Source Testing Field Handbook

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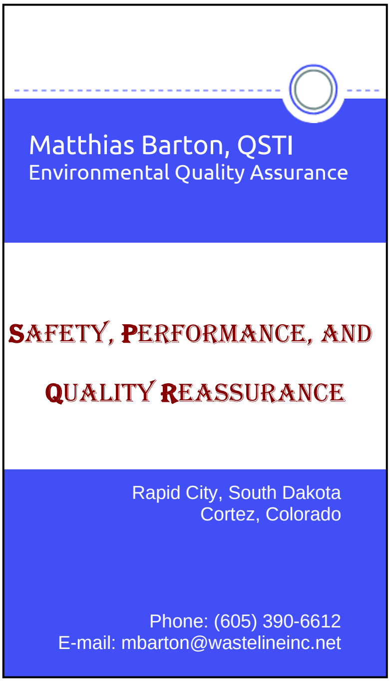

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1. Facility and Source Information

Information	Data
Facility Registration Service (FRS) Number:	
EPA Region and Contacts:	
State Agency Contacts:	
Facility Permit Number:	
Facility State ID:	
Other IDs:	
Other Permits:	
Facility Address:	
Facility Coordinates:	

Notes:

Other Notes or Drawings or Images:

Notes:

Information	Source 1	Source 2	Source 3
Permitted Source ID:			
Other Names:			
Operating Parameters:			
Operating Rates and Limits:			
Emission Rates and Limits:			
Testing Cycle:			
Emission Rates and Limits:			
Testing Cycle:			
Emission Rates and Limits:			
Testing Cycle:			
Method 1 Check:			
Overall Height of Source:			
Distance A (Dia. / Ft):			
Distance B (Dia. / Ft):			
Dimensions (Dia. / Eq.):			
Port Size(s) / Length(s):			
Area:			
Cyclonic Check: <20°			
Date of Cyclonic:			
Stratification Check: <5%			
Date of Stratification:			
Expected Moisture:			
Expected Velocity (ft/sec)			
Expected Flow (dscfm)			

Information	Source 4	Source 5	Source 6
Permitted Source ID:			
Other Names:			
Operating Parameters:			
Operating Rates and Limits:			
Emission Rates and Limits:			
Testing Cycle:			
Emission Rates and Limits:			
Testing Cycle:			
Emission Rates and Limits:			
Testing Cycle:			
Method 1 Check:			
Overall Height of Source:			
Distance A (Dia. / Ft):			
Distance B (Dia. / Ft):			
Dimensions (Dia. / Eq.):			
Port Size(s) / Length(s):			
Area:			
Cyclonic Check: <20°			
Date of Cyclonic:			
Stratification Check: <5%			
Date of Stratification:			
Expected Moisture:			
Expected Velocity (ft/sec)			
Expected Flow (dscfm)			

2. Quality Data Objectives

2.1 Questions to Ask your Testers

What safety training and certifications do you have?

Safety Manual/Handbook and Safety Policies

Is your Quality Manual available for review?

What are your Quality Assurance checks?

What assistance do you need to get this job done efficiently?

What work area do you need? On the ground? At the source?

What are your power requirements? 120v, 240v, 480v? How many circuits or amps?

Do you have the appropriate clearance and testing port locations?

Do you carry copies of your proof of calibrations to your jobs?

Do you use third party lab testing for verification?

Do you plan to use alternative approved test methods or other test methods?

Do you use deviations from the approved test methods?

Are these all approved in the Protocol?

Does the work conducted agree with the Protocol?

Are these questions documented in the report?

Does your proposed work schedule allow for unexpected changes?

Will you still provide quality work regardless of changes?

Will you throw out runs due to quality assurance?

2.2 Why Source Testers May Hide Information

Schedule conflicts – especially after unexpected delays

Being rushed – with unexpected delays or miscommunication

Worry about losing a client – would failing a client cause the client to drop the testing company

2.3 Questions to Ask your Facility

Do you have pictures of the testing location?

Do you have measurements and plans?

When was the last time someone inspected the location? Was anything noted?

Are there ports cut for testing? Have you opened them in the last month?

Can the ports be accessed, and equipment maneuvered, without creating a hazard?

Is there adequate room for the testing equipment? (Provide estimates for your train)

Are there known issues which occur at this facility which may pause or delay testing?

Are operations limited or intermittent?

(4 Hours per Day? Or 1 Hour on and 30 Minutes off?)

With compliance testing, has a protocol been submitted to the state?

Has the state taken receipt of this protocol or approved?

Has this been filed within the required days before testing?

Is the tester aware of a protocol if they did not create it?

2.4 Why Facilities May Hide Information

Schedule conflicts – especially after unexpected delays

Issues with past testing companies – failure or scrutiny

3. Constants and Conversions

A number of calculations are used in air emissions sampling. Testers should be familiar with the formulas listed throughout this handbook and the basis calculations necessary to carry out their duties properly. Note that the formulas provided in this section are basic and general; specific formulas for particular methods can be found in relevant sections of this handbook.

Note that many of the same problem types have the equation written each time and that the units are written throughout each problem. The reason this is done is to help the tester form a good habit, because carrying nits throughout a calculation will assist in identifying which units require conversion and as a check on the final result. This habit should be carried over during any evaluation or on jobs. When the units are written down, it will help a tester set up the problem correctly and see how the units will cancel out.

3.1 Molecular Weights and Densities

Constituent	Abr.	Molecular Weight	Density
Hydrogen	H_2	2.0159	0.08988
Carbon	C	12.0107	1.8-2.1
Nitrogen	N_2	28.0134	1.2506
Oxygen	O_2	31.9988	1.429
Sulfur	S	32.065	1.92-2.07
Chlorine	Cl	35.4527	3.2
Argon	Ar	39.948	1.784
Mercury	Hg	200.59	15.534
Water	H_2O	18.0153	1.000
Carbon Monoxide	CO	28.0104	0.001145
Carbon Dioxide	CO_2	44.0095	1.56
Nitric Oxide	NO	30.0061	1.22
Nitrogen Dioxide (Nitrogen Oxides)	NO_2 (NO_x)	46.0055	2.62
Sulfur Dioxide	SO_2	64.0188	2.264
Methane	CH_4	16.0425	0.000656
Ethane	C_2H_6	30.069	0.54
Propane	C_3H_8	44.0956	0.49
Hexane	C_6H_{14}	86.1764	0.65
Hydrogen Chloride	HCl	36.4609	0.0016423
Chlorine Gas	Cl_2	70.906	0.002898
Formaldehyde	CH_2O	30.026	0.8153

Notes:

3.2 Common Gases and Chemicals (DOT and NFPA)

Chemical	DOT #	Health (Blue)	Hazard (Red)	Instability (Yellow)	Special (White)
Acetone	1090	1	3	0	INH-1
Ammonia (Anhydrous)	1005	3	1	0	COR
Carbon Dioxide	1013	3	0	0	INH-2
Carbon Monoxide	1016	3	4	0	INH-3
Chlorine	1017	4	0	0	OX, INH-2
Dichloromethane (Methylene Chloride) (CH_2Cl_2)	1593	2	1	0	INH-2
Diesel (C_{10}-C_{15})	1202	1	2	0	INH-1
Ethane	1170	1	4	0	INH-1
Ethane Blend	3475				INH-1
Gasoline	1203	1	3	0	INH-1
Hexane	1208		3	0	INH-2
Hydrogen	1049	0	4	0	INH-2
Hydrogen Chloride	1050	3	0	1	INH-2
Hydrogen Sulfide (H_2S)	1053	4	4	0	INH-4
Methane	1971	2	4	0	INH-2
Nitric Acid	2032	4	0	1	OX, INH-4
Nitrogen (HNO_3)	1066	NA	NA	NA	INH-1
Nitrogen Dioxide	1067	3	0	0	OX, INH-3
Nitric Oxide	1660	3	0	0	OX, INH-3
Oxygen	1072	3	0	0	OX, INH-1
Propane	1978	2	4	0	INH-1
Sodium Hydroxide (NaOH)	1823	3	0	1	INH-1
Sulfur Dioxide	1079	3	0	0	INH-3
Sulfuric Acid (H_2SO_4)	1830	3	0	2	~~W~~,-INH-4

0-5, where 0 is a minimal hazard and 5 is a volatile hazard

OX – oxidizing
~~W~~ – Reacts unusually with water
INH – Inhalation Hazard

Notes:

3.3 Conversions

Unit	Variable		Converted	
		Length		
1 Centimeter	cm	=	0.3927 Inches	in / “
1 Meter	m	=	3.2808 Feet	ft / ‘
1 Yard	yd	=	3	ft
1 Mile	mi	=	5280	ft
1 Kilometer	km	=	3280.8	ft
		Velocity		
1 Meter per Second	m/s	=	3.2808 Feet per Second	ft/s
1 Mile per Hour	mph	=	1.4667	ft/s
1	mph	=	0.8684	Knot
1 Kilometer per Hour	km/h	=	0.27776	m/s
1	km/h	=	0.62138	mph
		Pressure		
1	“ Hg	=	33.864	mbar
1	“ Hg	=	0.0334211	atm
1	“ Hg	=	0.491154	psi
1	atm	=	29.921	“ Hg
1	atm	=	1.01325	bar
1	atm	=	1013.25	mbar
1	atm	=	101325	kPa
1	atm	=	760	mm Hg
1	atm		14.6959	psi
1	psi		2.036	“ Hg
1	psi		6.89476	kPa
		Area		
1 square centimeter	cm^2	=	0.15500 square inches	in^2
1 square meter	m^2	=	10.76391 square feet	ft^2
1 square mile	mi^2	=	2.5899	m^2
1 square yard	yd^2	=	0.8361274	m^2
1 acre	ac	=	4074	m^2
1 acre	ac	=	43,560	ft^2
1 square mile	mi^2	=	2.5900 square kilometers	km^2
		Volume		
1 cubic foot	ft^3	=	28.316	liter
1 liter	liter	=	0.03532	ft^3
1	liter	=	0.26418	gal
1	liter	=	1 cubic decimeter	dm^3
1 cubic meter	m^3	=	264.18	gal
1	ft^3	=	7.4806	gal
1	m^3	=	35.314	ft^3
1 cubic inch	in^3	=	16.3871	cm^3
1	in^3	=	35.316	ft^3
1 gallon	gal	=	128 ounces	Oz
1	oz	=	29.5735295 milliliter	Ml
		Mass		
1 ounce	oz	=	28.350	g
1 pound	lb	=	0.45359	kg

1 kilogram	kg	=	2.2046	lb
1 stone	st	=	14	lb
1 gram	g	=	15.432	grains
1 pound	lb	=	7000	grains
1 Quintal (hundredwt)	hwt	=	100	lb
1 Kip (kilopound)	kip	=	1000	lb
1 Short Ton	ST	=	2000	lb
1 Tonnes (Metric Ton)	MT	=	2204.62	lb
1 Long Ton	LT	=	2240	lb

Volumetric Flow Rate

1 cubic foot per minute	cfm	=	7.4805	gal/mi
1	cfm	=	0.4719	liter/s
1 cubic meter per second	m3/s	=	35.316	ft^3/s
1	m3/s	=	2119	cfm
1	gal/min	=	0.13368	cfm

Temperature

Degrees Fahrenheit	°F	Conv	(°F-32)*1.8	°C
Degrees Fahrenheit	°F	Add	°F+459.67	°R
Degrees Fahrenheit	°F	Conv	(°F-32)*1.8+273.15	°K
Degrees Celsius	°C	Add	°C+273.15	°K
Degrees Celsius	°C	Conv	°C*1.8+32	°F

Work and Heat

1 British Thermal Unit	BTU	=	777.65 Foot-Pound	ft-lb
1	BTU	=	1054.3	J
1	BTU	=	0.292875 – Watt-hr	W-hr
1 Joule	J	=	$9.4845X10^4$	BTU
1	J	=	107	ergs
1 Kilowatt-Hour	kW-hr	=	3414.4	BTU
1 Calorie	Cal	=	3.0860	ft-lb

Power

1 Horsepower	HP	=	550.0	ft-lb/s
1	HP	=	2545.5	BTU/hr
1	HP	=	745.70	W
1 Watt	W	=	3.4135	BTU/hr
1 kilo-watt	kW	=	1.3410	HP

Gas Concentration Conversions

Pounds per Standard ft^3	lb/scf	Conv	(ppm SO_2)*(1.660*10^{-7})	
Pounds per Standard ft^3	lb/scf	Conv	(ppm NO_X)*(1.194*10^{-7})	
Pounds per Standard ft^3	lb/scf	Conv	(ppm CO)*(7.270*10^{-7})	

Other

Standard Temperature			527.67	°R
Standard Temperature			293.15	°K
Normal Temperature			459.67	°R
Normal Temperature			273.15	°K

Notes:

3.4 Rates

Information Required	Variable	Example
Gram to Grain	Multiply By	15.43
Grain to Pound	Divide By	6999.99999
Pound to Ton	Divide By	2000
Pound to Kilogram	Divide By	2.20462262
Inch to Millimeter	Multiply By	25.4
Square – Inch to Millimeter	Multiply By	654.16
Cubic – Inch to Millimeter	Multiply By	16387.064
Inch to Meter	Divide By	39.37007
Foot to Meter	Divide By	3.2808
Square – Foot to Meter	Divide By	10.7639
Cubic – Foot to Meter	Divide By	35.3146667
Fahrenheit to Celsius	Subtract 32; then -	Multiply By 1.8
Fahrenheit to Rankine	Add	460.67
Celsius to Kelvin	Add	273.15

Notes:

3.5 Energy Output of Fuels

Unit	Variable		Conversion	
1 lb of Anthracite Coal		=	~12,700-12,910	BTU
1 lb of Bituminous Coal		=	~11,500-14,340	BTU
1 lb of Lignite Coal		=	~6200-6900	BTU
1 lb Subbituminous Coal		=	~8100-9150	BTU
1 cf of Propane	C_3H_8	=	~2,500	BTU
1 cf of C_3H_8		=	0.02748	Gallon
1 cf of C_3H_8		=	30.78	lbs
1 gallon of C_3H_8		=	4.23	lbs
1 gallon of C_3H_8		=	~91,500	BTU
1 m^3 of C_3H_8		=	~87.900	BTU
1 Liter of C_3H_8		=	~23,700	BTU
1 lb of C_3H_8		=	~21,600	BTU
1 m^3 of Natural Gas	NG	=	~36303	BTU
1 mmcf of NG		=	~1,025	BTU
1 cf of NG		=	~0.001025	BTU
1 gallon of NG		=	~87,000-91,000	BTU
1 lb of NG		=	~20,000-21,000	BTU
1 gallon of Ethanol	E100	=	~76,000	BTU
1 lb of E100		=	~12,500	BTU
1 gallon of Gasoline (U87)	U87	=	6.1	lbs
1 gallon of U87		=	~115,000-125,000	BTU
1 lb of U87		=	~19,000-21,000	BTU
1 gallon of 85% Ethanol	E85	=	~14,500	BTU
1 lb of E85		=	~88,000	BTU
1 gallon Diesel		=	~139,200	BTU
1 gallon Diesel		=	7.1	lbs
1 lb Diesel		=	~19,605	BTU
1 gallon of Kerosene		=	~135,000	BTU
1 lb of Kerosene		=	~19,795	BTU
1 cf of Hydrogen		=	~319	BTU
1 lb Hydrogen		=	~51,000-61,000	BTU
1 lb Pine Wood Bark		=	~9,200	BTU
1 lb Hardwood Bark		=	~8,400	BTU
1 lb Wood		=	~7,870	BTU
1 lb Waste Paper		=	~6,500	BTU
1 lb Sawdust		=	~3,850	BTU
1 Therm (US)		=	100,000 (@ 59F)	BTU

Notes:

3.6 Constants

Information Required	Variable	Unit
Standard Temperature	527.67	°R
Standard Temperature	293.15	°K
Normal Temperature	459.67	°R
Normal Temperature	273.15	°K
Standard Temperature and Pressure	17.636	°R/" Hg
Standard Temperature and Pressure	0.3858	°K/mm Hg
Normal Temperature and Pressure	15.36	°R/" Hg
Normal Temperature and Pressure	0.3594	°K/mm Hg
Standard Pressure, Temperature at ΔH	0.0319	“ Hg/°R(cfm^{2})
Standard Pressure, Temperature at ΔH	0.001255	mm Hg/°K(m^{3}/m)^{2}
Isokinetic Pressure & Temperature Multiplier	0.09450	(" Hg*100)/(°R*60)
Isokinetic Pressure & Temperature Multiplier	4.320	(mm Hg*100)/(°K*60)
Volume of Water Vapor per Weight	0.04716	ft^{3}/g
Volume of Water Vapor per Weight	0.001335	m^{3}/g
Volume of Water Vapor per Volume	0.04706	ft^{3}/ml
Volume of Water Vapor per Volume	0.001333	m^{3}/ml
Velocity Constant	85.49	ft/sec
Velocity Constant	34.967	m/sec
Boltzmann Constant	1.380649X10^{-23}	J K^{-1}
Avogadro Constant	6.02214076*10^{23}	mol^{-1}
Ideal Gas Law Constant	21.8499	“ Hg ft^{3}/lb-mole °R
Ideal Gas Law Constant	0.06236	mm Hg m^{3}/g-mole °K
Molar Volume 1 lb-mole of air - STP	385.33	dscf/lb-mole
Molar Volume of 1 mg-mole of air – STP	0.024055	m^{3}/mg-mole
Density of Water at 527.67 Rankine	62.428	lb/ft^{3}
Density of Water at 527.67 Rankine	0.9982	g/cm^{3}
Density of Water at 527.67 Rankine	0.002201	lb/ml
Density of Water at 527.67 Rankine	0.9982	g/ml
Gravitational Constant	32.174	ft/sec^{2}
Gravitational Constant	9.80665	m/sec^{2}
Isokinetic Constant (English)	0.09450	(P$_{std}$*100)/(T$_{std}$*60)
Isokinetic Constant (Metric)	4.320	(P$_{std}$*100)/(T$_{std}$*60)
Cubic meters per Gram-Mole	24.04 -/ 24.45	m^{3}/g-mole

Notes:

Notes:

4. Safety

Source testers are exposed to a number of occupational hazards. Whether at a facility regulated by OSHA, MSHA, or dictated by common sense and plant policy, safe working practices are an important part of a source tester's job.

4.1 Environment, Safety, and Health Program

Protecting the safety and health of employees is a key concern in any organization. The question of how best to accomplish the goal of sending everyone home safety at the end of each shift and project should always be at the forefront of any organizations planning efforts. Staff knowledge and management support alone has proved effective in some small organizations, but ineffective in others. A formal environmental, safety, and health (ESH) program is a reliable and effective means of consistently protecting workers from occupational injuries and illnesses. Formal written programs can address specific hazards and prevention measures (e.g., fall prevention) as well as specific regulatory mandates that require a written program (e.g., hazard communication, respiratory protection). Furthermore, there is widespread agreement that written management systems improve organizational performance, including performance in occupational health and safety.

The following measures are suggested to actively, continually, and effectively communicate safety policy and programs to employees, supervisors, and managers.

- Develop or improve existing model safety tools and plans to facility meeting basic safety compliance requirements.
- Create a safety communication vehicle (newsletter or section in daily/weekly/monthly briefings) to regularly communicate to employees on safety policies, programs, new developments, performance, and positive examples.
- Encourage active communication, cooperation, and coordination between the individuals with corporate- or management-level safety functions and the supervisors and field staff with safety responsibilities through a safety coordination group that meets regularly.
- Set up an intranet safety page with corporate policies, procedures, model programs, and links to outside resources (e.g., federal and state regulations).
- Adopt incentive programs to promote active participation in safety compliance and excellence.

While cost may be an issue, there will be financial returns in reduced injury and environmental costs. Measures should certainly include no-cost and low-cost measures such as featuring “Safety Employee of the Month/Year” in the safety publication and recognition at employee events. Consider low-cost awareness programs, such as caps or shirts for reaching milestones or performance goals as well as more sophisticated moderate-cost programs.

4.1.1 Accident prevention.

The best way to prevent losses caused by accidents and occupational illness is to develop a solid, working program for accident prevention. Systematically looking at workplace operations, establishing proper job procedures, and ensuring all employees are properly trained can help prevent workplace injuries and illnesses.

Consider these potential hazards:

- Chemical Hazards
  - Absorption
  - Inhalation
  - Ingestion
  - Contact
  - Injection
  - Skin
- Biological Hazards
  - Bloodborne pathogens
  - Building-related illness
  - (TB)
  - Legionnaire's disease
  - Mold
  - Plant and insect poisons
  - Tuberculosis
- Ergonomic Hazards
  - Awkward positions
  - Contact stress
  - Forceful exertions
  - design
  - Repetition
  - Vibration
  - Work area
- Physical Hazards
  - Caught in/on/between; pinch points
  - Electrical
  - Fire or explosion
  - Noise
  - mal stress
  - Radiation
  - Slips and falls
  - Striking against
  - Struck by
  - Ther

When evaluation options for corrective measures to potential hazards, consider the hierarchy of controls:

- Administrative
- Elimination
- Engineered
- Personal protective equipment (PPE)
- Substitution

4.1.2 Accident Reporting

All accidents should be reported as soon as possible so each accident can be investigated thoroughly – before evidence is altered or destroyed – and causes corrected.

After the appropriate medical attention is provided, accidents should be reported to the employee's immediate supervisor. The supervisor should then complete an injury report form that documents the initial findings. The form used for initially reporting an injury should be simple but informative. The form should include the who, what, when and where, and how of the incident. A complete injury report will include the answers to the following questions:

1. What exact job the injured employee was doing?
2. What tools, materials, or equipment was being used to accomplish work assignment?
3. What specific action caused the accident?
4. What action did the employee do or not do that caused the injury?
5. What safety protection devices were provided?

6. What, if any, unsafe conditions or defects in equipment, materials, or tools were there at the job site where the accident occurred?
7. What, if anything, was wrong with work methods employed or other acts that caused the accident?
8. What safeguards were being used (or not) and what safeguards should have been used?
9. What steps will be taken to prevent similar injuries?

4.2 PPE

PPE is designed to protect the eyes, face, head, respiratory tract, and body extremities from potentially hazardous conditions. It includes such items as goggles, face shields, hard hats, respirators, dust masks, gloves, protective clothing, welding aprons, and safety shoes. The workplace (or job site) must be assessed to determine if hazards are, or may be, present that will require PPE use. The right PPE must be selected and employees fitted and trained in its proper use.

4.2.1 Eye and Face Protection

Eye and face protection is necessary when there is potential exposure to flying particles and dust (wood, glass, metal, or particulate matter); molten metal (welding spatter); potential injurious light radiation (welding glare); or chemicals in any form – liquid, vapor, or gaseous. Eye and face PPE can include safety glasses with side shields, chemical goggles, or a full-face respirator. All devices must comply with strict federal standards.

Remember, not all eye or face protection will protect you from all hazards. Protective glasses with side shields are fine for particulates but provide no protection from hazardous chemical vapors. Remember, the PPE must fit the hazard.

4.2.2 Respiratory Protection

The first step in controlling potentially hazardous dusts, mists, fumes, smoke, or gases in the workplace is the installation of engineering controls such as mechanical ventilation systems. But if such measures are not fully effective, (or infeasible, such as at a field worksite), then respiratory PPE must be used.

The two basic categories or respirators are air-purifying and atmosphere supplying. The first device simply filters the ambient air by using an air-purifying filter, cartridge, or canister. The second type actually provides breathing air to the user from an independent source. The category of respirator; style, whether half or full-face; and type of filter or canister all must be carefully selected. Employees must be properly fitted for PPE and trained in when and how to use it. A medical evaluation of a person’s ability to effectively wear and use a respirator must also be conducted.

4.2.3 Head Protection

When working in an area where the potential exists for head injuries resulting from falling objects or impact hazards, employees must wear head protection, which usually comes in the form of hard hats. Again, as with other forms of PPE, hard hats must be manufactured to federal standards and worn properly to afford proper head protection.

4.2.4 Foot Protection

Just as with the head, there are potential hazards to the feet from falling or rolling materials, sharp objects that can pierce the sole, or electrical shock; employees must wear appropriate protective footwear. This footwear commonly takes the form of steel-toe safety shoes, often equipped with steel shanks and heavy-duty soles.

