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Short-term Laboratory Investigations On The Cold Temperature Combustion And Emission Performance of a Biofuel Blend

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Considerations

- Promote use of renewable energy source to reduce harmful emissions; GHGs, PM, PM and smog precursors, acid deposition precursors
- Supplement dwindling conventional energy supplies and increase national energy sufficiency
- Gain economic benefits from reduced conventional fuel costs
- Reduce waste disposal costs for the materials that can be converted as energy source
- May reduce deterioration of equipment material that are related to sulphur emissions by reducing fuel sulphur content

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Exploratory work

Short-term evaluation of

- An optimum biofuel blend for residential space and water heating
- Combustion equipment compatibility
- Cold temperature performance
- Emission performance with respect to No. 2 heating oil
- Particulate emission characteristics that could demonstrate potential benefits of using biofuels

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Laboratory experiments

- Soybean methyl ester from Ontario, Canada
- 20% volume blended with regular No. 2 heating fuel

Residential-scale wet-base hot water boiler

High-efficiency oil burner with retention head

Experiments conducted in temperature-controlled test room

Test temperatures : 5°C, 10°C, 15°C, multiple experiments

Gaseous emissions: O_2, CO_2, CO, $NO_{x,}$, $SO_{2,}$

Particulates: Total PM, $PM_{2.5}$, PM_{10} & chemical components

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Properties of Experimental fuels

Properties	No.2 Fuel	B-20 Blend
Ultimate analysis (wt %)		
Carbon	87.00	85.10
Hydrogen	13.10	12.90
Nitrogen (ug/g)	86.00	67.00
Sulphur (wt %)	0.19	0.15
Ash (wt %)	<0.001	<0.001
Water content- (wt %)	<0.01	<0.01
Total acid number (mg KOH/g)	0.09	0.32
Density @ 15°C (kg/m^3)	847.2	855.2
Specific gravity (60/60F)	0.848	0.856
Gross calorific value (cal/g)	10831	10527
kinematic viscosity @40°C (cSt)	2.234	2.549
Cloud point °C	-16.4	-3.6
Pour point °C	-38	-24

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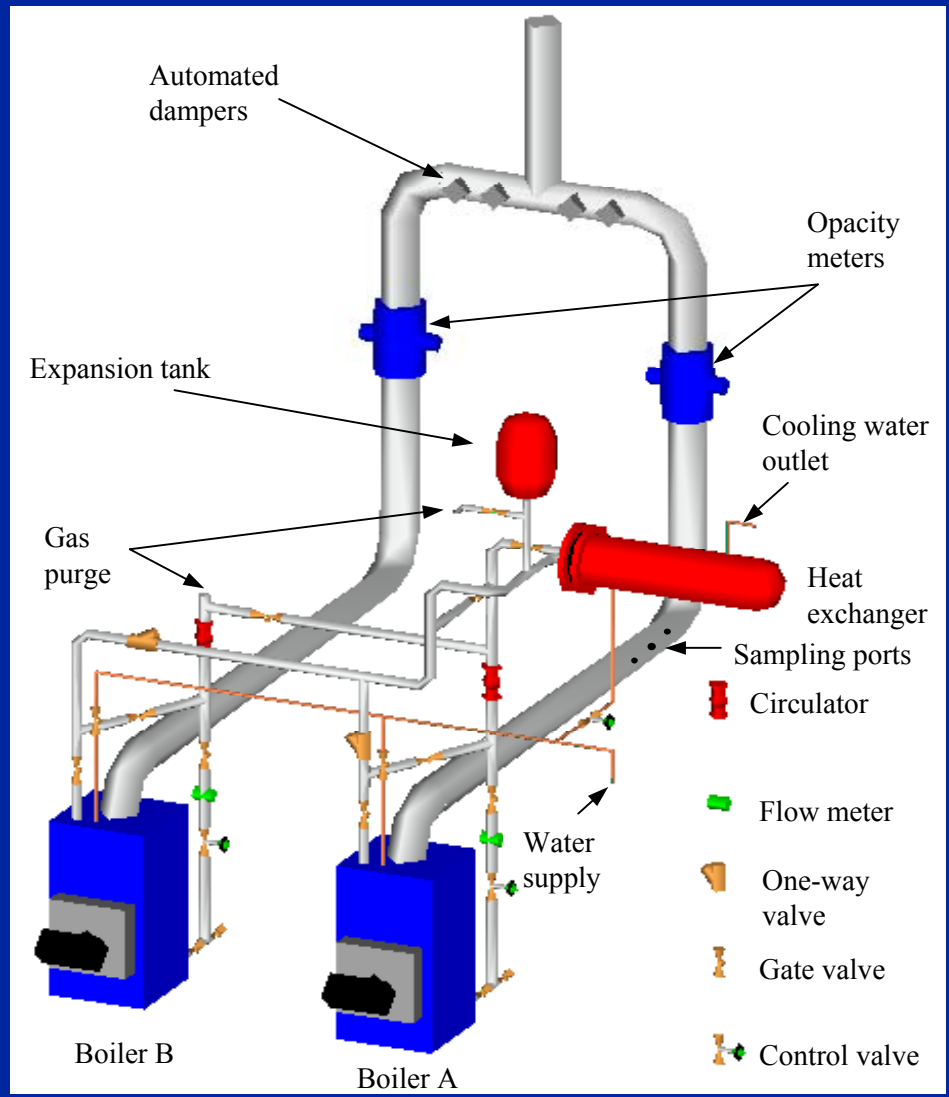
Residential Oil Combustion Laboratory Test Rig



