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Combustion of Boron Slurry Fuel in a Slinger Combustor

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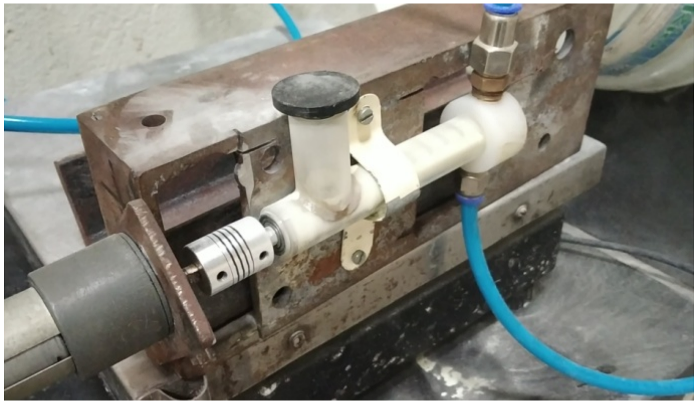
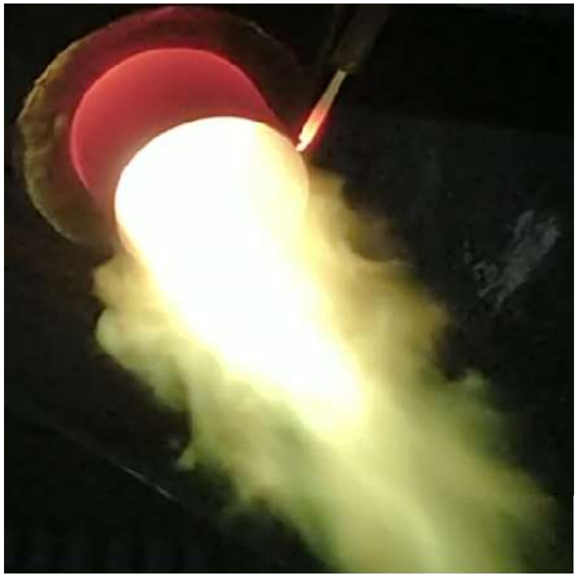
Background…1

- Boron (B11) is a high energy material (Z=5, A_r = 10.8) with energy density of roughly 1.3 times more than hydrocarbon fuels (gravimetric basis, 58 to 44 kJ/g) and 2 times more in terms of volumetric energy density (136 to 42 kJ/cm^3) which makes it attractive as a potential additive to liquid fuels in aerospace research
- FCRC has a CARS project with GTRE to produce Boron, and study the same in a combustor developed at FCRC in accordance with GTRE requirements
- In this connection FCRC has successfully produced ~3 kg of nano Boron as per the project requirements

Background…2

- Combustion studies conducted earlier in a 30 kW liquid fuel combustor at ambient pressure indicated that dispensation of Boron in slurry form is highly challenging as Boron particles settle down fast while dispensing in powder form could be comfortably carried out
- Recently we have succeeded in dispersing Boron in liquid fuel by surface treatment process. **Combustion studies in a mini slinger combustor discussed.**
- Before that, my colleague, Dr. Sowrirajan will present studies on Boron dispersion and settlement





Settlement Studies – Is Dispersion Difficult?

- Studies by various researchers across globe unanimously indicate that the fuel additives at nano scale improve catalytic role during combustion leading to efficient and complete combustion
- While several studies are found related to injecting boron nano-particles into different gaseous flames or by adding into conventional liquid fuels, it is observed that the **key issue posed by all these studies are in dispersing the nano particles uniformly in to liquid fuel** which seem unresolved completely for decades
- This is due to **inherent property of Boron nanoparticles to aggregate** and form large agglomerate settling fast inside storage vessel
- This again impose a serious limitation to practical applications of boron nano-particles in liquid fuels as they could lead to the clogging of fuel injection systems

Can surface preparation of Boron be a solution to this problem? ….

