blast type atomizer has been chosen, in which the gel jet breaks up in a coaxial converging outer high speed air stream. The principal sketch of this injector type can be seen in Fig. 5. The Mehrstoffdüse Modell 0/4 from the Schlick company consists of an inner tube, through which the gel fuel is guided, and an outer tube, whereas the air flows through the annulus between the inner and the outer tube. In both feeding lines swirlers are positioned, through which the gel fuel and the air is guided under an angle of 30° in the same direction of rotation. Hereafter both air and gel flows are led through conical end segments in which they are accelerated. The exit diameter \( d_1 \) for the gel at the injector end cross section is 1.5 mm. The exit area of the annular air jet is located between the diameters \( d_2=6.2 \) mm and \( d_3=9 \) mm.

The second injector type of the investigation presented here is a like-on-like doublet impinging jet atomizer, which is often used in rocket propulsion systems with storable liquid fuels. The sketch of the modular experimental set-up as well as the characteristic features of the atomization process are presented in Fig. 6. The spray behavior will be discussed later in chapter 5 in comparison with the concerning shadowgraph images. The injector heads with the orifices can quickly be changed and the impingement half angle \( \theta \) as well as the distance between both injector arms can be varied very easy to allow parametric studies of the influence of various parameters. For the present investigation Schlick nozzles Mod. 629 with an exit diameter of 0.7 mm have been chosen. The experiments presented here have been conducted under ambient conditions concerning pressure and temperature.
Three different test fuels with Jet A-1 have been used for the investigation, whose composition by weight is presented in Tab. 2. Test fuel 1 is a gel on a particulate basis, where 6 wt-% of Aerosil (SiO$_2$ particles in the sub-micron range) is added to the liquid Jet A-1 and stirred until gellation has been reached. No degasification of the gel has been made during or after the production. This gel shows a distinct yield stress of $\tau_0 = 9$ Pa (see Ref [16]), so that it seems to be “solid” at zero and low stress conditions with the elasticity, which is typical for gels. The test fuels 2 and 3, however, are gels with organic-based gellants, which are combustible and therewith maybe helpful to increase the thrust in comparison to the incombustible SiO$_2$. Two different Thixatrol types are used as gelling agents together with 5-Methyl-2-Hexanon (IMH) as solvent. Thixatrol Plus is an organic diamide wax mixture and Thixatrol ST is a modified castor oil derivative. These test fuels 2 and 3 are clotted viscous fluids, which show the shear thinning behavior but no distinct yield stress seems to exist at low and zero-stress conditions.

<table>
<thead>
<tr>
<th>Test fuel No.</th>
<th>Test fuel</th>
<th>Aerosil</th>
<th>Other Gelant 1</th>
<th>Other Gelant 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>94 % Jet A-1</td>
<td>6.0 % Aerosil</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>85 % Jet A-1</td>
<td>7.5 % Thixatrol Plus</td>
<td>7.5 % IMH</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>85 % Jet A-1</td>
<td>7.5 % Thixatrol ST</td>
<td>7.5 % IMH</td>
<td>–</td>
</tr>
</tbody>
</table>

### 5.0 RESULTS AND DISCUSSION

Figure 7 presents three typical shadowgraph images of Jet A-1/6%Aerosil-gels (test fuel 1) obtained at three different momentum flux ratios $M$. This parameter is defined as the ratio of the momentum fluxes of the air flow and the gel flow

$$M = \frac{\rho_{\text{air}} u_{\text{air}}^2}{\rho_{\text{gel}} u_{\text{gel}}^2}$$
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It can be seen that different break-up regimes occur with increasing momentum flux ratios. At $M=170$ the gel jet leaves the nozzle exit plane with a nearly constant diameter $D=\approx d_1$. At the break-up length $L_b$ of about $\approx 2D$ the wind stress at the gas/gel interface strips off first droplets with a broad range of diameters as can be seen between the borders of the spray cone. Hereafter an instability of the jet occurs with an amplitude of several jet diameters $D$. In this region ligaments are formed, which are separated in the following from the jet and may break up into smaller ones and/or smaller droplets. At about 5-6$D$ the formation of larger patches occur, which have an irregular shape and attached ligaments, which may be connected to other patches. A significant decay of these patches downstream could not be observed under the experimental conditions. A comparison with images of the jet breakup process of Newtonian fluids shows similar structures to the non-axisymmetric Rayleigh-type breakup mode as has been described e.g. in Refs. [23-25].

