



Introduction to Modern Atmospheric Effects

5th Edition

This book is designed to inform you about current fog-making technologies and give suggestions for their safe and effective use. PLASA does not endorse any specific fog-making technology, product, or technique.

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Basic Fog Use Guidelines

- Determine the appropriate technology for the application.
- Make only as much fog as necessary.
- Deliver the fog only where it is necessary.
- Deliver the fog only when it is necessary.
- Avoid exposing people to the direct output of fog machines.
- Monitor and control liquid accumulation.
- Post appropriate warnings.
- Follow manufacturers' instructions.
- Read this book.

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The PLASA Technical Standards Program

The PLASA Technical Standards Program was created to serve the PLASA membership and the entertainment industry in technical standards related matters. The goal of the Program is to take a leading role regarding technology within the entertainment industry by creating recommended practices and standards, monitoring standards issues around the world on behalf of our members, and improving communications and safety within the industry. PLASA works closely with the technical standards efforts of other organizations within our industry, including USITT and VPLT, as well as representing the interests of PLASA members to ANSI, UL, and the NFPA. The Technical Standards Program is accredited by the American National Standards Institute.

The Technical Standards Council (TSC) was established to oversee and coordinate the Technical Standards Program. Made up of individuals experienced in standards-making work from throughout our industry, the Council approves all projects undertaken and assigns them to the appropriate working group. The Technical Standards Council employs a Technical Standards Manager to coordinate the work of the Council and its working groups as well as maintain a “Standards Watch” on behalf of members. Working groups include: Control Protocols, Electrical Power, Floors, Fog and Smoke, Followspot Position, Photometrics, Rigging, and Stage Lifts.

PLASA encourages active participation in the Technical Standards Program. There are several ways to become involved. If you would like to become a member of an existing working group, as have over four hundred people, you must complete an application which is available from the PLASA office. Your application is subject to approval by the working group and you will be required to actively participate in the work of the group. This includes responding to letter ballots and attending meetings. Membership in PLASA is not a requirement. You can also become involved by requesting that the TSC develop a standard or a recommended practice in an area of concern to you.

The Fog & Smoke Working Group, which authored this informational book, consists of a cross section of entertainment industry professionals representing a diversity of interests. PLASA is committed to developing consensus-based standards and recommended practices in an open setting.

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G = General interest
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U = User

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Introduction

"The spells of the hero, beneath the castle, conjure up volumes of vapor, which at first, float dimly in the air, thicken into a film, and then a mist, till the dark masses of clouds roll over and melt into each other, and the stage is entirely enveloped, like the summit of some sky-clearing mountain."

So reported the *New York Mirror* about a dramatization of *Ivanhoe* at the Bowery Theatre in 1831. Atmospheric effects have been part of theatrical productions since long before this show, almost since the beginning of theatre. The Greeks used burning pitch and resinous torches, and in Shakespeare's time the smoke from black powder charges blew across the stage of the Globe outside London. Over the years a wide variety of methods have been used to make something that looks like smoke, clouds, haze, or mist on stage. Many people working in the entertainment industry today can remember loading electric heater cones with ammonium chloride (sal ammoniac), pumping a bee smoker, or lighting smoke cookies or pellets to gain the desired effect. Titanium tetrachloride, which produces thin white smoke when exposed to the air, has been used, even though contact with moisture produces corrosive hydrogen chloride gas as well as a cloud of white titanium dioxide. With the exception of steam, the early atmospheric effects techniques offered very little control over where the effects would go and could not be easily stopped and started on cue. Many of them were unacceptably toxic by modern health standards, and many of them were fire hazards

Today's widely used atmospheric effects are fundamentally different from most of the earlier effects in that they are almost always fog effects. The fog might be shot from a machine in a big burst that looks like smoke, or it might roll across the floor as low, white clouds, or it might float almost invisibly in the air as a thin haze, but almost all modern atmospheric effects are fogs: tiny droplets of liquid floating in the air. Glycol-based fog systems (often called a "smoke machine") produce a fog in which the droplets are a mixture of water and glycol or glycerin. The familiar dry ice fog machine produces a fog in which the droplets are water. The machines known as "hazers" produce a thin haze of highly refined mineral oil, glycol, or some other fluid. All of them produce aerosols of liquid droplets suspended in the air.