4.2.5 Hearing Protection

Continual exposure to elevated noise levels can seriously damage your hearing. If noise levels are too high, employees must be supplied with hearing protection. Hearing protection can be provided by simple disposable earplugs or high-tech earmuffs. The protection needed all depends on the nature of the hazard and job.

4.2.6 Other PPE

Other PPE can take the form of gloves, welding aprons, chemical protective suits, coveralls, and back support braces. All are designed to protect a very important person – you – from potential hazards you might encounter on the job.
For additional information go to: www.osha.gov/personal-protective-equipment

		Vapor Density	Explosive Range			
Name of Gas	Chem. Form.	(Air=1)	LEL	UEL	Common Properties	Physiological Effects
Acetone Vapors	C_3H_6O	2-3 (Air=1)	2.6%	12.8%	Colorless, volatile, sweet odor	Irritation of eyes, nose, and throat; headache, dizziness, central nervous system depression
Carbon Dioxide	CO_2	1.53 (Air=1)	N/A	N/A	Colorless, odorless, heavier than air	Respiratory distress at high concentrations, dizziness, asphyxiation
Carbon Monoxide	CO	0.967 (Air=1)	12.5%	74%	Colorless, odorless	Headache, dizziness, nausea, convulsions, unconsciousness, death
Ethane	C_2H_6	1.05 (Air=1)	3%	12.5%	Colorless, odorless	Asphyxiant in high concentrations
Formaldehyde	CH_2O	1.03 (Air=1)	7%	73%	Colorless gas with a strong, pungent smell	Eye, nose, throat irritation; potential carcinogen
Gasoline Vapors	N/A	3-4 (Air=1)	1.4%	7.6%	Volatile, aromatic odor	Respiratory irritation, dizziness, headache
Helium	He	0.138 (Air=1)	N/A	N/A	Colorless, odorless, lighter than air	Asphyxiant in high concentrations
Hexane Vapors	C_6H_{14}	2.9 (Air=1)	1.2%	7.7%	Colorless, volatile, gasoline-like odor	Nerve damage, dizziness, nausea, headache
Hydrochloric Acid Fumes	HCl	Heavier than air	N/A	N/A	Sharp, pungent odor	Respiratory irritation, lung damage
Hydrogen	H_2	0.07 (Air=1)	4%	75%	Colorless, odorless, lighter than air	Asphyxiant in high concentrations
Hydrogen Sulfide	H_2S	1.19 (Air=1)	4.3%	46%	Colorless gas with a rotten egg odor	Eye irritation, respiratory distress, unconsciousness, death at high concentrations

Methane	CH_4	0.554 (Air=1)	5%	15%	Colorless, odorless, lighter than air	Asphyxiant in high concentrations
Methylene Chloride Vapors	CH_2Cl_2	Heavier than air	N/A	N/A	Colorless, volatile with a sweetish odor	Central nervous system effects, headache, dizziness, nausea
Nitric Acid Fumes	HNO_3	Heavier than air	N/A	N/A	Reddish-brown color with a sharp, acrid odor	Respiratory irritation, lung damage
Nitrogen	N2	0.967 (Air=1)	N/A	N/A	Colorless, odorless	Asphyxiant in high concentrations
Nitrogen Oxides	NO, NO_2	Varies	Varies	Varies	Brownish, toxic, pungent	Respiratory problems, lung irritation, and long-term health effects
Oxygen	O_2	1.1 (Air=1)	N/A	N/A	Colorless, odor	Normal air contains 20.95%. Humans tolerate down to 12%. Below 5% to 7% likely to be fatal.

4.3 Fire and Electrical Safety

4.3.1 Electrical Hazards

Grounding. All electrical equipment, such as motors, electric power hand tools, generators, switch boxes, or transformers must be grounded adequately. Grounding protects all persons from getting an electrical shock. To protect against grounding, workers should place an insulating medium between the workers and the ground or grounded equipment to prevent any part of the body from becoming a ground or providing a path for electric current.

Extra precautions are required when working on damp or wet surfaces. If necessary, additional insulation should be used to prevent any part of the body from coming in contact with the wet or damp surface.

4.4 Confined Space Entry

A confined space has limited openings for entry or exit, is large enough for entering and working, and is not designed for continuous worker occupancy. Confined spaces include underground vaults, tanks, storage bins, manholes, pits, silos, underground utility vaults, pipelines, and stack platforms.

Permit-required confined spaces are confined spaces that:

- May contain a hazardous or potentially hazardous atmosphere
- May contain a material that can engulf an entrant
- May contain walls that converge inward or floors that slope downward and taper into a smaller area that could trap or asphyxiate an entrant
- May contain other serious physical hazards such as unguarded machines or exposed live wires
- Must be identified by the employer or client, who must inform exposed employees or contractors of the existence and location of such spaces and their hazards.

What to do

Do not enter permit-required confined spaces without being trained and without having a permit to enter

Review, understand, and follow employer's or plant's procedures before entering permit-required confined spaces and know how and when to exit.

Before entry, identify any physical hazards

Before and during entry, test and monitor for oxygen content, flammability, toxicity, or explosive hazards as necessary.

Use employer's fall protection, rescue, air-monitoring, ventilation, lighting, and communication equipment according to entry procedures.

Maintain contact at all times with a trained attendant either visually, via phone, or by two-way radio. This monitoring system enables the attendant and entry supervisor to order you to evacuate and to alert appropriately trained rescue personnel to rescue entrants when needed.

4.5 Safety Tips for Test Crews and Dispersed Work Locations

Reductions in manpower and increases in workload have increased the number of field employees who are working alone.

While lone work may not automatically decrease a worker's safety performance, there is no doubt that working alone increases a worker's vulnerability to a variety of safety issues. This vulnerability applies not only to those who regularly work outdoors but also to any employees whose work frequently takes them out into the community. All these workers may encounter threats to their safety.

The following four steps can help you reduce the safety vulnerability of remote workers. These tips apply to all employees, and their management, who must work alone or with others in remote locations where normal means of communication are unreliable or nonexistent.

1. Create a communications protocol.

- Designate a key point of contact (POC) who is not a part of the remote team.
- Know who is working remotely and how long the work should take.
- Set regular check-in times for the entire work period. At each check-in, the POC should record the time and the information given by the remote worker.
- Evaluate lighting conditions; are they sufficient to ensure worker safety?
- POCs should relay any anticipated changes in weather.

2. Establish an emergency communications protocol

- If a check-in time is missed, the POC should try, for 30 minutes, to reestablish communications. If that fails, the POC must:
    a. Assembly a search team and place the team on standby.
    b. Contact medical personnel, informing them that an emergency response may be needed.
- If an event includes an injury, after ensuring that medical attention has been provided, the responsible supervisor shall ensure that the appropriate incident/injury reporting process is initiated.

3. Evaluate the potential hazards to the remote worker with a detailed safety risk assessment.

- Before entering a remote work location, all team members should identify and discuss potential safety issues:
    a. Planning for weather conditions – both forecast and unexpected.

   b. Facing potential emergencies such as flooding, electrical contact, running out of fuel in cold climates, and so on.
   c. Handling serious injuries or illnesses that might occur far from medical facilities.
   d. Guarding against animal attacks, snakes, and insects.
   e. Making contact with emergency agencies.
   f. Having appropriate PPE.
   g. Having the tools required to complete the job safely.

- Team members should also assess the risks and review work-related documentation such as a job hazard analysis (JSA) to ensure all mitigation and control measures have been addressed.

4. Conduct a daily safety tailgate meeting before work begins.

- Discuss potential hazards and special precautions the work requires.
- Discuss the job's processes, procedures, and tasks and the order in which then will be performed.
- Review appropriate safety procedures and PPE considerations. Inspect tools and ensure all PPE meets safety standards.
- Discuss assignments. All must know their jobs and the jobs of their co-workers
- Establish a "buddy system" where co-workers watch out for each other.
- Ensure those with new job assignments, new tools, or new equipment are properly and completely trained on safety processes, procedures, and tool/equipment operation.
- Everyone should regroup and discuss potential safety issues when new substances, processes, procedures, tools, or equipment are introduced to the worksite.
- Report hazards and unsafe equipment to the supervisor before work begins.
- Discuss unusual and nonroutine situations.
- Discuss emergency procedures. Determine ahead of time who's in charge in an emergency situation and who is the backup.
- Know where all emergency resources are located: emergency plan, fire extinguisher, first-aid and burn kits, and communication devices.

Notes:

	Severity of injury or illness Consequence and Remedial Action				
Likelihood of Occurrence or Exposure	**CATASTROPHIC** Death or permanent total disability 5	**CRITICAL** Disability in excess of 6 months 4	**MINOR** Disability in excess of 3 months 3	**MARGINAL** Minor injury, lost workday accident 2	**NEGLIGIBLE** First Aid or Minor Medical Treatment 1
FREQUENT Likely to Occur Repeatedly 5	**HIGH** Operation not Permissible 25	**HIGH** Operation not Permissible 20	**HIGH** Operation not Permissible 15	**SERIOUS** High Priority Action 10	**MEDIUM** Take Remedial Actions at Appropriate Time 5
PROBABLE Likely to Occur Several Times 4	**HIGH** Operation not Permissible 20	**HIGH** Operation not Permissible 16	**HIGH** Operation not Permissible 12	**SERIOUS** High Priority Action 8	**MEDIUM** Take Remedial Actions at Appropriate Time 4
OCCASIONAL Likely to Occur Sometimes 3	**HIGH** Operation not Permissible 15	**HIGH** Operation not Permissible 12	**SERIOUS** High Priority Action 9	**MEDIUM** Take Remedial Action at Appropriate Time 6	**LOW** Risk Acceptable: Remedial Action Discretionary 3
REMOTE Not likely to occur 2	**SERIOUS** High Priority Action 10	**SERIOUS** High Priority Action 8	**MEDIUM** Take Remedial Action at Appropriate Time 6	**MEDIUM** Take Remedial Action at Appropriate Time 4	**LOW** Risk Acceptable: Remedial Action Discretionary 2
IMPROBABLE Very unlikely – may assume exposure will not happen 1	**MEDIUM** Take Remedial Action at Appropriate Time 5	**MEDIUM** Take Remedial Action at Appropriate Time 4	**LOW** Risk Acceptable: Remedial Action Discretionary 3	**LOW** Risk Acceptable: Remedial Action Discretionary 2	**LOW** Risk Acceptable: Remedial Action Discretionary 1

Notes:

5. Flow Rate Procedures

This section is to describe the four wet test methods primarily utilized for determining the volumetric flow rate of a sample gas stream through the sampling location.

5.1 Method 1

The purpose of Method 1 is to select the correction sampling location in regards to the distances from disturbances based on general assumptions based on air modeling. The quantity of points is then calculated to collect representative data of the source conditions. These points must be validated by checking for cyclonic flow, or swirling, following the procedure outlined in Method 1 Section 11.4. **The absence of cyclonic flow must be determined at a site before any sampling is performed, and in best practices this information (current or historical) must be documented in every report.**

Information Required	Variable	Example	Units
Distance Downstream	A	144	“
Distance Upstream	B	360	“
Duct Diameter	D_1	38	“
Area of Stack		7.876	ft^2
Duct Diameter (Elliptical)	D_2	34	“
Area of Stack		7.047	ft^2
Duct Width (Rectangular)	D_W	25	“
Duct Length (Rectangular)	D_D	46	“
Equivalent Diameter		2.700	“
Area of Stack		7.986	ft^2

Duct dimensions are Inner Diameters, remember to measure and subtract wall and port thicknesses.

Notes:

5.1.1 Method 1 Calculations

1. A_s, Area of Elliptical Shape EPA Method 1 Section 11.3.1.3

   $A_s = D_1 * D_2 * 0.7854$

2. EDs, Equivalent Diameter of Rectangular Shape EPA Method 1 Equation 1-1

   $ED_s = \frac{2 * D_W * D_D}{D_W + D_D}$

3. A_s, Area of Rectangular/Circular

   $A_s = \frac{(ED_s)^2 * \pi}{4} = (ED_s)^2 * 0.7854$ OR $= \frac{(D_1)^2 * \pi}{4} = (D_1)^2 * 0.7854$

4. Diameters Upstream and/or Downstream

   $D_A = \frac{A}{D}$ OR $= \frac{B}{D}$

The following uses the Circular Dimensions (D_1)

Calculations	Example	Calculation
Diameters Downstream (A)	3.79	144/38
Diameters Upstream (B)	9.47	360/38
Total Points, stack is > 24”	12	
Number of Ports	4	
Points per Port	3	12/4
Point 1	1 $^{9}/_{16}$	38*4.4
Point 2	5 $^{1}/_{4}$	38*14.6
Point 3	10 $^{5}/_{8}$	38*29.6

Notes:

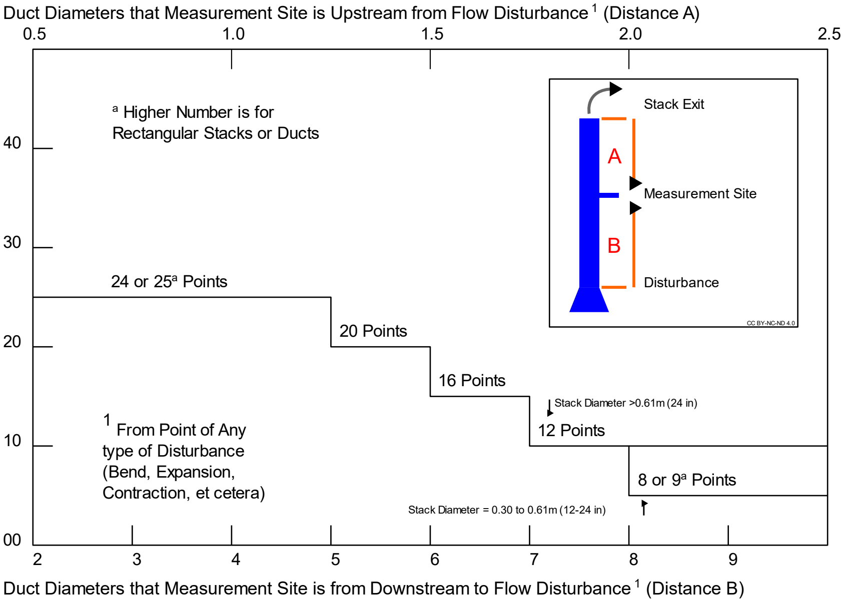
5.1.2 Percent of stack diameter

Percentage from inside wall to traverse point

Traverse point number on a diameter	Number of traverse points on a diameter					
	2	4	6	8	10	12
1	14.6	6.7	4.4	3.2	2.6	2.1
2	85.4	25.0	14.6	10.5	8.2	6.7
3		75.0	29.6	19.4	14.6	11.8
4		93.3	70.4	32.3	22.6	17.7
5			85.4	67.7	34.2	25.0
6			95.6	80.6	65.8	35.6
7				89.5	77.4	64.4
8				96.8	85.4	75.0
9					91.8	82.3
10					97.4	88.2
11						93.3
12						97.9

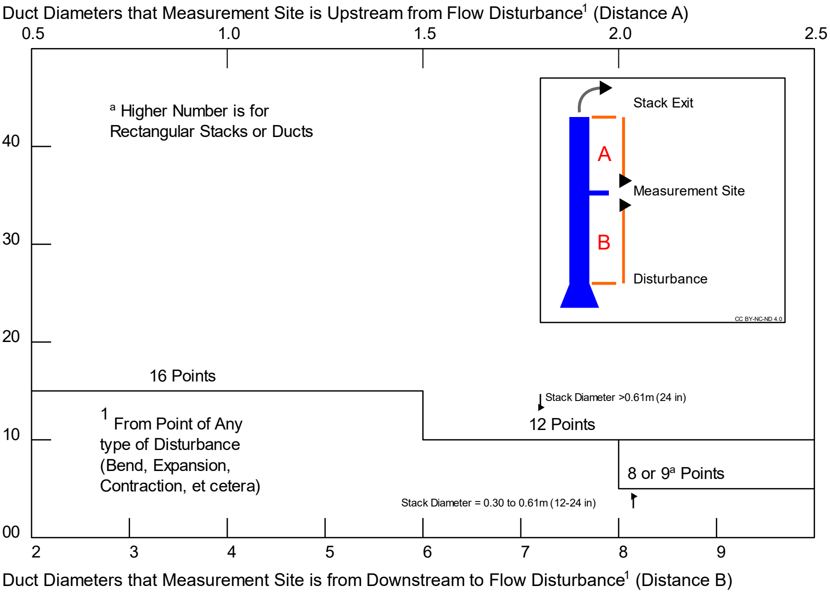
Notes:

5.1.3 Isokinetic Sampling Points



Method 1 Figure 1-1 Number of traverse points for isokinetic sampling

5.1.4 Non-Isokinetic Sampling Points



Method 1 Figure 1-2 Number of traverse points for non-isokinetic sampling

5.2 Method 2

The purpose of Method 2 is to determine the average velocity and calculation of the volumetric flow rate of a gas stream. The pitot (PEE-TOH) tube, differential pressure gauge, and temperature indicator must all be certified to meet the design requirements described in this method and documented to confirm calibrations within one year of the testing and after the testing. A staußcheibe pitot tube must be compared to a standard tube to calculate the coefficient, or geometric determinations use a generic coefficient. The differential pressure gauge must be an inclined manometer, or be calibrated against an inclined manometer. The temperature sensor must be capable of accurately reading temperatures within 10 percent of the absolute temperature of a source at an accuracy of 1.5 percent of the absolute temperature. E.G. a source that has a temperature of 300 °F must be verified to read a temperature of approximately 800 °R with an accuracy of 12 °R.

Information Required	Variable	Example	Units
Transverse Tube Axis	α1	0.1	°
Transverse Tube Axis	α2	1.3	°
Longitudinal Tube Axis	β1	1.2	°
Longitudinal Tube Axis	β2	2.0	°
Pitot Tip Tube Axis	Z / γ	2.7	°
Pitot Tip Tube Alignment	W / θ	6.7	°
Distance from opening	P_a	0.3090	“
Distance from opening	P_b	0.2470	“
Distance between openings	A	0.5560	“
Mean of opening distance	P	0.2780	“
Diameter Pitot Tube (inner)	D_t	0.2500	“
Coefficient (S Type Allowed)	C_p	0.84	none
Barometric Pressure	P_{bar}	29.40	“ Hg
Static Pressure of Stack Gas	P_{static}	-0.16	“ H_2O
Temperature of Stack Gas	T_s	198	°F
Calibration Value	T_{cv}	212	°F
Calibration Display	T_{cd}	210	°F

Pitot tip can use 0.84 for Coefficient if Geometric is within tolerance

Notes:

5.2.1 Method 2 Calculations

5. C_p, Pitot Tube Coefficient — EPA Method 2 Equation 2-3

$$C_p = C_p(std)\sqrt{\frac{\Delta P(std)}{\Delta P}}$$

ΔP(std) and ΔP is the average of Six readings, three from Side A and three from Side B.

6. P_s, Absolute Pressure of Stack Gas, “Hg — Conversion “H_2O to “Hg

$$P_s = P_{bar} + \frac{P_g}{13.6}$$

7. T_c, Temperature Sensor Calibration Check — EPA Method 2 Section 10.3

$$Temperature\ Range = (T_s * 10\%) \pm T_s$$

$$\%\ Dev = \frac{T_{cd} - T_{cv}}{T_{cv}} * 100$$

Calculations	**Variable**	**Example**	**Units**
Transverse Allowable Error	<10		°
Longitudinal Allowable Error	<5		°
Z (A Sine γ)	<0.32 / 0.126	0.0262	cm / ”
W (A Sine θ)	<0.08 / 0.032	0.0262	cm / “
P/D_t	1.05 < 1.50	1.112	
Coefficient (Standard)	C_p	0.84	none
Average ΔP	S-Type	1.122	“ H_2O
Average ΔP	Standard	0.745	“ H_2O
Coefficient (S Type Calc.)	C_p	0.814	none
Absolute Pressure of Stack Gas	P_s	29.39	“ Hg
Temperature of Stack Gas	T_s	198	°F
Temperature Sensor Range	592.2-723.8	672	°R
% Deviation	<1.5%	0.30	%

Notes:

5.3 Method 3

The purpose of this Method is to determine Oxygen and Carbon Dioxide concentrations for the calculation of molecular weight. Alternatively, IAW Method 2 Section 8.6, if the process is emitting essentially air then you can assign the molecular weight of 29.0 (See Section Additional Calculations: Ambient Conditions). Or, IAW Method 3 Section 1.3, for processes burning natural gas, coal, or oil you can assign the molecular weight of 30.0.

Information Required	Variable	Example	Units
Carbon Dioxide	CO_2	12.44	%
Oxygen	O_2	5.87	%
Nitrogen	N_2	81.69	%
Carbon Monoxide	CO	0.00	%

5.3.1 Method 3 Calculations

8. Dry Molecular Weight EPA Method 3 Equation 3-1

$$M_d = 0.440 * (CO_2\%) + 0.320 * (O_2\%) + 0.280 * (N_2\% + CO\%)$$

Read M_d as g/g-mole in Metric or lb/lb-mole in SAE

Method 3, Section 12.3 under Equation 3-1 comments on the lack of assuming 0.9 percent Argon. They introduce a negative error of 0.4 percent in the equation. The tester may choose to include argon in the analysis using procedures subject to approval of the Administrator.

Calculation	Variable	Example	Units
Dry Molecular Weight	M_d	30.23	lb/lb-mole

5.3.2 Method 3B

Method 3B includes the calculation of a Fuel Factor for Data Validation purposes when measuring and calculating the Oxygen and Carbon Dioxide concentration. The table on the following page includes the acceptable Fuel Factor ranges based on the fuel type. In the Section Attachments is a Fuel Factor table built based on these equations.

5.3.3 Method 3B Calculations

9. Percent Excess Air EPA Method 3B Equation 3B-1

$$\%EA = \frac{\%O_2 - 0.5\%CO_2}{0.264\%N_2 - (\%O_2 - 0.5\%O_2)} * 100$$

10. O_2 and CO2 based Fuel Factor, F_o EPA Method 3B Equation 3B-2

$$F_o = \frac{20.9 - \%O_2}{\%CO_2}$$

11. Adjust CO_2 with CO EPA Method 3B Equation 3B-3

$$\%CO_2(adj) = \%CO_2 + \%CO$$

12. Adjust O_2 with CO EPA Method 3B Equation 3B-4

$$\%O_2(adj) = \%O_2 - 0.5\%CO$$

13. Calculate Fuel Factor, F_o EPA Method 3B Equation 3B-5

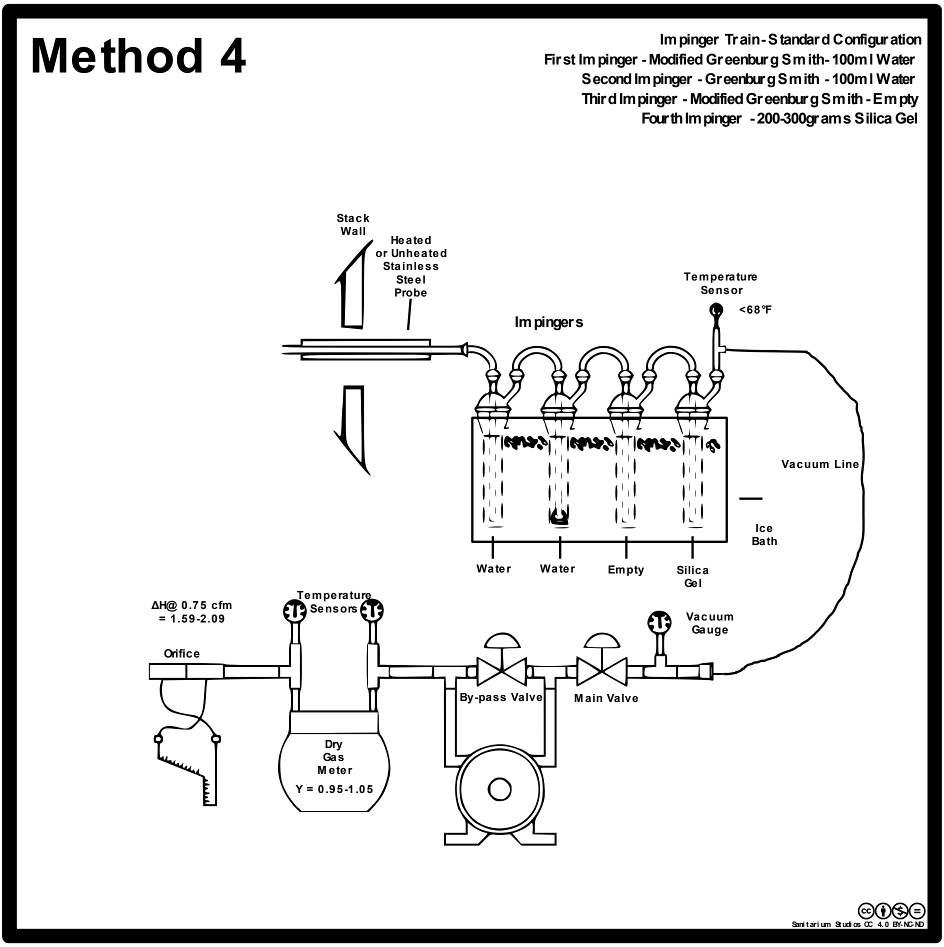
$$F_o = \frac{0.209F_d}{F_c}$$

Fuel Type	F_o Range
Coal:	
Anthracite and Lignite	1.016-1.130
Bituminous	1.083-1.230
Oil:	
Distillate	1.260-1.413
Residual	1.210-1.370
Gas:	
Natural	1.600-1.836
Propane	1.434-1.586
Butane	1.405-1.553
Wood	1.000-1.120
Wood bark	1.003-1.130

Notes:

5.4 Method 4

5.4.1 Method 4 Diagrams



Method 4

Impinger Train - Standard Configuration
First Impinger - Modified Greenburg Smith - 100ml Water
Second Impinger - Greenburg Smith - 100ml Water
Third Impinger - Modified Greenburg Smith - Empty
Fourth Impinger - 200-300grams Silica Gel

Notes:

5.4.2 Method 4 Calculations

The purpose of Method 4 is for the determination of moisture content within a gas stream. There are additional procedures which can be utilized for determination of moisture, calculations for this are included under the Section Additional Calculations Moisture Determination.