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Gaseous Emissions: Steady State

Stack emissions		1	2	3	4	5	6	Average B-20	Average No.2 Fuel
O_2	%	4.4	5.0	4.6	4.8	4.9	4.6	**4.7**	**4.6**
CO_2	%	13.2	12.8	13.0	12.9	12.7	12.9	**12.9**	**12.9**
CO	ppm	39	28	35	31	28	30	**32**	**30**
SO_2	ppm	79	76	78	75	78	78	**77**	**96**
NO_x	ppm	110	109	112	106	109	110	**109**	**104**

Gaseous Emissions : at 3% O_2

Stack emissions		1	2	3	4	5	6	Average B-20	Average No.2 Fuel
O_2	%	3.0	3.0	3.0	3.0	3.0	3.0	**3.0**	**3.0**
CO_2	%	14.3	14.4	14.2	14.3	14.3	14.2	**14.3**	**14.2**
CO	ppm	42	32	38	34	31	33	**35**	**33**
SO_2	ppm	86	86	86	83	87	86	**85**	**101**
NO_x	ppm	119	123	123	118	122	120	**121**	**114**

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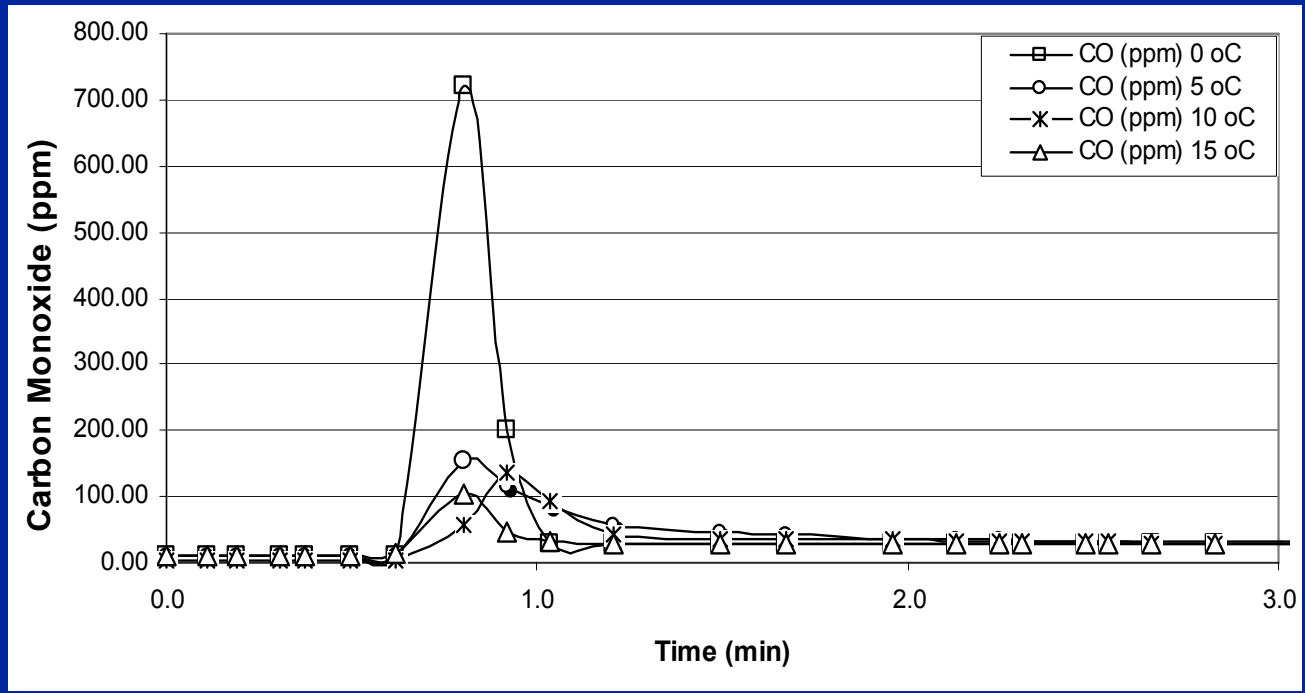
Transient CO emissions



