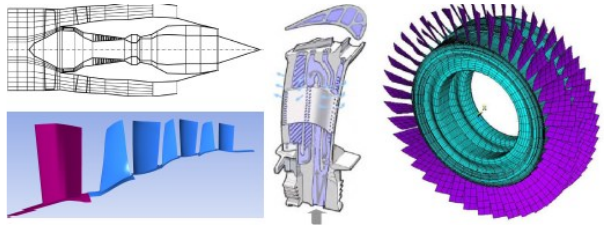
First Annual Webinar: Aero Gas-Turbine Engine Development in India
(Virtual Mode)
28th & 29th January 2022



Theme: ENABLING TECHNOLOGIES INITIATIVE FOR PROPULSION SYSTEMS

Combustion Characteristics of Boron Impregnated Slurry Fuel

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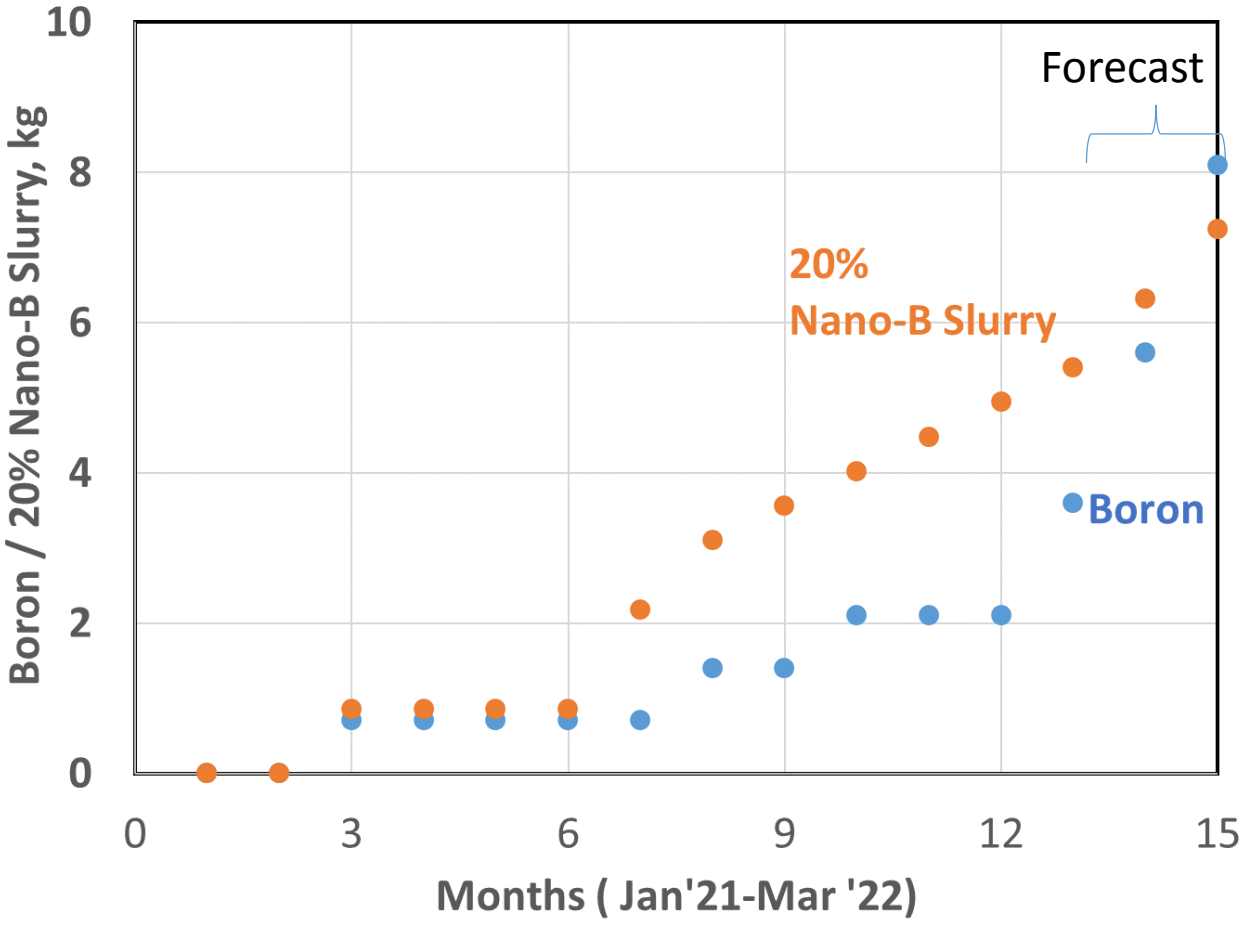
FIRE & COMBUSTION RESEARCH CENTER

Contents

Background

- Elemental Boron is a high energy material being considered globally for enhancement of fuel energy density in aviation and propulsion sector.
- FCRC is producing Nano-Boron and its hydrocarbon fuel slurries. Studies are underway to understand Boron combustion at ambient and higher pressures
- Preliminary outcomes of this DRDO-GTRE funded research project at ambient pressures for JetA1 slurries will be presented here

Boron Production at FCRC



Combustion Chamber

Leaching Equipment

Washing Equipment

Drying Equipment

FCRC employs magnesiothermic reduction B_2O_3 in NaCl and N_2) followed by leaching of the `products

$B_2O_3 + 3\ Mg \rightarrow 2\ B + 3\ MgO$ (combustion)

$MgO + 2\ HCl \rightarrow MgCl_2 + H_2O$ (Leaching)

Boron-JetA1 Slurry Preparation Studies

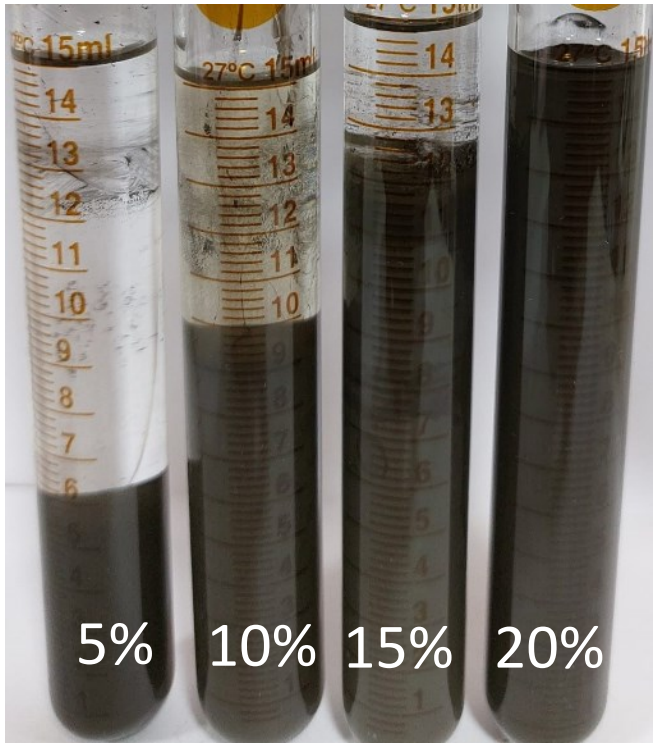
•Boron is ground to nano size in ball mill in JetA1/JP10 for 24 to 72 hours to obtain stable 20% Boron nano slurry. Particle size analysis using Transmission Electron Microscopy (CeNSE , IISc) indicate a size below 30 nm.

•Slurries of 5%, 10%, 20% and 30 % (w/w) in JetA1 are prepared

• While 10% slurry starts settling in about 30 minutes and settles to 20% level in a day, 20% slurry found to be stable up to one month

