Visible Emissions Evaluations Handbook

Reading Visible Plumes

Visible Pollution Problems

EPA Method 9 Requirements

Smoke Reading Tips

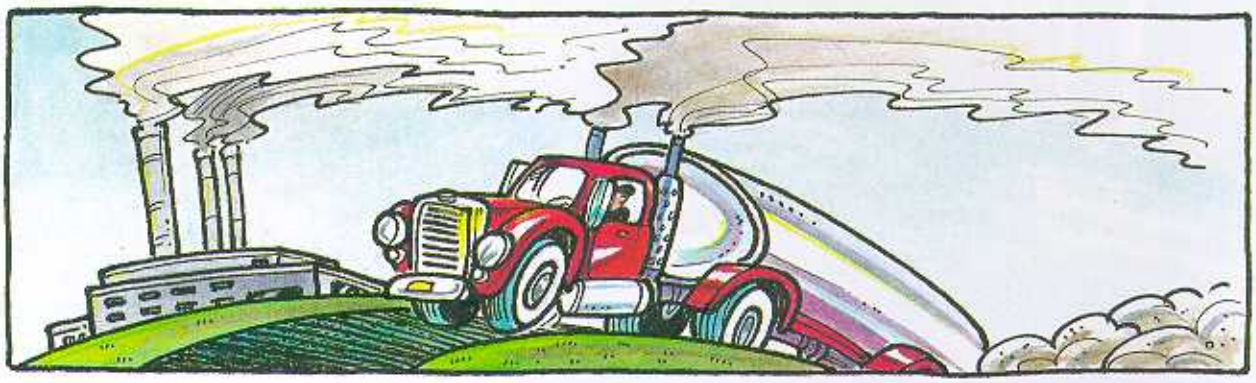
Air Resources Board
Compliance Division
Compliance Assistance Program

In Cooperation With Local
Air Pollution Control Districts

What are "Visible Emissions?" AIR POLLUTION !

Visible Emissions (VE) are just that - something visible emitted (coming out) from an air pollution source into the ambient (outdoor) air. Visible emissions are airborne plumes of solid and/or liquid **particles**, also known as **particulate matter (PM)**. Except for water vapor ("steam") plumes, the darker and/or denser a plume, the more PM air pollution it may contain.

Visible emissions are usually emitted from source equipment by means of an exhaust stack or duct, but they can also be **fugitive emissions** generated by materials handling, transfer, or other activities. The plume of smoke you see coming from a smokestack is a VE, as is the plume of dust behind a vehicle on an unpaved road.



Human Activities Which Produce Visible Emissions:

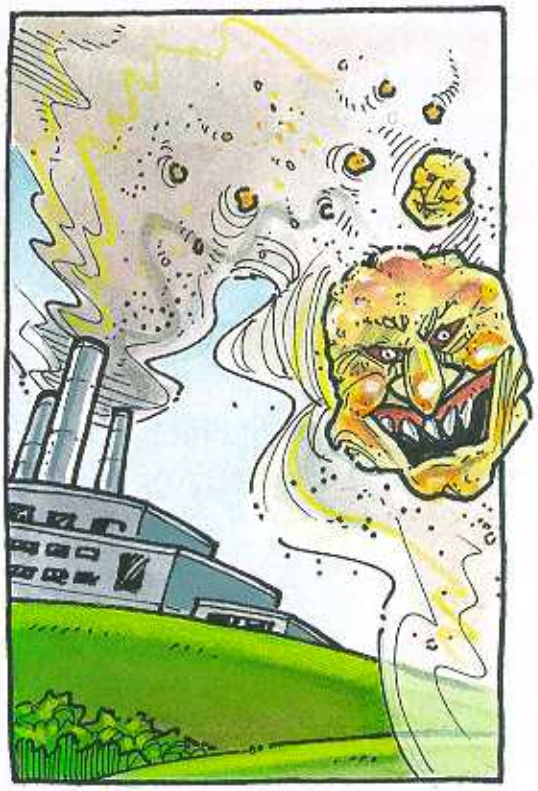
1. **Combustion, or Burning. A major PM source,** combustion occurs in vehicle engines, in household and industrial furnaces, incinerators, and stoves, and in the open, wherever burning occurs. **Smoke** and **exhaust** are familiar names for combustion air pollution.