Besides the burning pitch, black powder, and fumed sal ammoniac mentioned above, there are many non-fog machine ways of making smoke on stage, but they are outside the scope of this book. These methods include smoking tobacco in cigarettes and pipes; vaping e-cigarettes, e-cigars, and electric hookahs; burning incense; igniting firecrackers and gerbs; blowing dry

pigment or other dust into the air; and other technologies not specifically detailed here. These all put visible aerosols into the air, but are not widely used to create atmospheric effects, and are not technologies covered in this book. This book is about modern atmospheric effects that are produced by machines specifically designed to create "smoke" or fog effects on stage.

The ease with which atmospheric effects now can be created by machines designed to produce them has made fog effects routine, but important information about the effects—how they work, how to use them effectively, what to avoid—has been scarce. This book describes modern atmospheric fog effects in simple terms. From each section, you will get a basic understanding of the technology, its effective use, as well as benefits and cautions. The established exposure limits for the chemicals used are included when they are available. Next, there is a brief discussion about how to work with a fog once you have put it in the air, and a table that summarizes the technologies. Near the end of the book, there is a brief glossary of terms. The technologies of modern atmospheric effects have grown beyond our current vocabulary to describe them. This glossary will help everyone speak the same language in the field of entertainment atmospherics. Finally, a list of additional reading material is provided.

This book is not a substitute for the operator's manual that fog machine manufacturers include with their products. All fog machines are not the same, and rules of thumb or the instructions for one machine may be completely wrong for another. If you do not have an operator's manual for your particular machine, get one. The manual includes important details of the fog machine's operation, which are beyond the scope of this book. Be sure you read the fog machine operator's manual carefully and follow the manufacturer's recommended operating procedures.

Fog and Smoke: What's the Difference?

This book covers fog effects. These may look like smoke, but they are not. Smoke is created by burning something. This something may be designed to be burned to produce smoke, such as smoke pellets or pyrotechnic smoke bombs, or this something may be whatever is cheap and handy that will burn, like autumn leaves or burlap sacks. A technology that is similar to smoke is the use of fumed solids, such as ammonium chloride. These fumed solids are not technically smokes because they are not produced by burning, but as atmospheric effects their characteristics are quite similar so it is convenient to treat them as smokes. Smoke and fumes both are composed of small, solid particles; fog consists of liquid droplets. The distinction is important.

Many people use "smoke" in conversation to mean either smoke or fog, with no distinction between the two. However, smoke and fog are two different things. In preparing this book, we have very carefully used the words fog and smoke according to this distinction: smoke is composed of solid particles, while fog is composed of liquid droplets. In a few places, however, we defer to the colloquial usage to avoid an overly formal language. In those few places where we use "smoke" colloquially, the informal usage is signaled to you by putting the word "smoke" in quotes.

Modern atmospheric effects are most often fog effects. However, smoke effects are sometimes still used. All effects have their good and bad points. The good points for smoke are:

- It is an extremely simple technology.
- It can produce colored smoke.
- Small amounts of smoke can be produced with very little equipment in a small space. A tiny incense cone burning in an ashtray may produce enough smoke for some applications.

The bad points are:

- Smoke is difficult to start and stop on cue.
- Smokes, with few exceptions, are toxic.
- Smoke tends to collect on things: Colored smokes stain and fumed chlorides leave white dust.
- Burning and heating things can create a fire hazard.

For most applications the disadvantages of smoke out-weigh the advantages. Thus, fog machines of various types are used for the vast majority of modern atmospheric effects.

Types of Fog Effects

Before discussing the technologies available for making atmospheric effects, it is important to understand what kinds of effects can be made. There are probably as many different fog effects as there are colors in the rainbow, but it is convenient to group them into four categories:

- haze
- fog
- low-lying fog

- mist

Haze is a subtle atmospheric effect that is almost invisible to the audience or camera until beams of light shine through it. Haze is really an effect for making the volume of a performance space visible, and it should be imperceptible except for the effect it has on the light in the space. It is used often in rock concerts to make the beams of light from the automated luminaires visible, and it is used in film work to add a subtle diffusion to the scene and to lighten the shadows and reduce contrast.

Most of the time it is desirable to have the haze persist with great uniformity for a long time. Thus hazes are produced with fluids that evaporate very slowly. The droplets are extremely small, generally from slightly larger than one micron to less than one micron in diameter, so they will hang in the air and not fall to the floor. Hazes are very light, so very little fluid is used to produce a haze.

Fog is much denser than a haze. It has texture to it and the viewer can often see air currents as the droplets are lifted and carried by the air. Fog often looks like smoke. The droplets of fog are larger, generally from 2 to 5 microns in diameter, so the movement of the fog in the air is more obvious than it is with a haze. The larger droplets also tend to float for a shorter length of time than do the tiny droplets in a haze. Because the droplets are larger and because the fog is generally denser than a haze, more fluid is used to create a fog than is used to create a haze.