•30% slurry is also found stable but did not flow

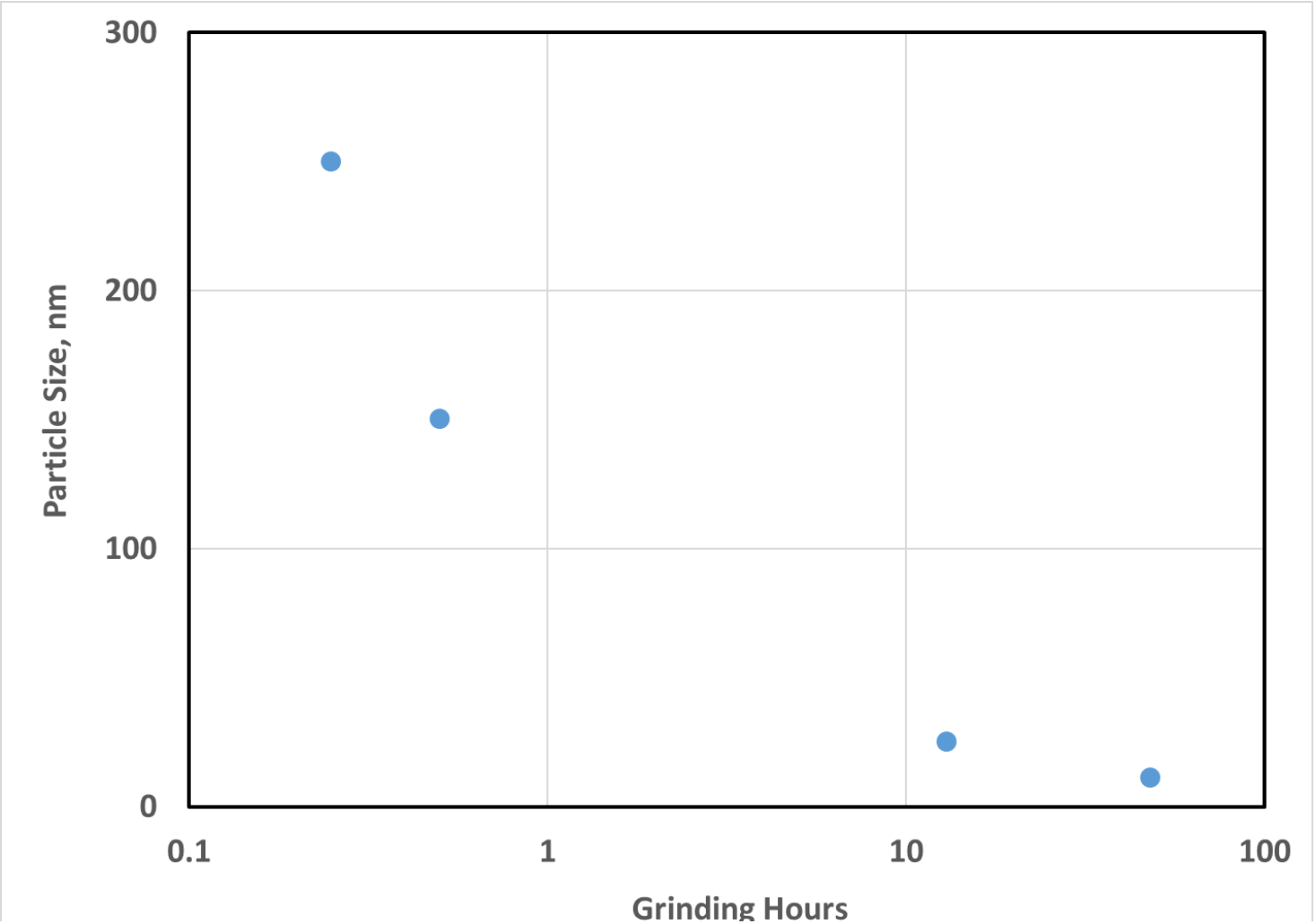
Grinding and storing Boron in slurry mode will help eliminate surface oxidation



2 wks 4 wks

Nano B Slurries

Particle size studies on ball milled JetA1 Slurries

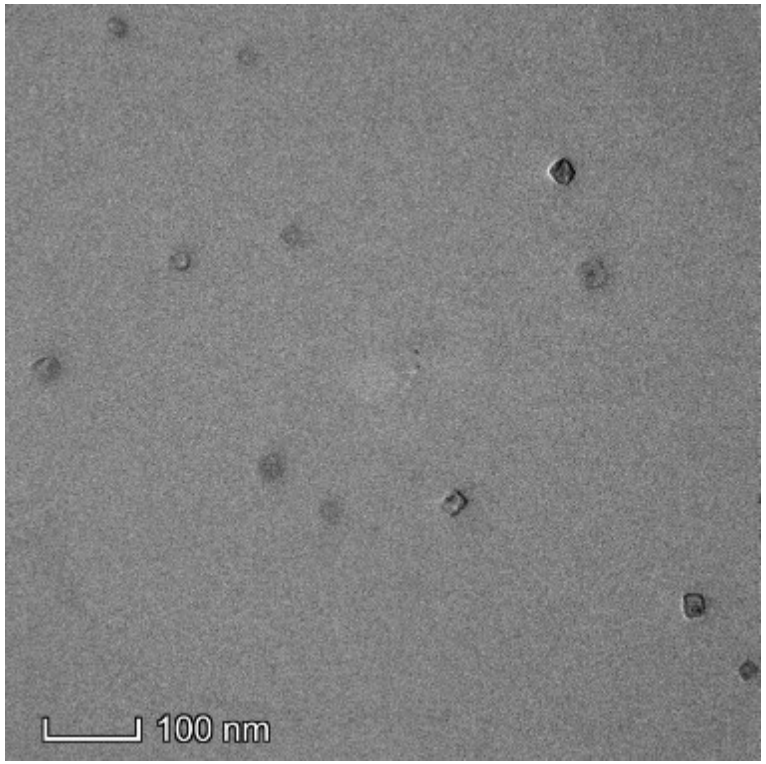


Grinding	Particle size	
hrs	nm	
0.25	250	
0.5	150	
13	25	
48	11	
n	-0.61225	

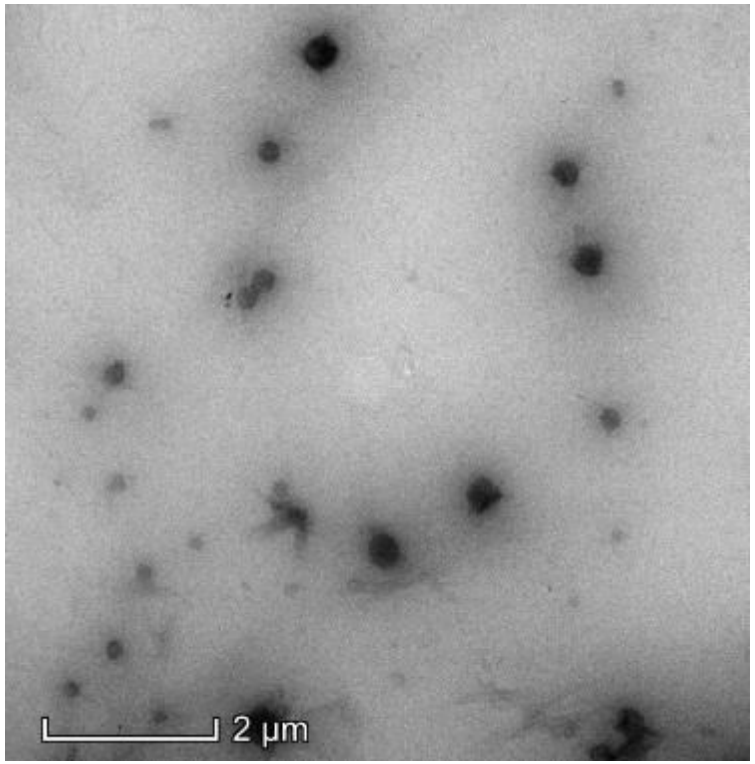
Particle Size (nm) = $250\ (hrs/0.25)^{-0.6}$

Studies to understand particle size reduction of milling Boron in slurry mode indicated that the particles size reduce to a level of <25nm in 24 hrs milling duration, milling with 20% (w/w) concentration found to be effective

TEM studies - Images



20% B Slurry- 24 hrs Milling



10% B Slurry- 24 hrs Milling

TEM analysis at CeNSE, IISc of slurries of 10% and 20% (w/w) indicate that milling with 20% (w/w) slurry concentration of Boron in Jet A1 found to be efficient in particle size reduction – size of particles reduced from 250 nm to <25 nm in 24 hrs as against <50 nm in the case of 10% slurry concentration