When Method 4 is used, common practices entail using a console used for isokinetic testing. This console is a dry gas metering system that must be calibrated to verify the accuracy of the dry gas stream passing through the meter as well as the temperature sensors of different points of the gas stream sampling process (Gas Stream Source, any heated elements for sampling, Gas Condition System, and Dry Gas Meter Temperatures. Multiple procedures for the calibration of isokinetic consoles are included in this handbook under Isokinetic Testing Procedures Calibration.

Note that the procedures for Method 4 are inclusive within Method 5. Method 4 was derived from the equations that exist in Method 5, under requirements for having moisture calculated with non-isokinetic testing.

Information Required	Variable	Example	Units
Meter Calibration	$\Delta H@$	1.0050	
Meter Calibration	Y	1.8044	
Volume of Gas Collected	V_m	41.219	ft^3
Volume of Liquid Condensate	V_{lc}	97.0	g
Meter Temperature	T_m	71.9	°F
Meter Flow Rate	ΔH	1.53	
Standard Correction	$K_{1(std)}$	17.636	T_{std}/P_{std}
Normal Correction	$K_{1(N)}$	15.36	T_N/P_N
Volume of Water Vapor	K_2	0.04706	ft^3/ml
Weight of Water Vapor	K_3	0.04716	ft^3/g

Notes:

5.4.3 Method 4 Calculations

14. $V_{m(std)}$, Volume of Dry Gas Sampled — EPA Method 4/5 Equation 4/5-1

$$V_{m(std)} = V_m * Y * K_1 * \frac{\left(P_{bar}+\frac{\Delta H}{13.6}\right)}{T_m}$$

$K_1 = T_{std}/P_{std}$

17.636 °R/" Hg

1.3858 °K/mm Hg

15. $V_{w(std)}$, Volume of Water Vapor by weight — EPA Method 4/5 Equation 4/5-2

$$V_{w(std)} = K_3 * V_{lc}$$

$K_3 = \frac{\rho * R}{MW_w} * \frac{T_{std}}{P_{std}}$

0.04716 ft^3/g for English

0.001335 m^3/g for Metric

16. B_w, Moisture Content, % — EPA Method 4/5 Equation 4/5-3

$$B_w = \frac{V_{w(std)}}{V_{w(std)}+V_{m(std)}}$$

17. $B_{w(sat)}$, Moisture Content of Saturated Stack Gas, %

$$B_{w_{sat}} = \frac{10^{\left(8.361-\left(\frac{1893.5}{\left(\frac{T_S-32}{1.8}\right)+273}-27.65\right)\right)-0.05}}{P_S*25.4*100} \quad \text{OR } B_{w_{sat}} = \frac{10^{6.37-\left(\frac{2,827}{T_S+365}\right)}}{P_S*100}$$

Calculations	Variable	Example	Units
Water Vapor Sample, Standard	$V_{w(std)}$	4.575	std. ft^3
Gas Sampled, Standard	$V_{m(std)}$	40.543	std. ft^3
Moisture Concentration	B_w	10.14	%
Saturated Conditions	$B_{w(sat)}$	75.59	%

Notes:

5.5 Flow Rate Calculations

18. M_s, Wet Molecular Weight — EPA Method 1 Equation 2-6

$$M_s = M_d(1 - B_w) + 18.0 * B_w$$

19. K_p, Velocity Constant

$$K_p = \sqrt{2 * \rho * g * R}$$

/12 in-ft	85.49 ft/sec for English
*1000 m-cm	34.967 m/sec for Metric

20. V_s, Velocity of Stack Gas, ft/sec — EPA Method 2 Equation 2-7

$$V_s = K_p * C_p * \sqrt{\Delta P} * \sqrt{\frac{T_s}{P_s * M_s}}$$

21. Q_a, Actual stack gas volumetric flow rate, acfm

$$Q_a = V_s * A_s$$

22. Q_{stdwet}, Standard Stack Gas Volumetric Flow Rate per Minute, scfm

$$Q_{std(wet)} = \frac{\left[\frac{sec}{min}\right] * \mathrm{V}_s * \mathrm{A}_s * P_s * (std)}{T_s}$$

23. Q_{std}, Dry Standard Stack Gas Volumetric Flow Rate, dscfm

EPA Method 2 Equation 2-8

$$Q_{std} = \frac{\left[\frac{sec}{min}\right] * \mathrm{V}_s * \mathrm{A}_s * P_s * (std) * (1 - B_w)}{T_s}$$

Method 2 prescribes this calculation on a per hour basis; [sec/hour] = 3600

Calculations	Variable	Example	Units
Wet Molecular Weight	M_s	29.05	lb/lb-mole
Velocity	V_s	63.87	ft/sec
Velocity Equation Constant	K_p	85.49	ft/sec
Actual Stack Gas Flow Rate	Q_a	502.62	acfs
Wet Standard Flow Rate	Q_{stdwet}	19,187	scfm
Dry Standard Flow Rate	Q_{std}	21,351	dscfm

Notes:

5.6 Method 19 – Mass Volumetric Flow Rate

A common use for Method 19 is to determine emission factors based on utilizing the heat output of the fuels in use. This can be used to determine a factor of how many pounds per million British thermal units (lb/mmBTU) or nanograms per joule (ng/J) and further utilized to calculate the pounds per hour (lb/hr) or kilograms per hour (kg/hr) based on the amount of fuel burned.

Equations for calculating uses these numbers are included in Section 8.3.3 of this handbook.

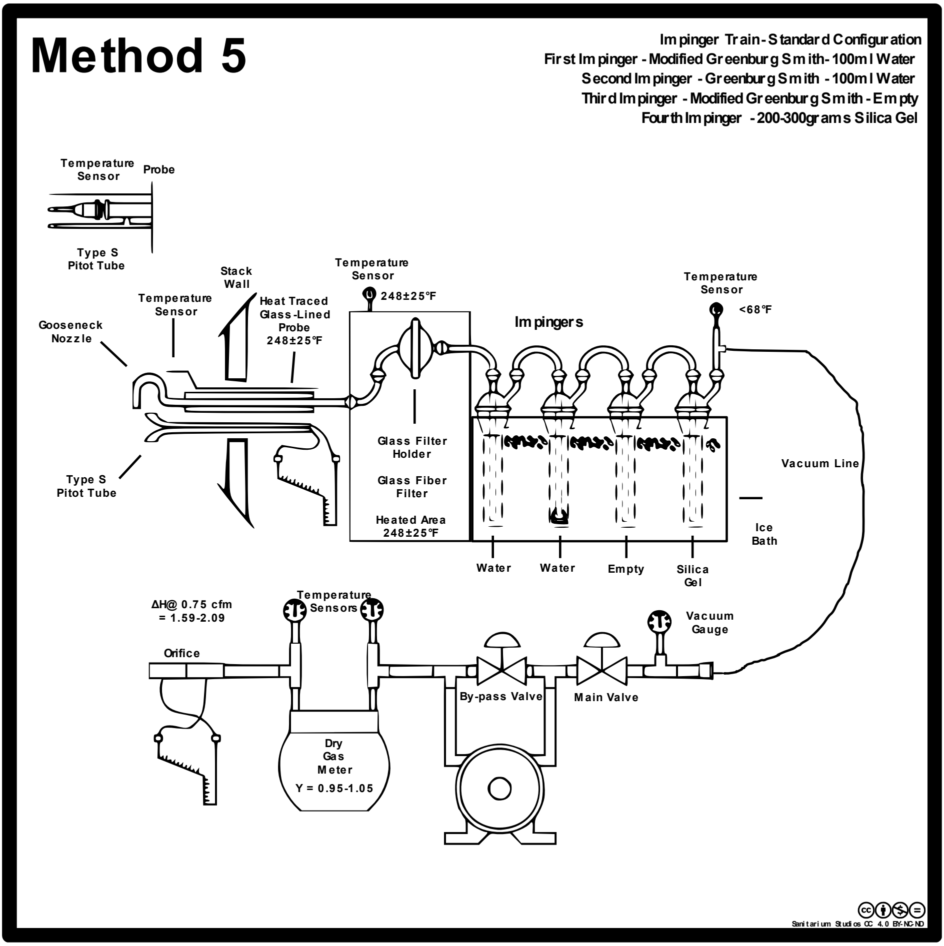
Fuel Type	**Dry Fuel Factor Fd**		**Wet Fuel Factor Fw**		**Carbon Fuel Factor Fc**	
	dscm/J	**dscf/mmBTU**	**wscm/J**	**wscf/mmBTU**	**scm/J**	**scf/mmBTU**
Coal:						
Anthracite	$2.71*10_{-7}$	10,100	$2.83*10_{-7}$	10,540	$0.530*10_{-7}$	1,970
Bituminus	$2.63*10_{-7}$	9,780	$2.86*10_{-7}$	10,640	$0.484*10_{-7}$	1,800
Lignite	$2.65*10_{-7}$	9,860	$3.21*10_{-7}$	11,950	$0.513*10_{-7}$	1,910
Oil	$2.47*10_{-7}$	9,190	$2.77*10_{-7}$	10,320	$0.383*10_{-7}$	1,420
Gas:						
Natural	$2.34*10_{-7}$	8,710	$2.85*10_{-7}$	10,610	$0.287*10_{-7}$	1,040
Propane	$2.34*10_{-7}$	8,710	$2.74*10_{-7}$	10,200	$0.321*10_{-7}$	1,190
Butane	$2.34*10_{-7}$	8,710	$2.79*10_{-7}$	10,390	$0.337*10_{-7}$	1,250
Wood:	$2.48*10_{-7}$	9,240			$0.492*10_{-7}$	1,830
Wood Bark:	$2.58*10_{-7}$	9,600			$0.516*10_{-7}$	1,920
Municipal:	$2.57*10_{-7}$	9,570			$0.488*10_{-7}$	1,820

Notes:

6. Isokinetic Testing Procedures

6.1.1 Method Diagrams

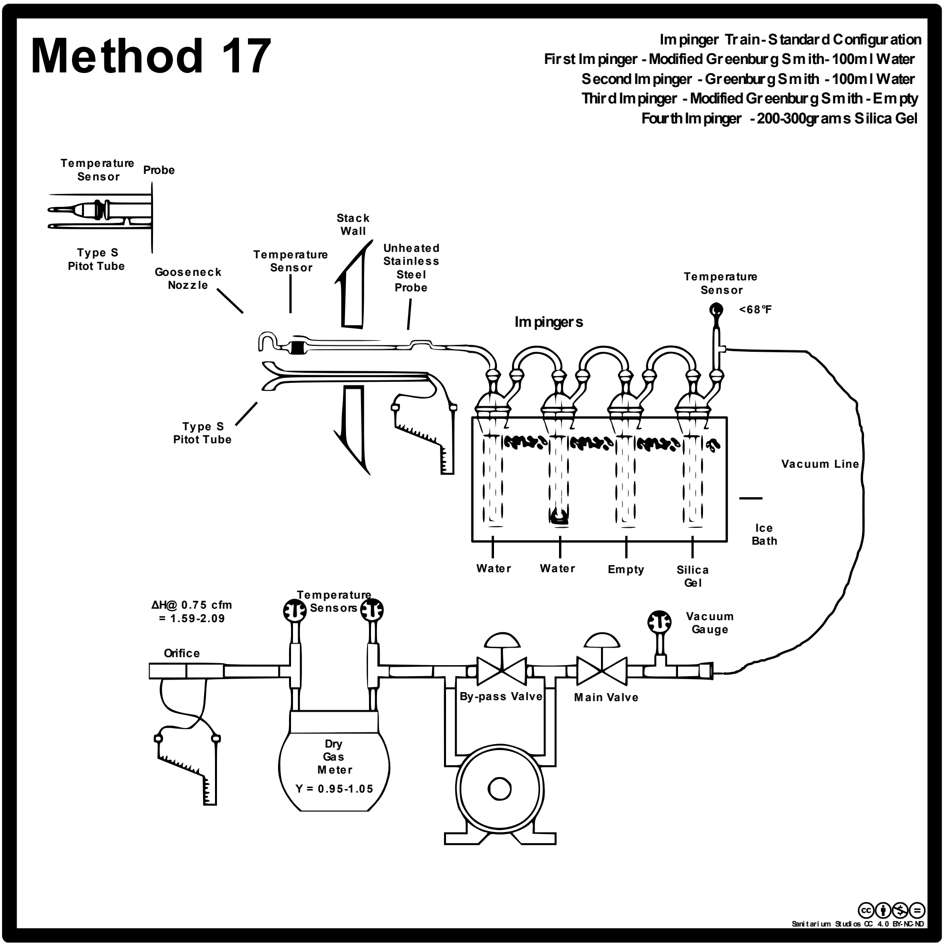
Filterable Particulate – Heated Filter



Sanitarium Studios CC 4.0 BY-NC-ND

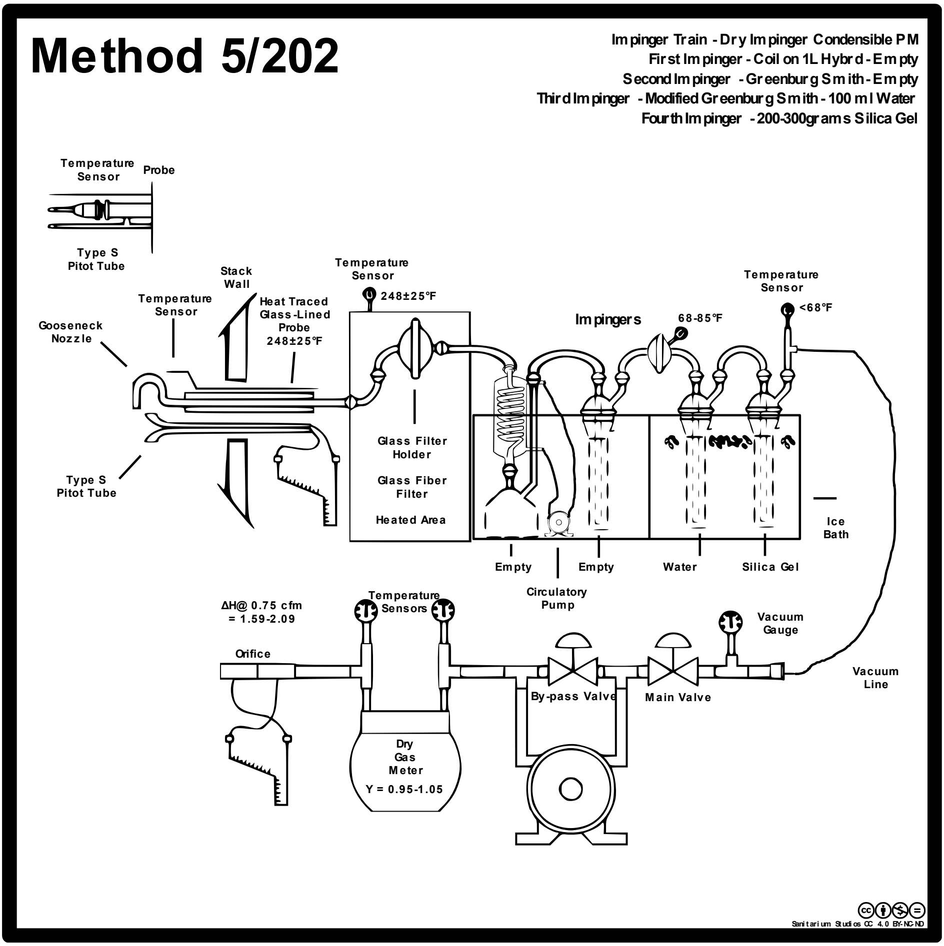
Notes:

Filterable Particulate – In-stack Filter



Notes:

Total Particulate Matter – Condensable and Filterable



Notes:

6.2 What is Isokinetic Testing?

Isokinetic testing occurs when sampling is conducted such that the velocity of gas being collected through a sampling nozzle is exactly equal to the velocity of the gas stream, or 100% Isokinetic.. When the velocity of the gas passing through the nozzle tip is lower than the velocity of the gas stream then the sampling is under isokinetic; the theory would be that larger particulate (greater than PM_5) will still be collected while being calculated with a lower volume, thus having a high bias. Small particulate (less than PM_1) is unaffected by the sampling rate, so there is theoretically no bias. When the velocity of the gas passing through the nozzle tip is higher than the velocity of the gas stream then the sampling is above isokinetic; the large particulate is not pulled in by this while collecting a higher gas volume, thus resulting in a low bias. It is best to maintain sampling that is within 10% of being isokinetic. Corrections can be made to testing results that are outside of isokinetic, but this is dependent on the deviation from 90-100% Isokinetic, and the size of the particulate at the source.

The calculation of the velocity of the gas stream passing through the nozzle tip is based on the pressure, temperature, and moisture of the gas stream. Wherein the percentage of isokinetic is the Velocity of the Stack divided by the Velocity in the Nozzle. For this purpose, to correctly calculate isokinetic sampling and maintain truly isokinetic sampling, the calibration and verification of the testing equipment is essential to maintain accurate data collection and calculation of isokinetic sampling rate.

6.3 K Factor

Information Required	Variable	Example	Units
Root ΔP average	√ΔP	1.0435	√" H_2O
Desired Volume	Desired $V_{m(std)}$	35.0	ft^3
Sample Time	θ	60	Minutes

K-Factor Calculations

24. Ideal Nozzle Size (squared), based on desired volume

$$Ideal\ D_n^2 = \frac{V_{desired}\sqrt{\frac{M_S*(T_S)}{P_S}}}{(493.4)*C_p*\theta*(1-B_w)*\sqrt{\Delta P}}$$

25. Ideal Nozzle Calculation, based on desired ΔH and ΔP

$$Ideal\ D_n = \frac{\Delta \mathrm{H}}{K*\Delta \mathrm{P}}$$

K1 is K Factor

26. Ideal Nozzle Size, based on desired volume standard

$$Ideal\ D_n = \sqrt{\frac{V_{m(std)}(desired)}{D1*\theta*\sqrt{\Delta P}}}$$

$$D1 = 493.4 * C_p\sqrt{\frac{P_s}{M_s*T_s}} * (1 - B_w)$$

27. K Factor

$$K = 850 * (C_p)^2 * \Delta H@ * \frac{T_m}{T_s} * \frac{P_s}{P_b} * \frac{M_d}{M_s} * (1 - B_w)^2 * (D_n)^4$$ Average

$$K = 859.7 * 10^7 * \left(C_p\right)^2 * \Delta H@ * \frac{T_m}{T_s} * \frac{P_s}{P_b} * \frac{M_d}{M_s} * (1 - B_w)^2 * (A_n)^2$$ CAE

$$K = 846.72 * 10^7 * \left(C_p\right)^2 * \Delta H@ * \frac{T_m}{T_s} * \frac{P_s}{P_b} * \frac{M_d}{M_s} * (1 - B_w)^2 * (A_n)^2$$ SSPP

$$K = 846.872 * 10^7 * \left(C_p\right)^2 * \Delta H@ * \frac{T_m}{T_s} * \frac{P_s}{P_b} * \frac{M_d}{M_s} * (1 - B_w)^2 * (A_n)^2$$ EPA

28. Estimated volume

$$Est\ V_{m(std)} = 493.4 * C_p * \sqrt{\frac{P_s}{M_s * T_s}} * \sqrt{\Delta P} * (D_n)^2 * \theta * (1 - B_w)$$

29. Estimate DGM Calibration Accuracy, Y_c EPA Method 5, Section 9.2.1.1

$$Y_c = \frac{10}{V_m} * \left(\frac{0.0319 * T_m}{P_{bar}}\right)^{0.5}$$

Method 5 - 9.2.1.1 Before beginning the field test (a set of three runs usually constitutes a field test), operate the metering system (i.e., pump, volume meter, and orifice) at the ΔH@ pressure differential for 10 minutes. Record the volume collected, the DGM temperature, and the barometric pressure. Calculate a DGM calibration check value, Y_c.

Calculations	Variable	Example	Units
Diameter of desired nozzle	D_n	0.198	“
Diameter of available nozzle	D_n	0.210	“
K-Factor	K	1.36	none
Estimated Volume	Est $V_{m(std)}$	39.379	ft^3
Highest ΔP	Max	1.50	
Highest ΔH	Max	2.04	
Estimated Sample Rate <0.75	Average	0.66	cfm

6.4 Isokinetic Testing Results

Information Required	Variable	Example	Units
Average ΔH	ΔH		
Isokinetic	%I	103.7	%
Mass of Filter	M_F	10.10	mg
Volume of Filterable Acetone	V_{AW}	250	ml
Mass of Filterable Acetone	M_{AW}	5.30	mg
Acetone Blank Residue	M_a	1.5	mg
Acetone Blank Volume	V_a	200	ml

6.4.1 Isokinetic Testing Calculations

30. C_a, Acetone Blank Concentration EPA Method 5 Equation 5-4

$$C_a = \frac{M_a}{V_a * \rho_a}$$

M_a = Mass of Acetone Residue, mg
V_a = Volume of Acetone Sample, ml
ρ_a = Density of Acetone, 0.788 mg/ml

31. C_F, Acetone Correction Factor – 8 Allowable

$$C_F = C_a * 1000 * \rho_a$$

32. C_B, Acetone Blank Correction

$$C_B = \frac{V_{awF}}{1000} * C_F$$

33. Wa, Acetone Wash Blank EPA Method 5 Equation 5-5

$$W_a = C_a * V_{aw} * \rho_a$$

34. %I, Percent Isokinetic EPA Method 5 Equation 5-8

$$I\% = K_5 * \frac{T_s * V_{m(std)}}{P_s * V_s * A_n * \theta * (1 - B_{ws})}$$

$K_5 = 0.09450$ for English Units
$K_5 = 4.320$ for Metric Units

35. A_n, Sampling Nozzle Area, ft^2

$$A_n = \pi \frac{D_{n(ft)}}{2}^2$$

Calculations	**Variable**	**Example**	**Units**
Acetone Blank Concentration	C_a	0.007614	mg/mg
Correction Factor	C_F	7.5	mg/L
Acetone Blank Correction	C_B	1.875	mg
Corrected Front Wash Residue		3.425	mg
Mass of Filterable Particulate	M_n	13.525	mg/sample

Notes:

6.5 Calibration

6.5.1 Wet Test Meter Calibration

Purpose

A wet test meter (WTM) is calibrated against the standard of one cubic foot of water. This standard can be utilized to then calibrate the accuracy of a metering system for purposes of creating a calibration coefficient, Y, to correct volume to standard conditions. Information on the procedures and benefits of wet test meters can be found in the EPA "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods", August 1988 (EPA-600/40-77-027b).

