# ACERC Annual Meeting

# Intermediate-sized Particles (ISP) Formation During Black Liquor Droplet Combustion

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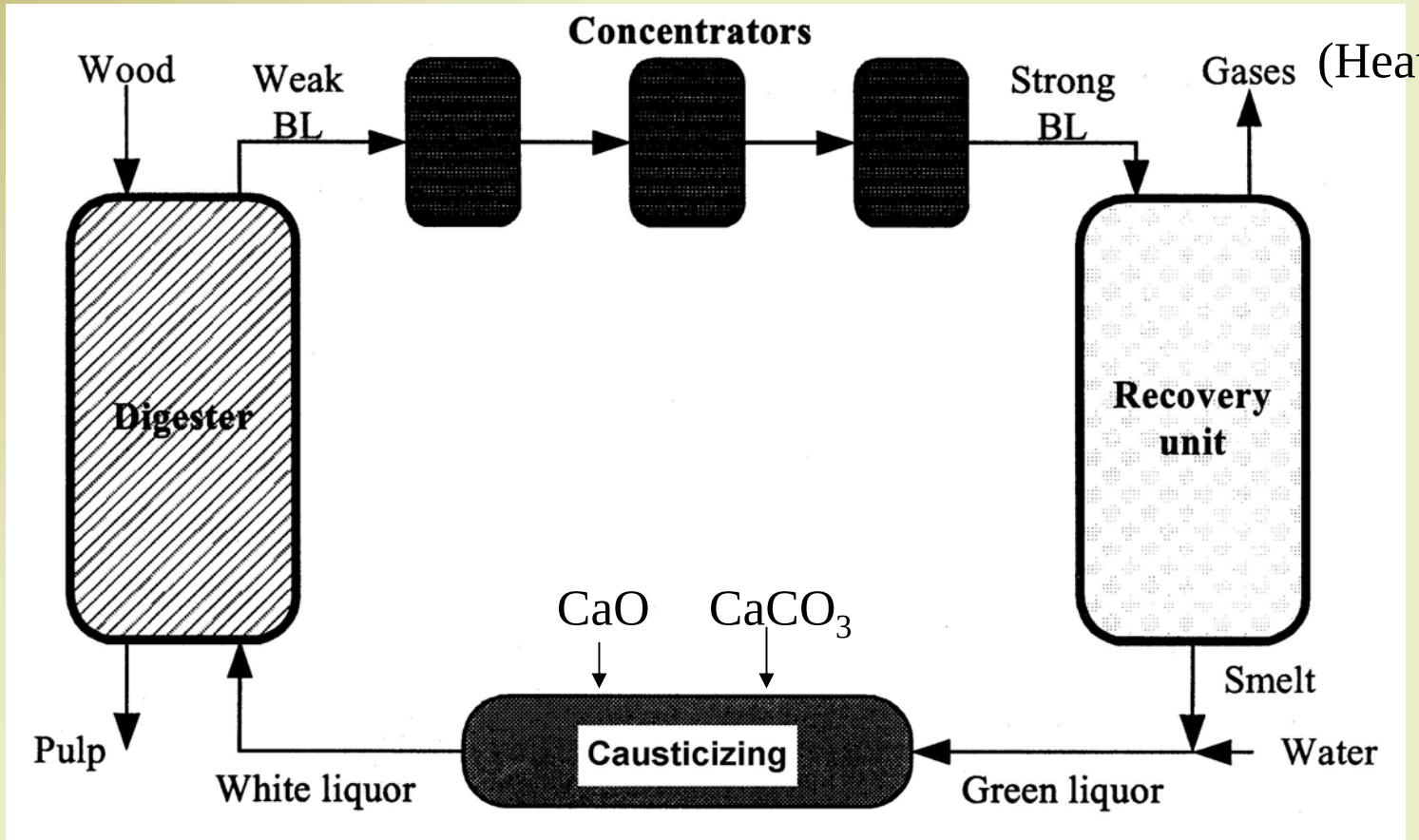
# Background

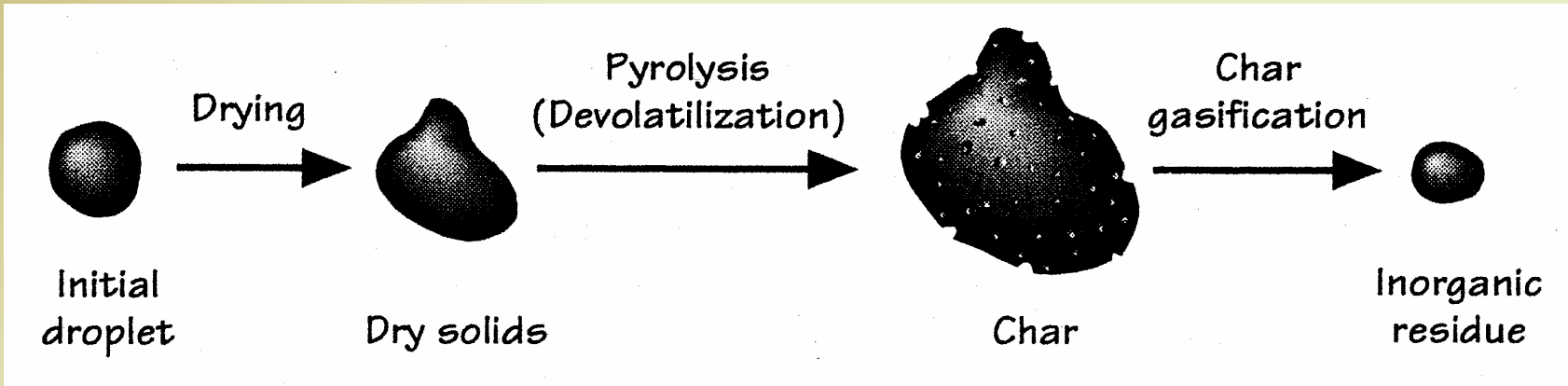



($NaOH$, $Na_2S$)

($Na_2CO_3$, $Na_2S$)

*from Mimms, A.; et al.; 1989: TAPPI*

# Single Droplet Combustion




- moisture contents out
- 1.5 $d_o$

- Volatile release
- rapid swelling, 2-5 $d_o$

- Direct Oxidation
- Gasification
- shrinking

*from Whitty, K.; 1997*

# Ash Particle

Three kinds of particles are categorized based on particle size and formation mechanism:

- Fume: condensed material from vaporized alkali compounds ($Na_2SO_4$, NaCl, $Na_2CO_3$, etc.)
- Carryover: black liquor spray particles entrained in the flue gas (partially burned droplet or char)
- Intermediate sized particle (ISP): fragment of black liquor, char or smelt?

# Questions

- How are ISP formed? (Formation mechanism)
- When are ISP formed?
- How many ISP are formed? (Significance)
- What are ISP like? (Size, shape, and morphology)
- What are the factors affecting ISP formation?