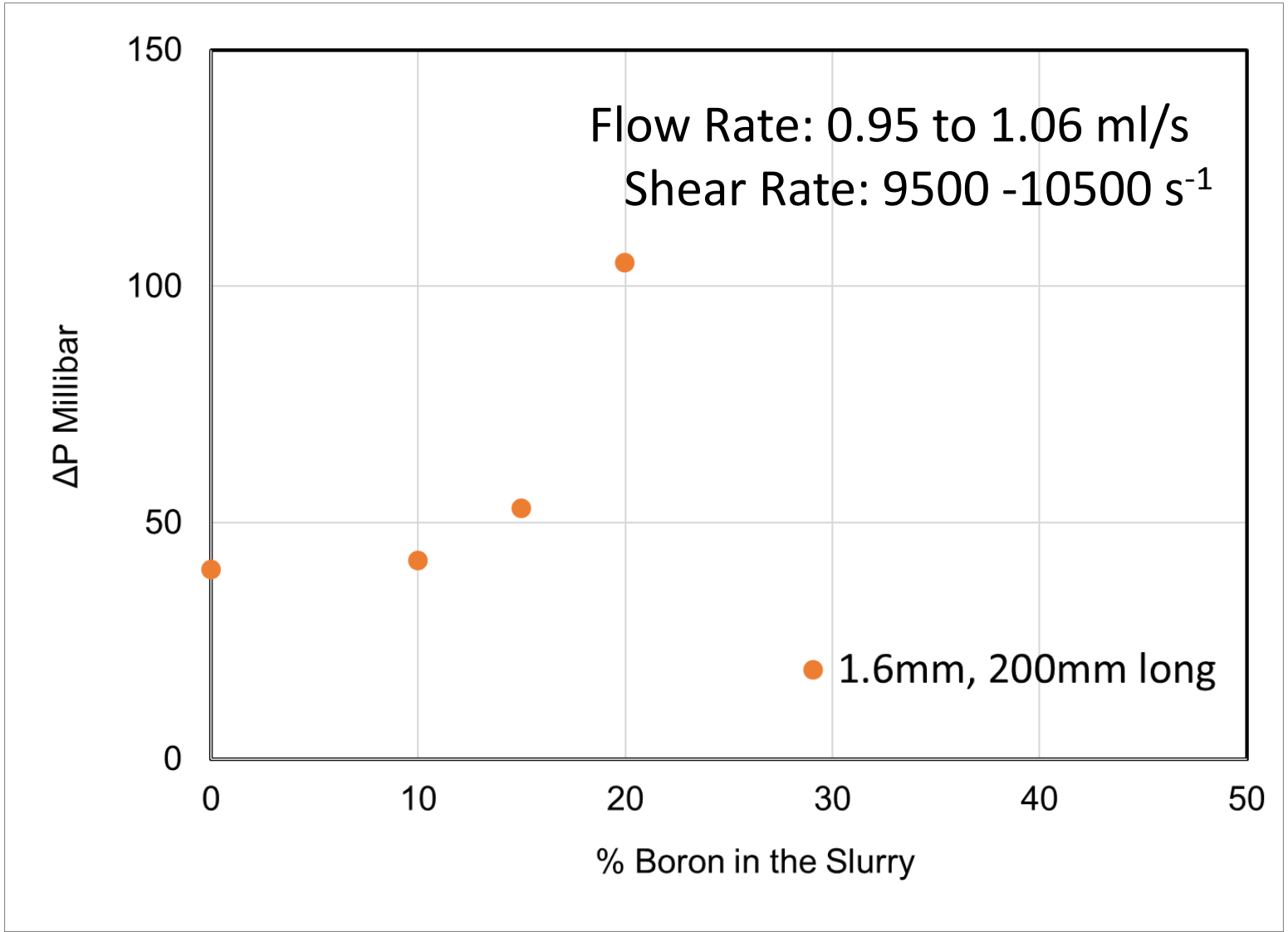
Boron Slurry Flow Studies: Fuel Manifold of STFE from GTRE

- Fuel Flow Rate varies between 0.057 kg/s - 0.097 kg/s
- The connecting tube of the fuel manifold is 4.2/4.4 mm ID (Inner Dia). From there, fuel enters into a 1.775 mm annular space (68.55 mm OD & 65 mm ID).
- Subsequently, it comes out of 0.68/0.7 mm dia; 12 holes on Static manifold.

Flow Rate **Q = 71 – 120 ml/s**	**Vel** **(m/s)**	**Shear Rate, s^{-1}**
Connecting Tube $\Upsilon=4Q/\pi r^3$	4.7-8.8	9800-16677
Static manifold $\Upsilon=6Q/(\pi(R_1+R_2)h^2)$	0.2-0.3	647 - 970
Holes, $\Upsilon=4Q/\pi r_{eq}^3$	15 - 26	15000 - 25000

Boron Slurry Flow Studies, 3 kg/h

Slurry flow studies are conducted with 1.6 mm SS tubes to get reasonable flow velocities



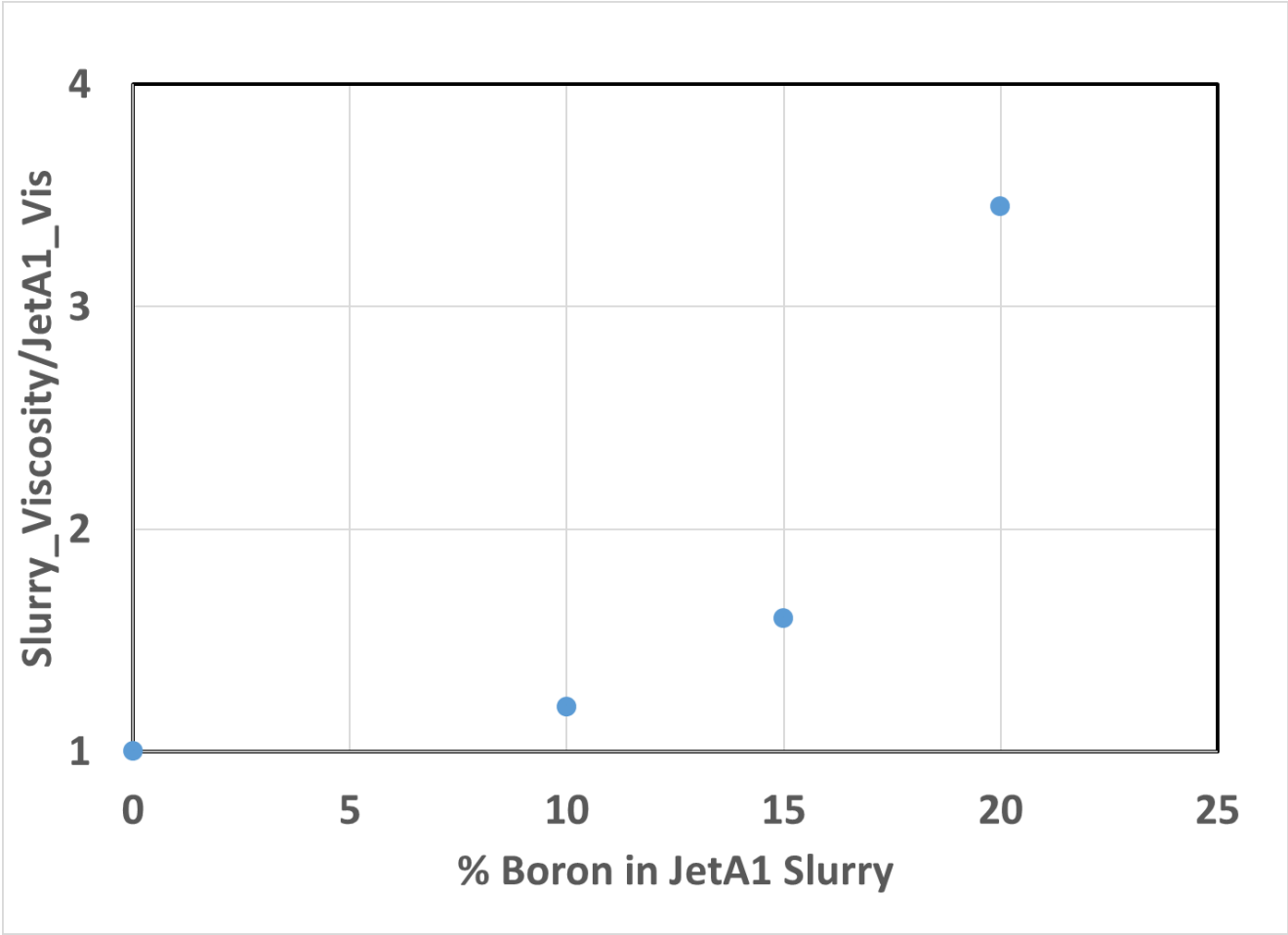
Apparent Viscosity of Boron in JetA1 Slurries

Laminar Flow:

$$Q = \frac{\Delta p\, \pi\, r^4}{8 \mu\, l}$$

$$\mu = \frac{\Delta p\, \pi}{8Q(l_1/r_1^4 + l_2/r_2^4)}$$

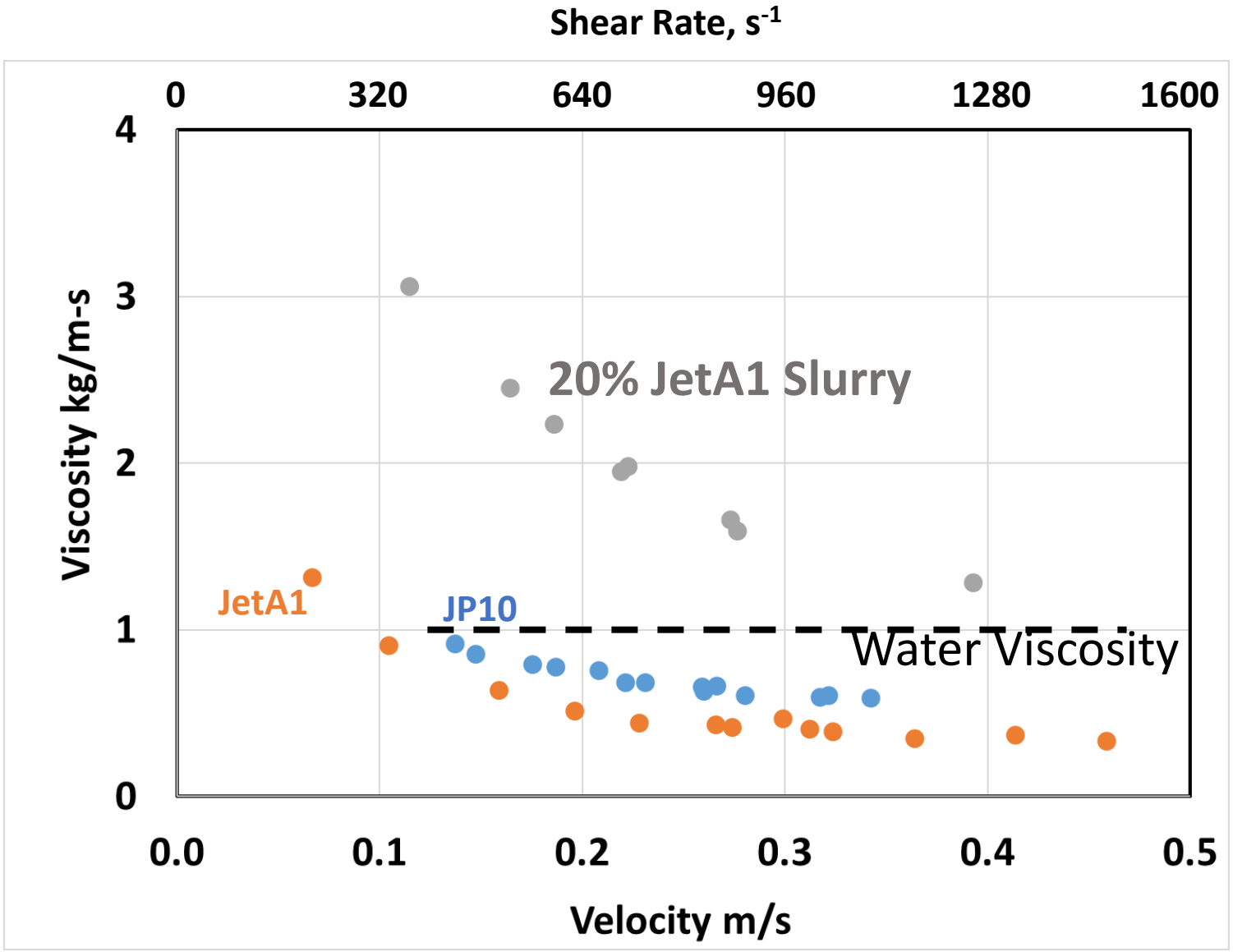
Viscosity of 20% Nano-B slurry is 3.3 times JetA1



D2 = 2.5 mm, L2=1.49 m

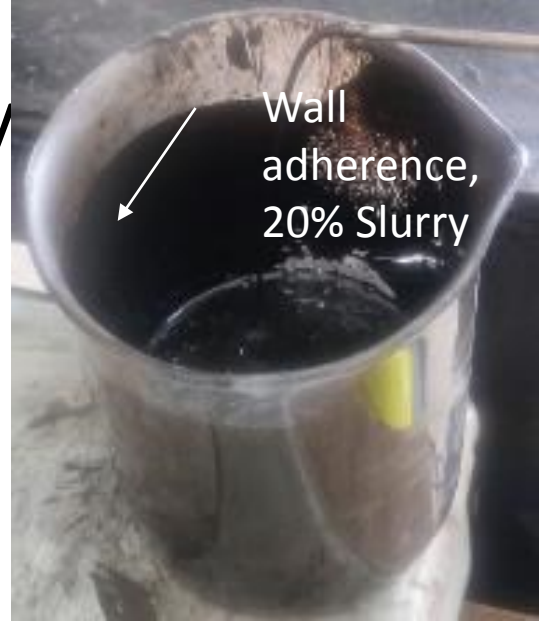
Apparent Viscosities of Boron in JetA1 Slurry

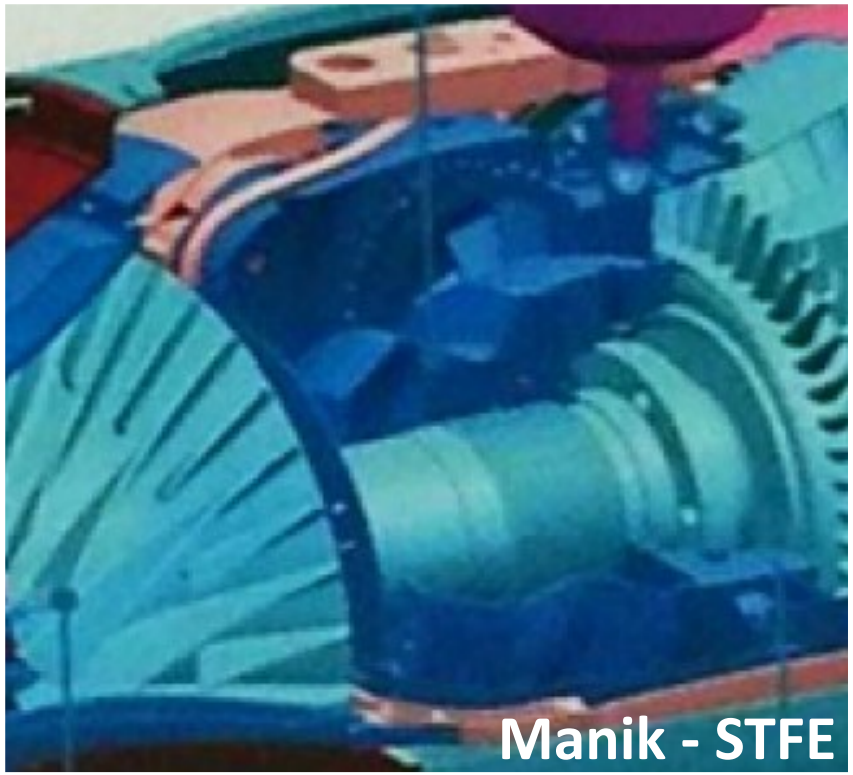
- Apparent Viscosities were computed in dispensation system at flow rates employed for trials
- 2.5 mm ID, 1.49 m long pipe was used in pressure range 0.1 to 0.3 bar
- 20% B Slurry viscosity was computed in the shear rate range 350 to 850 s^{-1}



Issues with dispensation of Nano B-Slurry

- Adherence to wall: Slurry dispensed from container tended to be of lower conc. vis-a-vis slurry in the tank unless the tank wall was passivated
- During experimentation it was realized density of slurry dispensed, (and therefore, its concentration) tended to be lower compared to slurry filled into the tank
- Loading 20% B nano B slurry, draining it and loading again yielded satisfactory
- Configuring STFE fuel supply with positive dispensation like piston/bladder is not possible- Exploration of surface coatings to minimize this tendency is needed