For a larger momentum flux ratio $M=530$ the increased wind stress strips smaller and more droplets from the gel jet downstream of $L_b$ as in comparison to $M=170$. The size of the ligaments is reduced and smaller droplets are formed. Furthermore droplets can also be seen in the wake between the gel jet and the annular air flow immediately downstream of the nozzle exit plane. Farther downstream of $L_b$ the jet breaks up into larger portions, whereas ligaments remain often between these portions.

Figure 7: Shadowgraph Images of Jet A-1/6%Aerosil Gel-Sprays (Test Fuel 1) at various Momentum Flux Ratios $M$, Coaxial Injector, $u_{gel}=2.5$ m/s.
At the highest investigated momentum flux ratio $M=1350$ the jet breaks up on the image of Fig. 7c at about 5-6D. Hereafter two streaks seem to appear in which most of the ligaments and many very small droplets are concentrated. The starting point of the expansion of the gel spray occurs more downstream and with a smaller spray angle $\beta$ as for $M=530$. This behavior seems mainly to be caused by the air flow, which is supersonic immediately behind the nozzle exit. So the ligaments and drops are suddenly exposed to the related strong shear flow. This regime is similar to the “superpulsating mode” of Chigier and co-workers [24,25], who gave the dynamics of the large-scale eddies as the reason for these strong fluctuations. Furthermore must be mentioned, that immediately downstream of the nozzle exit plane the gel jet, which leaves the nozzle exit, cannot be observed due to the high gel mass loading in the wake region.

Figure 8 shows two consecutive shadowgraph images of the jet breakup process of the Thixatrol Plus containing gel (test fuel 2) at a momentum flux ratio $M=140$. The jet is strongly bent and decays in larger segments as can be seen on the image as blurred shadows, which are located outside the focus area of the optical setup. This strongly radial movement is supported by the swirl of the air and the gel flows. At a breakup length $L_b \approx 2D$ the wind stress strips off ligaments. No droplets are formed from this fuel jet and also the ligaments seem not to decay to droplets. Furthermore thin sheets or membranes are formed from the jet, which brake into smaller ligaments. This “bag blowing” effect occurs at the position, where the annular air flow hits the bent gel jet.

**Figure 8:** Shadowgraph Images of Test Fuel 2 (Jet A-1/7.5%Thixatrol Plus/7.5% IMH) Gel-Sprays at $M=140$, Coaxial Injector, $u_{gel}=2.5$ m/s.
At higher M the jet breaks up at about 5-7D into larger sheets, which decay downstream into smaller ligaments as can be seen on the left image of Fig. 9. Comparing the spreading of the spray of the Thixatrol Plus gel with the Aerosil gel at similar M, larger spray angles occur for the Thixatrol Plus gel. At the highest momentum flux ratio M=2050 the liquid core length is reduced in comparison to the experiment with M=1400. Furthermore can be seen, that a large amount of smaller ligaments and fibers are formed, too. Summarizing these results can be said, that the observation of the breakup process of Jet A-1/-Thixatrol Plus-gels in the air blast atomizer shows a distinct ligament and fiber formation instead of the droplet formation.

Figure 9: Shadowgraph Images of Test Fuel 2 (Jet A-1/7.5%Thixatrol Plus/7.5% IMH) Gel-Sprays at Medium and High M, Coaxial Injector, $u_{gel}=2.5$ m/s.

Figure 10 shows 3 shadowgraph images of test fuel 3 with Thixatrol ST as gelling agent. At M=140 a breakup mode which is called membrane type breakup mode [23] can be seen. Due to the swirl a central recirculating zone (similar to vortex breakdown) exists at the end of the liquid core as has been described by Lasheras, Hopfinger and co-workers. Downstream of the decaying membranes larger patches, ligaments with a broad length range and also droplets with irregular shape occur. At the higher investigated momentum flux ratios the gel jet is atomized, whereas at the highest M the smallest droplets seem to be produced.
Due to the fact that no data are available to the authors about surface tension, shear viscosity in the injector exit plane but also elongational viscosity neither Reynolds numbers nor Weber numbers couldn’t be calculated for the classification of the test results in a regime diagram, which is commonly used for newtonian fluids. Nevertheless it is obvious, that the Weber number and therewith the surface tension must play an important role also for the atomization of gels if the results of the 3 test fuels are compared.

The diagram in Fig. 11 shows the spray angle $\beta$ in dependence upon the momentum flux ratio $M$ for the three investigated gelled test fuels, whereas the presented values are averaged from about 10 images. For all test fuels $\beta$ decreases with increasing $M$. The Aerosil based gel (test fuel 1) shows the smallest angles, whereas the ligament and fibers producing Thixatrol Plus based gel shows the largest angles.
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Figure 11: Spray Angle $\beta$ of Different Jet A-1 based Gels against Momentum Flux Ratio $M$, Coaxial Injector, $u_{gel}=2.5\text{m/s}$.