2. **Attrition: wearing, or grinding down by friction.** The everyday "wearing out" of tires, shoes, clothes, etc. leaves PM everywhere. Industrial attrition processes which may emit PM into the air include milling, sanding, grinding, drilling, demolishing, spraying, and abrasive blasting.

3. **Condensation: changing from a gas to a solid or liquid.** Air pollution vapors and fumes form two ways: **evaporation** of volatile liquids at normal temperatures, and **forced vaporization** of solids or liquids using heat or pressure. Visible PM forms by the **condensation** of vapors and fumes.

Smoke & Dust - The Most Common Visible Emissions

Smoke, the product of incomplete combustion, contains particulate matter **and** the major air pollution gases carbon monoxide (CO), oxides of nitrogen (NOX), and volatile organic compounds (VOCs).



Dust emissions are usually a result of attrition, but can also be windborne soil minerals, sea salt, pollen, etc.

Particles Are Visibility Reducers - the smaller the PM, the more it reflects light and obscures the view, causing visibility problems ranging from unsightly to dangerous. And the smallest PM, **aerosols,** can remain airborne for weeks.

Inhaled Particles Can Be Hazardous to Your Health...

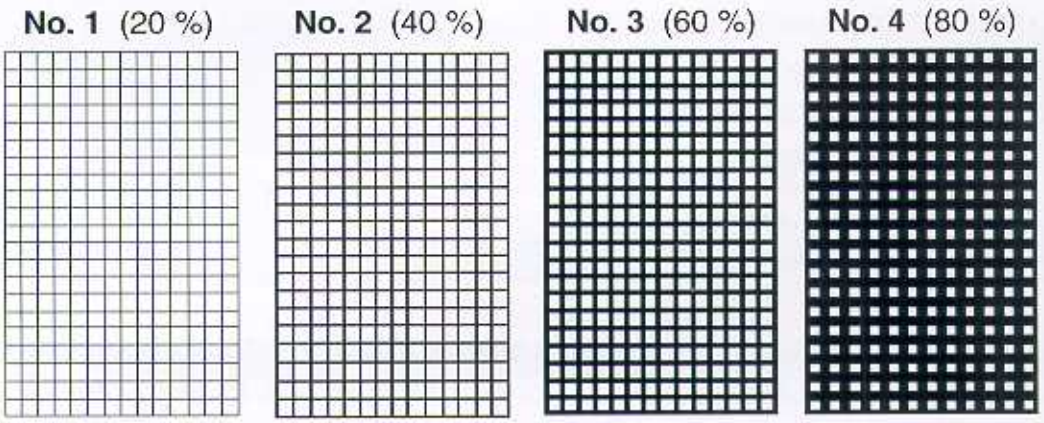
Smoke and dust aerosols are also **Inhalable Particulate Matter (PM10),** microscopic solid or liquid particles that are 10 microns in diameter or smaller (the average human hair is 70 microns across). **Most smoke particles are VERY small (less than a micron) droplets of condensed organic vapors (tars and gases) which escaped burning.** Other smoke PM includes **soot** (unburned carbon) and **ash** (unburnable minerals). When inhaled, PM10 particles easily travel deep into the lungs, causing irritation and coughing. **PM10 particles may be trapped in your lungs for years,** contributing to lung changes, chronic lung diseases, and cancer.

Smoke also contains VOCs which have been **changed by partial burning into toxic, irritating, and/or cancer-causing substances like benzene, formaldehyde, and benzo-a-pyrene,** a polycyclic aromatic hydrocarbon (**PAH**). VOCs adhere to soot particles which may be inhaled into the lungs.

The Ringelmann Chart

In the late 1800's in Paris, France, Professor Maximilian Ringelmann developed the **Ringelmann Chart** to measure the combustion efficiency of coal-fired boilers. The shade of the smoke plume shows how well a boiler is operating - the poorer its combustion efficiency, the more unburned carbon particles in the smoke and the darker the plume.

Professor Ringelmann's chart established four measured shades of gray between white, valued at zero, and black, at five. These specific shades of gray, Ringelmann No. 1 to Ringelmann No. 4, can be accurately reproduced by placing a grid of black lines of a given width and spacing on a white background. Viewed from a distance, the grid lines and background merge into the shades of gray, to be compared to the shade of the smoke plume.