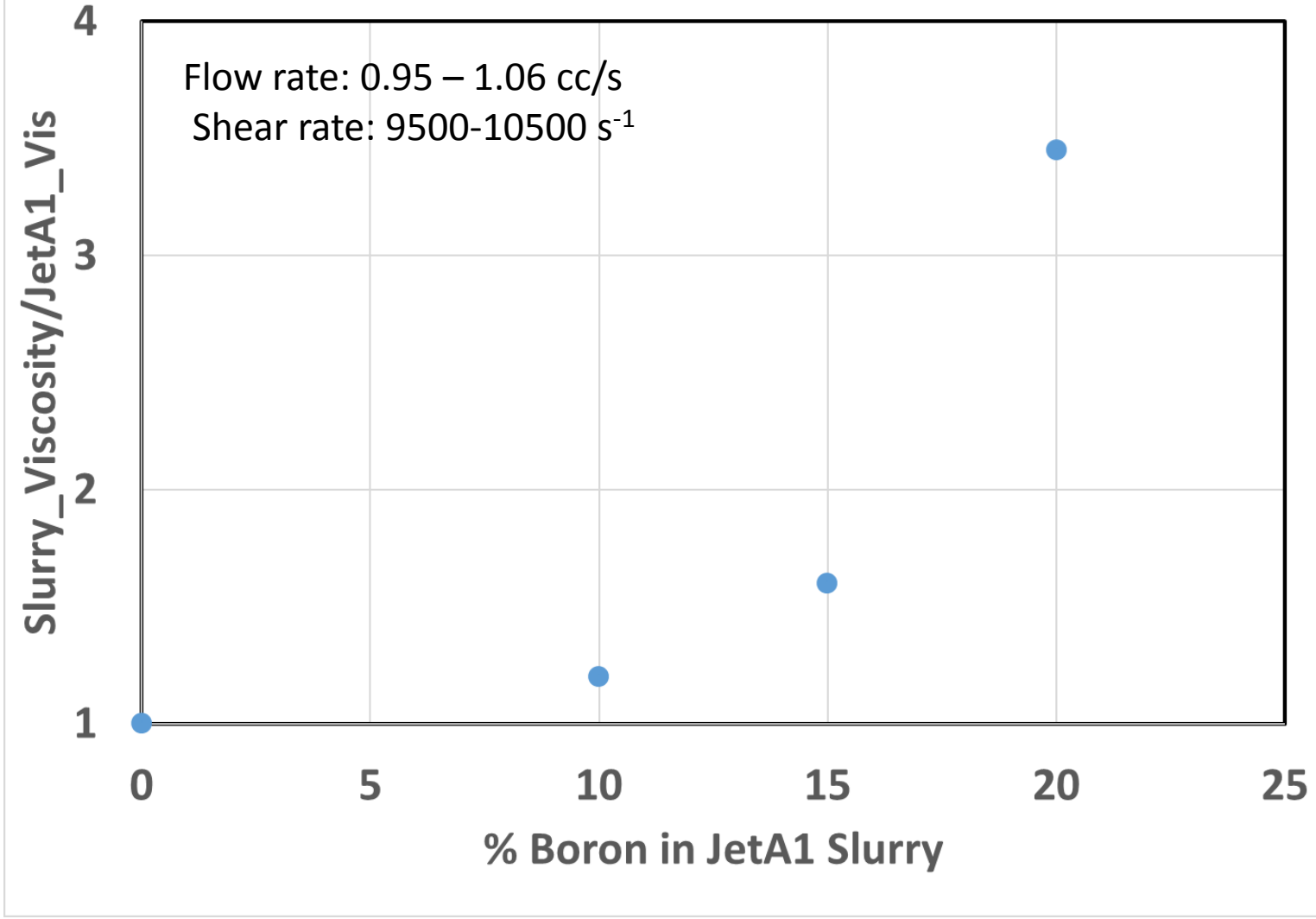


Slurry to JetA1 Viscosity Ratio

Apparent viscosity rise due to increased Boron fraction is captured well

JetA1– 1.6 mm dia

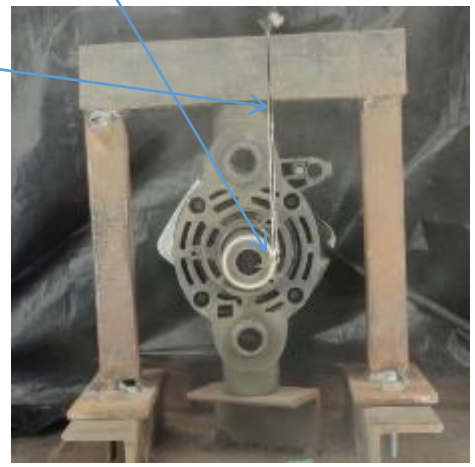
20% Slurry – 1.6 mm dia



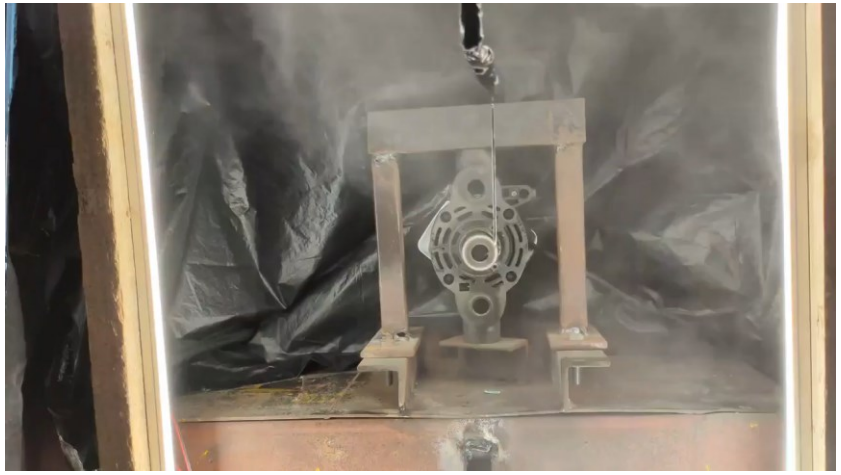
Slurry Atomization Studies in Slinger

Slinger

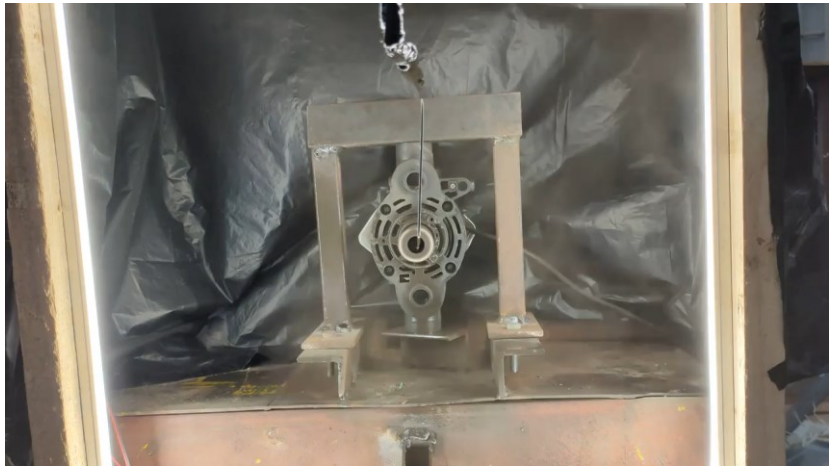
Fuel Tube
(1.3 mm)



