Introduction to Modern Atmospheric Effects

6th Edition

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

F&S/2018-3017r3

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.

NOTICE and DISCLAIMER

ESTA does not approve, inspect, or certify any installations, procedures, equipment or materials for compliance with codes, recommended practices or standards. Any markings, identification or other claims of compliance do not constitute certification or approval of any type or nature whatsoever by ESTA.

ESTA neither guarantees nor warrants the accuracy or completeness of any information published herein and disclaims liability for any personal injury, property or other damage or injury of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this document. In issuing and distributing this document, ESTA does not either (a) undertake to render professional or other services for or on behalf of any person or entity, or (b) undertake any duty to any person or entity with respect to this document or its contents.

Published by:

Entertainment Services and Technology Association
630 Ninth Avenue, Suite 609
New York, NY 10036
USA
Phone: 1-212-244-1505
Fax: 1-212-244-1502
standards@esta.org

The ESTA Technical Standards Program

The ESTA Technical Standards Program was created to serve the ESTA 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. ESTA works closely with the technical standards efforts of other organizations within our industry, as well as representing the interests of ESTA 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, Event Safety, Floors, Fog and Smoke, Followspot Position, Photometrics, Rigging, and Stage Machinery.

ESTA 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 ESTA 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 ESTA is not a requirement. There is a $100 per calendar year participation fee. A scholarship fund exists to help if this is too great a financial burden. 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. ESTA is committed to developing consensus-based standards and recommended practices in an open setting.

Contact Information

Technical Standards Manager
Karl G. Ruling
Entertainment Services and Technology Association
630 Ninth Avenue, Suite 609
New York, NY 10036 USA
1-212-244-1505 x703
karl.ruling@esta.org

Assistant Technical Standards Manager
Richard Nix
Entertainment Services and Technology Association
630 Ninth Avenue, Suite 609
New York, NY 10036 USA
1-212-244-1505 x649
erin.grabe@esta.org

Technical Standards Council Chairpersons
Mike Garl
Mike Garl Consulting LLC
1-865-389-4371
mike@mikegarlconsulting.com

Mike Wood
Mike Wood Consulting LLC
1-512-288-4916
mike@mikewoodconsulting.com

Fog & Smoke Working Group Chairpersons
M. Brad Dittmer
Stage Labor of the Ozarks
1-417-616-9948
slobrad17@gmail.com

Larry Schoeneman
DesignLab Chicago, Inc.
1-773-265-1100
Larry@dlabchicago.net

Acknowledgments

The Fog & Smoke Working Group members when this document was approved by the working group on __________ are shown below.

Voting members:

fill in

Observer (non-voting) members:

Fill in

Interest category codes:

CP = Custom-market Producer
DE = Designer
DR = Dealer or Rental company
G = General interest
MP = Mass-market Producer
U = User

Contents

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, how to monitor people's fog exposure, 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

```
   OH  H
H – C – C – H
    H  H
```

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.

```
   OH  H  OH  H
H – C – C – C – C – H
    H  H   H  H
```

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.

```
   OH  OH  OH
H – C – C – C – H
    H   H   H
```

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

```
     H   H   H   H   H   H   H   H   H   H   H   H   H   H   H
H – C – C – C – C – C – C – C – C – C – C – C – C – C – C – C – H
     H   H   H   H   H   H   H   H   H   H   H   H   H   H   H
```

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.

Cryogenic fog has the advantage of being odorless. Cryogenic fog systems put nothing in the air that is not already there in some quantity.

How They Work

All cryogenic fog effects involve bringing hot water or warm water vapor into contact with something that is very cold.