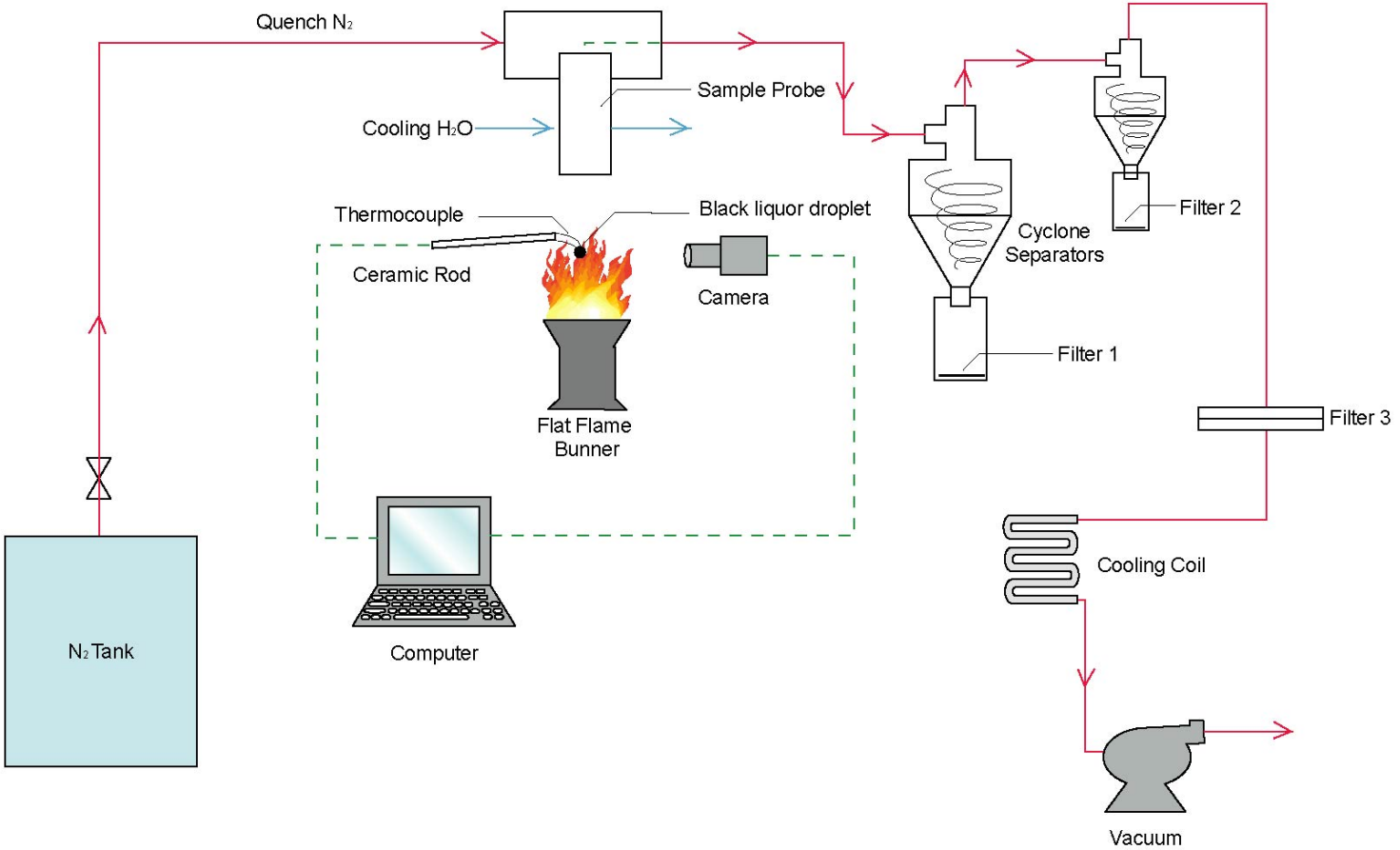
# Procedures

1. Monitor ISP formation during single droplet combustion with cameras
2. Collect ISP with cyclone separators and filters and measure the mass of ISP formed
3. Analyze the ISP collected with SEM
4. Investigate the effects of liquor type, solids content, and initial droplet size on ISP formation

# Experimental Method

- Suspended droplet on a thin wire or a TC
- Flat flame burner with 900-1000 °C
- Oxygen concentration range of 3-15%
- Camera recording speed of 60 frames per second
- Water-cooled, nitrogen-quenched collection probe
- Two cyclone separators with 20 µm and 5 µm cut-points (avoiding fume particles being collected)
- Two 1.6 µm borosilicate filters

# Experimental Setup



# Materials and Cases

- Five liquors from different paper mills (two softwood liquors and three softwood/hardwood mixed liquors)
- Two solids contents for each liquor (50% and 70%)
- Initial droplet mass range of 5-10 mg, dry basis
- At least 3 replications for each case with different initial droplet size
- About 40-50 droplets burned per run
- Total droplets burned: >1300 with over 30 cases total

# Liquor Composition

| | Softwood | | Softwood/Hardwood | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| C | 35.5 | 32.0 | -- | -- | -- |
| H | 3.45 | 3.40 | -- | -- | -- |
| N | - | 0.05 | -- | -- | -- |
| S | 5.25 | 5.79 | -- | -- | -- |
| Na | 18.8 | 22.0 | -- | -- | -- |
| K | 1.50 | 1.26 | -- | -- | -- |
| Cl | 0.10 | 0.55 | -- | -- | -- |
| O | 35.4 | 34.95 | -- | -- | -- |

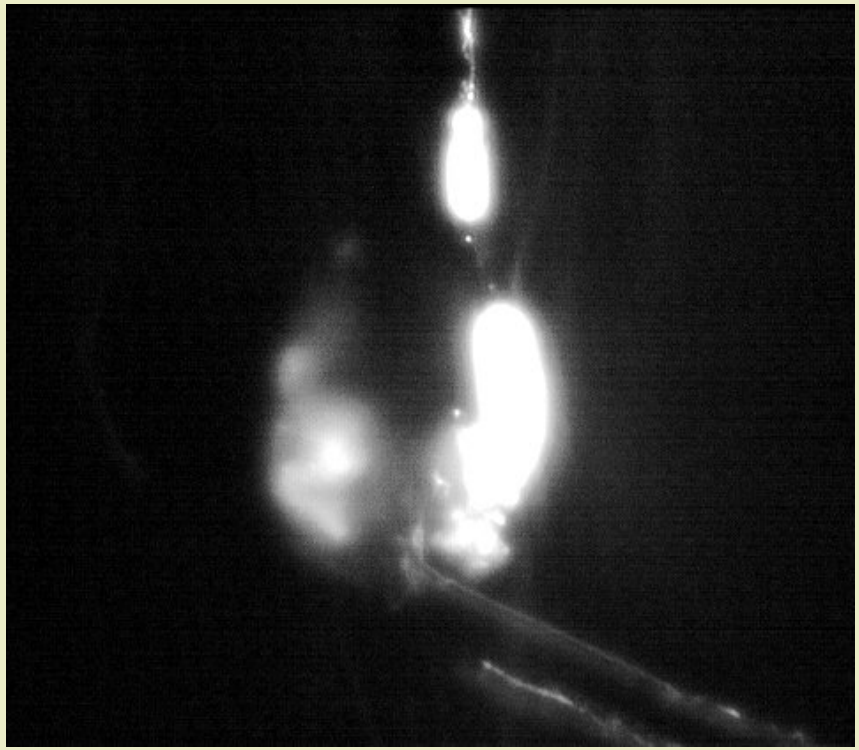
O – by difference.