0.5 m x 0.5 m
LED Light
Plane
22 W/m



Jet A1



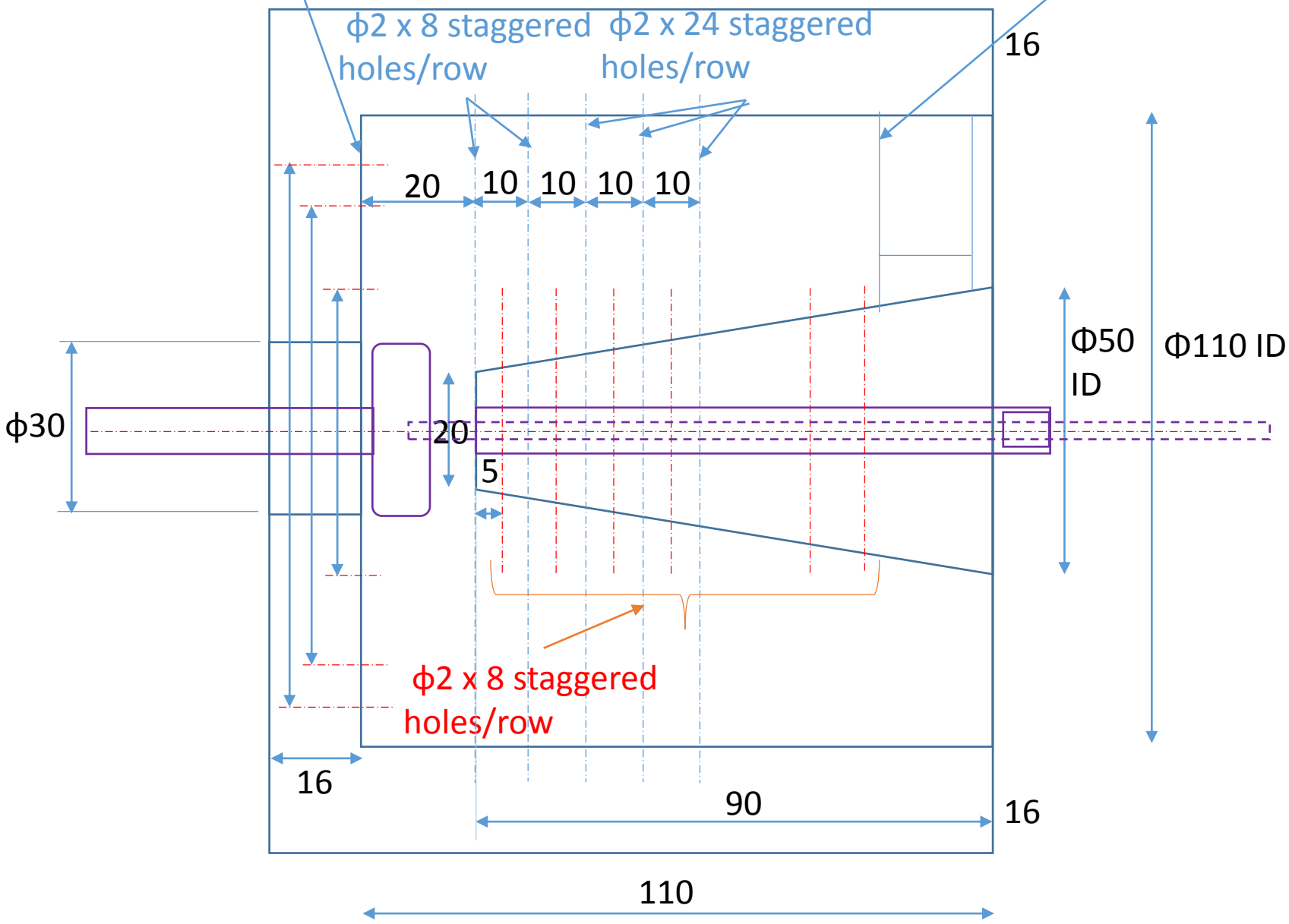
20% Boron Slurry

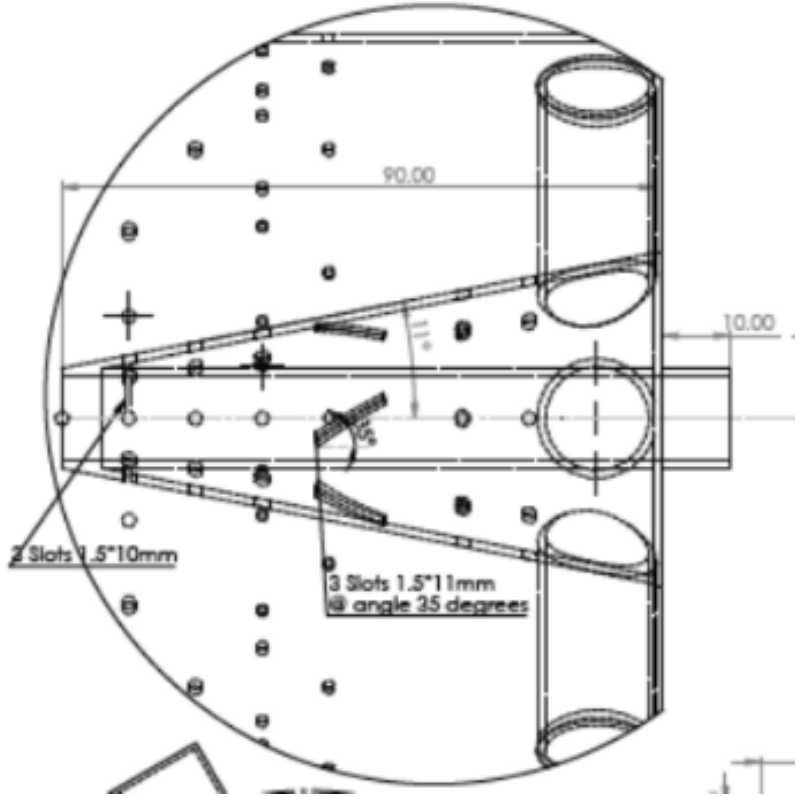
Atomization studies are being conducted at flow rate of 3 kg/h of JetA1 and 20% Boron slurry
A light plane/sheet created to capture the spray
20% Slurry appears to be atomizing well,
Quantification of spray studies is underway..

Combustor Details

Back plate ϕ2 x 8 holes per circle, staggered, 47, 80 & 98 PCD

Circular Strut inlets: 3 Nos, 120° Apart





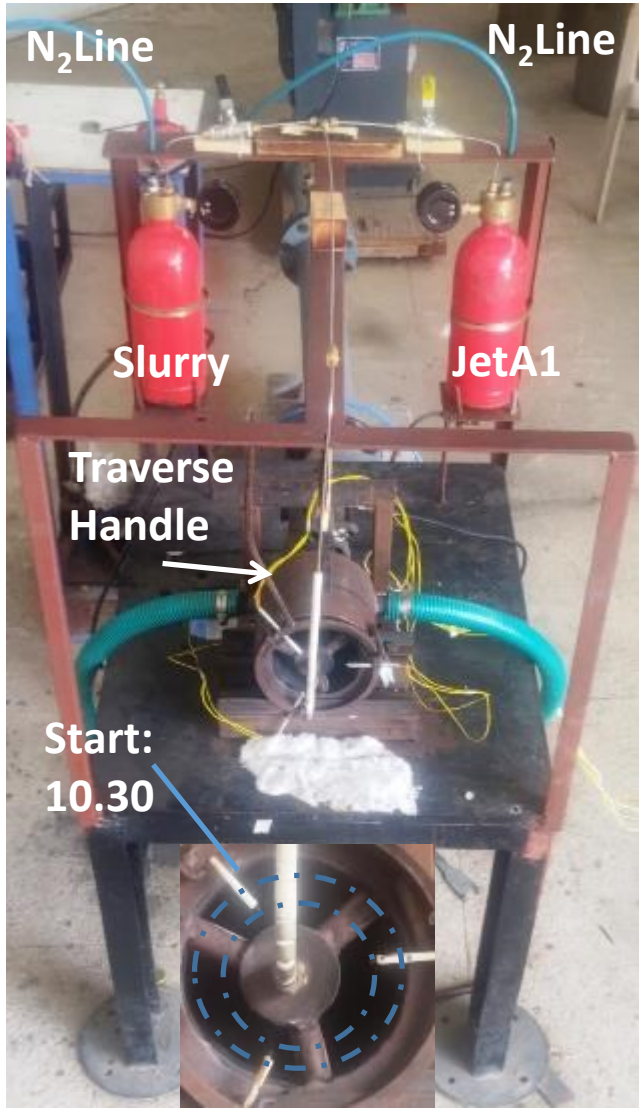
Back plate: 75 mm^2

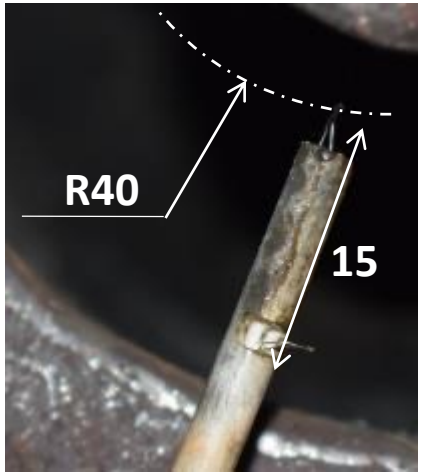
Liner area: 276 mm^2

Cone eq area: 220 mm^2

TC: K Type 200 µm

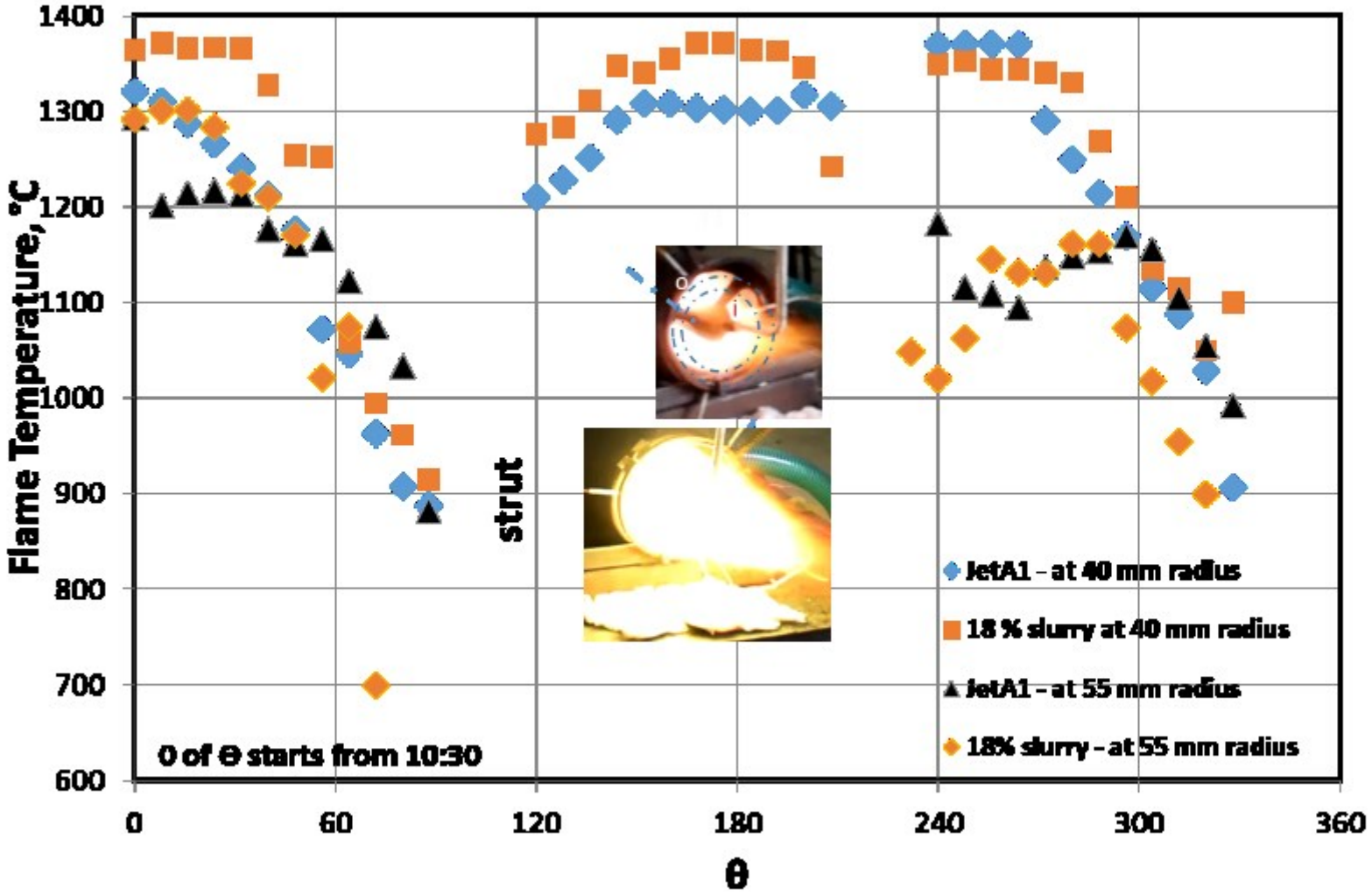
Combustor Setup Details





The combustion of the nano B slurry of size 10 to 25 nm with JetA1 in the slinger combustor.