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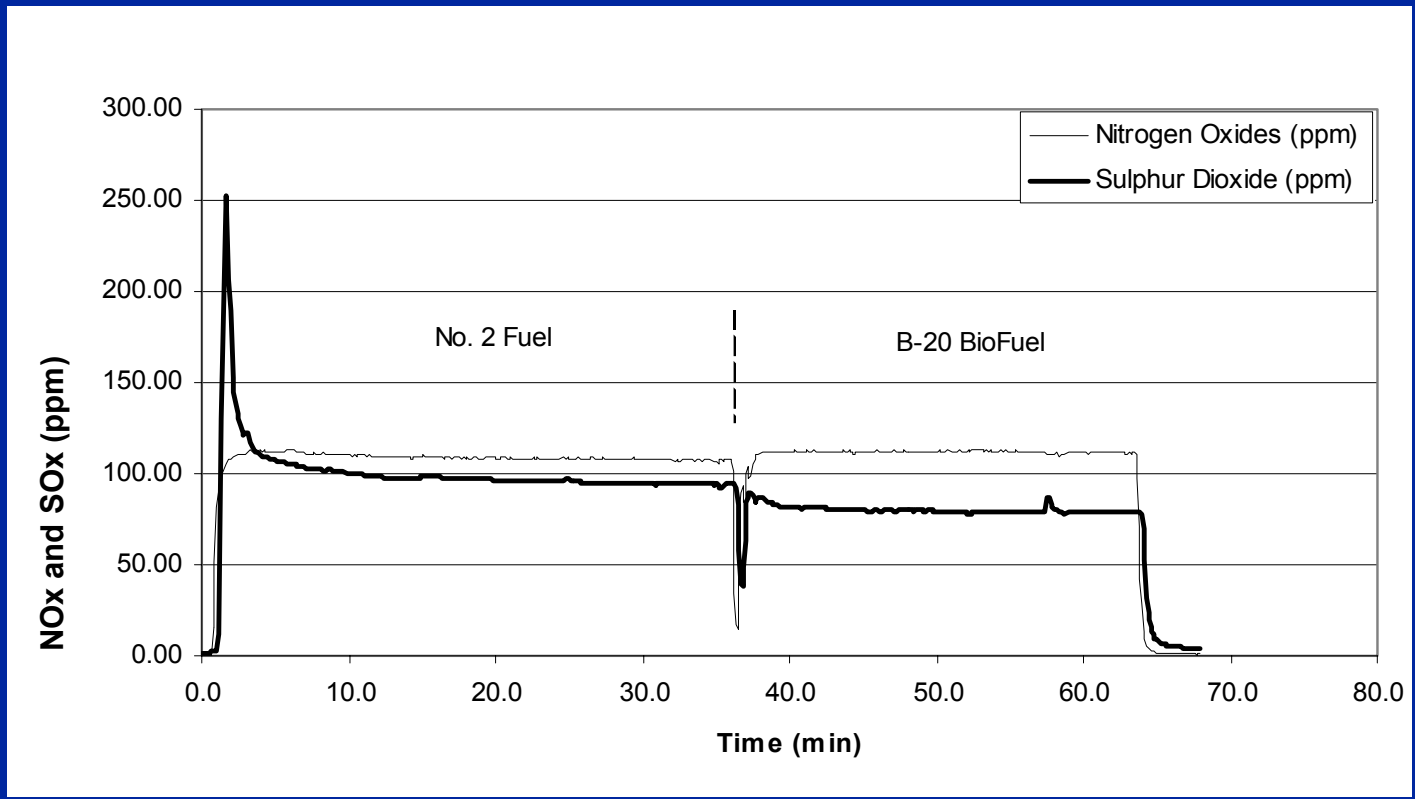
Comparison of No_x and SO_2 emissions



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North American Ambient PM Standards ($\mu g/m^3$)

	Annual (3-year average of arithmetic mean)	24-hour (3-year average of 98th percentile)
Canada: CWS		
$PM_{2.5}$	None	30
PM_{10}	Declared toxic under the Canadian Environmental Protection Act	
US: NAAQS		
$PM_{2.5}$	65	150
PM_{10}	50	150

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The U.S. Implementation Timeline

1997	EPA issues final $PM_{2.5}$ NAAQS
1998-2000	Ambient PM monitors put in place nationwide
1999-2003	Collect monitoring data
2002	EPA completes 5-year scientific review of standards
2003-2005	EPA designates non-attainment areas
2005-2008	States submit implementation plans for meeting the standard
2012-2017	States have up to 10 years to meet the standards plus one year extensions

Source: Office of Air and Radiation of the U.S. Environmental Protection Agency, 2000.