Settlement Studies – Surface Preparation to help Dispersion..1

- Key issue is agglomeration of nano-particles and this requires their surface needs to be prepared
- **Pawan Kumar Ojha, Srinibas Karmakar (2018),** encompass the challenges in dispersion and stabilisation of Boron nano-particles in liquid fuels and **recommend surface modification of particles by capping using ionic liquids** (1-methyl-4-amino-1,2,4-triazolium dicyanamide [MAT][DCA] and 1-butyl-3-methylimidazolium dicyanamide) or **by using surfactants like Tween 85** (polyoxyethylene sorbitan trioleate) and Trioctyl phosphine oxide (TOPO) in JP 10, however **their influence on combustion in terms of ignition delay time and combustion time is not reported** while there are reports related to increase in mole fraction of fluorine decreasing the ignition delay

Settlement Studies – Surface Preparation to help Dispersion..2

- **Michael N Bello etal (2018),** details on their studies with surface engineered nano-Aluminium and Alumina particles dispersion in Kerosene. They have used **Per-fluorinated Carboxylic acid** as the surface binding moiety to **induce oleo-phobic surface**. The coated particle undergoes two stage burning behaviour during combustion with average initial burn rate constant increased by about 121% when compared to pure kerosene

Thus the need is to prepare the Surface of Boron particle using a Per-fluorinated Surfactant ….

Settlement Studies: – FCRC Approach..3

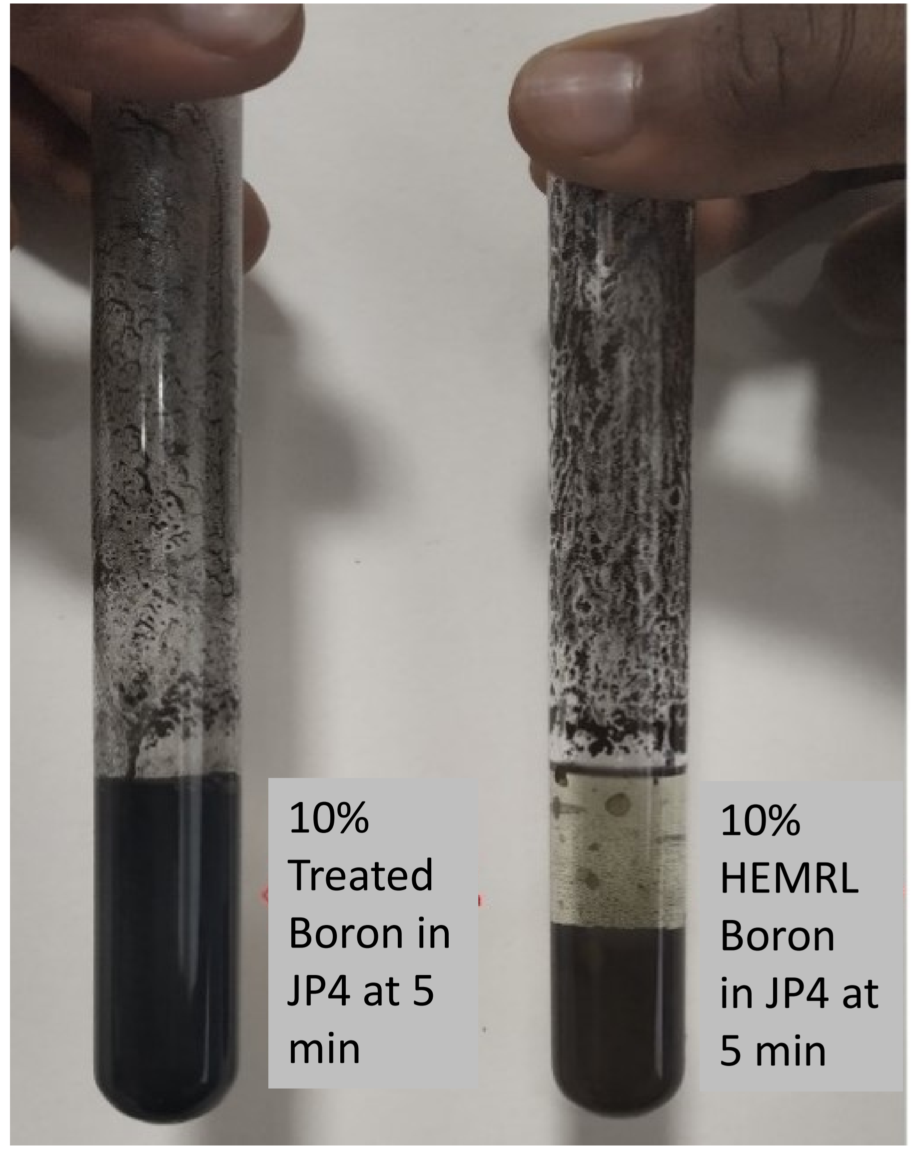
- Attempts are made at FCRC to disperse Boron by treating with Fluoro surfactants as they induce oleophobic properties to prevent agglomeration of Boron particle in fuel
- The process involves thorough mixing of Boron nano-particles in per-fluoro surfactant solutions whose typical composition shown (Source: KM Hinnant et al (2017)) This is followed by vacuum drying at ~70 °C for ~48h and fine grinding