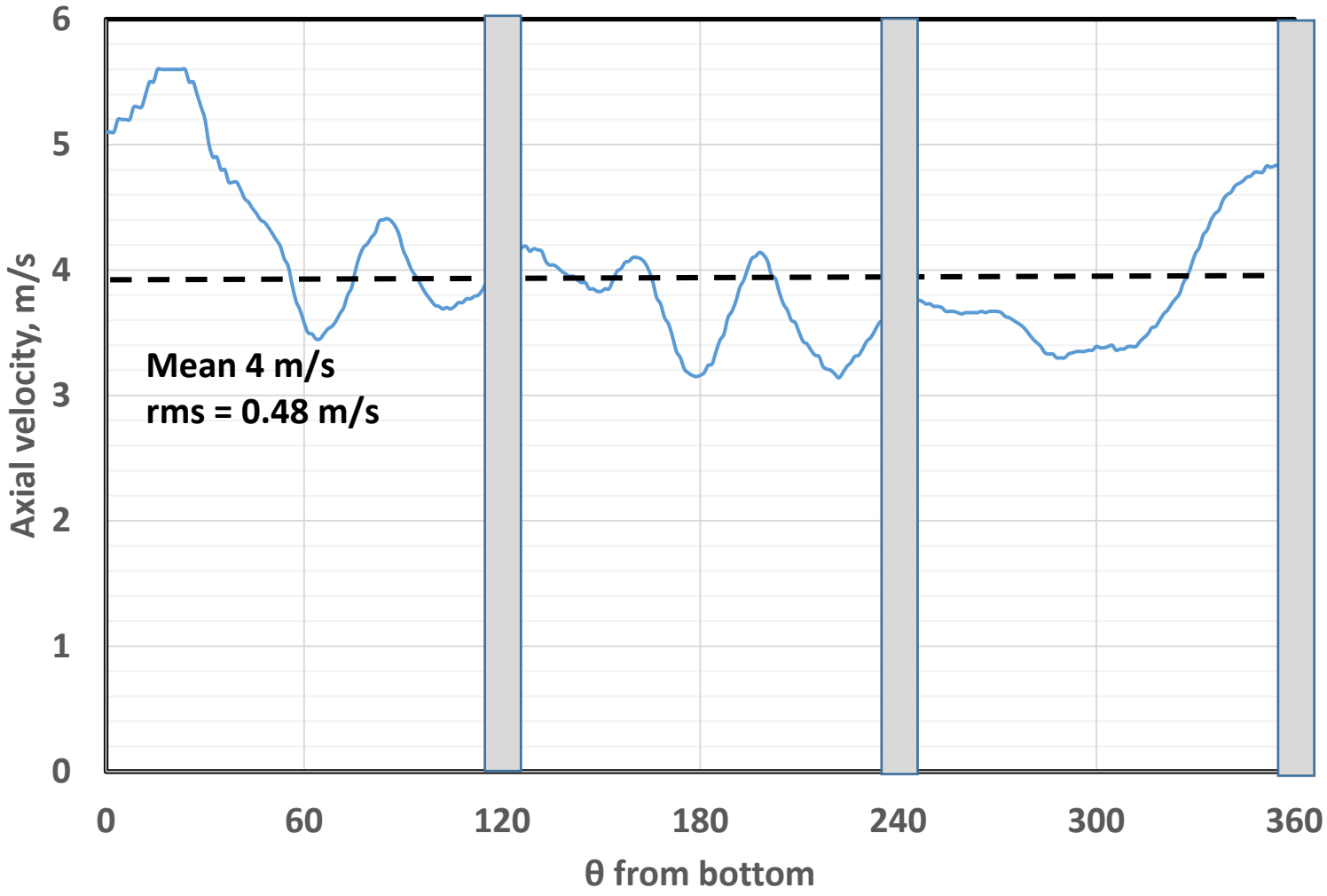
Azimuthal T plots for JetA1 and Slurry combustion

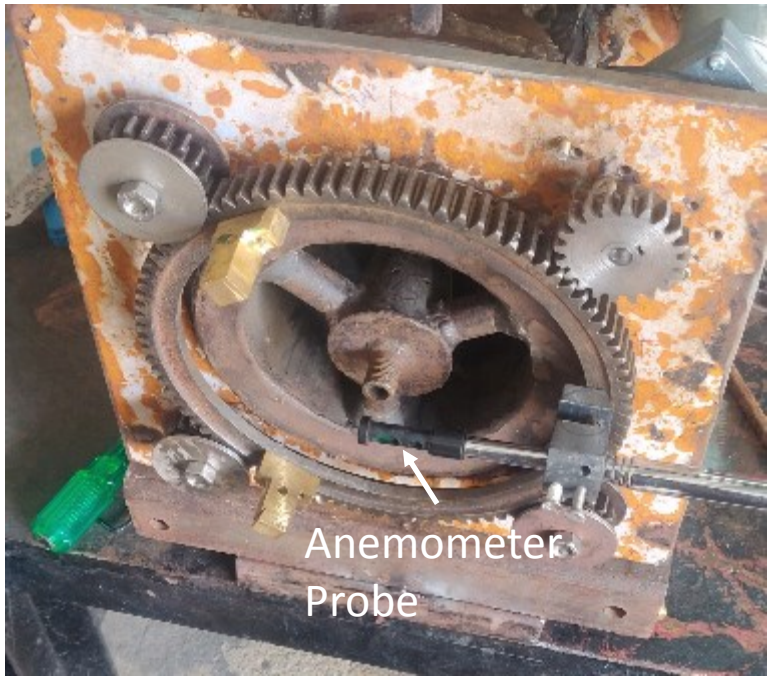


JetA1: 0.83 g/s
A/F: 23

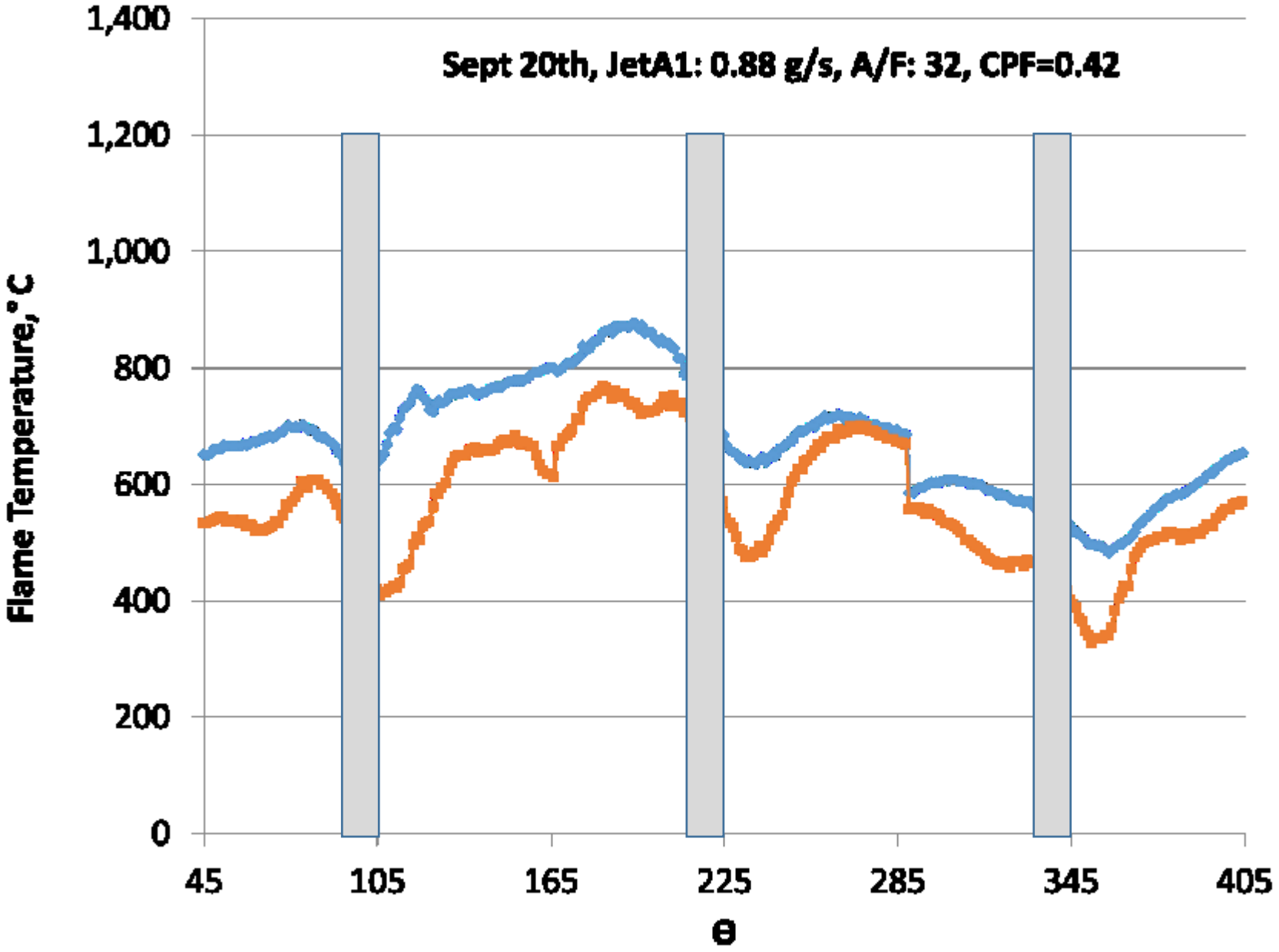
Average gas temperatures are at expected values for the operating power level and a/f.
16 mm dia three circular struts are in the exit plane diverting the flows from measuring