Scope

All personnel performing meterbox calibrations either with WTM and/or critical orifices should be familiar with this procedure to perform period calibration checks of the primary laboratory standard. This procedure should be followed at least once annually, or whenever the accuracy of the WTM is in question.

Materials Needed

The following materials (or equivalents) are needed to properly perform this procedure:

- WTM apparatus – a complete WTM assemble consisting of an American WTM (or equivalent), thermometer, draft gauge connected to the WTM inlet, saturator and associated hose and hardware connections.
- Container 1 – a leak free, rigid walled vessel with sufficient volume to displace at least one complete revolution of the WTM (10 gallons for a one cubic foot displacement WTM, 3 gallons for a 0.250 cubic foot displace WTM). Container 1 must have a leak free fitting to facilitate a hose connection to the WTM from a spot above the water line at full capacity (preferably in the cap) as well as a hose connection (with 3-4' section of hose) at the bottom of the vessel to drain water into container 2.
- Container 2 – a second leak free, rigid walled free vessel with sufficient volume to displace at least one complete revolution of the WTM. Container 2 does not require a top hose fitting or a cap. The bottom hose connection should be valved to facilitate control while emptying displacement water into a measuring beaker. In lieu of container 2, you can optionally use a series of gallon containers (3/4 of a gallon is approximately 3kg). Tare each container when empty before filling with water.
- Tubing clamp – a clamp of sufficient size to control the displacement water flow from one container to the next.
- 2-Liter plastic beaker – A leak-free 2-liter Nalgene beaker (or equivalent) that, when filled to capacity, does not exceed the maximum measurable mass of the balance.
- Balance (capacity at least 3,000 kg) – a balance with a weight rating of at least 3kg and an accuracy of +/- 0.5 g.

- Pyrometer – a fluke (or equivalent) pyrometer with solid thermocouple to record displacement water temperature. AN equivalent immersible thermometer may also be used.
- Calibration data sheet – To record container weights on and ambient conditions.
- Calibration calculator – Excel Spreadsheet – To calculate displacement to Y and document for inclusion into reports.
- Calibration Area – The area where the calibration is being performed should be a temperature-controlled area with a stable humidity. The wet test meter and contents must be stabilized to the ambient temperature and conditions. Vertical space for containers to be at separate levels is essential.

Background

WTMs are shipped by the supplier calibrated to an accuracy tolerance of ± 5%, usually against a primary standard. As per the EPA QA/QC Manual, it is required that the WTM have a calibration check performed immediately upon receipt of the instrument from the manufacturer and at least one annually thereafter. Ideally, this calibration check should be conducted by using a primary standard, such as a bell prover or spirometer. In lieu of these standards, a calibration check accurate to within ±1% can be conducted using the displacement method as outlined in this procedure.

Wet Test Meter Calibration Procedure

1. Check the bullseye level of the WTM. Adjust the bubble to the center of the bull's eye using the leveling knobs located on each of the three or four legs of the WTM.
2. Adjust the water level in the WTM so that the pointer (right hand side) is level with the meniscus of the water in the reservoir. If you must add water to the reservoir to accomplish this be sure to pull air through the WTM, at least one cubic foot or one revolution, and recheck the level after water has been exposed to all four chambers of the WTM. Inversely, perform the same one revolution "pull" if the reservoir is overfilled and water must be drained. (The pointer should appear in the reflection of the reservoir water as a single line tapering to a point intersecting with its mirror image at the bottom of the meniscus.)
3. Fill Container 1 with sufficient water to displace at least one complete revolution (one cubic foot) of the WTM (10 gallons). Any extra water in the vessel can be used to conduct a system leak check prior to performing the calibration check.
4. Check the WTM water level after the thermal stabilization period. Adjust water level if necessary, with water at the same temperature.
6. Record down the ambient temperature, humidity, and barometric pressure on your data sheet
7. Conduct system operation check. To accomplish this, open the tubing clamp at the Container 1 outlet and begin siphoning water through the system. Allow approximately one gallon of water to flow through the system. At this point record the WTM ΔP reading from the inlet manometer to the data sheet. If the ΔP is less than 0.4"w.v. the system is functioning normally, and you may proceed to step 9. If the ΔP is greater than 0.4" w.c. refer to step 8.
8. Most likely causes for excessive ΔP are: too much water in the saturator, inlet hardware (piping) is too small and creating excessive pressure drop, or the WTM is

defective. If removing water from the saturator and/or replumbing the WTM inlet do not drop the ΔP to under 0.4” w.c., then the WTM is most likely defective and should be repaired or sent out for repair and recalibration.

9. After approximately one gallon of water has siphoned through the system, plug the saturator inlet. If the flow of water ceases, the system is leak free. If flow continues, then there is a system leak which must be found and corrected before proceeding. At the conclusion of the system leak check, pinch the tubing connecting Container 1 and Container 2 as close as is practical to the end of the tube to ensure that the water volume in the tube is consistent from run to run.
10. Drain the displaced water from Container 2 back into Container 1, taking care to remove all the water from Container 2. Any water left in Container 2 at this time will bias the initial trial displacement volume.
11. Begin the calibration check. Record the WTM initial volume and temperature on the data sheet. Open the tubing clamp and allow water to begin siphoning through the system. Allow the WTM to displace at least one complete revolution and close the tubing clamp taking care to place the clamp in the same position as it was at the commencement of the trial. The volume displace by the WTM must be a whole number (i.e. 1.000 ft^3). The nature of the instrument is that it will measure accurately in whole number increments of the capacity, but fractions thereof, I.e. 2.500 ft^3, are not necessarily accurate, as each chamber in the meter does not displace the same volume.
12. Record the WTM final volume. At this time, convert the WTM volume from ft^3 to liters by multiplying by 28.317. At this time, also measure the displacement water temperature and record it on the data sheet.
13. Place the 2 liter plastic beaker onto the balance and compensate for the tare weight of the beaker by zeroing the scale. Drain the water in Container 2 into the 2 liter beaker using the valved fitting at the bottom of the vessel. Stop short of maximum capacity so to minimize the chance of spillage and measure the mass in grams on the balance. Dump the beakers contents back into Container 1. Repeat this process until Container 1 is completely empty.
14. Determine the total mass of the displacement water catch in grams and enter it on the appropriate line of the data sheet. Convert the resulting mass into volume (liters) by dividing the sum by 1,000. Record this on your data sheet.
15. Calculate the percent error using the following equation:

36. $$\%\,Error = 1 + \frac{WTM\ Volume - Displaced\ Volume}{Displaced\ Volume}$$ This value is equal to the Y_{ds}

The % error is acceptable if it is 0.995<1.005
If the percent error is acceptable, less than 0.001, then repeat steps 10-15 twice more for a total of three trials. Once you have completed three acceptable runs then calculate and record the average on the data sheet.
If any one of these runs deviates by more than 0.0005 from another run, then refer to step 16.

16. If the meter is slow, calculating a value less than 1, then the water level needs to be adjusted upwards. If the meter is fast, calculate a value greater than 1, then the water level needs to be adjusted downwards. Perform three tests before making an adjustment. If the WTM results in unstable numbers then check your sampling

area, are you weighing all the water from the containers, are you tracking the volume of the WTM correctly, is the temperature fluctuating during sampling.

Notes:

6.5.2 Secondary Standard – Dry Gas Meter

1. The DGM to be calibrated and used as a secondary reference meter should be of high quality and have an appropriately sized capacity (e.g., 3 liters/rev (0.1 ft^3 /rev)). A spirometer (400 liters (14 ft^3) or more capacity), or equivalent, may be used for this calibration, although a wet test meter is usually more practical. The wet test meter should have a capacity of 30 liters/rev (1 ft^3 /rev) and capable of measuring volume to within 1.0 percent. Wet test meters should be checked against a spirometer or a liquid displacement meter to ensure the accuracy of the wet test meter. Spirometers or wet test meters of other sizes may be used, provided that the specified accuracies of the procedure are maintained.
2. A spirometer, or equivalent, may be used in place of the wet test meter in the system. Run the pump for at least 5 minutes at a flow rate of about 10 liters/min (0.35 cfm) to condition the interior surface of the wet test meter. The pressure drop indicated by the manometer at the inlet side of the DGM should be minimized (no greater than 100 mm H_2O (4 in. H_2O) at a flow rate of 30 liters/min (1 cfm)). This can be accomplished by using large diameter tubing connections and straight pipe fittings.
3. Make triplicate runs at each of the flow rates and at no less than five different flow rates. The range of flow rates should be between 10 and 34 liters/min (0.35 and 1.2 cfm) or over the expected operating range.
4. Calculate flow rate, Q, for each run using the wet test meter volume, VW, and the run time, θ. Calculate the DGM coefficient, Y_{ds}, for each run. These calculations are as follows:

37. $$Q = \left(std_{[in/°R]}\right) * \frac{P_{bar} * V_{m(WTM)}}{\left(T_{m(WTM)} + T_{std}\right) * \theta}$$ EPA Method 5, Equation 5-9

38. $$Y_{ds} = \frac{V_{m(WTM)} * \left(T_{m(DGM)} + T_{std}\right) * P_{bar}}{V_{m(DGM)} * \left(T_{m(WTM)} + T_{std}\right) * \left(P_{bar} \frac{\Delta p}{13.6}\right)}$$ EPA Method 5, Equation 5-10

Meter temperatures are in °F or °C, Standard temperatures are 273.15 °K or 527.67 °R

5. Compare the three Y_{ds} values at each of the flow rates and determine the maximum and minimum values. The difference between the maximum and minimum values at each flow rate should be no greater than 0.030. Extra sets of triplicate runs may be made in order to complete this requirement. In addition, the meter coefficients should be between 0.95 and 1.05. If these specifications cannot be met in three sets of successive triplicate runs, the meter is not suitable as a calibration standard and should not be used as such. If these specifications are met, average the three Y_{ds} values at each flow rate resulting in no less than five average meter coefficients.
6. Prepare a curve of meter coefficient, Y_{ds}, versus flow rate, Q, for the DGM. This curve shall be used as a reference when the meter is used to calibrate other DGMs and to determine whether recalibration is required.

6.5.3 Critical Orifice

1. Allow a warm-up time of 15 minutes. This step is important to equilibrate the temperature conditions through the DGM.
2. Fully open the coarse adjust valve, and completely close the by-pass valve. Plug the inlet. Then turn on the pump, and determine whether there is any leakage. The leakage rate shall be zero (i.e., no detectable movement of the DGM dial shall be seen for 1 minute).
3. Before calibrating the critical orifice, determine its suitability and the appropriate operating vacuum as follows: Turn on the pump, fully open the coarse adjust valve, and adjust the by-pass valve to give a vacuum reading corresponding to about half of atmospheric pressure. Observe the meter box orifice manometer reading, ΔH. Slowly increase the vacuum reading until a stable reading is obtained on the meter box orifice manometer. Record the critical vacuum for each orifice. Orifices that do not reach a critical value shall not be used.
4. Obtain the barometric pressure, $P_{bar.}$
5. Conduct duplicate runs at a vacuum of 25 to 50 mm Hg (1 to 2 in. Hg) above the critical vacuum. The runs shall be at least 5 minutes each. The DGM volume readings shall be in increments of complete revolutions of the DGM. As a guideline, the times should not differ by more than 3.0 seconds (this includes allowance for changes in the DGM temperatures) to achieve ±0.5 percent in K’
6. Calculate $K^{|}$ with this equation:

39. $$K^{|} = \frac{(std)*V_m*Y*\left(P_{bar}+\frac{\Delta H}{13.6}\right)*(T_{amb})^{0.5}}{P_{bar}*T_m*\theta}$$ EPA Method 5, Equation 5-11

When does a Critical Orifice need Recalibration?

To determine the need for recalibrating the critical orifices, compare the DGM Y factors obtained from two adjacent orifices each time a DGM is calibrated; for example, when checking orifice 13/2.5, use orifices 12/10.2 and 13/5.1. If any critical orifice yields a DGM Y factor differing by more than 2 percent from the others, recalibrate the critical orifice.

Notes:

6.5.4 Dry Gas Meter Calibration

Calibration via WTM

1. Before calibrating the metering system, it is suggested that a leak check be conducted:
   a. Fully open the coarse adjust valve, and completely close the by-pass valve. Plug the inlet. Then turn on the pump, and determine whether there is any leakage. The leakage rate shall be zero (i.e., no detectable movement of the DGM dial shall be seen for 1 minute). Reference Method 5 Section 16.2.2.1.1
   b. Close the main valve on the meter box. Insert a one-hole rubber stopper with rubber tubing attached into the orifice exhaust pipe. Disconnect and vent the low side of the orifice manometer. Close off the low side orifice tap. Pressurize the system to 13 to 18 cm (5 to 7 in.) water column by blowing into the rubber tubing. Pinch off the tubing, and observe the manometer for one minute. A loss of pressure on the manometer indicates a leak in the meter box; leaks, if present, must be corrected. Reference Method 5 Section 8.4.1
2. Before its initial use in the field, the metering system shall be calibrated as follows: Connect the metering system inlet to the outlet of a wet test meter that is accurate to within 1 percent. The wet test meter should have a capacity of 30 liters/rev (1 ft^3 /rev). A spirometer of 400 liters (14 ft^3) or more capacity, or equivalent, may be used for this calibration, although a wet test meter is usually more practical. The wet test meter should be periodically calibrated with a spirometer or a liquid displacement meter to ensure the accuracy of the wet test meter. Spirometers or wet test meters of other sizes may be used, provided that the specified accuracies of the procedure are maintained. Run the metering system pump for about 15 minutes with the orifice manometer indicating a median reading as expected in field use to allow the pump to warm up and to permit the interior surface of the wet test meter to be thoroughly wetted. Reference Method 5 Section 10.3.1
3. At each of a minimum of three orifice manometer settings, pass an exact quantity of gas through the wet test meter and note the gas volume indicated by the DGM. Also note the barometric pressure and the temperatures of the wet test meter, the inlet of the DGM, and the outlet of the DGM. Select the highest and lowest orifice settings to bracket the expected field operating range of the orifice. Use a minimum volume of 0.14 m^3 (5 ft^3) at all orifice settings.
4. Use the following equations to calculate the Q, the meter flow rate, and the Y_d, meter DGM calibration coefficient. You can additionally calculate the ΔH using equations found in the Derivation of ΔH of this handbook.

40. $Q = \left(std_{[in/°R]}\ \right) * \frac{P_{bar} * V_{m(WTM)}}{\left(T_{m(WTM)} + T_{std}\right) * \theta}$ EPA Method 5, Equation 5-9

41. $Y_d = Y_{ds} * \frac{V_{m(DGM)}}{V_{m(WTM)}} * \frac{T_{m(WTM)}}{T_{m(DGM)}} * \frac{(P_{bar} + \frac{\Delta P}{13.6})}{(P_{bar} + \frac{\Delta H}{13.6})}$ CAE historical equation

42. $Y_{ds} = \frac{V_{m(WTM)} * \left(T_{m(DGM)} + T_{std}\right) * P_{bar}}{V_{m(DGM)} * \left(T_{m(WTM)} + T_{std}\right) * \left(P_{bar} \frac{\Delta p}{13.6}\right)}$ EPA Method 5, Equation 5-10

With the Method 5 Equation, Meter temperatures are in °F or °C, Standard temperatures are 273.15 °K or 527.67 °R – Most equations in EPA Methods require correcting data to °K or °R.

Either the Method 5 Equation or the CAE equation can be used – they both generally will produce similar results.

5. The average Y_d value must be between 0.95 and 1.05, no individual Y_d may deviate by more than 0.02 from the mean, or more than 0.03 from any other Y_d value. It is preferential for the average Y_d value to be between 0.98 and 1.02.

Calibration via Critical Orifice

43. $V_{m(std)} = \frac{17.636 * V_m * (P_b + \frac{\Delta H}{13.6}}{(T_m)}$ EPA Method 5, Equation 5-12

44. $V_{cr(std)} = \frac{P_b * \theta * K}{\sqrt{T_{amb}}}$ EPA Method 5, Equation 5-13

45. $Y = \frac{V_{cr(std)}}{V_{m(std)}}$ EPA Method 5, Equation 5-14

Average the DGM calibration values for each of the flow rates. The calibration factor, Y, at each of the flow rates should not differ by more than ±2 percent from the average.

Recalibration

1. Calibration After Use. After each field use, the calibration of the metering system shall be checked by performing three calibration runs at a single, intermediate orifice setting (based on the previous field test), with the vacuum set at the maximum value reached during the test series. To adjust the vacuum, insert a valve between the wet test meter and the inlet of the metering system. Calculate the average value of the DGM calibration factor. If the value has changed by more than 5 percent, recalibrate the meter over the full range of orifice settings.
2. The equation for Y_c is found at the beginning of this Section in this handbook, or in Method 5 Section 9.2.1.1, can also be used to determine the need for recalibration.
3. You may calculate Y_{qa} after each testing series. This procedure is covered under Alternative-009, and under Section 16.3.1.3 of Method 5. A leak check and positive leak check are required when using this calculation, refer to the beginning of the Dry Gas Meter Calibration Section in this handbook. You must average three or more Y_{qa}'s obtained from a test run series and compare this against the meter coefficient, Y. The average of the Y_{qa} must be within 5 percent of the Y. Use the following equation to calculate Y_{qa}

46. $\mathrm{Y_{qa}} = \frac{\theta}{V_m} * \sqrt{\frac{0.0319 * T_m}{\Delta H@ * \left(P_{bar} + \frac{\Delta H_{avg}}{13.6}\right)} * \frac{29}{M_d}} * \sqrt{\Delta H_{avg}}$

EPA Method 5, Equation 5-15

6.6 Derivation of ΔH

Using the calibration data obtained during the selected calibration procedure, determine the ΔH@ for the metering system orifice. The ΔH@ is the orifice pressure differential in units of in. H_2O that correlates to 0.75 cfm of air at 528 °R and 29.92 in. Hg. The ΔH@ is calculated as follows:

Wet Test Meter

47. $\Delta H@ = \frac{0.0319*\Delta H}{P_b(T_{m(DGM)})} * \left(\frac{(T_{m(WTM)})*\theta}{V_{m(WTM)}}\right)^2$ Derivation of ΔH, Equation 1

Method 5 Equation – works with Spirometer, WTM, or Critical Orifice

48. $\Delta H@ = 0.0319 * \Delta H * \frac{T_{m(DGM)} * \theta^2}{P_{bar}*Y^2*(V_{m(DGM)})^2}$ Method 5, Section 9.2.1

Derivation

The flow rate through an orifice meter is defined by the following equation:

49. $Q_m = K_m\sqrt{\frac{T_m*\Delta H}{P_{bar}*M_d}}$ Derivation of ΔH, Equation 2

Q_m = Volumetric Flow Rate through the orifice meter, cfm
K_m = Orifice meter calibration constant [“Hg lb-mole / °R “H_2O]
M_d = Molecular Weight of Ambient Air, assume 28.84

Instead of using the orifice meter coefficient K_m, the term ΔH@ was derived to reflect the general sampling conditions of sampling trains and orifice meters designs with a calibration constant that could be related to the desired flow rate. For example, a ΔH@ of 1.84 means that the orifice pressure differential ΔH would be about 1.84 when sample gas is flowing through the orifice meter. The reference conditions for ΔH were chosen to be 0.75 dcfm air at 68°F and 29.92 in. Hg

50. $\Delta H@ = \frac{(Q_@)^2*P_@*M_@}{(K_m)^2*T_@}$ Derivation of ΔH, Equation 3

Where the subscript “@” represents the reference conditions of 0.75 dcfm of air at 68°F and 29.92 in. Hg.

Substituting the values for the reference conditions (except M@) into Equation 3, the following is obtained:

51. $\Delta H@ = \frac{0.75^2*29.92*M_@}{(K_m)^2*528} = 0.0319 * \frac{M_@}{(K_m)^2}$ Derivation of ΔH, Equation 4

Now, the relationship between Q_m and the volumetric flow rate through the wet test meter (Q_w) is as follows (the subscript “w” refers to the flow rate conditions at the wet test meter):

52. $\frac{P_{bar}*Q_m}{T_m} = \frac{P_w*Q_w}{T_w}$ Derivation of ΔH, Equation 5

Substituting Equation 2 into Equation 5 and solving for K_m^2:

53. $\frac{P_{bar}*K_m}{T_m}*\sqrt{\frac{T_m*\Delta H}{P_{bar}*M_d}}=\frac{P_w*Q_w}{W_y}$ $(K_m)^2=\frac{M_d*T_m*(P_w)^2*(Q_w)^2}{\Delta H*(T_w)^2*P_{bar}}$

Derivation of ΔH, Equation 6

In the Method 5 calibration set-up, the pressure at the orifice meter and the wet test meter are at barometric pressure. Thus, $P_w = P_{bar} = P_b$, Equation 6 simplifies to:

54. $(K_m)^2=\frac{M_d*T_m*P_{bar}*(Q_w)^2}{\Delta H*(T_w)^2}$ Derivation of ΔH, Equation 7

Substituting Equation 7 into Equation 4 :

55. $\Delta H@=\frac{0.0319*M_@*\Delta H*(T_w)^2}{M_d*T_m*P_{bar}*(Q_w)^2}$ Derivation of ΔH, Equation 8

Since air is being used to calibrate the orifice, $M@ = M_d$. In addition, $Q_w = V_m/\theta$, which is the volume measured by the wet test meter divided by time, and $T_{m(DGM)}$ is the same temperature measured at the outlet of the dry gas meter, i.e., $T_{m(DGM)} = T_o$. Furthermore, $T_{m(WTM)} = t_{m(WTM)} + 460$, and $T_o = t_o + 460$. Making these substitutions in Equation 8 yields:

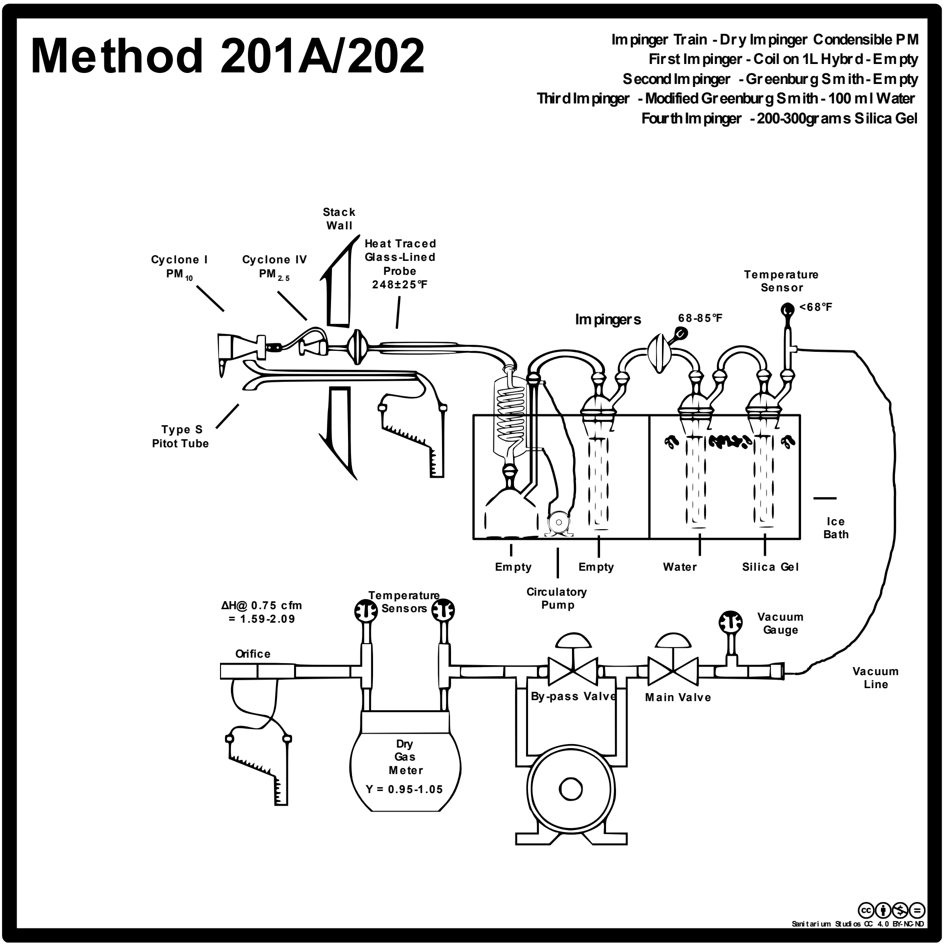
56. $\Delta H@=\frac{0.0319*\Delta H}{P_b(T_{m(DGM)})}*\left(\frac{(T_{m(WTM)})*\theta}{V_{m(WTM)}}\right)^2$ Derivation of ΔH, Equation 1

Bibliography

1. Code of Federal Regulations, Title 40, Part 60. U.S. Government Printing Office, Washington, D.C. July 1, 1987
2. Shigehara, R.T., Adjustments in the EPA Nomograph for Different Pitot Tube Coefficients and Dry Molecular Weights. In: Stack Sampling Technical Information – A Collection of Monographs and Papers, Vol. III. U.S. Environmental Protection Agency. Publication No. EPA-450-2-78-042c. October 1978. pp. 48-49.
3. Smith, W.S., R.M. Martin, D.E. Durst, R.G. Hyland, T.J Logan, and C.B. Hager. Stack Gas Sampling Improved and Simplified with New Equipment. Presented at the 60th Annual Meeting of the Air Pollution Control Association, June 11-16, 1967, Cleveland, Ohio. APCA Paper N. 67-119.