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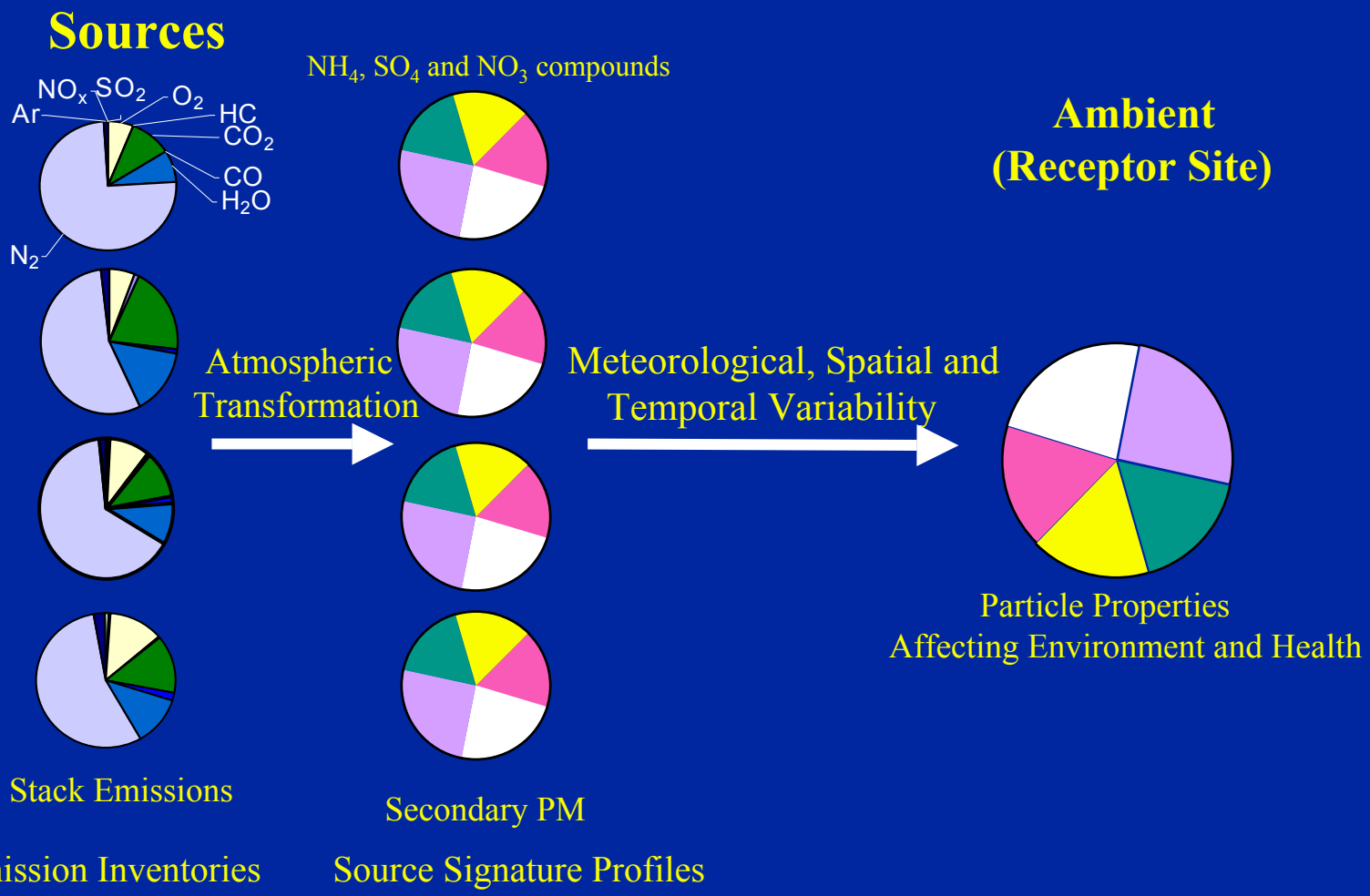
Simplified Source Apportionment