Fog may be required to last for a long time during film shoots, but in live performance it is usually desirable to have it dissipate fairly quickly. Slow and fast evaporating fluids are used to meet these different needs.

Low-lying fog is a fog that hugs the floor. It is generally extremely dense and obscures the floor so performers look like they are walking on clouds. Most people are familiar with dry ice fog, which is of this type. Many other kinds of machines are now available that will produce this effect, although dry ice machines remain popular.

Low-lying fogs may start to rise as they warm, as the heavy gases dissipate, or as air currents mix the fog with the general air. Fast evaporating fluids are used so that as the fog disappears as it rises. The droplet size in low-lying fogs varies over a wide range. Low-lying fogs are usually quite dense, and they evaporate quickly, so usually a large amount of fluid is needed to produce the effect. However, low-lying fog effects in live performance are generally short, and the

fluid used is often water, so the quantity of fluid used is rarely an important consideration.

Mists look like something between a drizzle and fog. The droplets are quite large, usually 10 microns and larger, so they readily fall and are not carried by the air for any great distance. Because the droplets are so large, their movement in the air is quite obvious. Mists are most often used for localized, specific effects, like creating the mists around a waterfall at a theme park or an extremely damp tropical scene in a film. They might be used for a storm scene on stage or film since they make the movement of the swirling wind quite visible.

Mists readily fall out of the air, so they must be constantly replenished. The surface underneath the mists also will tend to get wet from the falling droplets. Water is almost always the fluid of choice because of the volumes that must be used, and because the fluid will often land on the floor and must be cleaned up or drained somehow.

Fluids Used For Making Fogs

There are essentially four different types of fluids used for making fogs:

- water
- water mixed with one or more glycols or glycerin
- pure glycol
- highly refined mineral oil

Each type has its unique properties and its advantages and disadvantages.

Water has these advantages:

- It's cheap.
- It's uncontroversial. The health effects of water are rarely questioned.

Water has these disadvantages:

- It evaporates the most quickly of all the fog fluids.
- It has the lowest index of refraction of all the commonly used fluids, so it scatters light the least.

The index of refraction of a transparent material is a measure of how optically dense it is. Air has an index of 1, while water has an index of about 1.35. The different glycols and mineral oil have other indices, generally higher than water

and much higher than the index for air. As light crosses the boundary from a medium with one index to a medium with another index at an angle, it is bent from its original path. The greater the difference in the two indices, the greater the bending. The greater the bending, the more the light is scattered.

Mixtures of water and one or more glycols or glycerin are among the most popular fog fluids. Sometimes these are called "glycol-based" fluids because they contain glycol or glycerin, which is a substance enough like the glycols used in fogs that some people make no distinction. Sometimes they are called "water-based" fog fluids because they contain water, but they are not entirely water. They have these advantages:

- They evaporate more slowly than water.
- They have a higher index of refraction than water.
- Different formulations of glycol and water can create a variety of fog effects.

They have the following disadvantages:

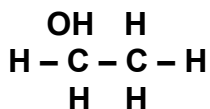
- They are more expensive than water.
- They are slippery, and spills must be carefully cleaned to avoid slip-and-fall hazards.

These fluids are most often mixtures of water and one or more of the following glycols or glycerin:

- propylene glycol
- triethylene glycol
- diethylene glycol
- dipropylene glycol
- 1,3-butylene glycol
- glycerin, also known as glycerol

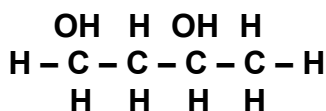
These are all types of alcohol. Unlike the ethyl alcohol that we are all familiar with in wine, beer, and whiskey, these are poly-hydroxyl alcohols. That is, instead of having one hydroxyl unit (an oxygen atom-hydrogen atom pair) as ethyl alcohol does, these have two or three hydroxyl units. Just like ethyl alcohol, these alcohols mix very readily with water. Unlike ethyl alcohol, they do not evaporate quickly, and, if mixed with water, they keep water from evaporating quickly. They also have higher indices of refraction than do plain water, so they scatter light more effectively. Different mixes of these alcohols and water give different fog fluids their different properties.

Examples of Alcohols



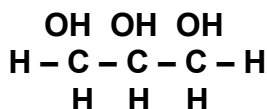
Ethyl alcohol, the alcohol found in beer, wine, and whiskey.