  - 1:2 ratio of Boron: Surfactant mixture increases the particle size by about 60 nm (as determined gravimetrically)
  - Per-fluoro surfactants reduced purity by ~2% with no effect on combustion

Compound	%
Water	98.1-98.5
Diethyl glycol butyl ether	0.9-1.2
Alkyl sulphate salts	0.03-0.15
Amphoteric fluoroalkylamide derivative	**0.03-0.15**
Perfluoroalkyl sulfonate salts	**0.03-0.15**
Hydrocarbon surfactant	0.03-0.18

Settlement: Experimental Studies..4

- Experiments are conducted for flowability and dispersion of boron particles in JP 4 fuel
- Upon *comparing* with 10% loading of treated Boron (FCRC) with Boron from HEMRL having mean particle size it is observed that HEMRL Boron (particle size ~70 nm) settles faster without getting dispersed



Boron Slurry Flow Studies

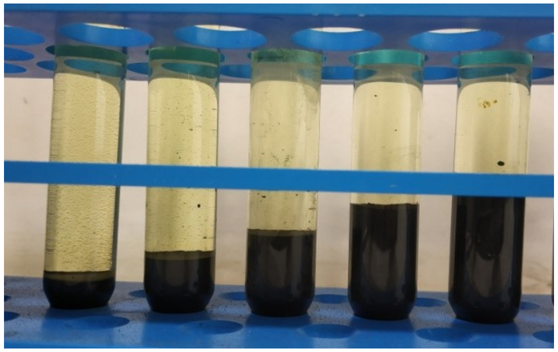
- Studies were conducted with 20 ml volumes of 5, 10, 15, 20, 30% loading of treated Boron in JP4 and allowing it flow through 100mm long pipe with ID 1.5mm and 2mm (Refer Table)
- Results indicate that a 10% loading of Boron in JP4 fuel is able to flow freely both in vertical orientation and horizontal orientations