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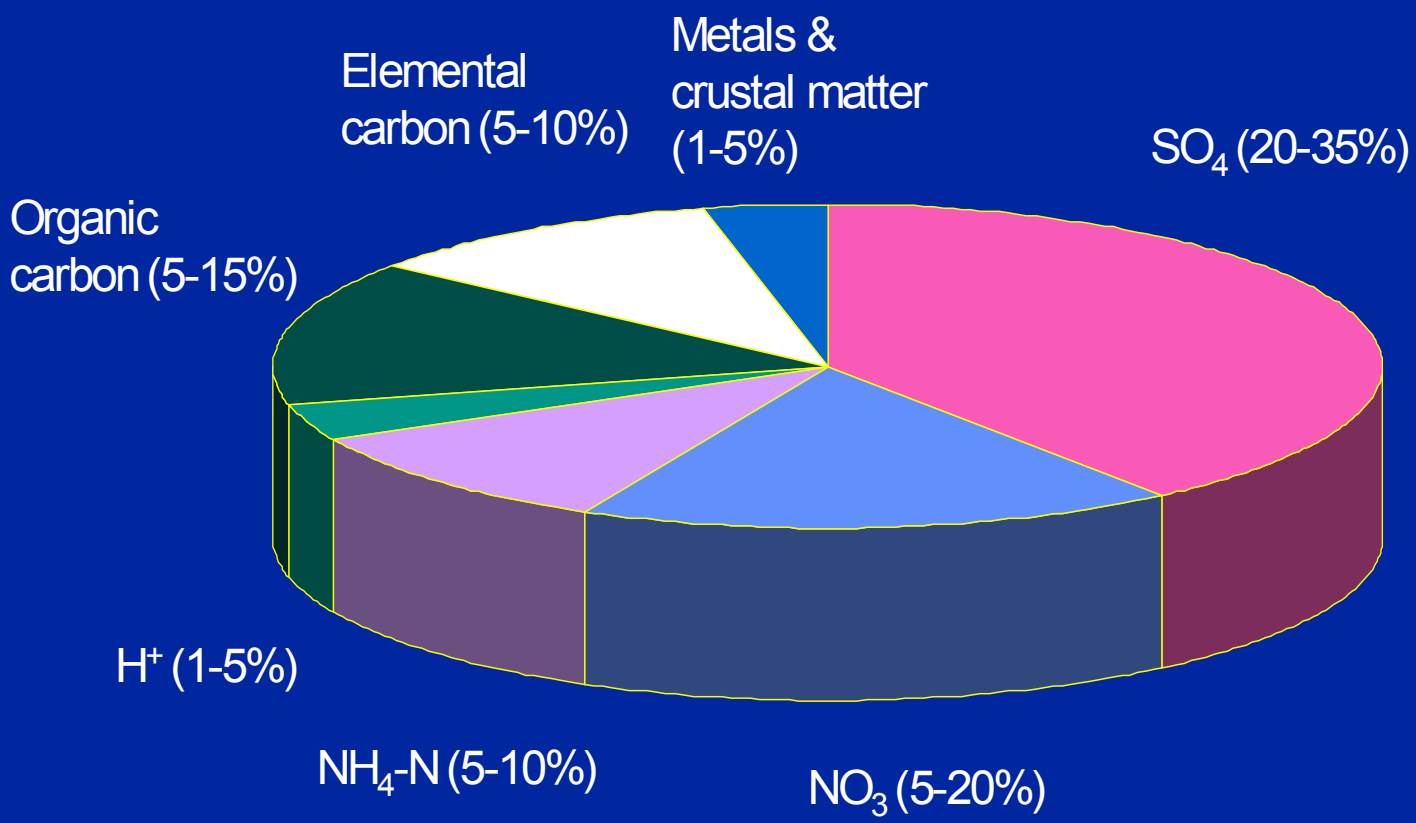
Approximate Fine Particle Mass <2.5µm



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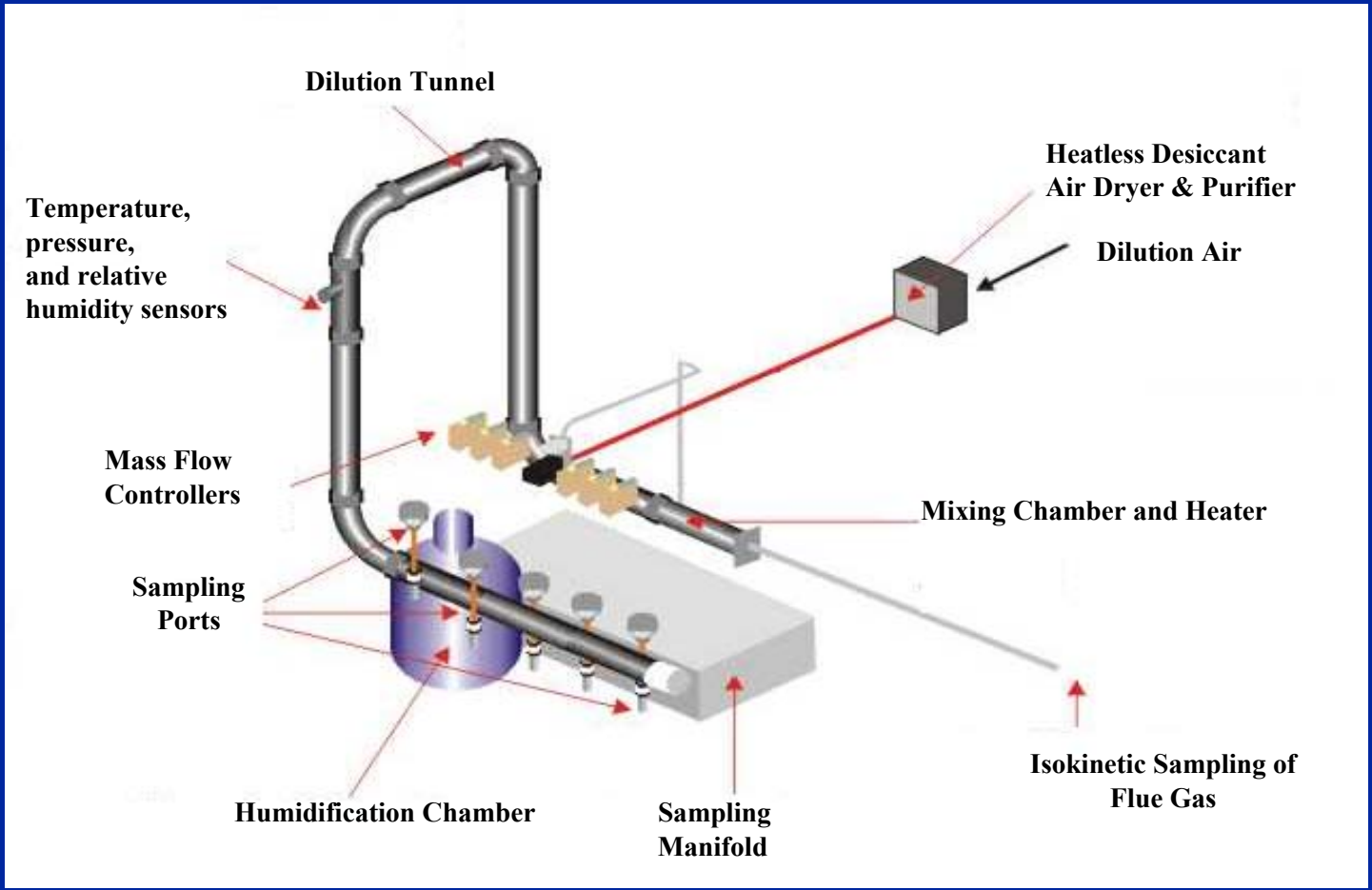
CETC Source Dilution Sampling System 1