Analysis for C, D, and E in progress

# Results

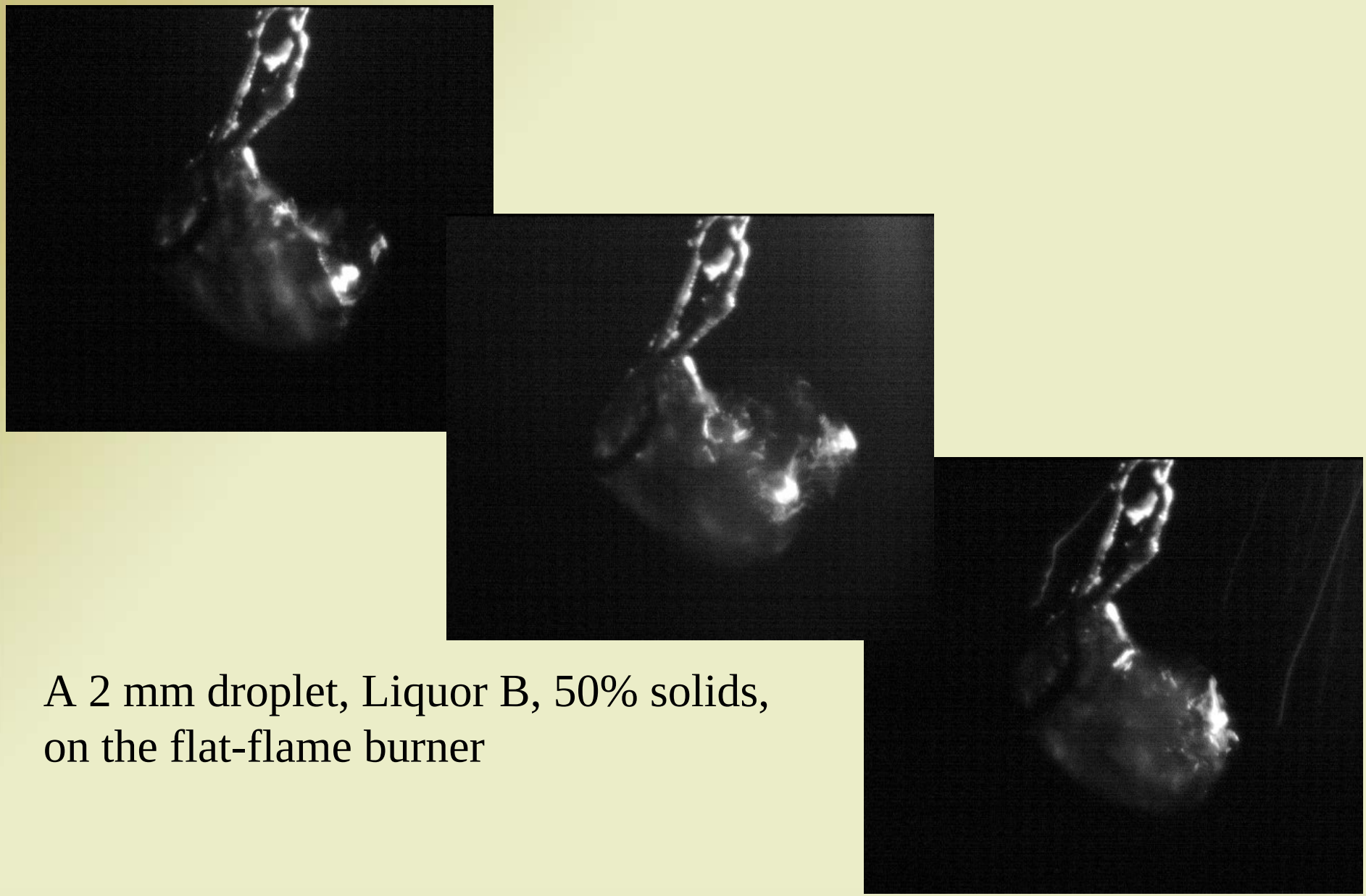
1. Monitor droplet combustion

# Drying



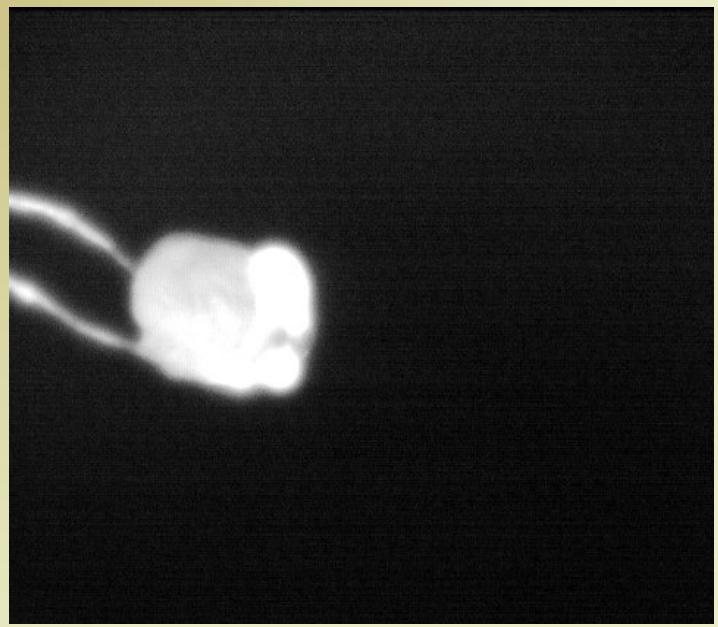
A 1.5 mm droplet, Liquor B, 50% solids, on the flat-flame burner