Ringelmann Chart (not to scale)

Regulating Visible Emissions

The Ringelmann Chart became one of the first tools used to measure visible emissions. Introduced into the United States in 1897, it was soon accepted as the standard measure of smoke density and was used by engineers for power plant testing and smokeless combustion studies. In 1910, the Chart was officially adopted as part of the Smoke Ordinance for Boston, Mass.

Many city, state, and federal regulations now set smoke density limits based on the Ringelmann Smoke Chart. Although not originally designed as a regulatory tool to control air pollution, it gives good practical results when used by well-trained observers.

Ringelmann and Equivalent Opacity

Because the Ringelmann Chart is only useful in evaluating black or gray visible emissions, a principle of "equivalent opacity" was developed to apply Ringelmann values to white and other colors of smoke plumes. It is based on the premise that **the darker the plume, the more opaque it is,** as more particles are present to block the light and reduce visibility.

Plume opacity is measured in **percent:** the greater the opacity, the more the background behind the plume is obscured, the less light can come through the plume, and the higher the Ringelmann number.

Percent Light Transmission	Percent Opacity	Ringelmann Number
0	100	5
20	80	4
40	60	3
60	40	2
80	20	1
100	0	0

The Relationship Between Light Transmission, Opacity, and Ringelmann Number

California Visible Emission Limits

State law, Section 41701 of the California Health & Safety Code states,

"...no person shall discharge into the atmosphere from any source whatsoever any air contaminant, other than uncombined water vapor, for a period or periods aggregating more than three minutes in any one hour which is:

(a) As dark or darker in shade as that designated as No. 2 on the Ringelmann Chart, as published by the United States Bureau of Mines, or

(b) Of such opacity as to obscure an observer's view to a degee equal to or greater than does smoke described in subdivision (a)."

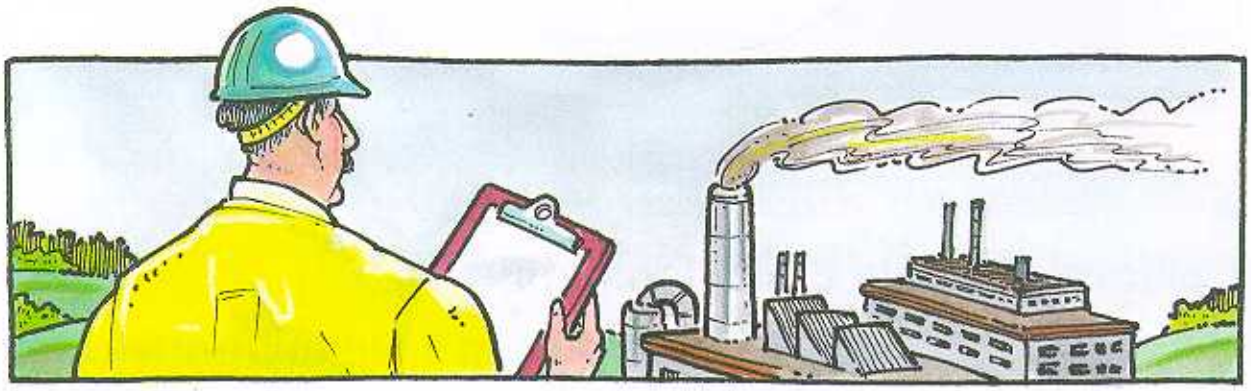
Ringelmann No. 2 is equivalent to 40 percent opacity. Most air pollution control districts in California have a stricter limit: 20 percent opacity, or No.1 on the Ringelmann Chart. **Know your local emission limit!**

What is EPA Reference Method 9?

It is very important that the training and certification of VE observers is standardized, as evaluating the density of visible emissions is an activity which requires training. To ensure that reliable and repeatable VE observations can be conducted anywhere in the US, in 1974 the federal Environmental Protection Agency (EPA) adopted Reference Method 9.

The protocol for Method 9, "Visual Determination of the Opacity of Emissions From Stationary Sources," is in the Code of Federal Regulations: 40CFR Ch. I, Part 60, Appendix A, Method 9. It gives the requirements for the training and testing of VE observers, the steps to follow and the data to record while documenting a VE observation. Method 9 also gives the calibration and design specifications for the equipment used to train and certify observers.