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CETC Source Dilution Sampling System 2

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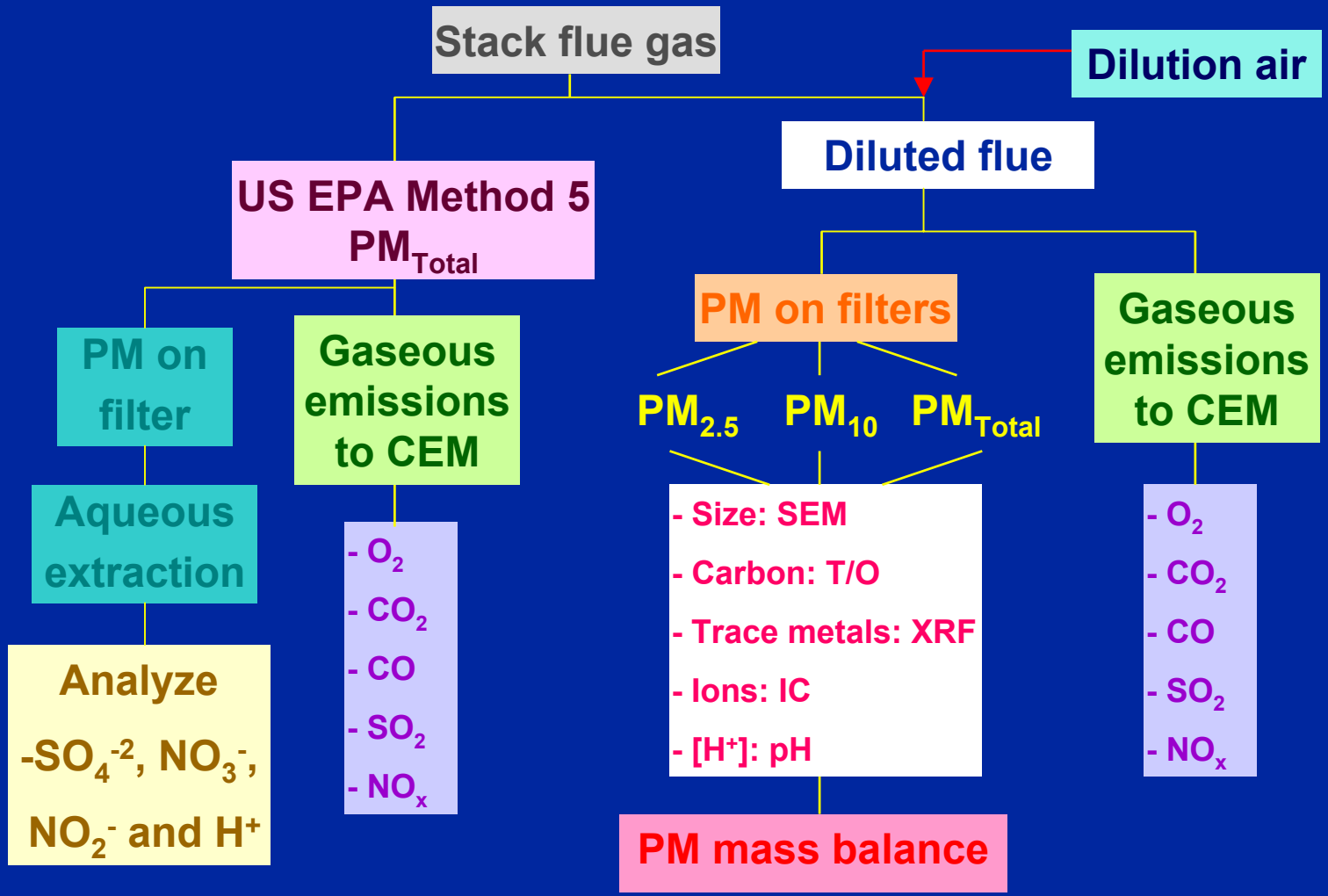
Sample Collection and Analysis Procedure