Figure 12 presents two shadowgraph images from the experiments with the doublet like-on-like impinging jet atomizer. For these experiments only test fuel 1, i.e. Jet A-1/6%Aerosil has been used. The image plane in Fig. 12 is perpendicular oriented to the injection plane, which is spanned by the two gel jets. At the intersection point of both jets a thin planar fluid sheet is formed, which is oriented perpendicular to the jet plane, so that the top view on this sheet can be seen on the images. From this sheet bow-shaped ligaments are peeled of and decay further downstream to smaller ones and droplets. This behavior has also been described for newtonian fluids, see e.g. [5]. The average distance between the ligament bows has been determined as about 10 mm for $80^\circ<\theta<100^\circ$ and for the jet velocity $u=35\text{m/s}$. The decay of the ligaments further downstream into smaller ones is caused by stretching as a result of the radial movement, surface tension and possibly elongational viscosity, too. The ligament bows are often not totally separated from each other and are connected with portions of the gel sheet, as can be seen especially on the left image of Fig. 12. Also the gel sheet shows wavy surface structures, which are sometimes very pregnant as can be seen on the right image of Fig. 11. These structures can be accounted as the precursors of the bow-shaped ligaments, which are separated at the rim of the sheet. Above impinging angles $2\theta=90^\circ$ ligament separation could be observed sometimes in “backflow” direction as can be seen on the left side, i.e. the injector side, on the right image of Fig. 12.

Figure 12: Shadowgraph Images of the Gel Spray from a Like-on-Like Doublet Impinging Jet Atomizer, Jet A-1/6%Aerosil (Test Fuel 1), $d=0.7\text{mm}$, $u=35\text{m/s}$, $2\theta=100^\circ$. 
6.0 CONCLUSIONS

Gelled fuels are viscoelastic fluids, whose viscosity decreases with increasing shear rate. Due to a yield stress they are non-flowable at zero or very low shear rates. The velocity profile of gel flows in cylindrical tubes show a flow region in the core of the tube, which can be described as a plug flow.

The spray behavior of gelled fuels in an air blast atomizer and an doublet like on like impinging jet atomizer have been investigated using the shadowgraph technique. Different breakup regimes can be seen with increasing momentum flux ratio M with the air blast atomizer. For the Aerosil-based gel the non-axisymmetric Rayleigh-type breakup mode has been observed at low M. At M=1350 a disintegration of the jet with the production of small droplets can be seen. The Thixatrol based gels show also different types of breakup modes, but with fundamental different atomization behavior. At high M the disintegration of the Thixatrol Plus gel produces mainly ligaments and small fibers, whereas small droplets are produced with the Thixatrol ST gel.

For the impinging jet atomizer a gel sheet is formed at the intersection of both gel jets, which is perpendicular oriented to the plane spanned by the to gel jets and which shows a wavy surface structure. From this sheet bow-shaped ligaments are separated periodically and decay further downstream.

7.0 NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Units</th>
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<tr>
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<td>Diameter</td>
<td>[m]</td>
</tr>
<tr>
<td>K</td>
<td>Pre-exponential factor, power-law fluid</td>
<td>[Pa s^n]</td>
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<tr>
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<td>Length</td>
<td>[m]</td>
</tr>
<tr>
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<td>[m]</td>
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<tr>
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8.0 ACKNOWLEDGEMENT

The production of the gel fuels and the rheological measurements with the Couette flow viscometer by R. Brändle, J. Liebl and R. Pein, as well as the assistance of A. Feinauer in the experiments will kindly be acknowledged.

9.0 LITERATURE


Characterization of Flow and Spray Behavior of Gelled Fuels with Regard to Air Blast and Impinging Jet Atomizers


SYMPOSIA DISCUSSION – PAPER NO: 15

Discusser’s Name: Hans Besser

Question:
What is the rational for studying air blast atomizers with respect to the application in an operational gel motor? Is it mainly to differentiate the spray behavior of different gels?

Author’s Name: H. Ciezki

Author’s Response:
The type of air blast atomizer used is commercially available and, according to the manufacturer, is useful for the atomization of viscous media. The first experiments presented here have been conducted to show the influence of an external shear flow on the atomization behavior of these non-newtonian fluids. Due to the results for the investigated gelled fuels, more attention should be paid to get a good atomization of future selected fuel/gellant and/or oxidizer/gellant combinations for combustion experiments.