Method 9 requires recording readings in percent opacity for both black and white plumes. VE readings are taken every 15 seconds. The VE source is in violation if the **average of any group of 24 consecutive readings** (6 minutes) taken in a 1-hour period exceeds the standard.



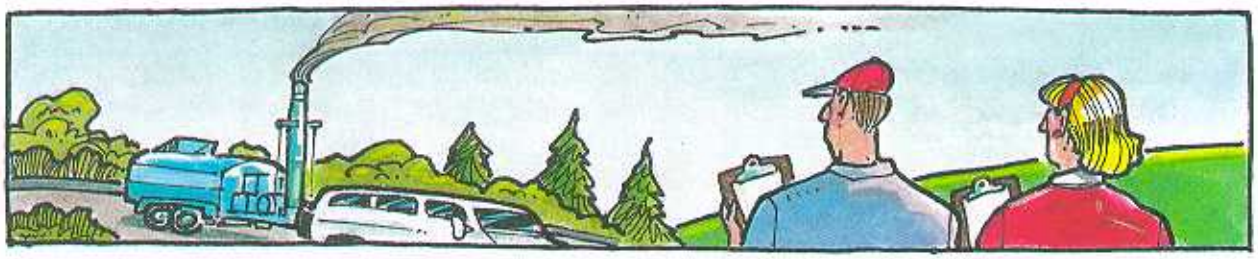
What's Different in California?

California follows all of the requirements of Method 9, except that density is recorded in Ringelmann numbers for black and gray plumes, and in percent opacity for white and colored plumes.

The California law also provides that an **aggregate of any of 13 or more readings which exceed the standard** (totalling over 3 minutes,) taken in any 1-hour period, constitutes a violation.

VE Observer Training

Several times a year the Compliance Division (CD) of the Air Resources Board provides EPA certified Visible Emission Evaluation (VEE) training and certification, both day and night, to state, district, and industry personnel in a three-day course called the Fundamentals of Enforcement - FOE, or "Smoke School." CD also conducts many one-day VE recertification classes around the state throughout the year. As a "smoke reader," a person is required by Method 9 and state policy to recertify every six months. **Phone (800) 952-5588 for more information about attending Smoke School.**



VE Certification Requirements

CD maintains a mobile smoke generator which makes both black and white smoke. It has a built-in transmissometer which measures light transmission through the stack and accurately "reads" and records the opacity of the smoke plume. The operator produces both black and white plumes of varying Ringelmann numbers and opacities and announces the values to the trainees to "calibrate" their eyes.

Certification runs alternate between 25 consecutive white and then 25 consecutive black smoke readings. Smoke plumes of various opacity and Ringelmann values are generated at random by the operator, who sounds a horn to signal the trainees when to take a reading and record it.

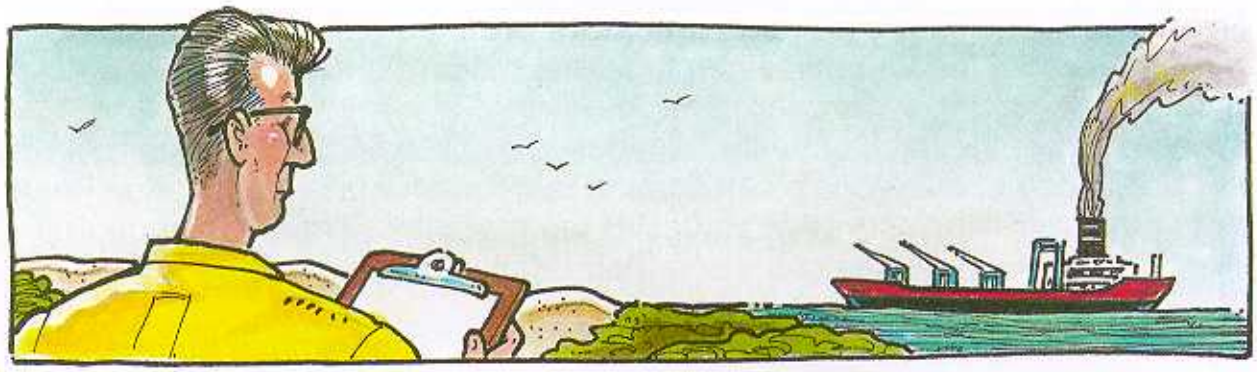
When a run of 25 black or white readings is completed, the operator collects the back copy of everyone's certification test form for later verification, then calls out the transmissometer values of the readings. Trainees grade their own tests and can immediately see their relative reading accuracy.