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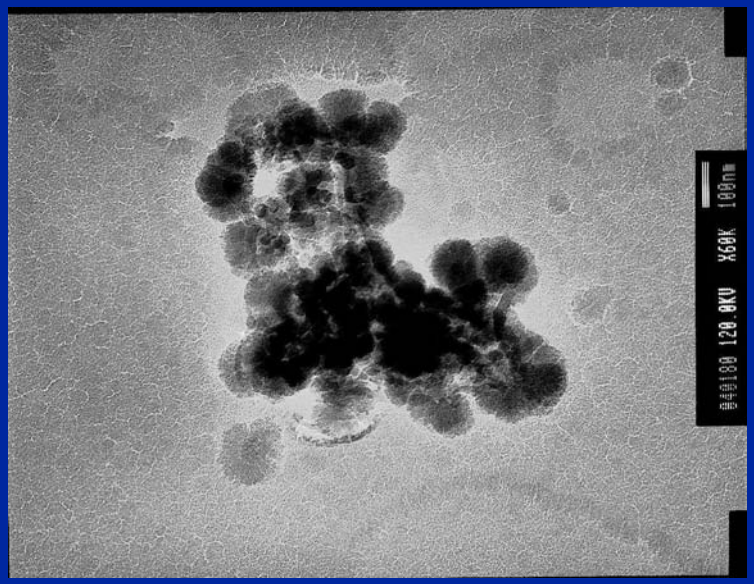
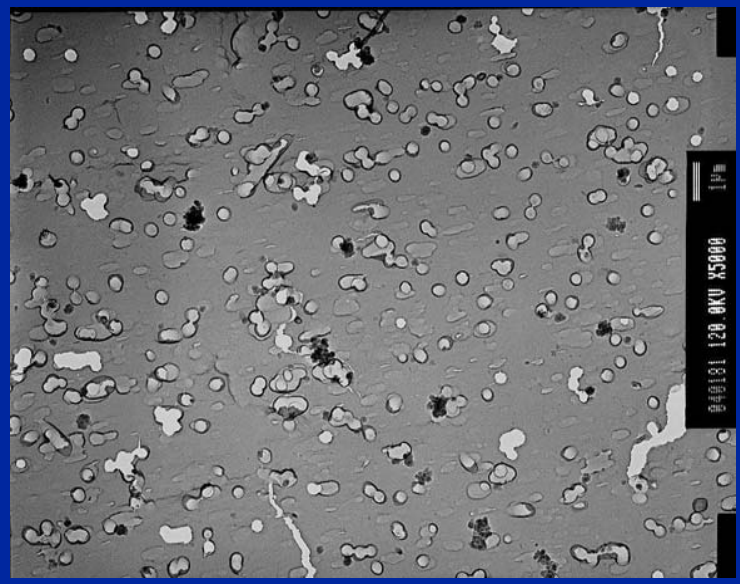
TEM Images – $PM_{2.5}$ Agglomerate for No. 2 Fuel Oil