Ethyl alcohol has one hydroxyl unit (the oxygen-hydrogen pair at the top left) bonded to one of the carbon atoms.



1,3 butylene glycol, one of the glycols used in major brands of fog fluid.

Butylene glycol has hydroxyl units bonded to the first and third carbon atoms in the chain, hence the "1,3" numbers in the compound's name.



Glycerin, also called glycerol, another compound used in fog fluids.

Glycerin has three carbon atoms, and each one has a hydroxyl unit bonded to it.

These poly-hydroxyl alcohols are ubiquitous, and people have been using them in products and industrial processes for generations. They are found in deodorants, hand cream, and cake frosting, as well as in brake fluid, ink, and antifreeze. The literature on glycerin goes back over 100 years. These are among the most common and most benign chemicals used today.

All fog fluids containing an appreciable amount of water evaporate in some reasonable length of time. Longer lasting fog effects can be produced if the fluid contains no water. Haze effects, for example, are usually produced with fluids that contain very little or no water. The reason for this is that hazes are fogs with extremely small droplets. The ratio of the droplet volume to its surface area is such that volatile fluids will make the droplets evaporate and disappear too quickly. Therefore, most hazes are made with highly refined mineral oil, or with

fluids that are composed entirely of polyethylene glycol 200 (PEG 200) or triethylene glycol. These all evaporate very slowly, or not at all, at normal room temperature.

Pure PEG 200 and triethylene glycol fluids have these advantages:

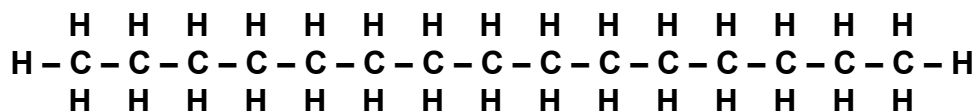
- They evaporate very slowly, so the effect produced by them lasts a long time.
- They have high indices of refraction so they scatter light well.

They have the following disadvantages.

- They evaporate very slowly, so the effect produced by them is difficult to clear.
- They may leave a slippery deposit on surfaces if heavily used and basic housekeeping procedures are not followed.

Highly refined mineral oil, which is what is used in mineral oil fog, is a simple, straight-chain alkane. The more atoms in an alkane molecule, the thicker and less fluid it is. Canning waxes have 26 or more carbon atoms, while the gas methane has only one. Mineral oil fog fluids are between waxes and gases and have 12 to 18 carbon atoms.

Highly Refined Mineral Oil



An oil with 15 carbon atoms.

Mineral oil has these advantages:

- It never evaporates, so the effect produced lasts a long time.
- It has a high index of refraction so it scatters light well.

It has the following disadvantages.

- It never evaporates, so the effect produced is difficult to clear.

- It can leave a slippery deposit on surfaces if heavily used and basic housekeeping procedures are not followed.

Ways of Making Fog

No matter what fluid is used to make fog, some method must be used to create the tiny droplets and put them in the air. These methods can be broken down into three different categories:

- cryogenic fogs
- heated fogs
- mechanical fogs

Cryogenic Fogs

Dry ice is the oldest and most common of the cryogenic fog technologies. It employs very simple mechanical equipment that anyone can understand. Also, dry ice is relatively inexpensive and widely available.

Liquid nitrogen was first used to create fog effects in the 1970s. The first use was in large rock and roll productions where pressurized liquid nitrogen was sprayed directly into the atmosphere creating a micro weather system. The technique was called a “nitrogen burst effect.” Around 1985, Jim Doyle, a special effects technician, refined the equipment and methods for creating fog with liquid nitrogen and built the first commercial machines designed specifically for the task. In 1992, he received an Academy Award for his pioneering work in designing liquid nitrogen fog machines.

In response to the need for large scale cryogenic fog effects, a **liquid synthetic air** (LSA) has been developed. This cryogenic liquid is a homogeneous mixture of liquid nitrogen and liquid oxygen that produces a gaseous mixture with a ratio of nitrogen and oxygen very close to the ratio in the atmosphere. Atmospheric effects using synthetic air function identically to liquid nitrogen fog effects. An Academy Award was given in 1998 for this advancement in the technology.

Cryogenically-created water fogs are virtually identical to naturally occurring fogs. However, natural fogs occur when the relative humidity of the air is 100%. Artificial fogs are rarely used in such humid atmospheres, so artificial fog disappears more quickly than natural fog through evaporation. A cryogenic fog tends to lie low to the floor, because of its low temperature.