Opacity readings are recorded in 5% increments, Ringelmann numbers in quarter fractions. To pass, no single reading may be off by more than 15%, and the average error for all 25 readings may not exceed 7.5%. To certify, trainees must pass two consecutive runs - one of black and one of white smoke.

The VE Observation Form

The VE Observation Form (see facing page) contains the information required by Method 9 when documenting a VE in the field. It also includes additional information which may be necessary. The information on the form is organized into ten sections, numbered on the form opposite. The sections include:

1. **Company Identification -** *the complete name and address of the facility where the VE observation is taken, the phone number, and the district source ID number.*
2. **Process and Control Device -** *list the types of equipment used in the process and the air pollution control equipment, and their operating status during observation.*
3. **Emission Point Identification -** *record the distance to and height of plume origin, relationship to observer's position; describe enough to distinguish from other sources.*
4. **Emissions Description -** *shape, color, presence of water vapor, point where read.*
5. **Background, Weather Conditions -** *description, color background, percent of cloud cover, temperature, humidity, wind speed and direction.*
6. **Observer Position, Source Layout -** *see description on page 9.*
7. **Additional Information -** *facts about the source that are not addressed elsewhere.*
8. **Data Set -** *the date, start time, end time, and the readings in 15 second intervals for the observation period, with any necessary comments.*
9. **Observer Identification -** *reader's name, signature, date of this VE reading, reader's employer, certification agency and date most recently certified.*
10. **Forms Interrelation -** *record the number of the next form used when the readings from an observation continue on another form.*



Remember, this is the official record of your VE observation, so make it complete!

CARB VISIBLE EMISSION OBSERVATION FORM

No.

COMPANY NAME (1)		
STREET ADDRESS		
CITY	STATE	ZIP
PHONE (KEY CONTACT)	SOURCE ID NUMBER	

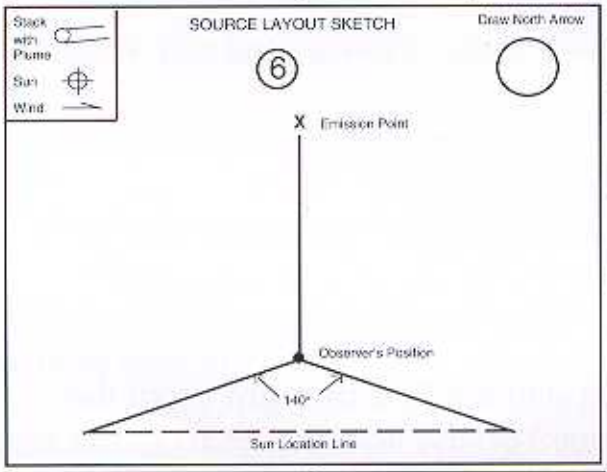
PROCESS EQUIPMENT (2)	OPERATING MODE
CONTROL EQUIPMENT	OPERATING MODE

DESCRIBE EMISSION POINT (3)	
HEIGHT ABOVE GROUND LEVEL	HEIGHT RELATIVE TO OBSERVER Start End
DISTANCE FROM OBSERVER Start End	DIRECTION FROM OBSERVER Start End

DESCRIBE EMISSIONS (4) Start End	
EMISSION COLOR Start End	IF WATER DROPLET PLUME
POINT IN THE PLUME AT WHICH OPACITY WAS DETERMINED Start End	

DESCRIBE PLUME BACKGROUND Start End		
BACKGROUND COLOR (5) Start End	SKY CONDITIONS Start End	
WIND SPEED Start End	WIND DIRECTION Start End	
AMBIENT TEMP Start End	WET BULB TEMP	RH, percent

SOURCE LAYOUT SKETCH (6)



ADDITIONAL INFORMATION (7)	

OBSERVATION DATE	START TIME	END TIME

MIN \ SEC	0	15	30	45	(8) COMMENTS
1					
2					
3					
4					
5					
6					
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OBSERVER'S NAME (PRINT)	
OBSERVER'S SIGNATURE (9)	DATE
ORGANIZATION	
CERTIFIED BY	DATE

CONTINUED ON VEO FORM NUMBER (10)	