Notes:

6.7 Cut Points – 10 Microns and 2.5 Microns



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Method 201 and Method 201A are for separating particulate based on particle size. A Method 201 cyclone, or Cyclone I in Method 201A, are designed to separate particles larger than 10 microns from particles less than 10 microns. The introduction of Cyclone IV in Method 201A allows to further separate the particles less than 2.5 microns.

Sampling with a Cyclone requires sampling at a constant rate that is calculated to cause a cut point based on the cyclone design. For the Cyclone I, this cut point should be between 9-11 microns; for the Cyclone IV, this cut point should be between 2.25-2.75 microns. For sampling in this fashion to retain isokinetic sampling rates, the sampling duration at each point will be a calculated dwell time based on the stack velocity at each separate point. Because the dwell times will change based on the velocity profile, there is additional constraints caused by the limits of a minimum and maximum velocity for maintaining isokinetic sampling. As there is more error with maintaining isokinetic sampling rates, the method allows for a higher deviation of up to 80-120% isokinetic. However, when using these methods to determine a total particulate matter, then the tester is required to maintain the 90-110% limits as set forth in Method 5.

The particulate that is dropped out in Cyclone I is larger than 10 microns. The particulate that passed through Cyclone I but is dropped out by Cyclone IV is less than 10 microns but larger than 2.5 microns. The particulate that passes through Cyclone IV up to the filter is less than 2.5 microns (technically larger than 0.3 microns due to the filter efficiency). The particulate that is less than 10 microns is considered PM_{10} and includes the particulate matter in Cyclone IV, after Cyclone IV, and any Condensable Particulate Matter (CPM) if applicable. The particulate matter that passes through Cyclone IV, and CPM, is considered $PM_{2.5}$. The particulate matter collected in Cyclone I is only applicable if using Method 201A to determine total particulate matter.

It is not advised to use Method 201A to determine total particulate matter. There are several factors which will bias this number, from the sampling rate, maintaining isokinetic rate, and any biases that occur during recovery, up to and including the recovery of stainless steel.

Notes:

6.7.1 Cut Point Calculations

Information Required	Variable	Example
Stack Gas Viscosity	μ	199.74
Cunningham Correction Factor	C	1.0757
Lower Limit Cut Diameter (CI)	D_{50LL}	10.137
Overlap for Cut Point (CI)	D_{50T}	10.569
Sampling Rate with CI and CIV	Q_s	0.492
Reynolds Number	N_{re}	2662
Velocity of Stack	V_s	67.042
Meter Box Orifice Pressure Drop	ΔH	0.391
Desired Nozzle	D	0.151
Velocity of Nozzle	V_n	65.740
Minimum Nozzle/Stack	R_{min}	0.734
Maximum Nozzle/Stack	R_{max}	1.244

Expected Nozzle/Stack	R	0.981
Minimum Stack Gas Velocity	V_{min}	48.261
Maximum Stack Gas Velocity	V_{max}	81.795
ΔP Minimum Pressure	ΔP_{min}	0.559
ΔP Maximum Pressure	ΔP_{max}	1.604
Predicted Isokinetic	Iso%	102.04
Standard Sampling Rate	Qs_{st}	0.303
Sampling Rate	Q_s	0.351
Cyclone Viscosity	μ_{cyc}	195.726
Cut Diameter of CI	D_{50I}	10.46
Cut Diameter of CIV	D_{50IV}	2.308

57. μ, Viscosity – Eq. 3

$$\mu = C1 + C2\sqrt{T_s} + C3(T_s)^{-2} + C4\left(C_{O_2}wet\right) - C5(B_{ws}) + C6\,(B_{ws})(T_s)^2$$

Where
C1 = -150.6162
C2 = 13.4622
C3 = $3.86153*10^{6}$
C4 = 0.591123
C5 = 91.9723
C6 = $1.51761*10^{-5}$

58. C, Cunningham Correction Factor – Eq. 4

$$C = 1 + 0.0057193 * \frac{\mu}{P_s * D50IV} * \left(\frac{T_s}{M_s}\right)^{0.5}$$

Note The Cunningham Correction Factor is predicated on The Reynolds Number, and the Reynolds Number is predicated on the Cunningham Correction Factor; these two numbers will thus be reiterated later on during a test.

59. D_{50LL}, Lower Limit Cut Diameter for Cyclone I – Eq. 5

$$D_{50LL} = 9.507 * C^{0.3007} * \left(\frac{M_s * P_s}{T_s}\right)^{0.1993}$$

60. D_{50T}, Cut Diameter for Cyclone I for the Middle of the Overlap Zone – Eq. 6

$$D_{50T} = \left(\frac{11 + D_{50LL}}{2}\right)$$

61. Qs, Sampling Rate using Cyclone I and Cyclone IV – Eq. 7

$$Q_s = Q_I = 0.07296 * \mu * \frac{T_s}{M_s * P_s}^{0.2949} * \frac{1}{D50T}^{1.4102}$$

62. Nre, Reynolds Number – Eq. 10

$$N_{re} = 86400 * Ps * \frac{M_s}{T_s} * \frac{Q_s}{\mu}$$

Note The Cunningham Correction Factor is predicated on The Reynolds Number, and the Reynolds Number is predicated on the Cunningham Correction Factor; these two numbers will thus be reiterated later on during a test.

63. ΔH, Meter Box Orifice Pressure Drop – Eq. 1

$$\Delta H = \left[\frac{Q_s(1 - B_w)P_s}{T_s}\right]^2 \left[\frac{1.083(T_m)M_d(\Delta H@)}{P_{bar}}\right]$$

64. D, Desired Nozzle – Eq. 14

$$\mathrm{D} = \left[\frac{3.056Q_s}{V_s}\right]^{0.5}$$

65. Vn, Velocity Nozzle – Eq. 15

$$V_n = \frac{Qs}{60 * A_n}$$

66. Rmin, Minimum Nozzle/Stack Velocity – Eq. 16

$$R_{min} = 0.2457 + \left(0.3072 - \frac{0.2603 * \mu * Q_s^{0.5}}{V_n^{1.6}}\right)^{0.5}$$

67. Rmax, Maximum Nozzle/Stack Velocity – Eq. 17

$$R_{max} = 0.4457 + \left(0.569 - \frac{0.2603 * \mu * Q_s^{0.5}}{V_n^{1.6}}\right)^{0.5}$$

68. R, Nozzle/Stack Velocity

$$R = \frac{V_n}{V_s}$$

69. Vmin, Minimum Gas Velocity – Eq. 18/19

$$V_{min} = IF(R_{min} > 0.5, V_n * R_{min}, V_n * 0.5)$$

70. Vmax, Maximum Gas Velocity – Eq. 20/21

$$V_{max} = IF(R_{max} > 1.5, V_n * 1.5, V_n * R_{max})$$

71. Δpmin, Minimum Velocity Pressure – Eq. 22

$$\Delta p_{min} = 0.00013686 * P_s * \frac{M_s}{T_s} * \left(\frac{V_{min}}{C_p}\right)^2$$

72. Δpmax, Maximum Velocity Pressure – Eq. 23

$$\Delta p_{min} = 0.00013686 * P_s * \frac{M_s}{T_s} * \left(\frac{V_{max}}{C_p}\right)^2$$

73. Estimated Volume

$$V_{m(std)_{estimated}} = \left(493.4(Cp)\left(\frac{P_s}{M_s T_s}\right)^{0.5}(1 - B_w)\right) t_r \sqrt{\Delta P}(D^2)$$

Where t_r = Total projected run time

74. Predicted Isokinetic

$$\text{Iso}\ \% = \frac{0.0945(\mathrm{T_s}) V_{m(std)_{estimated}}}{(P_s) V_s (A_n) t_r (1 - B_w)}$$

75. Dwell Time – Eq. 24

$$t_n = \left[\frac{Cp\sqrt{\Delta P_n}}{Cp_{initial}\left(\sqrt{\Delta P_1}\right)_{avg}}\right]\left[\frac{t_r}{N_{tp}}\right]$$

Where N_{tp} = Total number of traverse points

76. Qsst, Sampling Rate – Eq. 29

$$Qs_{st} = \frac{Vm_{std}}{\Theta}$$

77. Q_s, Sampling Rate – Eq. 32

$$Q_s = \frac{29.92}{528} Qs_{st}\left(\frac{1}{1 - B_w}\right)\left(\frac{T_s}{P_s}\right)$$

78. μ, Gas Viscosity – Eq. 3 – Reiteration same calculation as above?

$$\mu = C1 + C2\sqrt{T_s} + C3(T_s)^{-2} + C4\left(C_{O_2}wet\right) - C5(B_{ws}) + C6\ (B_{ws})(T_s)^2$$

79. N_{re}, Reynolds Number – Eq. 10 - Reiteration

$$N_{re} = (86400)Ps\left(\frac{M_s}{T_s}\right)\left(\frac{Q_s}{\mu}\right) \qquad = (86400)Ps\left(\frac{M_s}{(T_s + 460)}\right)\left(\frac{Q_s}{\mu}\right)$$ = 2906

80. μ_{cyc}, Cyclone Viscosity

$$\mu_{cyc} = C1 + (C2)T_s + (C3)T_s(2) + (C4)C_{O_2dry} - (C5)B_w$$

Where
C1 = 51.05
C2 = 0.207
C3 = $3.24*10^{-5}$
C4 = 53.147
C5 = 74.143

81. D_{50I}, Cut Diameter Cyclone I – Eq. 33 (Method 201 uses μ_{cyc}; Method 201A uses μ)

$$D_{50I} = 0.15625 * \frac{T_s}{P_s * M_s}^{0.2091} * \frac{\mu_{cyc}}{Q_s}^{0.7091}$$

82. D_{50IV}, Cut Diameter Cyclone IV – Eq. 34/35

$$D_{50IV} = IF\left(N_{re} < 3162, 0.0024302 * \frac{\mu}{Q_s}^{1.1791} * \frac{1}{C}^{0.5} * \frac{T_s}{M_s * P_s}^{0.679}, 0.019723 * \frac{\mu}{Q_s}^{0.8058} * \frac{1}{C}^{0.5} * \frac{T_s}{M_s * P_s}^{0.30580.679}\right)$$

Note The value calculated by this equation must be used to reiterate C, and then reiterate this D_{50IV}. These values need to continue to be reiterated until the difference between two numbers is less than 0.01:

83. Z, Ratio between D_{50} and D_{50-1} Values – Eq. 39 and 40

$$0.99 \leq \left[Z = \left(\frac{D_{50}-1}{D_{50}}\right)\right] \leq 1.01$$

Notes:

6.8 Condensable Particulate Matter

Method 202, or the ‘Wisconsin Backhalf’, is used for determining the presence of particulate matter which will pass through a heated filter and drop out as the moisture in the gas stream condenses. When performing Method 202 testing, or having a source testing company performing the testing at your facility, it is best to read through the best practices and to ask practical questions about the preparation, operation, and analysis of the samples. Any of these steps being performed incorrectly can result in a bias for high results and potentially failing results at no fault of the facility.

https://www.epa.gov/sites/default/files/2020-08/documents/m202-best-practices-handbook.pdf

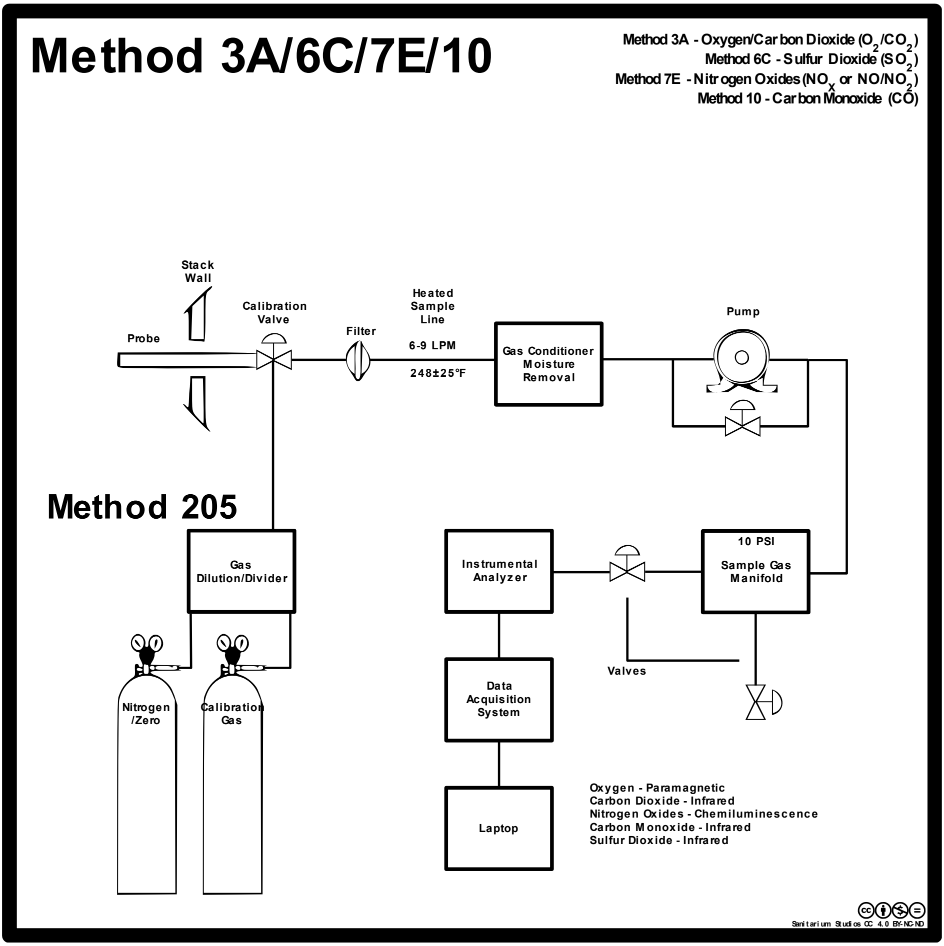
https://www.epa.gov/sites/default/files/2020-08/documents/m202-appa-best-practice-reduce-blanks.pdf

State programs may also have similar testing procedures, such as Oregon DEQ with Oregon Method 5, OM-5.

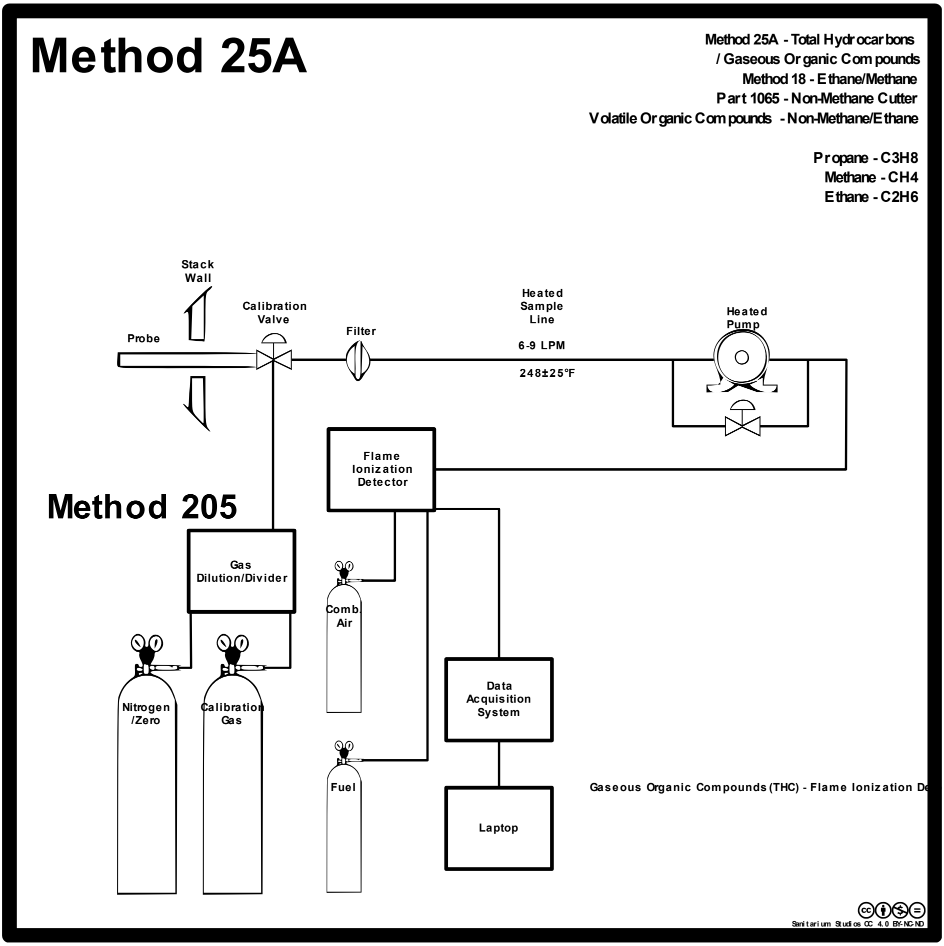
Notes:

7. Instrumental Analyzer Procedures

7.1 Instrumental Analyzer Diagrams



Notes:


Method 25A
Method 25A - Total Hydrocarbons
/ Gaseous Organic Compounds
Method 18 - Ethane/Methane
Part 1065 - Non-Methane Cutter
Volatile Organic Compounds - Non-Methane/Ethane
Propane - C3H8
Methane - CH4
Ethane - C2H6
Stack Wall
Probe
Calibration Valve
Filter
Heated Sample Line
6-9 LPM
248±25°F
Heated Pump
Flame Ionization Detector
Method 205
Gas Dilution/Divider
Comb. Air
Nitrogen /Zero
Calibration Gas
Data Acquisition System
Fuel
Laptop
Gaseous Organic Compounds (THC) - Flame Ionization De
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Notes:

7.2 Methods

Methods 3A, 6C, 7E, and 10 are commonly utilized Instrumental Analyzer testing procedures. These methods refer to Method 7E for purposes of calculations. Method 25A and 25B are examples of analyzer methods that do not reference to Method 7E; however, best practices are to utilize the drift correction procedures for any analyzer or gas chromatography method.

Below are calculations used to qualify data collected by Method 3A, 6C, 7E, and 10. This section references both procedures of Method 7E and Method 25A, as well as Method 205.

7.3 Calibration and Drift

Information Required	Variable	Example	Units
Actual Concentration of Span	CS	252.4	ppm$_{vd}$
Actual Conc. of Upscale	C_{MA}	126.20	ppm$_{vd}$
Value Direct – Zero	$C_{DIR(Zero)}$	-0.20	ppm$_{vd}$
Value Direct – High Level	$C_{DIR(High)}$	251.00	ppm$_{vd}$
Value Direct – Mid/Upscale	$C_{DIR(Mid)}$	124.01	ppm$_{vd}$
Value System – Zero	$C_{S(Initial)}$	0.77	ppm$_{vd}$
Value System - Upscale	$C_{S(Initial)}$	120.36	ppm$_{vd}$
Value System Final – Zero	$C_{S(Final)}$	0.66	ppm$_{vd}$
Value System Final – Upscale	$C_{S(Final)}$	120.93	ppm$_{vd}$
Average of Zero	C_0	0.715	ppm$_{vd}$
Average of Upscale	C_M	120.645	ppm$_{vd}$
Average of Gas Concentration	C_{AVG}	139.23	ppm$_{vd}$

7.4 Instrumental Analyzer Calculations

84. Analyzer Calibration Error (Linearity), Tolerance is 2% of Calibration Span

$$ACE\ (Linearity) = \left|\frac{C_{DIR}-C_V}{CS}\right|$$

EPA Method 7E Equation 7E-1

Where

CS = Value of Span

C_V = Actual Concentration of Gas

C_{DIR} = Value Measured

85. System Bias (Upscale), Tolerance is 5% of Calibration Span

$$SB\ (Upscale) = \left|\frac{C_{SB}-C_{DIR}}{CS}\right|$$

EPA Method 7E Equation 7E-2

Where

C_S = Value Measured

86. System Calibration Error (Dilution Systems)

$$SCE = \left|\frac{C_{SBF}-C_{SBI}}{CS}\right|$$

EPA Method 7E Equation 7E-3

Where:

D_F = Dilution Factor

87. Drift Assessment, Tolerance is 3% of Calibration Span

$$Drift = |SB_{Final} - SB_{Initial}|$$

EPA Method 7E Equation7E-4

$$Drift = \left|\frac{C_{S(Final)}-C_{S(Initial)}}{CS}\right|$$

88. Effluent Gas Concentration, bias and drift corrected results

$$C_{Gas} = (C_{Avg} - C_O)\frac{C_{MA}}{(C_M-C_O)}$$

EPA Method 7E Equation 7E-5B

Where
C_{Gas} = Average adjusted run value
C_{Avg} = Average unadjusted run value
C_{M} = Average Initial and Final Upscale Value
C_{O} = Average Initial and Final Zero Value

This equation is based on using a Zero Value gas for the Low Gas Calibration; using a zero value gas is preferable due to zero bias error during direct calibration.

89. $Stratification\ \% = \left|\frac{C_{(16.7\%\ AND\ 50.0\%\ AND\ 83.3\%)}}{C_{MEAN}} - 1\right|$

90. $Eff_{NO_x} = \frac{C_{DIR}}{C_V} * 100$ EPA Method 7E Equation 7E-7

91. $NO_{X(Corr)} = NO + \left(\frac{NO_x - NO}{Eff_{NO_2}} * 100\right)$ EPA Method 7E Equation 7E-8

92. $\%\ Decrease = \frac{NO_{x_{Peak}} - NO_{x_{Final}}}{NO_{x_{Peak}}} * 100$ EPA Method 7E Equation 7E-9

Calculations	Allowable	Example	Units
Span Tolerance from Conc.	100-500%	139-696	ppm
Conc. Tolerance from Span	20-100%	50.5-252.4	ppm
Upscale Division of Span	40-60%	50%	%
Upscale Allowable of Span	40-60%	101-151	ppm
Direct Zero Error	<2%	0.08	%
Direct High Error	<2%	0.55	%
Direct Mid Error	<2%	0.87	%
System Initial Drift Zero	<5%	0.38	%
System Initial Drift Upscale	<5%	1.45	%
System Final Bias Zero	<3%	0.04	%
System Final Drift Zero	<5%	0.34	%
System Final Bias Upscale	<3%	0.23	%
System Final Drift Upscale	<5%	1.22	%
Drift Corrected Number		145.76	ppm

7.5 Initial Calibration

The operating procedures vary between a Full Extractive System or a Gas Dilution System. Both procedures call for a 3 Point Calibration prior to testing. With a Full Extractive System this calibration is performed by introducing the gases directly to the analyzer (Equation 7E-1), with a Gas Dilution System the 3 Point Calibration is through the system (Equation 7E-3).