X 60K



Field Image X 5K

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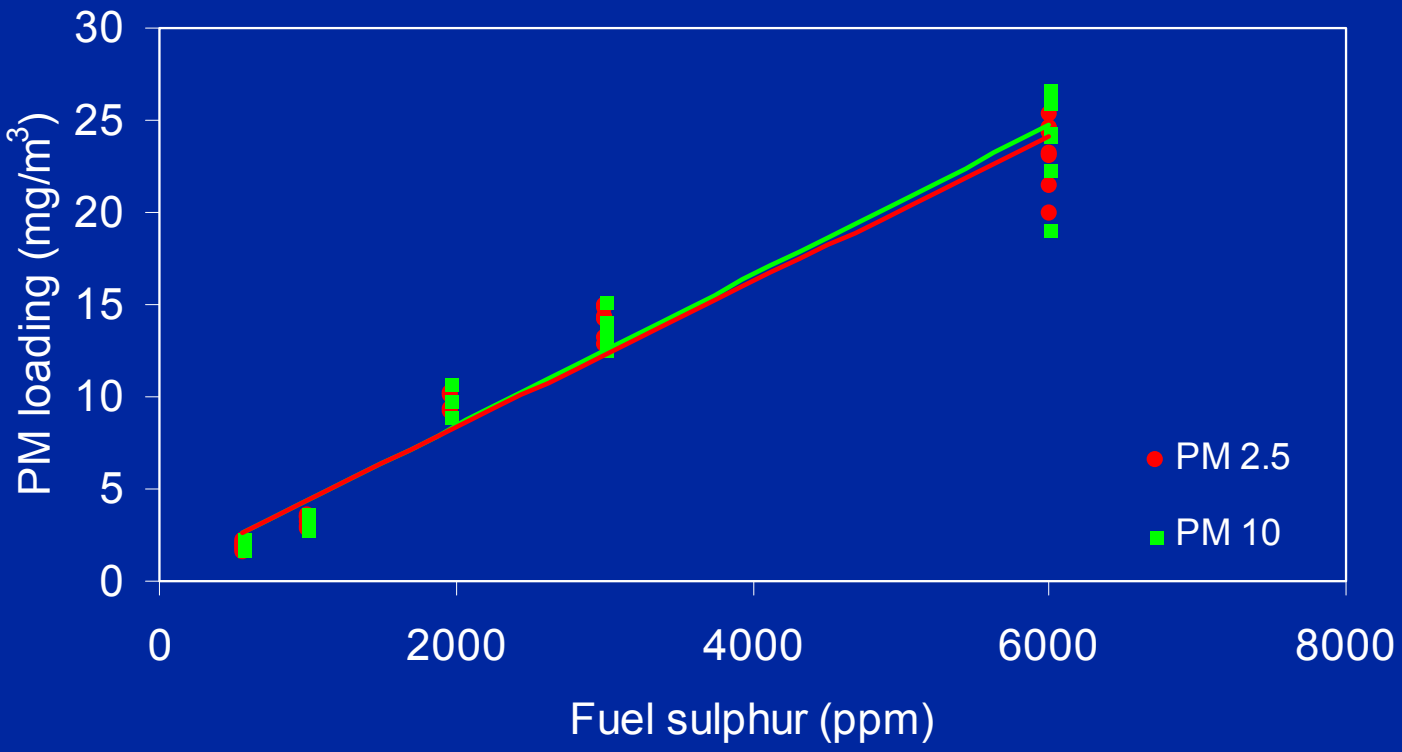
$PM_{2.5}$ and PM_{10} Emissions vs Fuel Sulphur



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Particulate Emissions

Fuel	Run	$PM_{2.5}$ mg/m^3	PM_{10} mg/m^3	PM_{Total} mg/m^3
B-20 Biofuel	1	12.89	12.66	12.73
	2	14.00	11.82	13.42
	3	12.67	11.79	11.89
	AVG	13.19	12.09	12.68
	RSD (%)	5.41	4.06	6.04
No. 2	1	15.74	15.48	15.18
	2	13.95	14.00	14.65
	AVG	14.84	14.74	14.92
	RSD (%)	8.54	7.08	2.51

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Fine Particulate Characteristics

Fuel	Constituents	$PM_{2.5}$ mg/m^3	PM_{10} mg/m^3	PM_{Total} mg/m^3
B-20	Metal as oxides	0.11	na	0.26
	Organic carbon	0.64	0.62	0.71
	Elemental carbon	0.04	0.05	0.05
	Sulphates	5.9	5.5	5.6
	Water associated with sulphate	6.5	6.1	6.2
	Total mass by composition analysis	**13.2**	**12.3**	**12.8**
	Total mass by gravimetry	**13.2**	**12.1**	**12.7**
No. 2	Metal as oxides	0.18	na	0.19
	Organic carbon	0.63	0.57	0.61
	Elemental carbon	0.21	0.23	0.21
	Sulphates	6.7	6.3	6.6
	Water associated with sulphate	7.4	6.9	7.3
	Total mass by composition analysis	**15.1**	**14**	**14.9**
	Total mass by gravimetry	**14.8**	**14.7**	**14.9**

Note: Mass balances are average values for multiple runs

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Summary of findings

Research update from a short-term laboratory investigation only

This information should be considered preliminary

Data is specific to a 20% soy bean methyl ester blend and the selected experimental conditions.

Additional experiments are underway to verify these results

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Summary of Findings

A 20% soybean methyl ester/No. 2 fuel oil blend

Showed normal combustion performance on a residential oil-fired boiler

No modifications to the procedure or the equipment were required

Cold start transient CO emissions increased at temperatures < 15°C

May Indicate incomplete combustion and increased PM

Additional cold temperature tests are being planned. May be possible to predict specific optimum temperature conditions.

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Summary of Findings

Combustion of B-20 biofuel blend indicated several potential benefits

benefits

enefits

fuel oil

fuel oil

n of SO_2

5 % lower

similar

7±7.5 %.

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Summary of Findings

PM Characteristics

Particles emitted fall in the $PM_{2.5}$ range – similar to No. 2 fuel

Particles are mainly made up of sulphate and associated water

Only minute quantities of trace elements are detected in the PM

Organic and elemental carbon concentration data need to be verified – low carbon content caused poor data accuracy

Other blending ratios may exhibit different PM characteristics

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Future research

Long-term studies to determine appliance performance and unit component integrity

e.g. the BNL field trials

Effects of biofuel on equipment components - oil heating industry

Long-term chemical/ thermal stability of biofuel blends

Cold temperature performance for safe application in cold climates

More laboratory experiments to confirm the preliminary data

Additional research on fine PM emissions from different biofuel blending stocks