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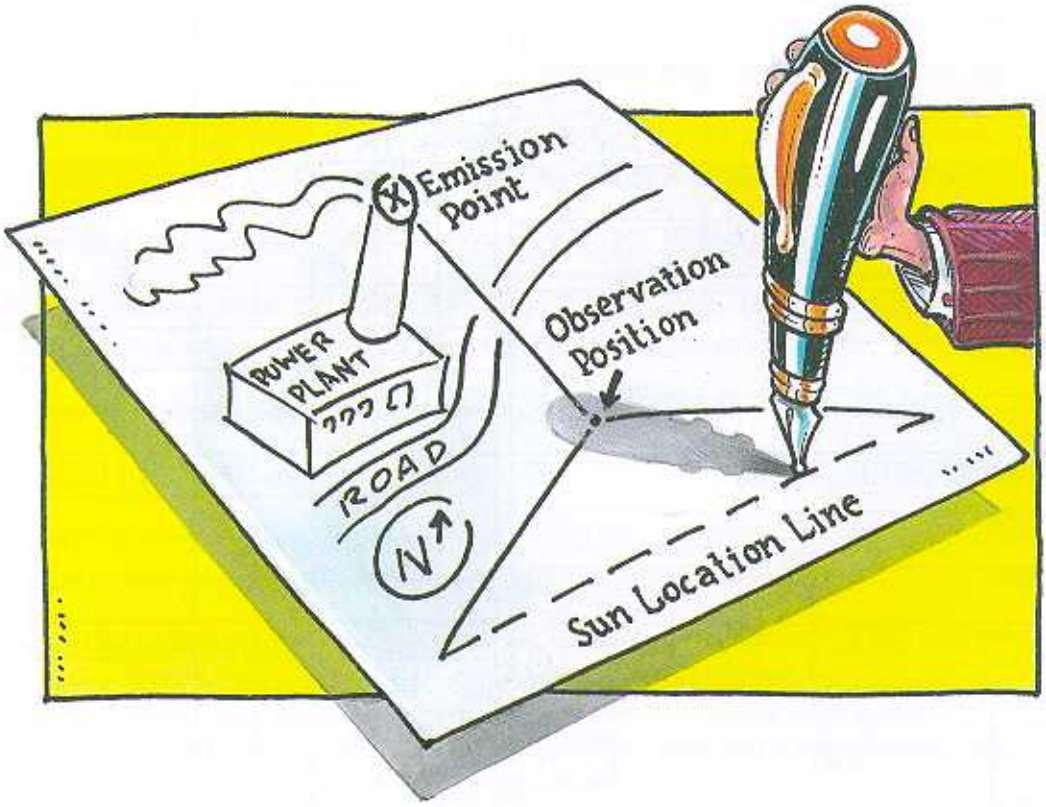
The Source Layout Sketch

Your sketch should include as many landmarks as possible. You want to clearly identify your position relative to the emission point, site landmarks, topographic features, sun position, and wind direction, in such a way that this observation won't be confused with others made at this facility.



The Sun Location Line

To determine the sun's location, you point the **line of sight** (from the observer's position to the emission point on the layout sketch) at the stack and stand a pen upright on the sun location line. Move the pen along the sun line until the shadow of the pen falls across the observer's position on the sketch. Then draw the sun at the point where the pen touches the sun line.

Advantages of Visible Emission Control Regulations

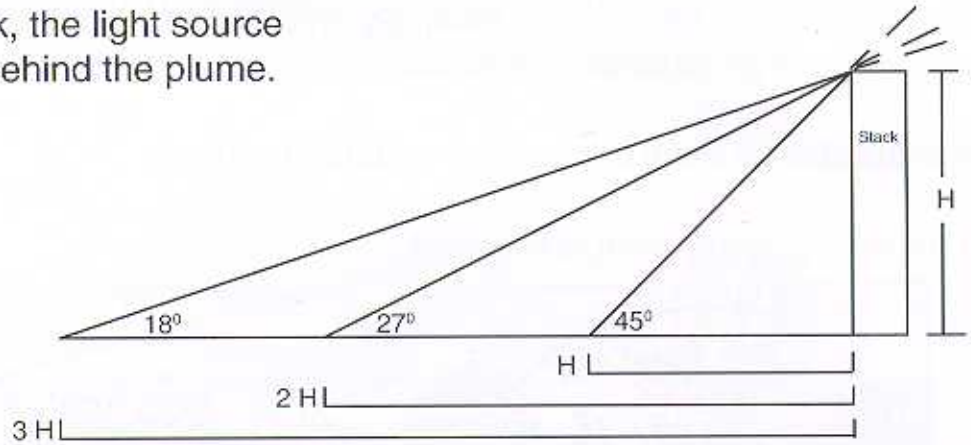
- ▼ The validity of using the Ringelmann Chart and the equivalent opacity concept has been established in air pollution control regulation, legislation and in the nation's courts.
- ▼ Observers can be trained in a relatively short time (one to two days) and need not have an extensive technical background.
- ▼ Recertification is easy and can be updated regularly.
- ▼ No expensive equipment is required.