Azimuthal Velocity Variation





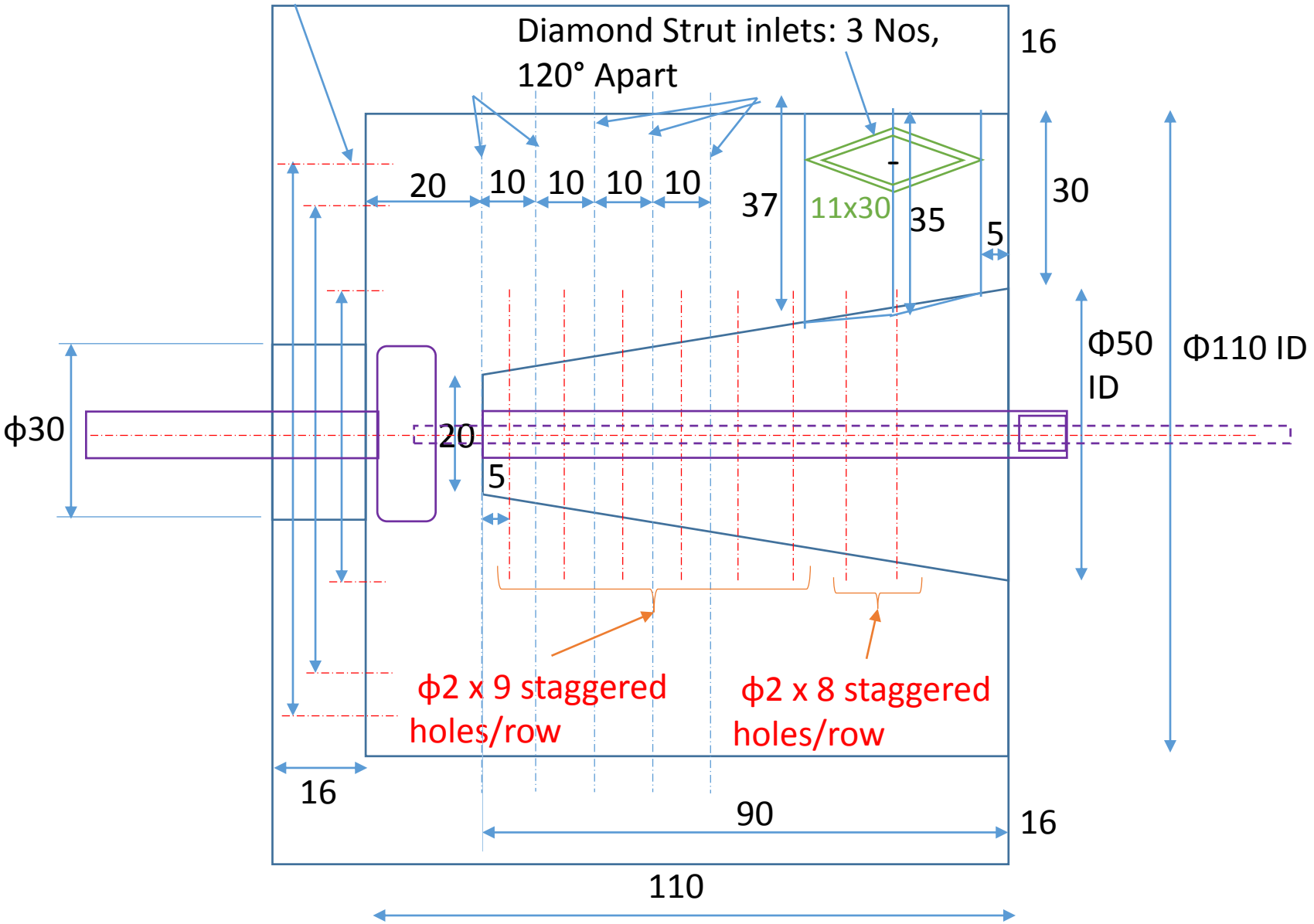
Two active inlets (connected by Y): Air flow rate: 26 g/s



$$CPF = \left[\frac{T_{04,\,max} - T_{04,\,avg}}{T_{04,\,avg} - T_{03,\,avg}} \right]$$

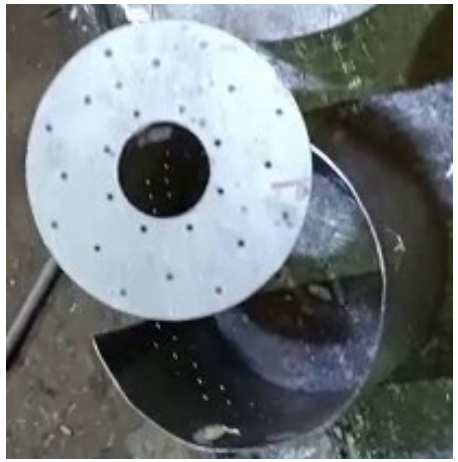
Combustor with Diamond Struts

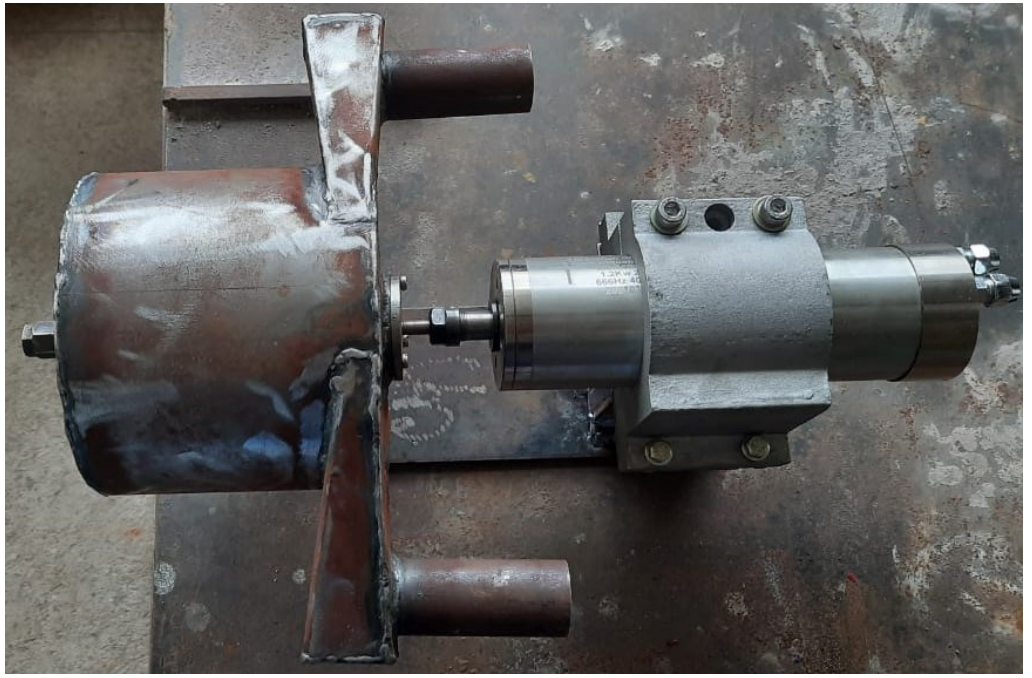
Back plate ϕ2 x 8 holes per circle, staggered, 47, 80 & 98 PCD



Diamond strut flow area: 297 mm^2

Combustor with diamond shaped Struts





Summary

- Boron production and slurry preparation techniques employed are discussed
- JetA1 slurry composition greater than 20% is found unsuitable
- JP10 slurry at 20% loading is satisfactory
- JetA1 and JP10 slurry flow behavior and apparent viscosities studied at slurry concentrations employed for testing
- Issues associated with slurry dispensation identified
- Combustion studies conducted on Boron impregnated nano slurries JetA1 are presented
- Automated traverse for TC rakes at combustor exit for pattern factor determination is developed and tested in JetA1 combustion
- A combustor with diamond strut configuration to help obtain uniform temperatures in the exit gas stream is presented

Thank you