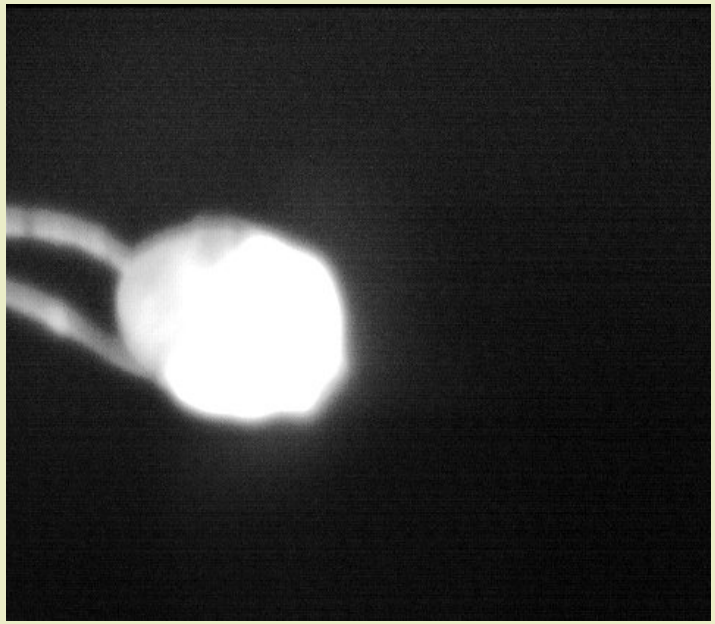
# Drying



A 2 mm droplet, Liquor B, 50% solids,
on the flat-flame burner

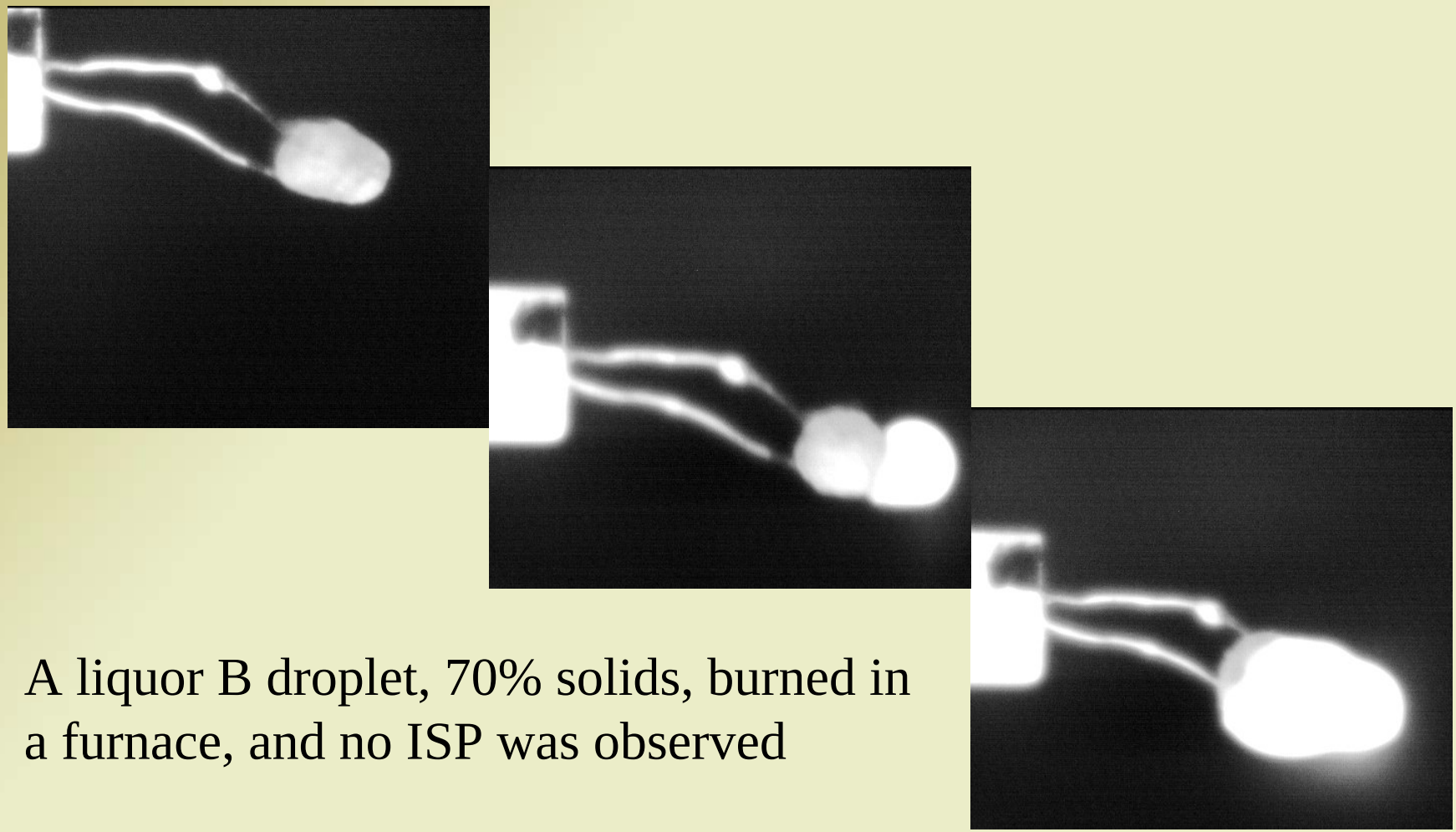
# Devolatilization and Swelling





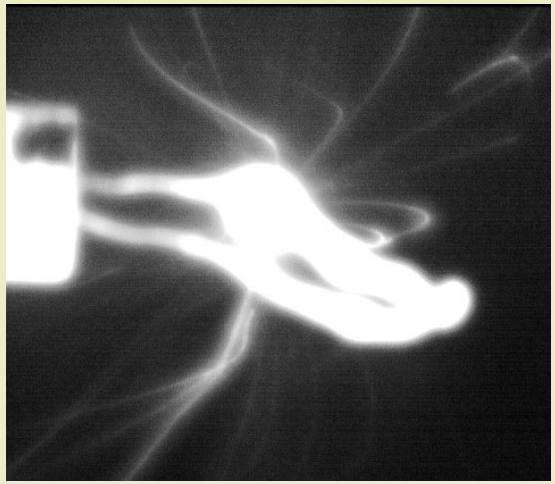
A liquor C droplet, 50% solids, burned in a furnace, and no ISP was observed

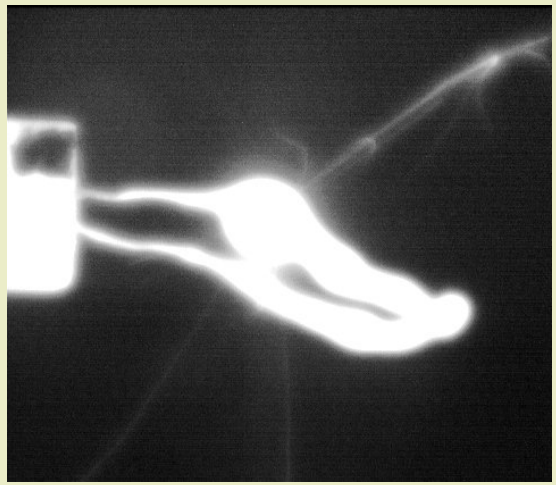
# Devolatilization and Char Burning



A liquor B droplet, 70% solids, burned in a furnace, and no ISP was observed

# Late Char Burning



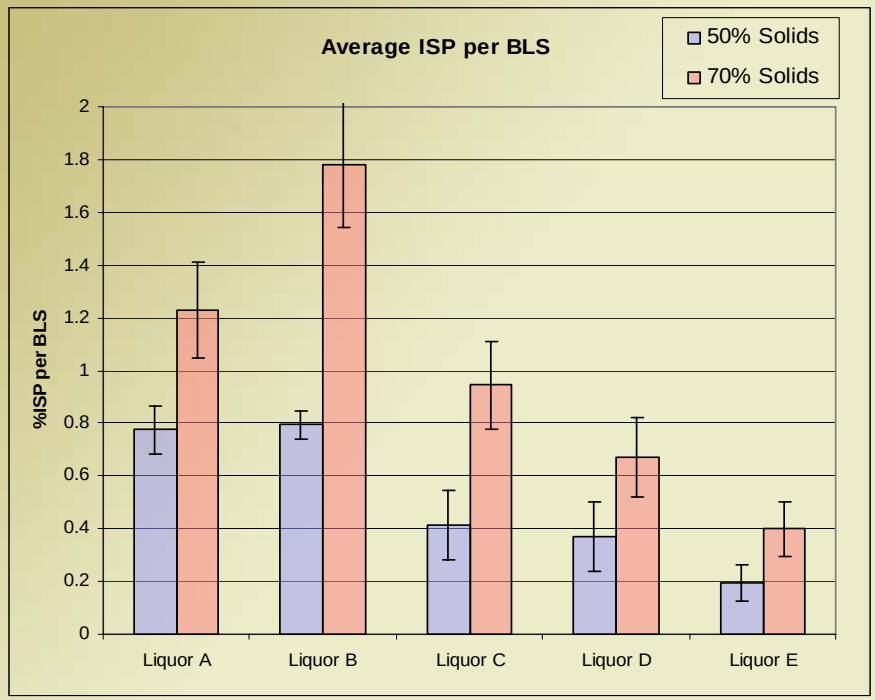


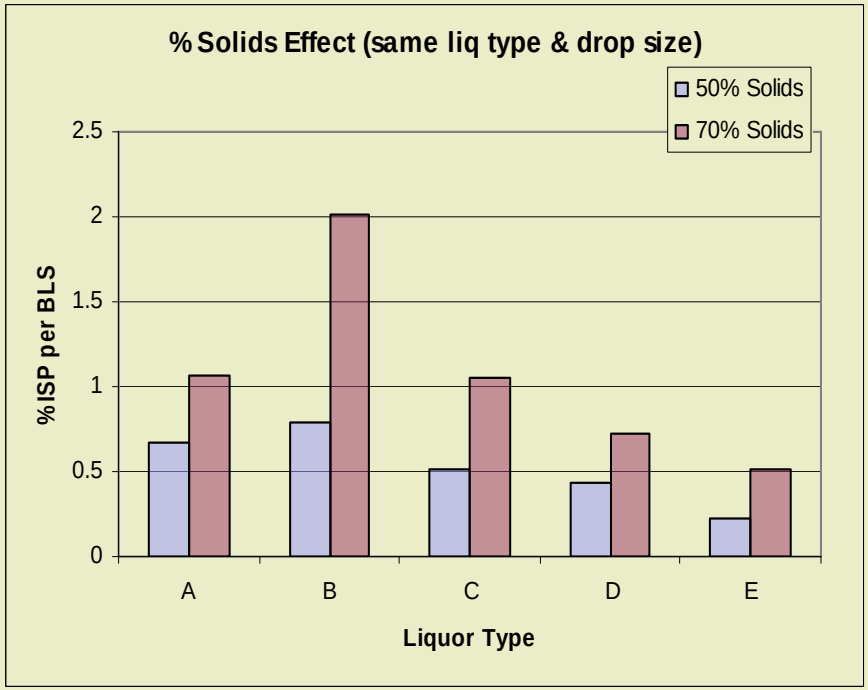
A liquor C droplet, 70% solids, burned in a furnace, formed ISP during late char burning