- ▼ Emission readings can be taken 24 hours a day, outdoors or indoors.
- ▼ A single person can read emissions from many sources in one day.
- ▼ Source operators can monitor their own visible emissions.
- ▼ Violators can be cited without resorting to expensive, time-consuming source testing.
- ▼ Questionable discharges can be pinpointed and actual emissions can then be determined by source tests.
- ▼ Control can be required for operations where a source test would be difficult or impossible.

Reading Tips

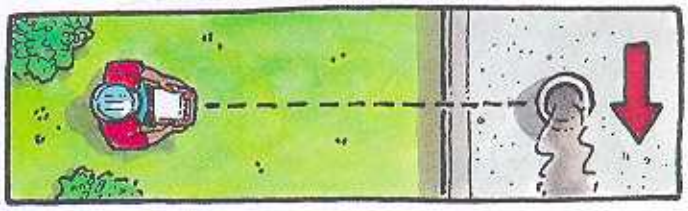
▼ Orient the sun within a 140 degree sector to your back during daylight hours (see page 9). On overcast days, the sun position is less important.

▼ After dark, the light source may be behind the plume.



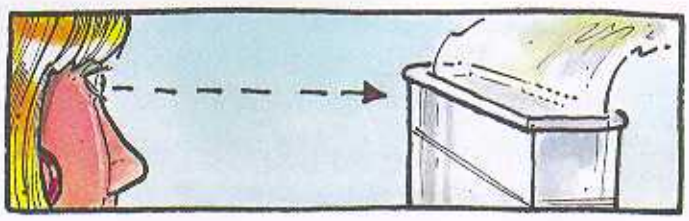
▼ Stand at least three stack heights but not more than a quarter mile from the stack, minimizing the angle of your line of sight through the plume.

▼ Read from where your line of sight is at right angles to the wind direction,if possible.



▼ Your line of sight should not include more than one plume at a time.

▼ When observing emissions from rectangular openings, your line of sight should be perpendicular to the longer axis of the opening, if possible.



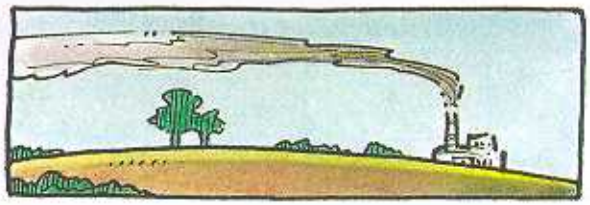
▼ Read at the point in the plume with the greatest opacity (without condensed water vapor), ideally while the plume is no wider than the stack diameter.

▼ If the plume is folded over by the wind, read only in the unfolded portion.

▼ Photos may be taken before or after but not during your reading, so as not to interfere with recording the observation.

▼ You should not look continuously at the plume (this causes eye fatigue) but observe the plume momentarily at 15 second intervals. A 15 second beeper is useful to help time your readings.

▼ A clearly visible background of contrasting color is better for greater reading accuracy.