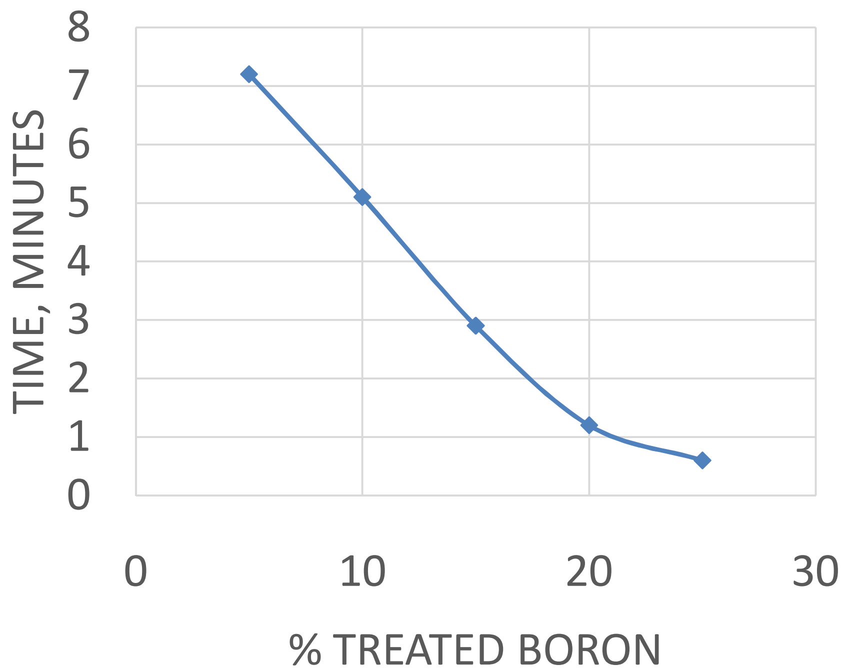
% Treated Boron in JP4	Flow through 1.5 mm ID		Flow through 2 mm ID	
	Horizontal	Vertical	Horizontal	Vertical
5	Flows (7s)	Flows (6s)	Flows (6s)	Flows (6s)
10	Flows (14s)	Flows (11s)	Flows (11s)	Flows (11s)
15	Flows (20 s)	Flows (15s)	Flows (18s)	Flows (15s)
20	~ 70%	~80%	~80%	~80%
30	Did not flow	Did not flow	Did not flow	Did not flow

Treated Boron

Untreated Boron

Settling time vs % treated Boron





% Treated Boron	Boron (g)	JP4 (g)	Settling Time min
5	0.5	9.5	7.2
10	1.0	9.0	5.1
15	1.5	8.5	2.9
20	2.0	8.0	1.2
25	2.5	7.5	0.6

Based on these data, it was decided to perform combustion studies with a 10% treated Boron loading as the same is observed flow in the fuel feeding pipe and is stable for about 5 minutes