# Results

## 2. Quantitative Analysis

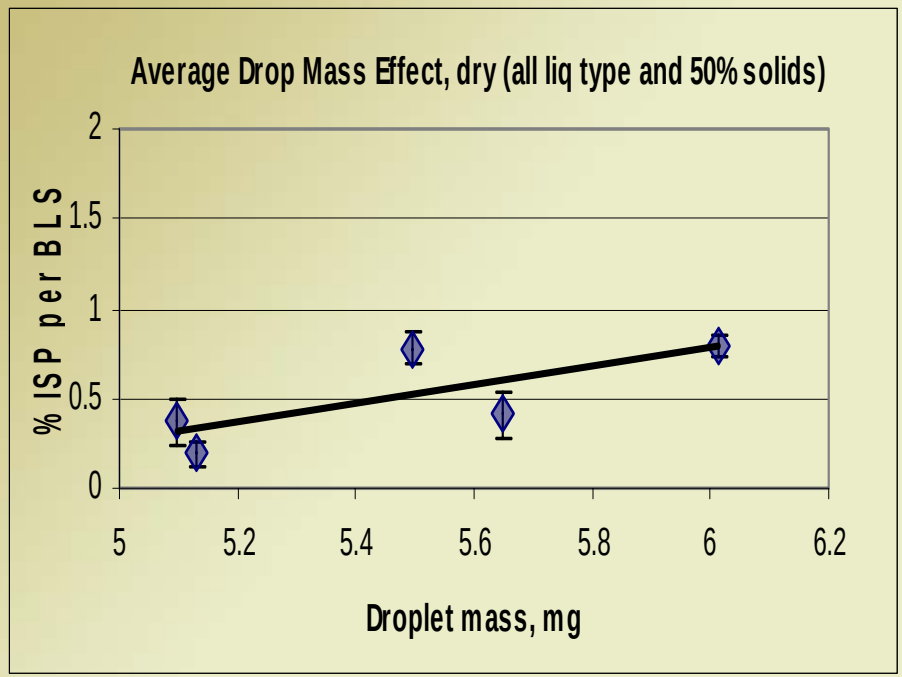
# Liquor Type and Solids Content Effects

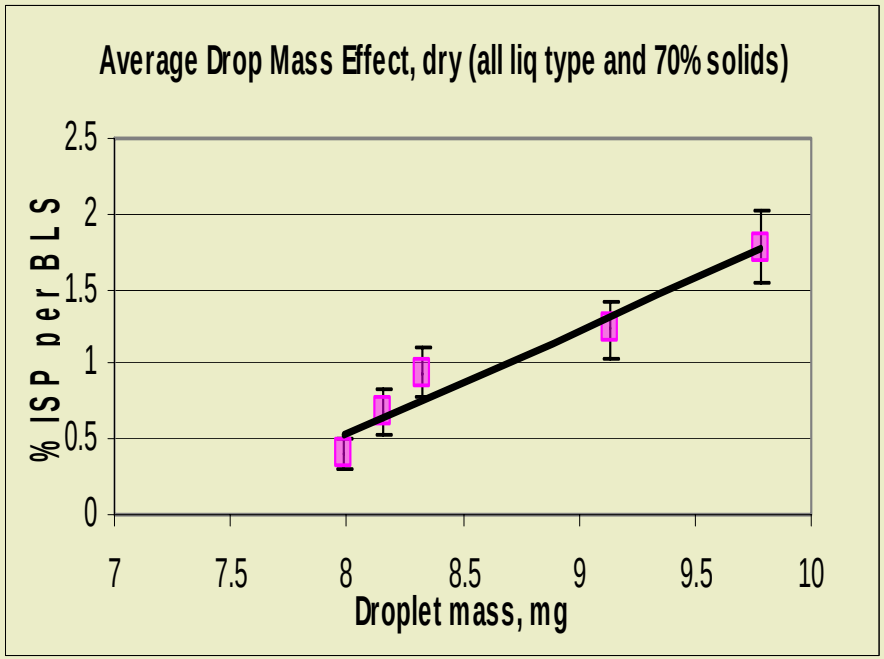



- ISP ranges from 0-2%. (reported value 5~15% S. Kochesfahani and H. Tran)
- Liquor type strongly affects ISP formation. (softwood > soft/hardwood mixed)
- The trend is the same for 50% and 70% solids content.
- Liquors with 70% solids formed more ISP than 50% solids liquors

# Initial Droplet Mass (Size) Effect



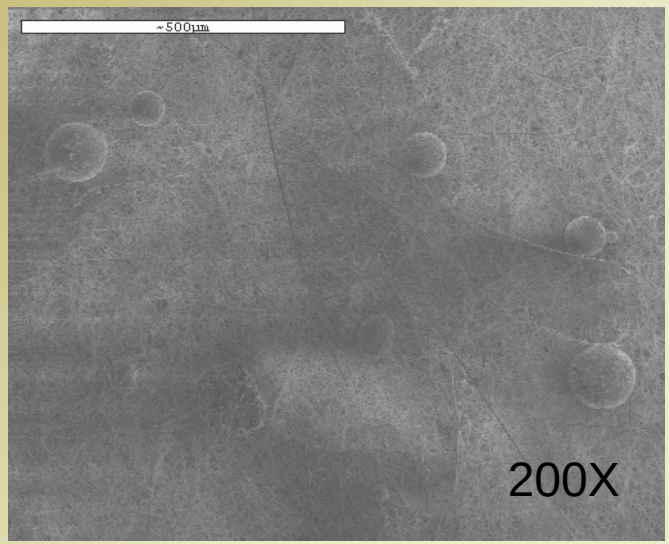

For both solids contents, ISP formation is proportional to the dry droplet mass (duration of oxidation), in the droplet size range of the investigation.