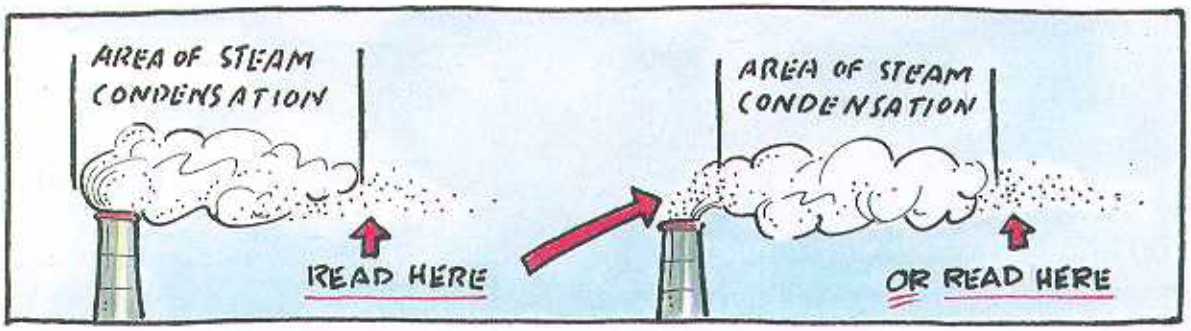
Water Vapor Plumes

Water vapor in plumes is a potential problem because it can mask other visible emissions in the plume.

Water vapor is present in the exhaust gas stream of many processes, such as drying, cooling and combustion, or it may be introduced by air pollution control equipment. When the hot gas stream enters the colder ambient air and the water vapor cools below its dew point, it condenses into an opaque white mist, becoming visible. If the relative humidity is low, this visible mist revaporizes and disappears as the plume is diluted further with ambient air

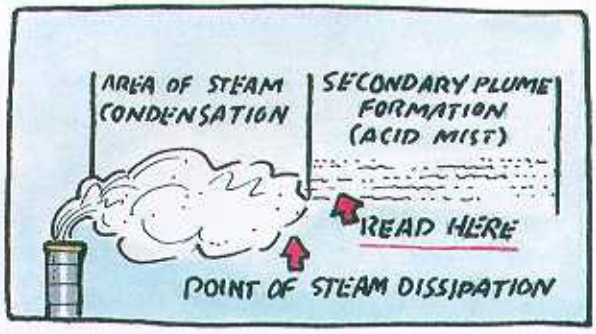
The chief characteristics of water vapor or "steam" plumes: opaque, white and billowy in bright sunlight, then becoming wispy and ending abruptly. A steam plume can be either "attached" or "detached" from the stack outlet. Read where there is no visible water vapor and the opacity is the greatest.

If water is present in the process, you should determine the air temperature and relative humidity as well as the moisture content and temperature of the gas stream, to tell whether formation of a steam plume is probable. If the relative humidity is above 60%, use the psychometric chart received in FOE to predict the occurrence of a steam plume which will <u>not</u> dissipate.



Secondary Plume Formation

Cooling gases in a plume can condense into solid or liquid PM, or particles may form in a chemical reaction between elements in the plume. This may occur with a steam plume or not. Unlike the steam plume, the secondary plume often persists far from the stack, is usually bluish-white due to very fine particles, and appears grainy rather than billowy.



Plume Shapes

Plume behavior is a good indicator of atmospheric stability (the amount of vertical air mixing) and can point to potential emission impacts downwind.

(neutral or slightly stable)

(very unstable)

(inversion below, mixing aloft)

(mixing below, inversion aloft)

(inversion condition)

VEE Equipment Kit

The basic equipment for conducting and recording a visible emission evaluation can be assembled and kept at hand in a small case. The kit ideally should include:

- VEE Forms - *to record all pertinent information,*
- Psychrometer - *to calculate relative humidity,*
- Range Finder - *to measure distance to the stack,*
- Inclinometer - *to measure angle of view to stack,*
- Compass,
- Binoculars,
- Wind Gauge,
- Stopwatch,
- Camera and Film,
- Water Bottle,
- Pen Flashlight,
- Writing Pens, and
- Ringelmann Chart.

Need More Information?

Air Resources Board (800) 952-5588 **District: _____**

Multi-County Districts

1 - Bay Area (415) 749-5000
2 - Feather River (530) 634-7659
3 - Great Basin (760) 872-8211
4 - Monterey Bay (831) 647-9411
5 - North Coast (707) 443-3093
6 - Northern Sierra (530) 274-9360
7 - South Coast (909) 396-2000
8 - Yolo-Solano (530) 757-3650
9 - San Joaquin Valley (559) 230-6000

County Districts

Amador (209) 257-0112
Antelope Valley (661) 723-8070
Butte (530) 891-2882
Calaveras (209) 754-6504
Colusa (530) 458-0590
El Dorado (530) 621-6662
Glenn (530) 934-6500
Imperial (760) 482-4606
Kern (661) 862-5250
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