The procedures prescribed in Method 7E for the 3-Point Calibration are not in accordance with manufacturer guidelines. Although the procedure resultantly provides the same detail of accuracy – this procedure is not based on adjustments being performed. Method 25A outlines a 4-Point Calibration being performed as a linearity test, this procedure follows manufacturer guidelines for making adjustments to verify accuracy. Following manufacturer guidelines, a zero gas should first be used, allowing for the zero scale on a analyzer to be adjusted. After the zero gas has been calibrated, then the high level should be introduced. Under Method 7E, this high level is the Calibration Span, under Method 25A the high level is 80-90% of the Calibration Span.

After verifying the zero and the high level, then a mid level, and low level for Method 25A, are checked. This procedure is a linearity check, which although deviates in order from the 3-Point check prescribed in Method 7E, still accomplishes the same verification of accuracy.

When performing this calibration, whether as a direct calibration or through a dilution system, the values achieved must maintain within 2% of the Calibration Span. Note that Method 25A actually allowed for a 5% error, but the 2% error of Method 7E can also successfully be used.

By calibration as a linearity check, an error may be identified during the procedure that would not otherwise be detected. While the high level may maintain within 2%, the mid level will not be lineary. Often times the culprit in this is a drift on the zero scale. If using the procedures in Method 7E, especially if using a Low level gas and not a Zero gas, this error will not be identified.

The second likely culprit occurs when using Method 205, and getting an incorrect division or dilution ratio in the gas. Note that Method 205 is not to be used for Part 75 RATA testing. When performing Method 205, ensure that the procedures are followed for calibrating the dilution system, properly performing the field check procedure to verify a dilution system, and that the gases utilized are maintained at constant pressure within the desired pressure range for the instrument.

Whether performing the 3-point calibration through direct introduction as a full extractive or with a gas dilution system, the **data must be inspected for quality assurance with calculations included in the report** (Equation 7E-1 and 7E-3). The Initial Calibration is to be performed within a reasonable time frame from when testing is performed – Method 25A prescribes in Section 8.4 that this is within 2 hours.

Although these procedures for using a Dilution system do not require performing a direct calibration; best practices would dictate that performing a direct calibration will ensure that the numbers being calibrated do not have any introduction of bias due to the dilution ratio; and then performing a 2-point system calibration error test as described below.

7.6 System Bias and Response Time

With a Full Extractive System you must perform a 2-point system calibration error test, or system bias test. A Gas Dilution System does not require a 2-point system error if the 3-Point Calibration was performed through the Dilution system at the correct Dilution Ratio.

The gas used as the upscale is based upon whether the high level or the mid level is a closer approximation to the analyzed concentration. The upscale gas and the zero gas will then be introduced through the sampling system, including any filtration system. Once stable numbers have been recorded for a system response for the upscale and zero gas, then **these numbers must be inspected for quality assurance with calculations included in the report** (Equation 7E-2 or 7E-3).

During the initial 2-point test, you must determine and calculate the system response time for **inclusion in the source testing report**. Observe the time it takes from introducing calibration gas to the system until you have achieved 95 percent of a stable response for both the low-level and upscale gases. The lower interval is the response time. The response time may be similar for each constituent due to the sample system, but will also vary between constituents due to the analysis principles and interference gases in the gas stream.

This 2-point test must be performed again after each test, or after a series of tests. Best practices is to perform a calibration at 70 minute intervals (no more then 3 21-minute runs), or when practical if being performed concurrently with other tests at longer durations.

Note that Alt-106 and other similar methods are for using a GC in the field. The analysis procedures refer to Method 25A requirements: a 4-Point Calibration. It is still advised as best practices to follow and maintain the system check procedures of Method 7E, and use the equations for calculating bias and performing drift correction.

7.7 Stratification

When testing a source for analytes according to instrumental analyzers, or even gas chromatography, the sampling location must be tested for stratification. When determining stratification, the tester may either select three points at 16.7, 50.0, and 83.3 percent of the stack diameter, or 12 points calculated according to Method 1. A source that has no stratification, that is maintains that the gas analyzed from each point is within 5 percent of the mean of all points, then testing can be performed at a single point. If a source has minimal stratification, the error is greater than 5 percent of the mean but less than 10 percent of the mean, then the test can be performed sampling at three points during the test. Sources that are considered stratified, one sampling point is outside of 10 percent from the mean of all points, then the sampling during the test must be from 12 points calculated according to Method 1. **The determination of stratification must be performed at a site before testing or during the first test, and in best practices this information (current or historical) must be documented in every report.** Note that when performing Performance Specification work, the stratification becomes optional, and the requirements deem a minimum of a 3-point traverse always be used. However, for stacks greater than 2 meters and in which stratification is not expected, this 3-point traverse is conducted at fixed points along a 2 meter dimension (0.4 meters or 15.75 inches, 1.2 meters or 47.25 inches, and 2.0 meters or 78.75 inches).

7.8 Converter Efficiency

There are two ways of performing a NOx Converter Efficiency Test.

You may use a certified NO_2 gas of sufficient concentration for the testing environment. Method 7E Section 7.1.4 suggests 40-60 ppm. The procedure in Section 8.2.4 do not prescribe a duration of analyzing data. Best Practices would be to collect five minute worth of data and calculate the efficiency of the five minute average. If the % of NO_2 is a known quantity in the Source, then the values can be corrected based on the known NO_2 value when performing the converter efficiency test in the field and failing the converter efficiency (10-15% of the NO emissions

Alternatively you may fill a Tedlar bag of suitable size with a mixture of air and NO gas to allow for a 30 minute analysis (20 Liter bag if the Analyzer has a 0.5L/Min Sample Rate; 80 Liter bag for 2 L/Min Sample Rate). During the thirty minute you must record the maximum value, or peak, and the final value. No value during the thirty minute test can drop below 2 percent of the peak value, and the calculated Percentage must be less than 2. This technique is not advisable as the Tedlar bag must be of sufficient size and cannot have any bias (leaks).

Although Converter Efficiency does not need to be performed immediately prior or after testing, **a source testing report should include documentation showing a routine schedule** – preferably the converter efficiency test performed following the testing program (whether 1, 2, or 4 weeks after the test but before the report is provided).

7.9 Gas Dilution Systems

Gases used during a testing program must be EPA Protocol Gases according to Method 7E. Some testing, or gas blends, may be only Certified Gases with less certainties. In either instance, often times a testing will be conducted using a bottle with a higher concentration then what is required in a majority of testing, requiring the use of a gas dilution system, or gas divider, to provide a lower concentration for calibrating within values within range of the tested concentration. The Gas Dilution System, not to be confused with a Gas Dilution System, must be verified through Method 205 – any time the power is interrupted (meaning anytime a source tester moves their equipment, or if there is a loss of power). This Method 205 testing procedure **must be included in any report** utilizing a Gas Dilution/Divider System, and the report should include multiple tests if multiple sources were tested at multiple points. Furthermore, the instrument must have an annual calibration performed against **NIST traceable standards that is also included in the report**.

The Source Tester must use two different bottles for performing a Method 205 test. The high level bottle will be divided to two separate concentrations, a separate bottle, mid level, will be used as a undivided verification bottle. The verification value and two separate concentrations will be introduced into the analyzer, each in triplicate. Each analysis cannot vary by more then 2 percent from the mean of a select concentration;

the mean at each select concentration must maintain within 2 percent of the concentration value.

The verification of a gas dilution/divider is critical for quality assurance. For example, a tester may be using a gas divider to divide to a 20% and 10% division for their high and mid level gases. However, if the gas divider actually has an error and is dividing this to 14% and 7%, matching in linearity, then this error would not be detected. In this instance it would cause approximately a 40% bias to the data. In this instance, if they using a 1000 ppm bottle, then they are using a high and mid of 200 and 100. However, the divider would actually be providing 140 which they are calling a 200, and detecting 70 ppm as 100. Because of this error, which would not show up in the linearity check, then they would be detecting 110 ppm as approximately 160 ppm – which, depending on the facility and limits, could be the difference between a pass and fail. The opposite could also happen admittedly, where 160 ppm is detected as 110 ppm. In either case though, the data is not quantitative or quality data and should not be utilized. A method 205 test is essential to verify the quality of the data.

Notes:

8. Performance Specifications Procedures

The purpose of the Performance Specifications is to determine and maintain the accuracy and validity of a Continuous Emission Monitoring System (CEMS) or Continuous Emission Rate Monitoring System (CERMS). There are three forms of testing conducted over the course of a year: Relative Accuracy Audit (RAA), Relative Accuracy Test Audit (RATA), and Cylinder Gas Audit (CGA). The schedule of how often these tasks need to be performed will vary based on permit conditions and regulations covering the facility. Best practices and most common involves conducted a CGA or RAA for three quarters of the year, and conducting a RATA during the fourth quarter – this can be found in 40CFR60 Appendix F Section 5. This section of this handbook will primarily reference this Section as well as Performance Specification 2 for examples.

8.1 Sampling location of CEMS

Performance Specification 2 Section 8.1.1 and 8.1.2 deal with the installation and measurement location. The location should match to the minimum criteria of Method 1 (2 diameters for dimension B and 0.5 diameters for dimension A), and the sampling point should be conducive to collect representative data.

The tester is not required to perform a stratification test, but by default must use a 3 point traverse. The location of these three points is dependent on the diameter (for less than 2.4 meters then 16.7&, 50%, and 83.3% can be used, for greater than 2.4 meters then 0.4, 1.2, and 2.0 meters can be used). Testing in this manner does not require performing a stratification test, as described in Section 8.1.3.2 of PS2 or in 6.6 of this handbook.

If stratification is suspected, then a stratification test is required using a 12 point traverse across the diameter of the stack. If this test proves that the source is unstratified, then the 3 points utilized must be at percentages (16.7, 50.0, and 83.3) across the overall diameter.

However – if the source is proven to be unstratified, then this can be used to show that a single sampling point provides a representative sample across the stack, per 8.1.3.2.

8.2 Calibration of CEMS

Analyzers utilized at a facility have a span set based on applicable regulations, permits, or source conditions. The span should not exceed such that the source conditions are less than 30 percent of the span (E.G. normal operations produce 50 ppm NOx while the span is set to 1000, meaning normal source conditions are 5.0% of the span; if normal operations are 50 ppm then the span should not exceed 160 [rounded to nearest 10 or 100]). The gases used to calibrate that span value should be within 50 to 100 percent of the span (E.G. 80-160 ppm).

As part of a Relative Accuracy Test Audit, a 7 Day Calibration Drift assessment test **must be performed and provided** to the Source Tester for their inclusion in their report. A 7-Day Calibration Drift assessment is performed by conducting daily calibration gas checks, but making no adjustments to the system. Over the course of the 7 days the analyzers must not drift outside of their specifications (2.5% of span for SO_2 and NOx, 0.5% of span for CO_2 and O_2, 5% of span for CO_2,) without making any adjustments.

8.3 Cylinder Gas Audit

A Cylinder Gas Audit is performed by challenging the CEMS with audit gases, gases of known concentrations that are not part of the routine calibration procedures and are within a range of the calibration span. (20-30% of the span and 50-60% of the span for pollutants; 5-8% and 10-14% for CO_2, and 4-6% and 8-12% for O_2).

8.4 Relative Accuracy Audit

A Relative Accuracy Audit is a test performed by conducting three Reference Method tests to calculate Relative Accuracy. This can be performed in lieu of a Cylinder Gas Audit, although generally the Cylinder Gas Audit is a more cost-effective measure.

8.5 Relative Accuracy Test Audit

A Relative Accuracy Test Audit can consist of any number of tests as long as at least 9 tests are performed, and in which only three tests can be excluded from the test results. Generally this will involve performing up to 12 test and discarding 3 of the runs; however, it is possible to perform 21 test and use 18 to calculate Relative Accuracy with (discarding the maximum of 3).

A RATA should be performed following a 7 Day Calibration Drift. However, the regulations do not outright specify that the 7 Day Calibration Drift must be performed immediately prior to the test. The 7 Day Calibration Drift should be performed within one month of the RATA to be considered as valid data.

After a RATA has been started, no adjustments are to be made to the CEMS. Daily calibrations and equipment inspections should have been performed before the testing is conducted. A RAA can be conducted prior to a RATA test, after which adjustments can be made before continuing with the RATA.

Before a RATA is performed, the facility should be properly inspected with all equipment checked or replaced as needed. For a CERMS system, pitot tips are a common cause of error, due to pitot tips being corroded or plugged with water or particulate.

During the RATA program, the Source Tester data needs to be monitored for quality assurance. The source tester must be monitoring for using correctly calibrated equipment (instrumental analyzer quality assurance [calibration span, calibration errors, converter efficiency, dilution verification], meter and pitot coefficients and adjustments, sample and chemical date of manufacturing and handling techniques). Remember that during a RATA, the source test is the reference method, the verifiable standard. As such, the data must meet and exceed all standards of quality assurance.

A Passing Relative Accuracy test will vary between Performance Specifications and regulations that apply to the facility.

8.6 Relative Accuracy Testing

Information Required	Variable	Example	Units
Number of Runs	N_R	9	Req'd 9-16
Mean of Reference Method	M_{oRM}	147.06	
Mean of CEMS		140.82	
Mean of Difference	M_{oD}	6.24	
Sum, Each Difference - Squared	$\sum_{i-1}^{N_R} d_i^2$	353.1836	
Sum, All Differences - Squared	$\left[\sum_{i-1}^{N_R} d_i\right]^2$	3153.9456	
Applicable Standard - Limit		250	

93. σ, NO_x Standard Deviation — Performance Specification 2, Equation 2-2

$$\sigma = \sqrt{\frac{\sum_{i-1}^{N_R} d_i^2 - \frac{\left[\sum_{i-1}^{N_R} d_i\right]^2}{N_R}}{N_R-1}}$$

$\sum_{i-1}^{N_R} d_i$ = Summation of the individual differences

94. CC, NO_x Confidence Coefficient — PS2, Equation 2-3, Table 2-1

$$CC = t_{0.975}\frac{\sigma}{\sqrt{Number\ of\ Runs}}$$

n^a	$t_{0.975}$	n^a	$t_{0.975}$	n^a	$t_{0.975}$	n^a	$t_{0.975}$	n^a	$t_{0.975}$
2	12.706	5	2.776	8	2.365	11	2.228	14	2.160
3	4.303	6	2.571	9	2.306	12	2.201	15	2.145
4	3.182	7	2.447	10	2.262	13	2.179	16	2.131

95. RA, NO_x Relative Accuracy, lb/hr RATA — PS2, Equation 2-4

$$RA = \frac{|M_oD|+|CC|}{M_oRM}(100) \qquad = \frac{|-77.3|+|5.77|}{461.03}$$

= 18.02% RA

Information Required	Variable	Example	Units
Standard Deviation	σ	0.59	
Confidence Coefficient	CC	0.44	
Relative Accuracy	RA	4.54	
Relative Accuracy – App. Std.	RA	2.67	

Notes:

8.7 Relative Accuracy Results

8.7.1 40CFR Part 60

Performance Specification 2

Nitrogen Oxides and Sulfur Dioxide

Calibration Drift - 2.5% of Calibration Span

Relative Accuracy - <20% of RM; If emissions are <50% of applicable standard then;

<10% using applicable standard

Relative Accuracy for SO_2 emissions between 0.20 and 0.30 lb/mmBTU <15%

Relative Accuracy for SO_2 emissions below 0.20 lb/mmBTU <20%

Performance Specification 3

Oxygen and Carbon Dioxide

Calibration Drift - 0.5% of Concentration

Relative Accuracy - <20% of RM; or <1.0% of concentration

Performance Specification 4

Carbon Monoxide

Calibration Drift - 5 % of Calibration Span

Relative Accuracy - <10% of RM, or <5% of applicable standard

Performance Specification 4A

Carbon Monoxide <400 ppm

Calibration Drift - 5% of Calibration Span

Relative Accuracy - <10% of RM, or <5% of applicable standard, or ±5 ppm plus the 2.5 percent confidence coefficient

Performance Specification 4B

Oxygen and Carbon Monoxide

Calibration Drift – Oxygen, same as PS3; Carbon Monoxide, <3% of calibration span

Relative Accuracy – same as PS3 and PS4, respectively

Performance Specification 5

Total Reduced Sulfur

Calibration Drift - <5% of calibration span

Relative Accuracy - <20% of RM, or <10% of applicable standard

Performance Specification 6

Rate Monitor

Calibration Drift – Same as respectable constituent

Relative Accuracy - <20% of RM; If emissions are <50% of applicable standard then;

<10% using applicable standard

Performance Specification 7

Hydrogen Sulfide

Calibration Drift - <5% of calibration span

Relative Accuracy - <20% of RM; or <10% of applicable standard

Performance Specification 8

Volatile Organic Compounds

Calibration Drift – <2.5% of span value

Relative Accuracy - <20% of RM; or <10% of applicable standard

Performance Specification 8A

Total Hydrocarbons

Calibration Drift – ±3 ppm of zero and high-level values

Calibration Error - ±5 ppm of zero, mid, and high-level gases

Performance Specification 9

Gas Chromatographic

Calibration Error - <10% of calibration gas values

Calibration Precision and Linearity – triplicate injections shall not deviate by <5% from the average measurement at each level

Measurement Frequency - <5 minute injections

Performance Audit Test Error – Each error must be <10% of the cylinder gas certified value

Performance Specification 12A

Mercury

Measurement Error – For Hg^o <5% of the span value, for $HgCl_2$ <10% of span value

Calibration Drift – <5% for 7 days

Relative Accuracy - <20% of RM, If RM mean is <5.0 µg/scm then absolute difference <1.0 µg/scm

Performance Specification 16

Predictive Emission Monitoring Systems

PEMS Relative Accuracy - <10% if >100 ppm or 0.2 lb/mmBTU; <20% if 10<100 ppm or 0.05<0.20 lb/mmBTU, or <2ppm if <10ppm - <1% concentration for diluent

PEMS Bias – If the mean is greater than the confidence coefficient then a bias factor must be used

PEMS Variance – Calculated F-value must not be greater than the critical F-value at the 95-percent confidence level

PEMS Correlation –r-value >0.8

Relative Accuracy Audits - <10% when >100 ppm, <20% when 20<100 ppm, or <2 ppm when <20 ppm

8.7.2 40CFR Part 75

Sulfur Dioxide Monitors

Relative Accuracy - <10%, or ±15 ppm if concentration <250 ppm

Nitrogen Oxide-Diluent Monitors

Relative Accuracy - <10%, or ±0.02 lb/mmBTU if <0.2 lb/mmBTU

Carbon Dioxide and Oxygen Monitors

Relative Accuracy - <10%, or <1% of concentration

Flow Monitors

Relative Accuracy - <10%, or ±2.0 fps if <10 fps

Moisture Monitors

Relative Accuracy - <10%, or ±1.5% Moisture

Nitrogen Oxide Monitors

Relative Accuracy - <10%, or ±15 ppm if concentration <250 ppm

Notes:

9. Additional Calculations

9.1 Ambient Conditions

Bwo = 0.027
Md = 28.84

Based On:

$\%N_2 = 79.1$
$\%O_2 = 20.9$
$\%CO_2 = 0.0$

96. $M_d = 0.440 * (0) + 0.320 * (20.9) + 0.280 * (79.1)$ = 28.84

Note: The above assumption is incorrect. Method 3 already postulates that there is an error due to this calculation not accounting for the 0.9 percent Argon.

If we account for the fact that there is 78.084% Nitrogen, 20.946% Oxygen, 0.934% Argon, 0.415% Carbon Dioxide, and trace amounts of Neon, Helium, Methane, and Krypton in the atmosphere then we calculate a higher molecular weight.

97. $Md = 28.968$

It is for this purpose that Method 2, Section 8.6, states that you can assign the molecular weight of 29.0 for processes emitting essentially air.

9.2 Moisture Determination

9.2.1 Saturated Conditions

Calculate the absolute stack pressure, P_s, determine the average stack temperature and compare against the tables in the attachments to this handbook. Calculate the saturated moisture content as follows.

98. $B_{wo} = \frac{SVP@T_s}{P_s}$ Divide “Hg by “Hg or mm Hg by mm HG

9.2.2 Wet Bulb/Dry Bulb Correlation

Information Required	Variable	Example	Units
Static Pressure of Stack	P_{static}	-0.16	“ H_2O
Barometric Pressure	P_{bar}	29.40	“ Hg
Wet Bulb Temperature	T_w	80	°F
Dry Bulb Temperature	T_d	100	°F

Obtain the Wet and Dry Bulb Temperatures

The temperature changes when a wet bulb is placed in an air stream. The temperature reaches equilibrium at the wet bulb temperature and then continues to rise as the water on the bulb dries. Above around 130°F, the moisture on the bulb dries to quickly to determine the stabilized temperature. Also, the stack gas velocity should be at least 10 ft/sec to acquire an accurate reading.

The dry bulb temperature is the normal temperature measured by a dry thermometer.

9.2.2.1. Wet Bulb/Dry Bulb Correlation

Use the Vapor Pressure Tables attached to this handbook. Find the SVP value based on the wet bulb temperature, T_w. At 110°F this is 2.5991.

With this value, you can calculate the vapor pressure:

99. $VP = SVP - (3.57 * 10^{-4}) * P_s * (T_d - T_w) * \left(1 + \frac{T_w - 32}{1571}\right)$

100. $B_{wo} = \frac{VP}{P_s}$

Calculate without a Saturated Pressure Table

$SVP = 0.0375 + 0.2103(T_1) + 0.28665(T_2) + 0.17595(T_3) + 0.04615417(T_4) + 0.00452083(T_5)$

Where:

101. $\boldsymbol{T_1} = \frac{T_w}{40}$

$\boldsymbol{T_2} = T_1(T_1 - 1)$

$\boldsymbol{T_3} = T_2(T_1 - 2)$

$\boldsymbol{T_4} = T_3(T_1 - 3)$

$\boldsymbol{T_5} = T_4(T_1 - 4)$

Calculations	Variable	Example	Units
Saturated Vapor Pressure	SVP	1.031	“ Hg
Vapor Pressure	VP	0.815	“ Hg
Moisture Content	B_{wo}	2.77	%

9.2.2.2. Psychrometric Chart

Using the Psychrometric Charts attached to this handbook to locate the dry bulb temperature on the x-axis and the wet bulb temperature along the curved saturation line. From their intersection read directly left to the y-axis to find the humidity, H, in pounds of water per pounds of dry air.

102. $B_{wo} = \frac{H * M_d}{H * M_d + 18}$

Calculations	Variable	Example	Units
Humidity	H	0.0175	lb H_2O/lb Air
Moisture Content	B_{wo}	2.73	%

9.2.3 Derivation of PPM$_{wet}$/PPM$_{dry}$

103. $C_{Dry} = \frac{C_{Wet}}{1-B_{ws}}$ EPA Method 7E Equation 7E-10

By Definition

104. $C_{Dry} = \frac{V_{pol}}{V_{dry}}$

105. $C_{Wet} = \frac{V_{pol}}{(V_{dry}+V_{vap})}$

106. $B_{wo} = \frac{V_{vap}}{V_{dry}+V_{vap}}$

Therefore

107. $1 - B_{ws} = \frac{V_{dry}+V_{vap}}{V_{dry}+V_{vap}} - \frac{V_{vap}}{V_{dry}+V_{vap}} = \frac{V_{vap}}{V_{dry}+V_{vap}}$

108. $C_{Dry}(1 - B_{ws}) = \frac{V_{pol}}{V_{dry}} * \frac{V_{vap}}{V_{dry}+V_{vap}} = C_{Wet}$

109. $B_{ws} = 1 - \frac{C_{Wet}}{C_{Dry}}$

9.2.4 Moisture Content Conversion

Derivation of the conversion of the moisture content measured on a mass/mass basis to a volume/volume basis and vice versa.

Mass to Moles

110. $\frac{n_w}{n_a} = H\left(\frac{kg\ water}{kg\ air}\right) * \left(\frac{kg-mole\ of\ water}{18\ kg\ of\ water}\right) * \left(\frac{M_d kg}{kg-mole\ of\ air}\right)$

111. $\frac{n_w}{n_a} = \frac{H*M_d}{18} \frac{n_a}{n_w} = \frac{18}{H*M_d}$

Volume to Moles

112. $B_{wo} = \frac{V_{vap}}{V_{vap}+V_{dry}} = \frac{n_w}{n_w+n_a}$

113. $\frac{1}{B_{wo}} = \frac{n_w+n_a}{n_w} = 1 + \frac{n_a}{n_w}$

Substitute Equations

114. $\frac{1}{B_{wo}} = 1 + \frac{18}{H*M_d}$

Rearrange

115. $B_{wo} = \frac{H*M_d}{H*M_d+18}$

116. $H = \frac{18*B_{wo}}{M_d*(1-B_{wo})}$

9.3 Pressure Corrections

Typically, any barometric pressure measurement that you will find from a local weather station has been corrected to a value relative to sea level. Barometric pressures are typically similar for a very large region, unless a storm is approaching. The pressure will differ based upon altitude, which can change dramatically over a small distance.