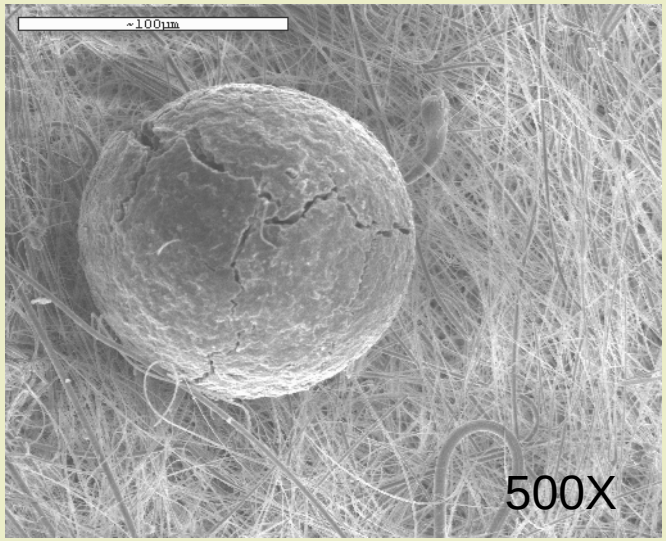
# Results

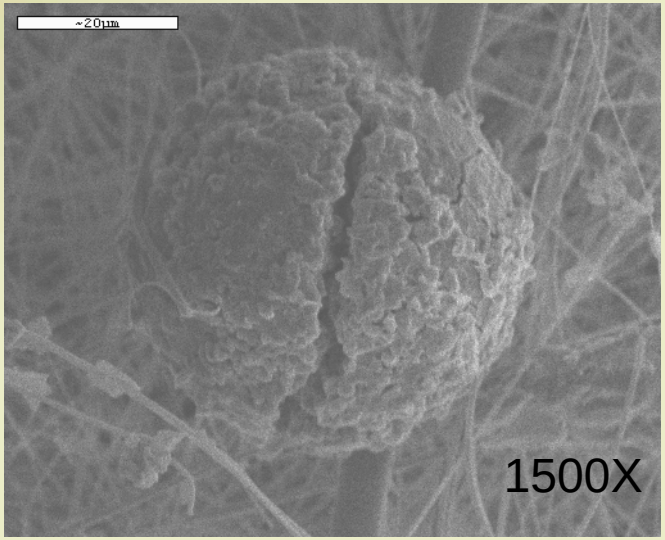
3. SEM Analysis

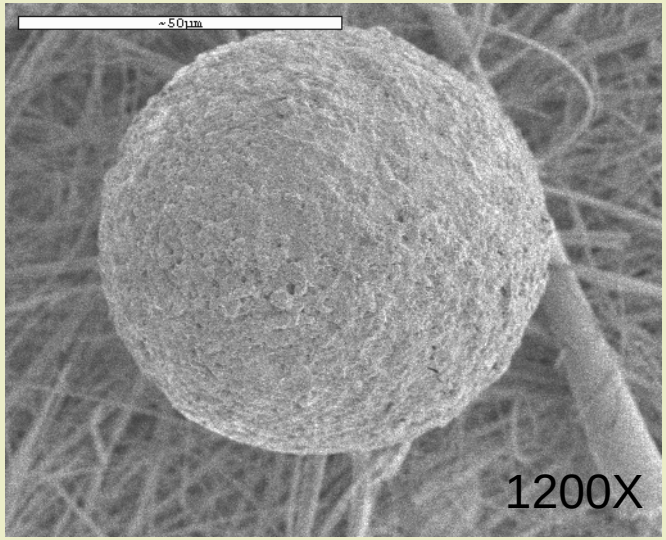
- Four samples from each filter
- Accelerating voltage: 2-10 kV
- Working distance: 15-23 mm
- Probe current: 1-10 nA
- Coating: gold with carbon paint