Slinger Combustor

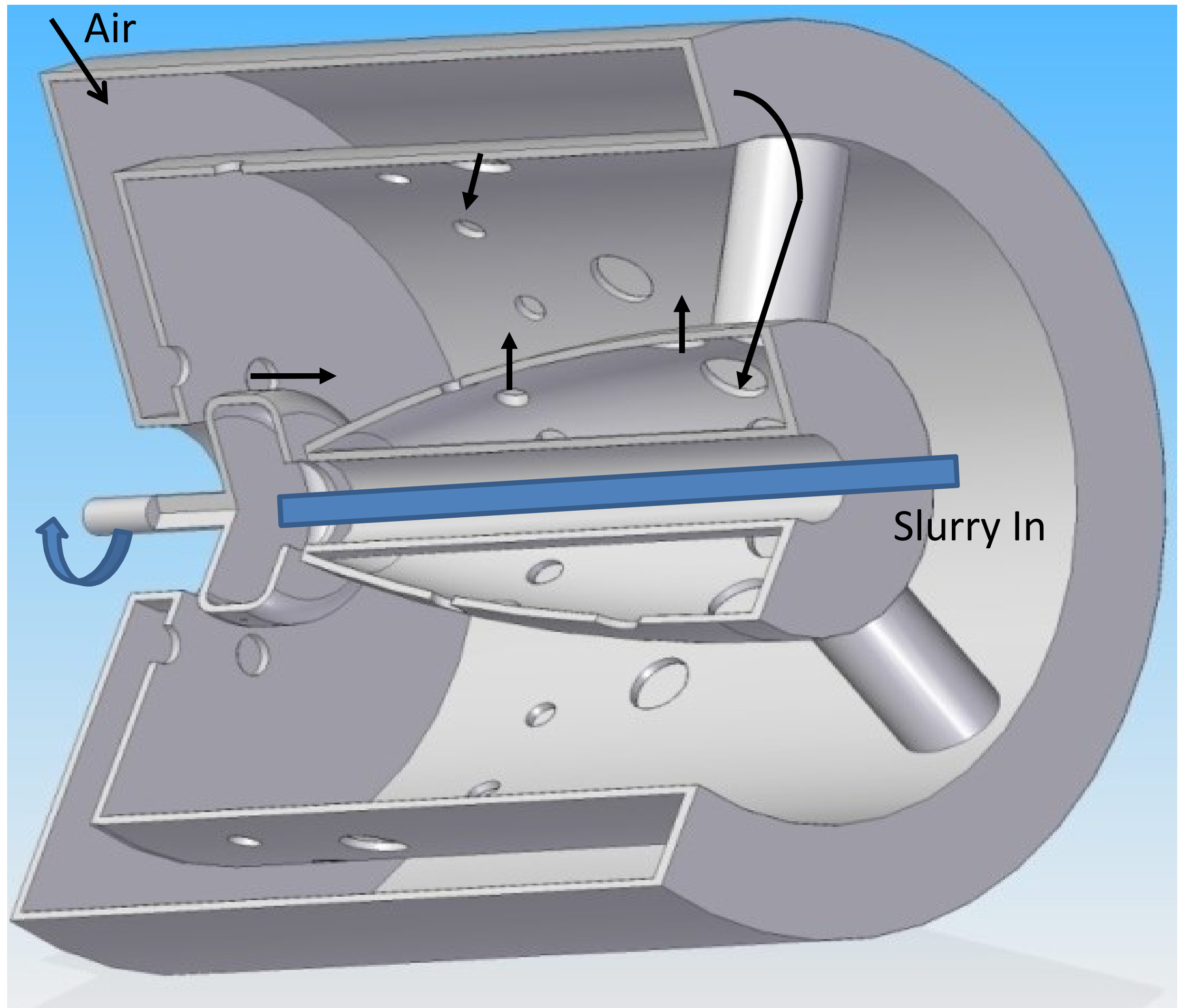
An ambient pressure slinger combustor of nominal diameter 150 mm and combustor volume of 1.1 l is built with gravity feed arrangement for slurry fuel supply.

The slinger cup of ~30 mm diameter with 18 numbers of 1 mm dia. holes equally spaced azimuthally on its periphery

Slinger rotated using a motor of nominal power 580 W, full speed 30000 rpm to get atomized slurry fuel spray.

Slinger Combustor Model

- Combustor was designed for 1 g/s fuel flow rate with air flow of about 25 g/s.
- It was fabricated using 1.2 mm MS
- Total of 110 holes of 2 mm dia
- Measured air flow rate was 22 – 23 g/s



Slinger Combustor Details

Atomization was excellent

10% Boron Slurry Combustion

Slinger Combustor T Data

- Temperature was recorded using 0.2 mm Dia R Type TC
- The temperature inside the flame was 1350 °C with kerosene.
- It jumped to 1450 °C soon after the slurry combustion got initiated.

Conclusions

- Coatings on Boron for obtaining slurry of greater stability have been developed.
- Boron slurry behavior with Boron loading has shown that slurry of 10 % can be handled with ease. Increasing beyond 15 % would cause issues for slurry flow.
- 10 % Boron slurry combustion has been established in a gas turbine combustor like configuration.
- A 100 °C jump from 1350 °C to 1450 °C is observed after insertion of 10% slurry into combustor.
- Issues of benefits of boron slurry for the gas turbine will be clear only when the gas turbine with slinger combustor is tested with the Boron slurry.
- The ability to produce coated nano-Boron needs to be capitalized upon for larger scale production should the test with full scale gas turbine be undertaken.

References

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