A mercury barometer can be utilized for determining barometric pressure at a given location. If using an aneroid or digital barometer, it needs to be adjusted to read true uncorrected barometric pressure.

Local airport and weather stations will report values from their own calibrated barometer, which can be utilized. These numbers will be corrected to sea level, requiring this number to be uncorrected for actual value.

9.3.1 Uncorrecting Pressure Readings

Pressure drops by 26 millimeters for every 1000 feet, this approximates 1 inch. For this purpose, doing a rough calculation of 1 inch for every thousand feet, or 0.1 inch for every hundred feet, is acceptable.

However, 26 millimeters is not quite equal to 1 inch. So alternatively, a correction factor can be calculated at a rate of 0.026 or 26/1000. Use the following equation once you have your elevation determined:

$$CF = \frac{760 - [Elevation * 0.026]}{760}$$

The CF can be multiplied by the barometric pressure corrected to sea level to determine the actual barometric pressure at your sampling location.

Notes:

9.4 Emission Calculations

9.4.1 Ideal Gas Law

117. $PV = nRT = nk_B N_A T$

Ideal gas law

P = Pressure
V = Volume
n = Molar Mass
R = Gas Constant
T = Temperature
k_B = Boltzmann Constant
N_A = Avogadro Constant

9.4.2 Molar Volume at STP

Standard Temperature and Pressure

118. $\frac{v}{n} = \frac{RT}{P} = \frac{21.8499*527.67}{29.921} = 385.3326\ dscf/lb - mole$ OR

119. $\frac{v}{n} = \frac{RT}{P} = \frac{0.06236*273.15}{760} = 0.024055\ m^3/g - mole$

9.4.3 Emission Equations

120. Conversion of sample to ppm

$$C_{ppm} = \frac{Sample*24.04}{M_w*V_{m_{std}}*28.316}$$

121. Conversion of mg/m³ (C_{CONC})to ppm for any gas

$$C_{ppm} = \frac{C_{CONC}*24.04}{M_w}$$

24.04 is commonly accepted for mg/dscm

24.45 is commonly accepted for mg/dNcm

122. Conversion of ppm to lb/dscf for any gas

$$lb/dscf = \frac{C_{ppm}*MW}{385.3*10^6}$$

SO_2 64.1088/3.853*10^8 = 1.660*10^7
NO_X 46.0055/3.853*10^8 = 1.194*10^7
CO 28.0104/3.853*10^8 = 7.270*10^7

123. Conversion of ppm to lb/hr using Q_{std}

$$lb/hr = \frac{C_{ppm}*MW*Q_{std}*60}{385.3*10^6}$$

124. Conversion from lb/dscf to lb/mmBTU using dry Fuel Factor

$$lb/mmBTU = \frac{lb/dscf*F_d*20.9}{20.9-\%O_2}$$

125. Conversion from lb/dscf to lb/mmBTU using carbon Fuel Factor

$$lb/mmBTU = \frac{lb/dscf*F_c*100}{\%CO_2}$$

126. Conversion of lb/hr to lb/mmBTU using Heat Input

$$lb/mmBTU = \frac{lb/hr}{mmBTU/hr}$$

127. Destruction Efficiency

$$\% = \frac{Inlet-Outlet}{Inlet} * 100$$

128. $C_{PM(gr/dscf)}$, Particulate Concentration, gr/dscf EPA Method 5 Equation 5-6

$$C_{PM} = \frac{K_3 * M_N}{V_{m(std)}}$$

K_3 = 0.0154 gr/mg for English Units

129. $C_{PM(gr/cf)}$, Particulate Concentration, gr/cf

$$C_{PM(gr/cf)} = \frac{K_3 * M_n}{V_m}$$

130. $C_{PM(@)}$, Particulate Concentration, @%O_2

$$C_{PM(@)} = C_{PM} * \frac{20.9 - C\%}{20.9 - C_{O_2}}$$

131. $C_{PM(Metric)}$, Correct from English Units to Metric, gr/dscf to mg/dscm

$$C_{PM(Metric)} = C_{PM} * 2288.35$$

132. $E_{PM(lb/hr)}$, Particulate Emissions, lb/hr

$$E_{PM} = \frac{Q_{std} * 60 * C_{PM}}{7000}$$

133. $E_{PM(FD)}$, Particulate Emissions, lb/mmBTU

$$E_{PM(FD)} = \frac{\mathrm{C}_{\mathrm{PM(gr/dscf)}} * F_d * 20.9}{7000 * (20.9 - \%O_2)}$$

134. $E_{PM(FC)}$, Particulate Emissions, lb/mmBTU

$$E_{PM(FC)} = \frac{\mathrm{C}_{\mathrm{PM(gr/dscf)}} * F_d * 100}{7000 * (20.9 - \%CO_2)}$$

Calculations	Variable	Example	Units
Mass of Filterable Particulate	M_n	13.525	mg/sample
Particulate Concentration	$C_{PM(gr/dscf)}$	0.0051	gr/dscf
Isokinetic	I%	103.6	%
Sample Nozzle Area	A_n	0.000241	ft^2
Particulate Concentration	$C_{PM(gr/cf)}$	0.0051	gr/cf
Particulate Concentration	$C_{PM(@)}$	0.0048	@7%O_2
Particulate Emissions	$C_{PM(Metric)}$	11.78	mg/dscm
Particulate Emissions	$E_{PM(lb/hr)}$	0.94	lb/hr
Particulate Emissions	$E_{PM(FD)}$	0.0089	lb/mmBTU F_d
Particulate Emissions	$E_{PM(FC)}$	0.0061	lb/mmBTU F_c
Dioxin Furan Concentration	$C_{23(gr/dscf)}$	5.71E-13	gr/dscf
Dioxin Furan Concentration	$C_{23(ng/dscm)}$	1.31	ng/dscm
Dioxin Furan Emissions	$E_{23(lb/hr0}$	1.04E-10	lb/hr
Mass of HCl	M_{26A}	137.5	mg/sample
HCl Concentration	$C_{26A(mg/dscm)}$	119.77	mg/dscm
HCl Concentration	$C_{26A(gr/dscf)}$	0.0523	gr/dscf
HCl Concentration	$C_{26A(ppm)}$	80.3	ppm

Notes:

10. Attachments

10.1 Blank Residue Limits

Solvent	Density g/ml	50 ml	100 ml	150 ml
Acetone	0.7857	0.0004	0.0008	0.0012
Benzene	0.8787	0.0004	0.0009	0.0013
Chloroform	1.4832	0.0007	0.0015	0.0022
Ethyl Ether	0.7138	0.0004	0.0007	0.0011
Hexane	0.6603	0.0003	0.0007	0.0010
2-Propanol	0.7855	0.0004	0.0008	0.0012
Methanol	0.7914	0.0004	0.0008	0.0012
Methylene Chloride	1.3266	0.0007	0.0013	0.0020
Toluene	0.8669	0.0004	0.0009	0.0013
Water	1.0000	0.0005	0.0010	0.0015
Hydrogen Peroxide	1.4649	.0007	.0015	.0022
3% Hydrogen Peroxide	1.0139	.0005	.0010	.0015
Residue in Grams				

Solvent	Density g/ml	200 ml	250 ml	500 ml
Acetone	0.7857	0.0016	0.0020	0.0039
Benzene	0.8787	0.0018	0.0022	0.0044
Chloroform	1.4832	0.0030	0.0037	0.0074
Ethyl Ether	0.7138	0.0014	0.0018	0.0036
Hexane	0.6603	0.0013	0.0017	0.0033
2-Propanol	0.7855	0.0016	0.0020	0.0039
Methanol	0.7914	0.0016	0.0020	0.0040
Methylene Chloride	1.3266	0.0027	0.0033	0.0066
Toluene	0.8669	0.0017	0.0022	0.0043
Water	1.0000	0.0020	0.0025	0.0050
Hydrogen Peroxide	1.4649	0.0029	0.0037	0.0073
3% Hydrogen Peroxide	1.0139	0.0020	0.0025	0.0051
Residue in Grams				

The maximum allowable blank for acetone used for an EPA M5 test is 0.001 percent of the acetone weight. (EPA Method 5 Section 12.8). The same criteria is used for Hexane in EPA Method 202.

To calculate the allowable blank residue weight for other solution volumes, divide the density by 100,000 (0.001 percent), then multiply by the new volume. Do all calculations first, then round the final value to four decimal places, which is the accuracy of the analytical balance.

135. $Limit\ on\ Liquid\ Blank = (Liquid\ Density\ g/ml) * (Volume\ ml) * \left(\frac{0.001}{100}\right)$

The density of acetone was taken from its VWR Scientific container. All other densities were taken from the CRC Handbook of Chemistry, 56th Edition, 1975-1976.

10.2 Saturated Vapor Pressure

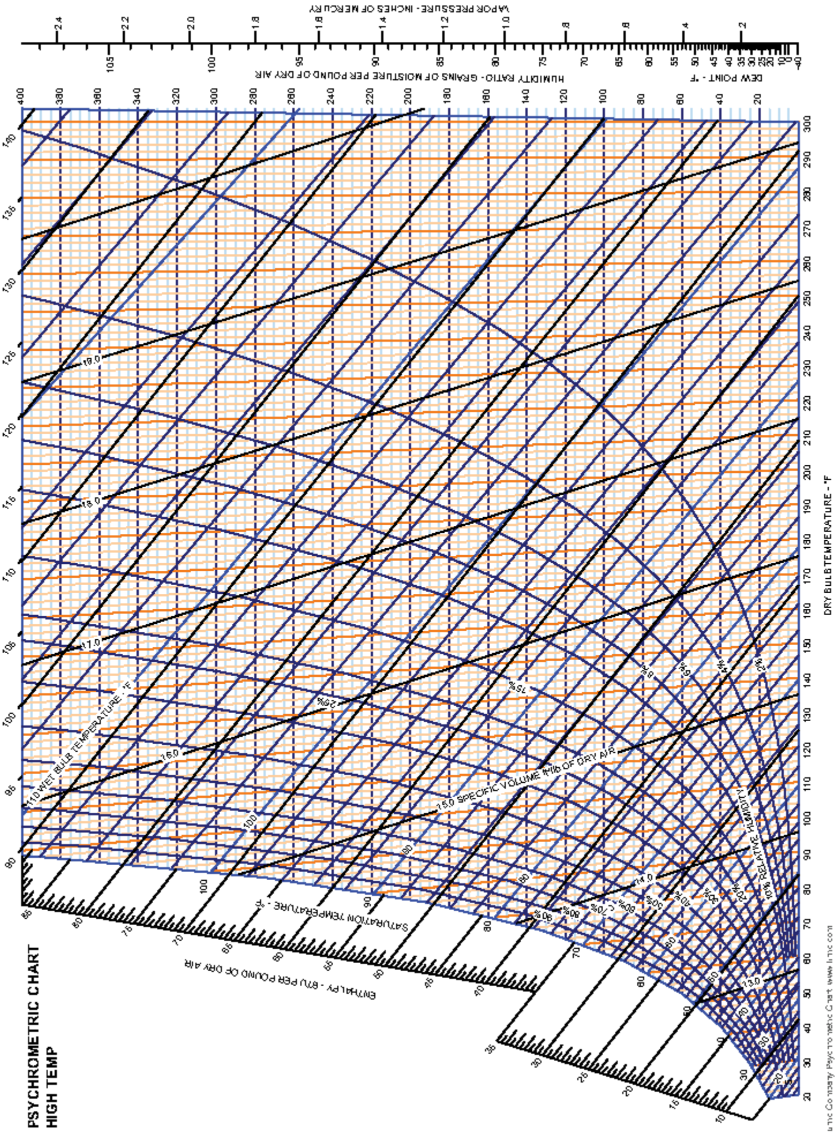
Temp.	SVP	Temp.	SVP
[°F]	[" Hg]	[°C]	[mm Hg]
30	0.166	-3.6	4.2
31	0.173	-1.8	4.4
32	**0.180**	**0**	**4.6**
33	0.188	1.8	4.8
34	0.195	3.6	5.0
35	0.203	5.4	5.2
36	0.212	7.2	5.4
37	0.220	9	5.6
38	0.229	10.8	5.8
39	0.238	12.6	6.1
40	0.248	14.4	6.3
41	0.258	16.2	6.5
42	0.268	18	6.8
43	0.278	19.8	7.1
44	0.289	21.6	7.3
45	0.300	23.4	7.6
46	0.312	25.2	7.9
47	0.324	27	8.2
48	0.336	28.8	8.5
49	0.349	30.6	8.9
50	0.363	32.4	9.2
51	0.376	34.2	9.6
52	0.390	36	9.9
53	0.405	37.8	10.3
54	0.420	39.6	10.7
55	0.436	41.4	11.1
56	0.452	43.2	11.5
57	0.468	45	11.9
58	0.486	46.8	12.3
59	0.503	48.6	12.8
60	0.522	50.4	13.2
61	0.540	52.2	13.7
62	0.560	54	14.2
63	0.580	55.8	14.7
64	0.601	57.6	15.3
65	0.622	59.4	15.8
66	0.644	61.2	16.4
67	0.667	63	16.9
68	**0.690**	**64.8**	**17.5**

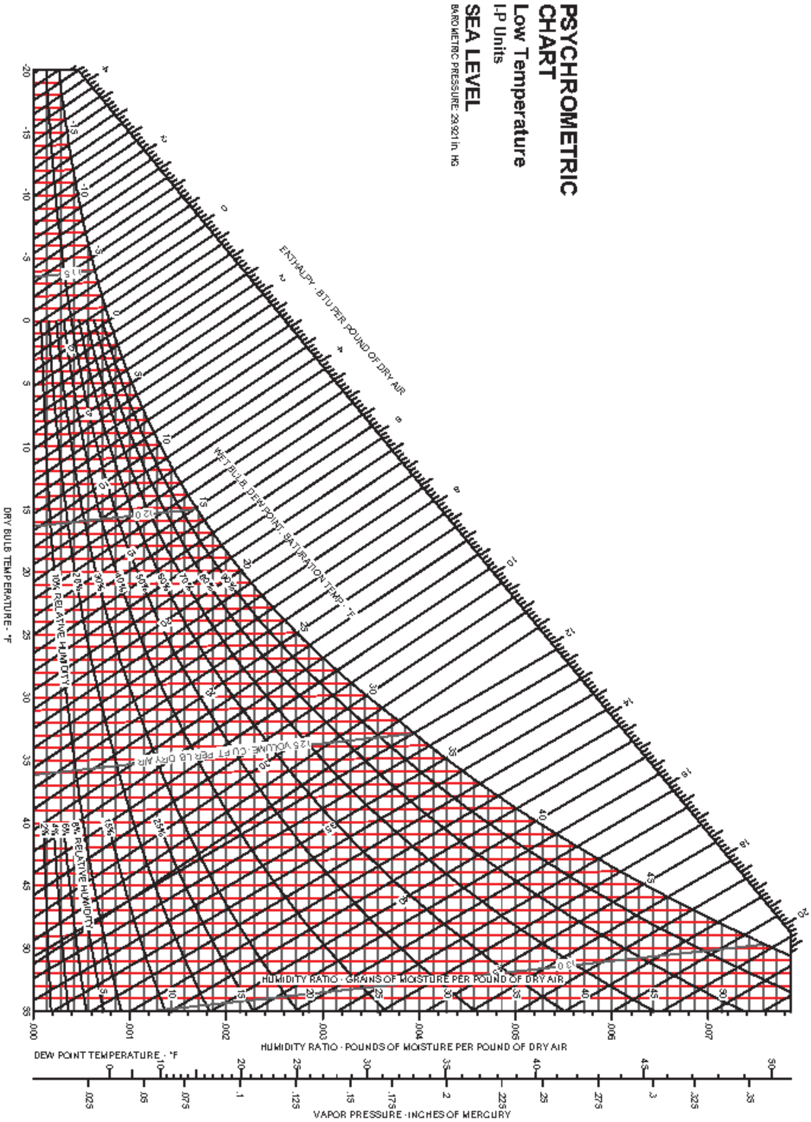
Temp.	SVP	Temp.	SVP
[°F]	[" Hg]	[°C]	[mm Hg]
69	0.714	66.6	18.1
70	0.739	68.4	18.8
71	0.764	70.2	19.4
72	0.791	72	20.1
73	0.818	73.8	20.8
74	0.846	75.6	21.5
75	0.874	77.4	22.2
76	0.904	79.2	23.0
77	0.935	81	23.7
78	0.966	82.8	24.5
79	0.998	84.6	25.4
80	1.031	86.4	26.2
81	1.066	88.2	27.1
82	1.101	90	28.0
83	1.137	91.8	28.9
84	1.174	93.6	29.8
85	1.212	95.4	30.8
86	1.252	97.2	31.8
87	1.292	99	32.8
88	1.334	100.8	33.9
89	1.376	102.6	35.0
90	1.420	104.4	36.1
91	1.466	106.2	37.2
92	1.512	108	38.4
93	1.560	109.8	39.6
94	1.609	111.6	40.9
95	1.659	113.4	42.1
96	1.710	115.2	43.4
97	1.763	117	44.8
98	1.818	118.8	46.2
99	1.874	120.6	47.6
100	**1.931**	**122.4**	**49.1**
101	1.990	124.2	50.5
102	2.051	126	52.1
103	2.113	127.8	53.7
104	2.176	129.6	55.3
105	2.241	131.4	56.9
106	2.308	133.2	58.6
107	2.377	135	60.4

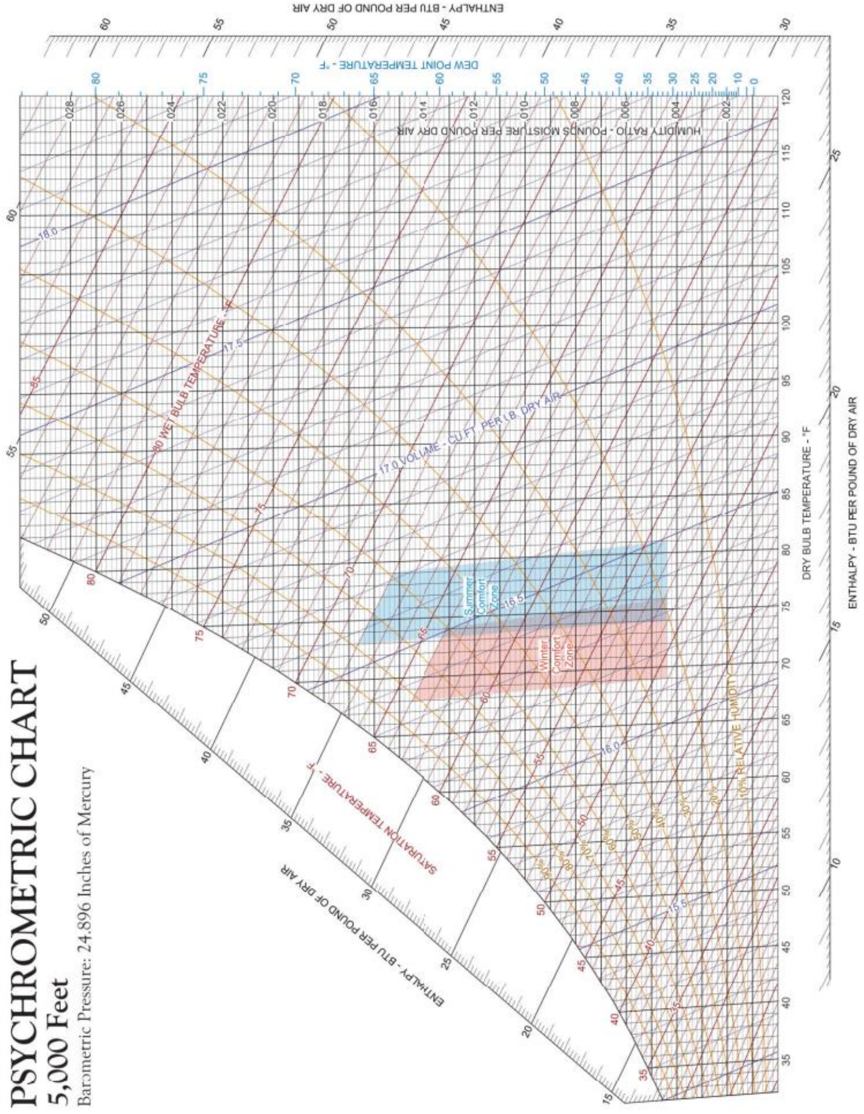
Temp.	SVP	Temp.	SVP
[°F]	[" Hg]	[°C]	[mm Hg]
110	2.594	140.4	65.9
115	2.993	149.4	76.0
120	3.444	158.4	87.5
125	3.952	167.4	100.4
130	4.523	176.4	114.9
135	5.163	185.4	131.1
140	5.879	194.4	149.3
145	6.678	203.4	169.6
150	7.567	212.4	192.2
155	8.554	221.4	217.3
160	9.649	230.4	245.1
165	10.860	239.4	275.8
170	12.196	248.4	309.8
175	13.668	257.4	347.2
180	15.286	266.4	388.3
185	17.062	275.4	433.4
190	19.008	284.4	482.8
195	21.136	293.4	536.9
200	23.460	302.4	595.9
205	25.993	311.4	660.2
210	28.749	320.4	730.2
212	**29.918**	**324**	**759.9**
215	31.744	329.4	806.3
220	34.994	338.4	888.9
225	38.515	347.4	978.3
230	42.325	356.4	1075.1
235	46.441	365.4	1179.6
240	50.883	374.4	1292.4
245	55.670	383.4	1414.0
250	60.823	392.4	1544.9
255	66.362	401.4	1685.6
260	72.310	410.4	1836.7
265	78.689	419.4	1998.7
270	85.524	428.4	2172.3
275	92.839	437.4	2358.1
280	100.660	446.4	2556.8
285	109.013	455.4	2768.9
290	117.926	464.4	2995.3
295	127.427	473.4	3236.6

Temp.	SVP	Temp.	SVP
[°F]	[" Hg]	[°C]	[mm Hg]
300	137.545	482.4	3493.6
310	159.755	500.4	4057.8
320	184.810	518.4	4694.2
330	212.983	536.4	5409.8
340	244.561	554.4	6211.9
350	279.850	572.4	7108.2
360	319.173	590.4	8107.0
370	362.873	608.4	9217.0
380	411.312	626.4	10447.3
390	464.870	644.4	11807.7
400	523.950	662.4	13308.3
410	588.973	680.4	14959.9
420	660.383	698.4	16773.7
430	738.646	716.4	18761.6
440	824.249	734.4	20935.9
450	917.702	752.4	23309.6
460	1019.539	770.4	25896.3
470	1130.319	788.4	28710.1
480	1250.624	806.4	31765.9
490	1381.061	824.4	35078.9
500	1522.262	842.4	38665.5
510	1674.887	860.4	42542.1
520	1839.622	878.4	46726.4
530	2017.177	896.4	51236.3
540	2208.295	914.4	56090.7
550	2413.743	932.4	61309.1
560	2634.319	950.4	66911.7
570	2870.848	968.4	72919.5
580	3124.186	986.4	79354.3
590	3395.221	1004.4	86238.6
600	3684.869	1022.4	93595.7
610	3994.078	1040.4	101449.6
620	4323.830	1058.4	109825.3
630	4675.136	1076.4	118748.5
640	5049.043	1094.4	128245.7
650	5446.629	1112.4	138344.4
660	5869.008	1130.4	149072.8
670	6317.328	1148.4	160460.1
680	6792.771	1166.4	172536.4

10.3 Psychometric Charts

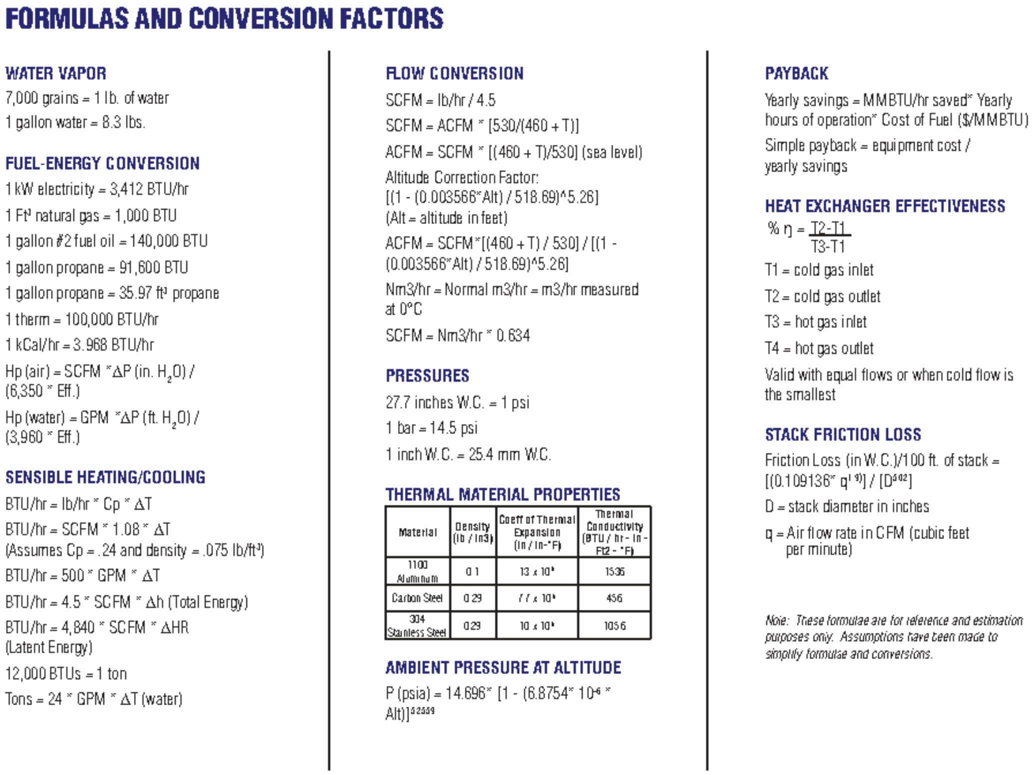



PSYCHROMETRIC CHART
Low Temperature
I-P Units
SEA LEVEL
BAROMETRIC PRESSURE: 29.921 in. HG
ENTHALPY - BTU PER POUND OF DRY AIR
-4
-2
0
2
4
6
8
10
12
14
16
18
20
WET BULB, DEW POINT, SATURATION TEMP - °F
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
12.5 VOLUME - CU.FT PER LB DRY AIR
11.5
12.0
13.0
10% RELATIVE HUMIDITY
20%
30%
40%
50%
60%
70%
80%
90%
8% RELATIVE HUMIDITY
2%
4%
6%
15%
25%
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
5
10
15
20
25
30
35
40
45
50
DRY BULB TEMPERATURE - °F
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
.000
.001
.002
.003
.004
.005
.006
.007
HUMIDITY RATIO - POUNDS OF MOISTURE PER POUND OF DRY AIR
DEW POINT TEMPERATURE - °F
0
10
20
25
30
35
40
45
50
.025
.05
.075
.1
.125
.15
.175
.2
.225
.25
.275
.3
.325
.35
VAPOR PRESSURE - INCHES OF MERCURY



PSYCHROMETRIC CHART
5,000 Feet
Barometric Pressure: 24.896 Inches of Mercury

10.4 Conversion Factors



FORMULAS AND CONVERSION FACTORS

WATER VAPOR

7,000 grains = 1 lb. of water

1 gallon water = 8.3 lbs.