# Bigger Particles (>50 µm)



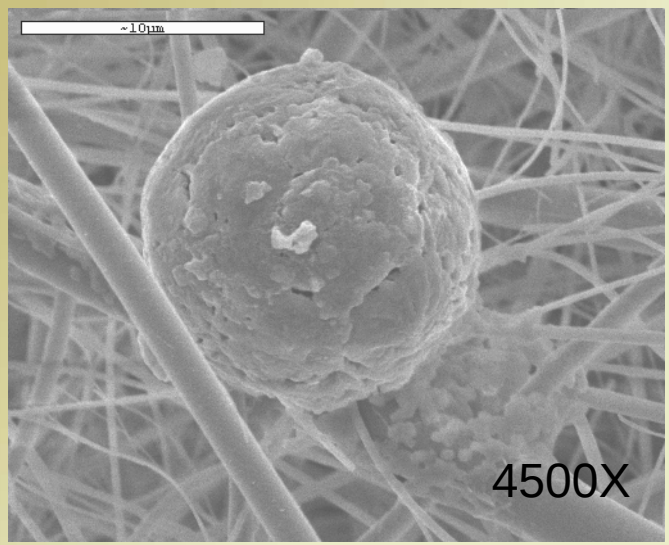



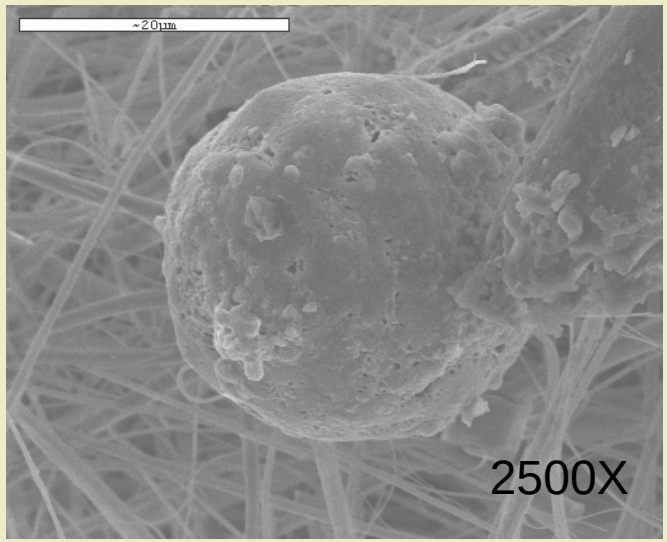



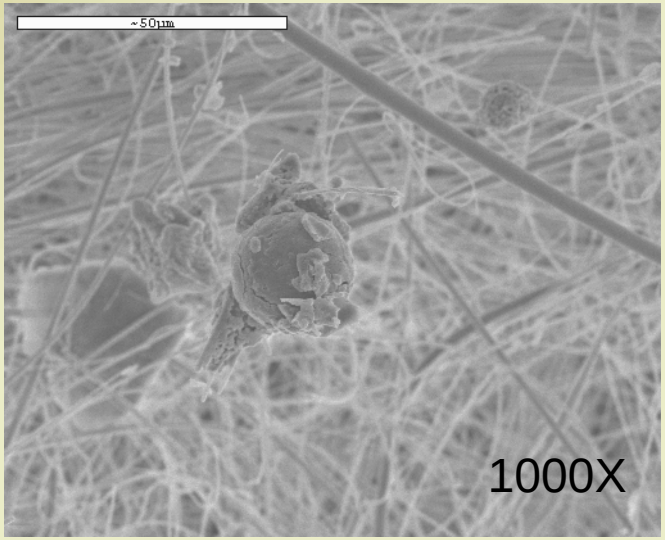



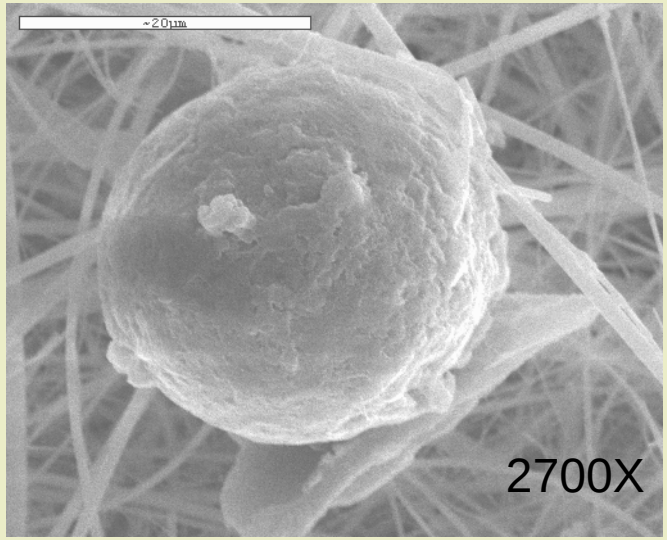

Spherical with cracking surface

# Medium Size Particles (10-20 µm)



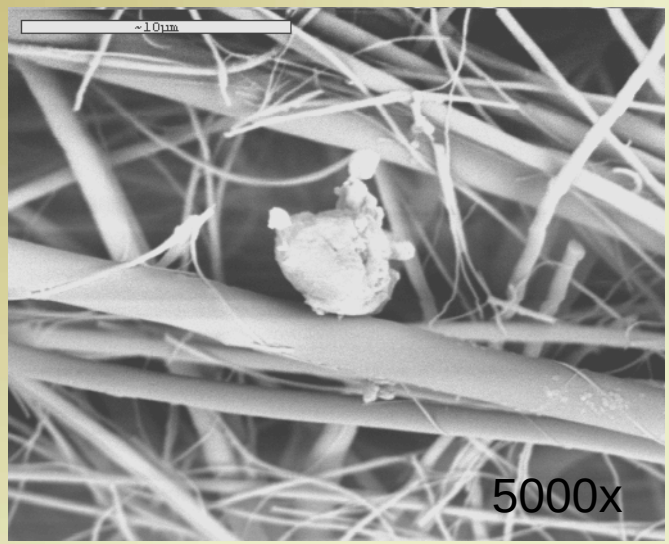



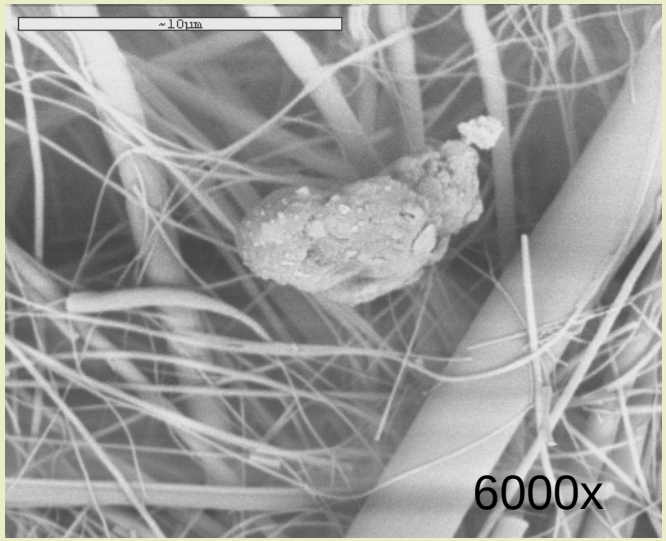



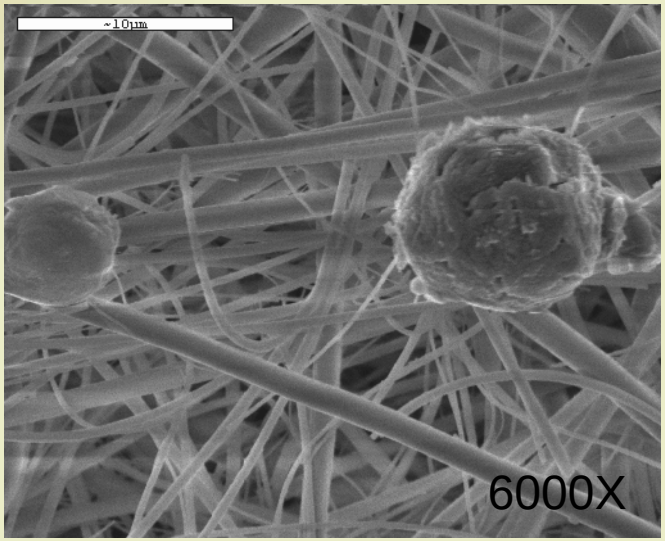



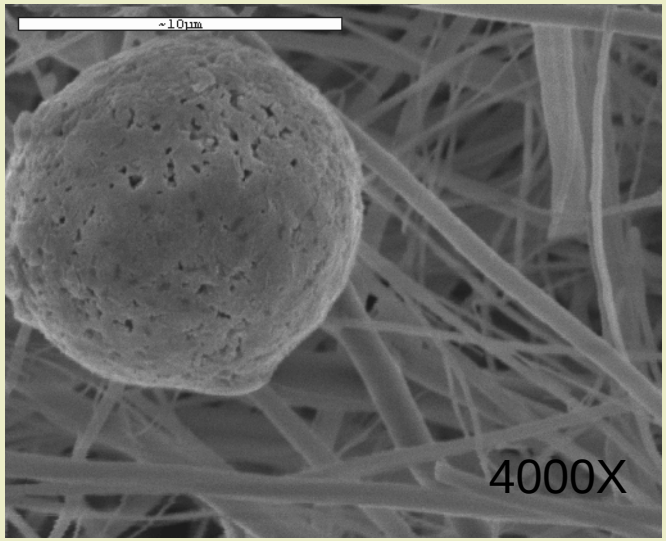

Agglomeration on surface

# Small Particle (<10 µm)



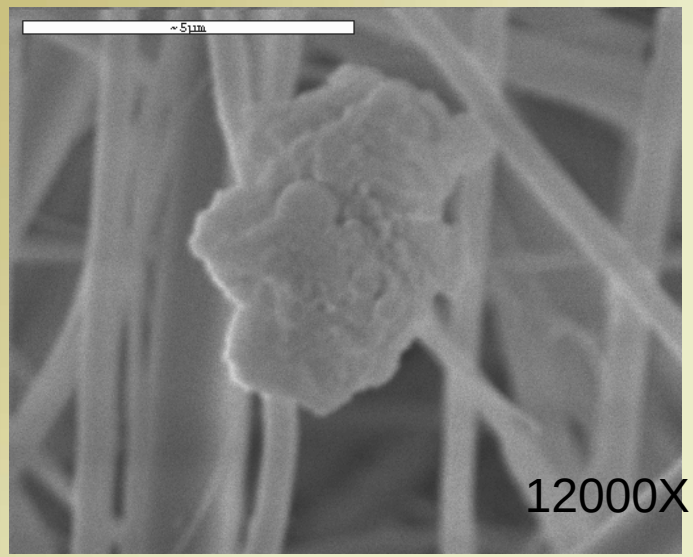



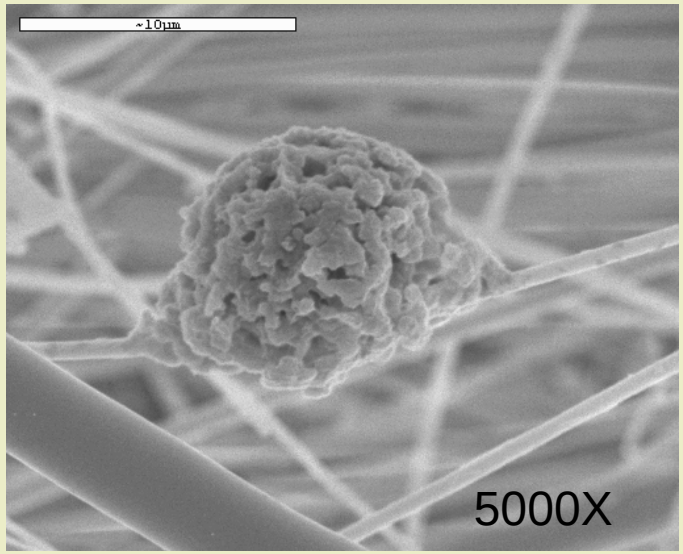



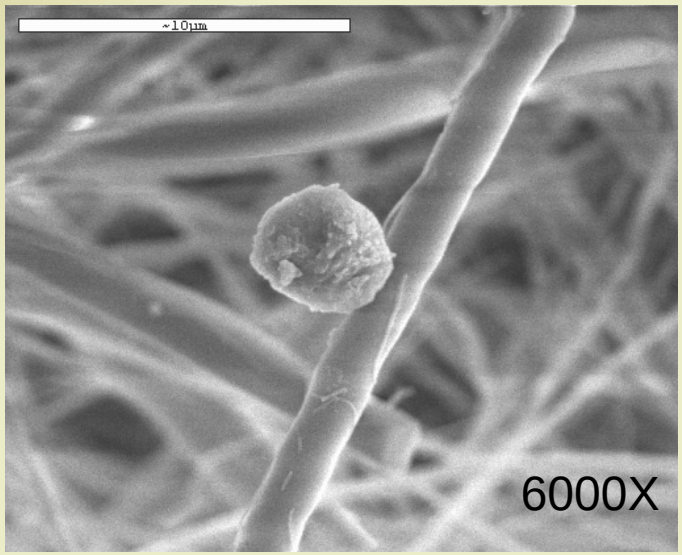



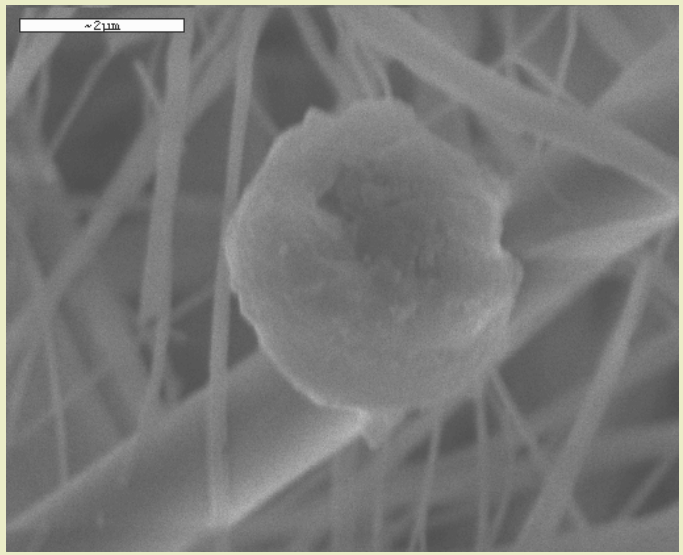

Irregular Shape

# Near Fume Particles (<5 µm)



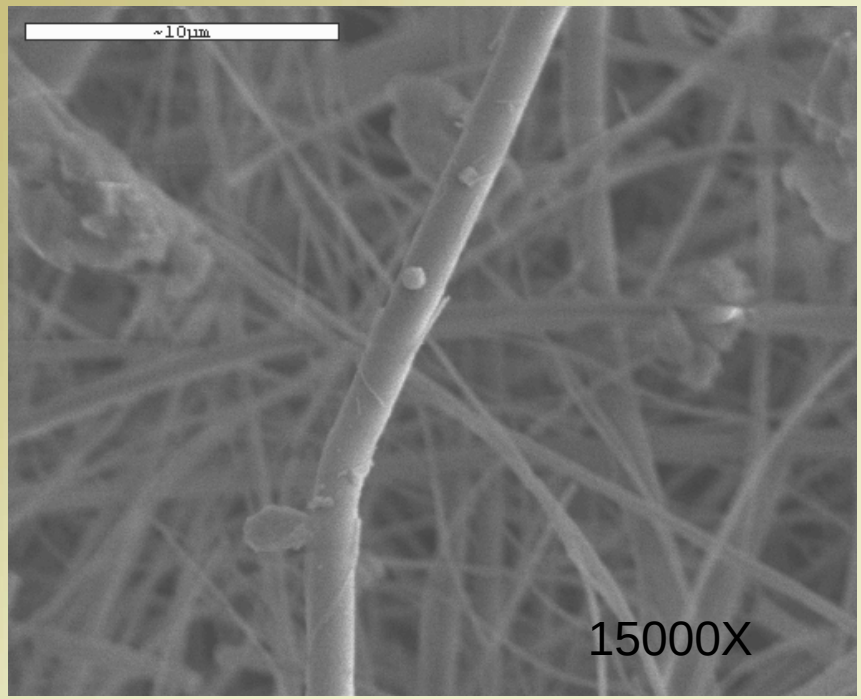



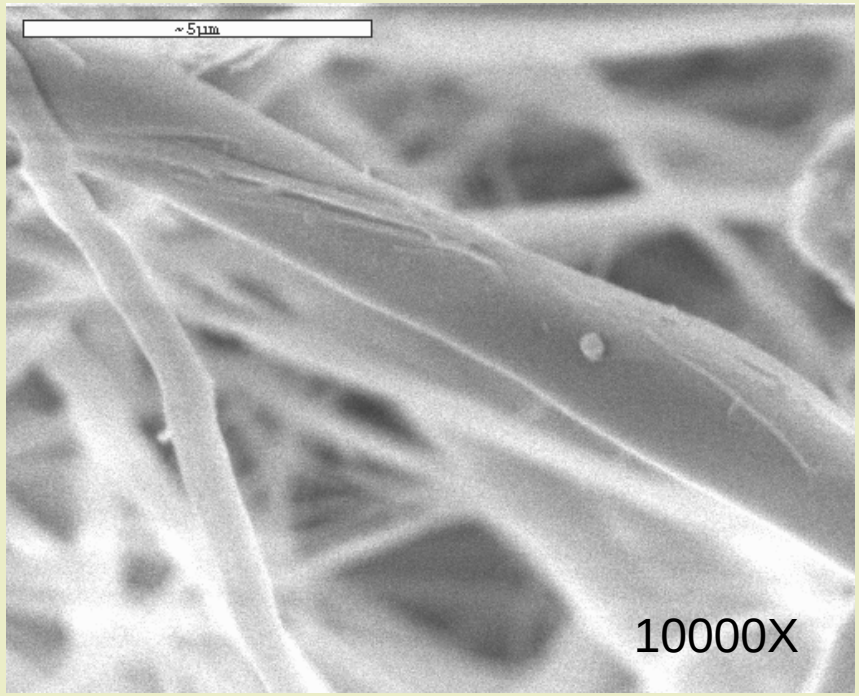




Various shapes and with/without agglomeration

# Fume particle (<1 µm)




Since the cut-points of the cyclones are 20 µm and 5 µm, very little fume collected.

# 4. Investigation of Effects

- The data show strong effects of liquor type, solids content, and droplet size
- Liquor type could be represented by sodium/carbon (Na/C) ratio
- Elemental composition of all the liquors are required.
- A prediction model could be developed based on the initial properties of black liquor including Na/C ratio, solids content, and droplet size

# Summary

- ISP formation accounts for 0-2% of dry solid mass.
- Small explosion creates small particles during drying, especially for low solids content liquors
- ISP are formed mainly during late char burning and early smelt oxidation (from video)
- Liquor type has significant effect on ISP formation, potentially due to the Na/C ratio of the liquor
- High solids content liquors form more ISP than low solids content liquors (so ISP are burning time related?)
- SEM images show that ISP have different shape, size, and surface morphology
- A model will be developed based on the effects of liquor type, solids content, and droplet size on ISP formation

# Future works

- More videos for all cases in the 3-D viewport furnace
- Image ISP formation from 3-orthogonal directions simultaneously
- Collect ISP formed from the droplet burning in the furnace
- Obtain the elemental composition of all the liquors for the model

# Acknowledgement

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