FUEL-ENERGY CONVERSION

1 kW electricity = 3,412 BTU/hr

1 Ft³ natural gas = 1,000 BTU

1 gallon #2 fuel oil = 140,000 BTU

1 gallon propane = 91,600 BTU

1 gallon propane = 35.97 ft³ propane

1 therm = 100,000 BTU/hr

1 kCal/hr = 3.968 BTU/hr

Hp (air) = SCFM * ΔP (in. H_2O) / (6,350 * Eff.)

Hp (water) = GPM * ΔP (ft. H_2O) / (3,960 * Eff.)

SENSIBLE HEATING/COOLING

BTU/hr = lb/hr * Cp * ΔT

BTU/hr = SCFM * 1.08 * ΔT
(Assumes Cp = .24 and density = .075 lb/ft³)

BTU/hr = 500 * GPM * ΔT

BTU/hr = 4.5 * SCFM * Δh (Total Energy)

BTU/hr = 4,840 * SCFM * ΔHR
(Latent Energy)

12,000 BTUs = 1 ton

Tons = 24 * GPM * ΔT (water)

FLOW CONVERSION

SCFM = lb/hr / 4.5

SCFM = ACFM * [530/(460 + T)]

ACFM = SCFM * [(460 + T)/530] (sea level)

Altitude Correction Factor:
[(1 - (0.003566*Alt) / 518.69)^5.26]
(Alt = altitude in feet)

ACFM = SCFM *[(460 + T) / 530] / [(1 - (0.003566*Alt) / 518.69)^5.26]

Nm3/hr = Normal m3/hr = m3/hr measured at 0°C

SCFM = Nm3/hr * 0.634

PRESSURES

27.7 inches W.C. = 1 psi

1 bar = 14.5 psi

1 inch W.C. = 25.4 mm W.C.

THERMAL MATERIAL PROPERTIES

Material	Density (lb / in3)	Coeff of Thermal Expansion (in / in-°F)	Thermal Conductivity (BTU / hr - in - Ft2 - °F)
1100 Aluminum	0.1	13 x 10^{-6}	1536
Carbon Steel	0.29	7.7 x 10^{-6}	456
304 Stainless Steel	0.29	10 x 10^{-6}	1056

AMBIENT PRESSURE AT ALTITUDE

P (psia) = 14.696* $[1 - (6.8754* 10^{-6} * Alt)]^{5.2559}$

PAYBACK

Yearly savings = MMBTU/hr saved* Yearly hours of operation* Cost of Fuel ($/MMBTU)

Simple payback = equipment cost / yearly savings

HEAT EXCHANGER EFFECTIVENESS

$\% \eta = \frac{T2-T1}{T3-T1}$

T1 = cold gas inlet

T2 = cold gas outlet

T3 = hot gas inlet

T4 = hot gas outlet

Valid with equal flows or when cold flow is the smallest

STACK FRICTION LOSS

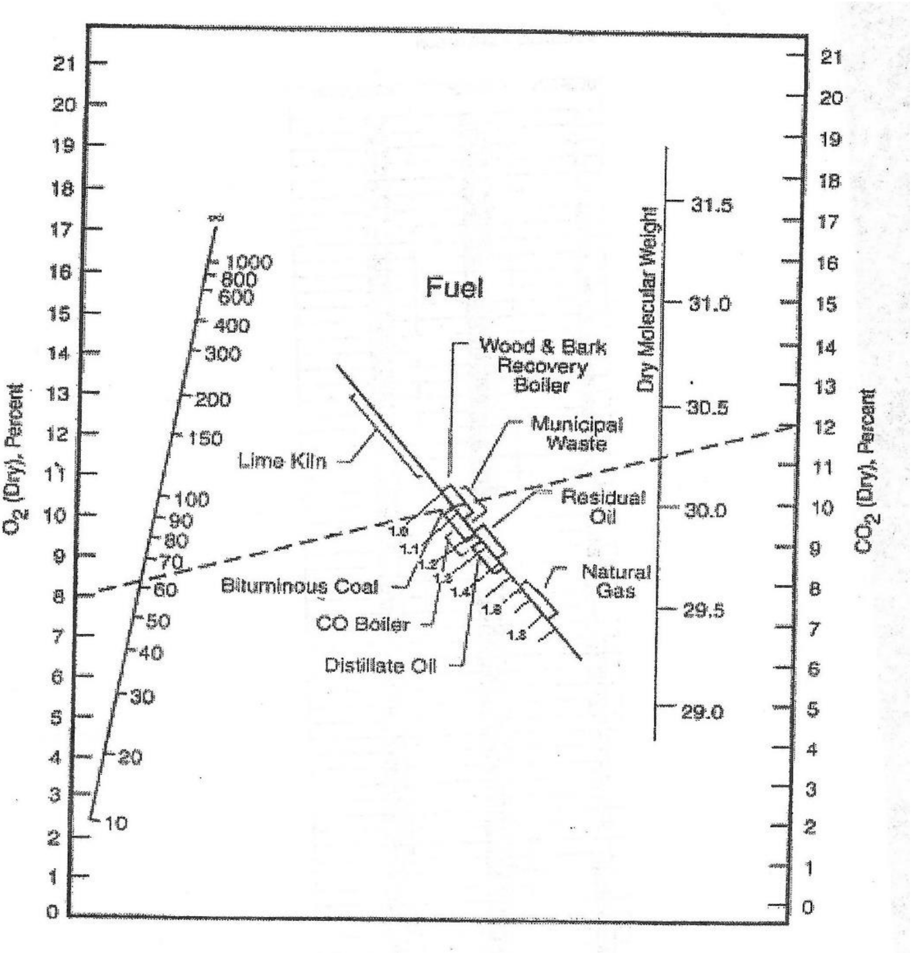
Friction Loss (in W.C.)/100 ft. of stack = $[(0.109136* q^{1.9})] / [D^{5.02}]$

D = stack diameter in inches

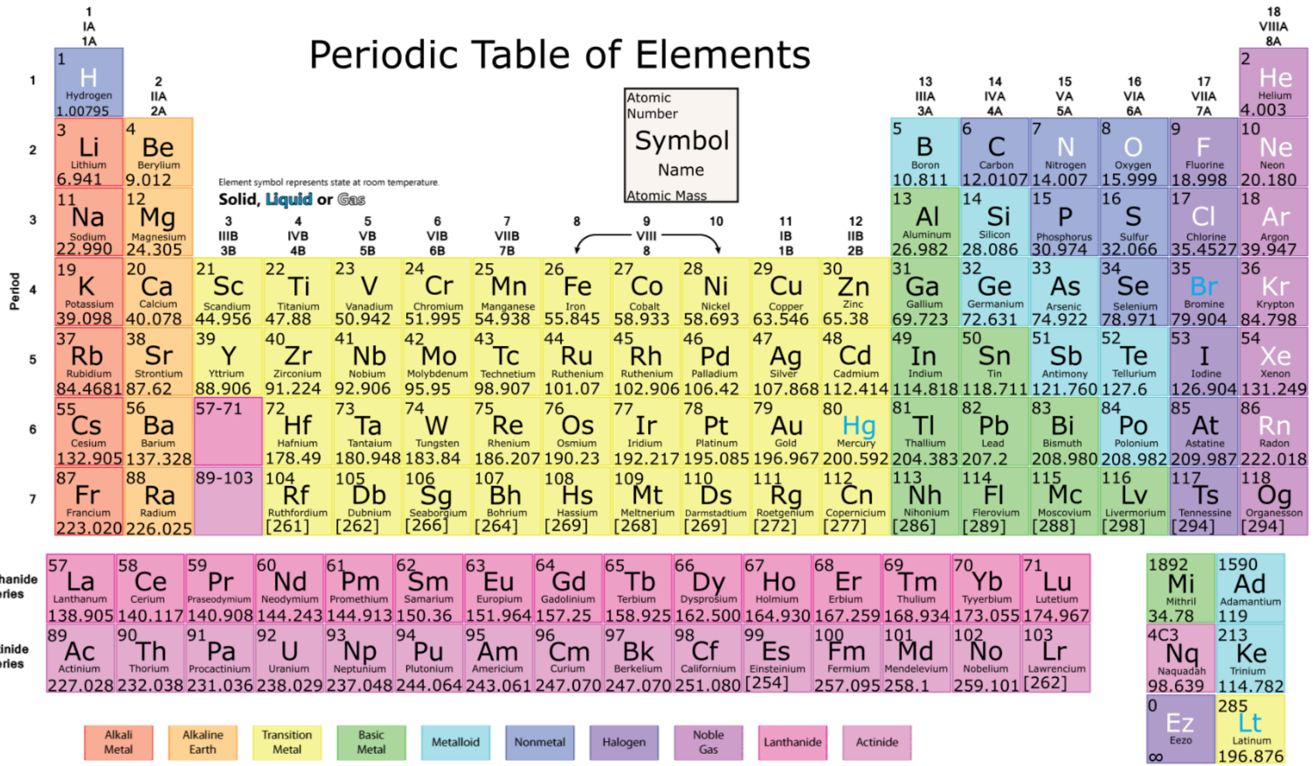
q = Air flow rate in CFM (cubic feet per minute)

Note: These formulae are for reference and estimation purposes only. Assumptions have been made to simplify formulae and conversions.

10.5 Method 3B F_o



10.6 Periodic Table



Periodic Table of Elements

Atomic Number
Symbol
Name
Atomic Mass

Element symbol represents state at room temperature.

Solid, Liquid or Gas

Period	1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1	1 H Hydrogen 1.00795																	2 He Helium 4.003
2	3 Li Lithium 6.941	4 Be Berylium 9.012											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
3	11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.947
4	19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.995	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 84.798
5	37 Rb Rubidium 84.4681	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Nobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Ruthenium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.249
6	55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71	72 Hf Hafnium 178.49	73 Ta Tantaium 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium 208.982	85 At Astatine 209.987	86 Rn Radon 222.018
7	87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Ruthfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meltnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roetgenium [272]	112 Cn Copernicium [277]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [288]	116 Lv Livermorium [298]	117 Ts Tennessine [294]	118 Og Organesson [294]

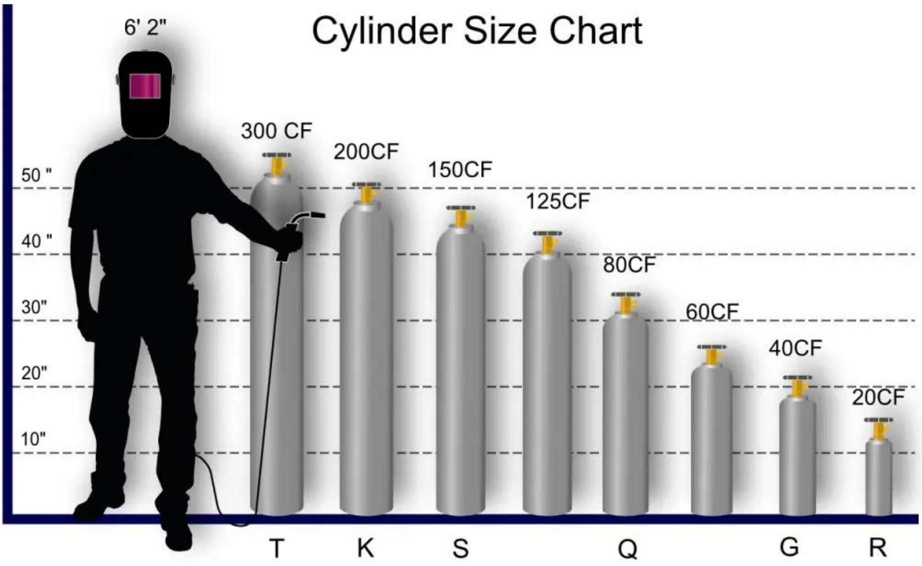
Lanthanide Series	57 La Lanthanum 138.905	58 Ce Cerium 140.117	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Tyyerbium 173.055	71 Lu Lutetium 174.967
Actinide Series	89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Procactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

1892 Mi Mithril 34.78	1590 Ad Adamantium 119
4C3 Nq Naquadah 98.639	213 Ke Trinium 114.782
0 Ez Eezo ∞	285 Lt Latinum 196.876

- Alkali Metal
- Alkaline Earth
- Transition Metal
- Basic Metal
- Metalloid
- Nonmetal
- Halogen
- Noble Gas
- Lanthanide
- Actinide

10.7 Cylinder Information

10.7.1 Cylinder Sizes and Volumes



SIZE (STEEL)	T	K	S	Q	G
Volume Compressed CF	300	200	150	80	40
Volume Compressed m^3	8.5	5.66	4.25	2.27	1.13
Volume CF	1.75	1.55	0.96	0.52	0.25
Volume litres	49.6	43.9	27.2	14.72	7.08
Height (inches)	55	51	46	31	20
Diameter (inches)	9.25	9	7.37	7	7
Average Weight lbs	143	133	76	65	29

SIZE (ALUMINUM)	AT	AS	AQ	AH	AG
Volume Compressed CF	250	150	80	30	20
Volume Compressed m^3	8.5	4.25	2.27	0.57	1.13
Volume CF	1.70	1.05	0.55	0.21	0.14
Volume litres	48.1	29.7	15.7	5.9	3.96
Height (inches)	51.9	48	32.9	16.6	17.1
Diameter (inches)	9.8	8.0	7.25	6.9	6.25
Average Weight lbs	90	48	30.7	14.6	8.8

10.7.2 Cylinder Identification

1. Cylinder specification
2. Cylinder serial number
3. Date of manufacture
4. Neck ring identification
5. Retest markings
6. Bar code label
7. Cylinder manufacturer's inspection marking
8. Cylinder tare (empty) weight

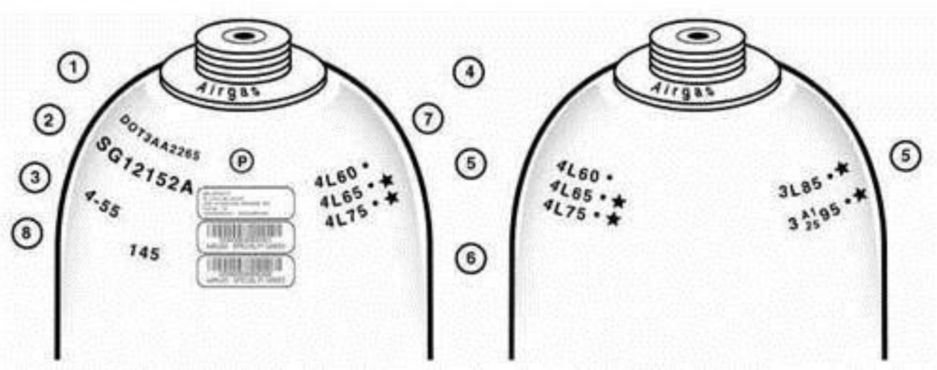


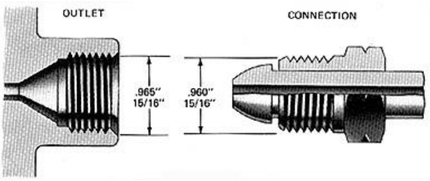
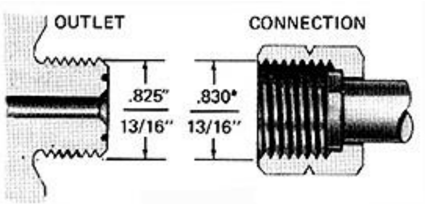
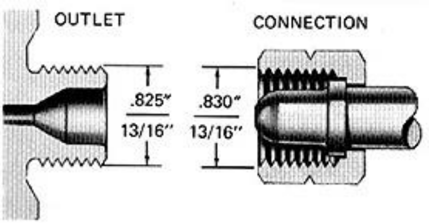
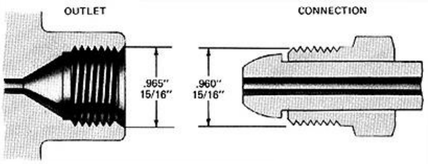
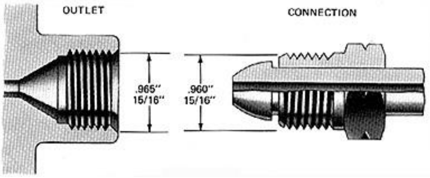
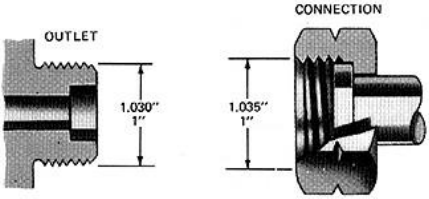
Image credit: Airgas

10.7.3 Cylinder IDs by Company

Dimensions	DOT Specification	Praxair	Airgas	Air Products
High Pressure Steel				
9.3" x 55"	3AA2400	T	300	A
9" x 51"	3AA2265/2015	K	200	B
10" x 51"	3AA3500	3K	2HP	–
10" x 51"	3AA6000	6K	3HP	BX
7" x 31"	3AA2015	Q	80	C
6" x 21"	3AA2015	G	35	D1
4" x 17"	3AA2015	F/MD	10	D1
4.2" x 7.25"	DOT39	C	–	–
2" x 12"	3E1800	LB/RB	LB	–
2" x 12"	3E1800	EB	LBX	–
4.5" x 31"	3AA2015	E	E	Med. E
High Pressure Aluminum				
9.8" x 52"	3AL2216	AT	–	–
8" x 48"	3AL2015	AS	150A	B(AL)
7.25" x 33"	3AL2216	AQ	80A	C(AL)
6.9" x 15.6"	3AL2216	A3	33A	DL(AL)
5.25" x 17.1"	3AL2015	A3/AH	–	–
3.2" x 11.8"	3AL2216	AG	–	–
Low Pressure Cylinders				
15" x 55"	4BA240	FS	400	AA
15" x 45"	4BA240	FX	350	A1
12" x 44"	4BA240	A8	380	–
12" x 32.5"	4BA240	–	–	–
12" x 32"	4E240	–	–	–
12" x 18"	4BA240	–	25	–
12" x 21"	4E240	–	–	–
9" x 17"	4BA240	–	–	–
10" x 16"	4E240	–	–	–
Low Pressure Steel				
29.75" x 55"	4BW-240	HT	–	A-5
15" x 52"	4AA-480	FA	–	AA
10" x 48"	3A-480	CL	–	A
10" x 47"	4BA-300	FC	65	A-3
12" x 51"	8AL	A5	380	A(C2H2)
15" x 45"	4BA-240	FX	110	425
12" x 17.66"	4BA-240	LP5	–	–

Dimensions	Air Liquide	Matheson	Linde	AGG
High Pressure Steel				
9.3" x 55"	49	1L/QK	49	49
9" x 51"	44	1A/QA	44	44
10" x 51"	44H	1H	43	–
10" x 51"	44HH	1U	46	–
7" x 31"	16	2/GA	16	16
6" x 21"	7	3/UA	7	7
4" x 17"	3	4/JA	3	3
4.2" x 7.25"	1	–	–	2
2" x 12"	LB	LB	LBS	LB
2" x 12"	LBX	7X	LBR	–
4.5" x 31"	Med E	–	OO5	5
High Pressure Aluminum				
9.8" x 52"	47AL	–	–	AT
8" x 48"	30AL	1R/QX	A31	A31
7.25" x 33"	16AL	2R/GX	A16	A16
6.9" x 15.6"	7AL	3R/UX	A07	A07
5.25" x 17.1"	3AL	–	–	A07/7A
3.2" x 11.8"	1AL	–	–	–
Low Pressure Cylinders				
15" x 55"	125	1K	126	–
15" x 45"	110	1F	350	–
12" x 44"	70	1B	110	–
12" x 32.5"	40 LP	–	L60	–
12" x 32"	40 LPAL	–	–	–
12" x 18"	22 LP	–	L20	–
12" x 21"	22 LP AL	–	–	–
9" x 17"	11 LP	–	–	–
10" x 16"	11 LP AL	–	–	–
Low Pressure Steel				
29.75" x 55"	–	–	–	454
15" x 52"	–	–	–	126
10" x 48"	57	1V	–	54
10" x 47"	55	1J	–	–
12" x 51"	70	1B	–	–
15" x 45"	A-1	IF	–	–
12" x 17.66"	–	–	–	LP20

10.7.4 Common Cylinder Valve Selections

CGA	Design	Common Uses
CGA-296		O_2 >23.5%
CGA 330 (Washer Required)		HCl, Ethylene, H_2S
CGA-350		CO, H_2, Hydrocarbons balanced in Nitrogen (Propane, Methane, Ethane)
CGA-580		Inert Gases: N_2, Ar
CGA-590 Explosive Gases		SF6, O2/CO2 blends <23.5%, Hydrocarbons balanced in Air
CGA-660 Corrosive Gases (Washer Required)		NO, NO_2, SO_2

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