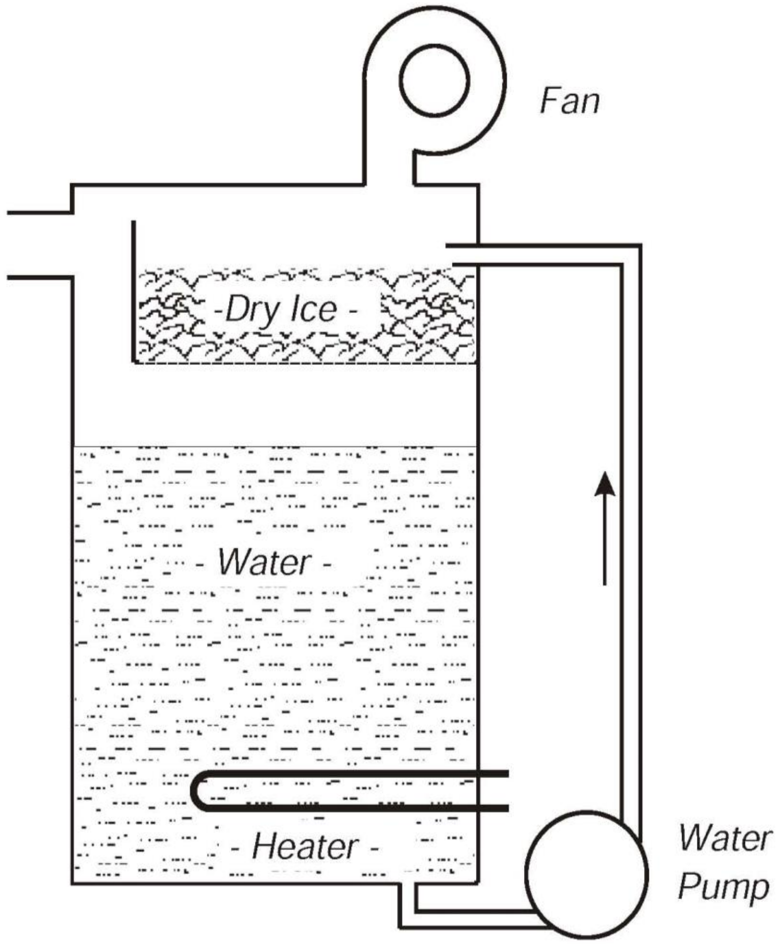

Figure 1. Dry ice machine

The **dry ice fog machine** is perhaps the most common cryogenic fog machine. Dry ice is carbon dioxide frozen solid at –112°F (–80°C). Usually the machine is a vertical tank from 30 to 50 gallons in capacity (114 to 190 liters) and approximately three-quarters full of water. Electric heating elements in the tank heat the water to a temperature between 100°F (38°C) and 200°F (93°C). A basket of dry ice is suspended over the water. In the simplest machines the fog is produced by manually lowering the basket into the hot water. In more sophisticated machines a pump pours or sprays the hot water over the dry ice. Either way, the dry ice quickly turns from a solid to a gas, violently agitating the water that is in contact with it, and spraying lots of tiny droplets into the air. At the same time, the cold carbon dioxide causes the water vapor in the air over the water to condense into tiny droplets. The fog thus created is forced out of a hose connected to the machine. It is propelled by the expanding carbon dioxide gas and, usually, also by a fan that blows air into the machine and thus blows fog out. The fan increases the volume of the fog, and dilutes with air the carbon dioxide that comes out of the machine with the fog.

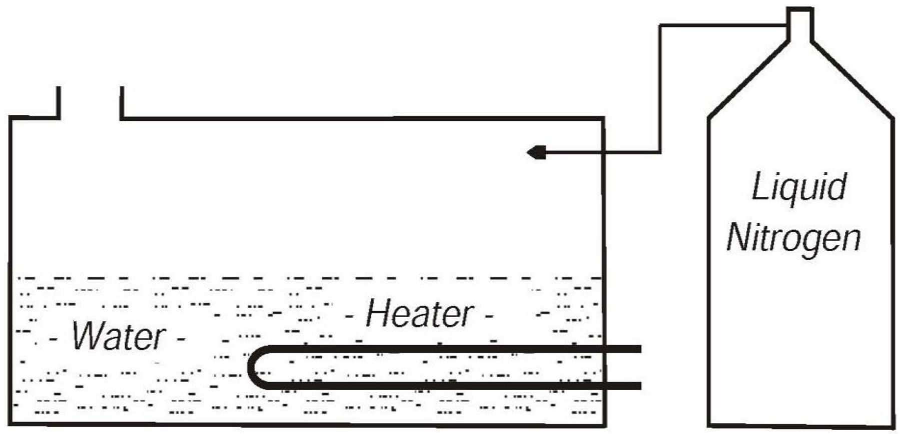

Figure 2. Liquid nitrogen machine

A **liquid nitrogen fog machine** also is essentially a large, electrically heated water tank, but with a big space for water vapor over the hot water. The cryogen used is liquid nitrogen, which remains a liquid as long as it is kept below –325°F (–198°C). The liquid nitrogen is sprayed into the water vapor-laden space above the hot water, causing the water vapor to condense into a fog. There is no violent agitation of the water. The liquid nitrogen expands greatly as it changes into a gas, and forces the fog out of the machine. Rarely, if ever, is a fan used to assist the flow of the fog. Liquid synthetic air may be used in a liquid nitrogen fog machine. In that case the fog is carried out of the machine in a stream of air rather than a stream of nitrogen gas.

Cryogenic burst effects create fog from the water already in the air. A cryogenic burst is created by spraying liquid nitrogen or liquid carbon dioxide directly into the air. The cryogen rapidly expands when it is released and drops the temperature of the surrounding moisture-laden air. Water vapor in the rapidly chilled air condenses into a miniature cloud.

Effective Use

All cryogenically made fogs have a natural tendency to hug the ground as a result of their low temperatures. Also, the carbon dioxide in fog made with dry ice is heavier than air and will move quickly to the lowest accessible space. Cryogenic fogs are well-suited to mysterious settings, but cannot be used to fill a space with mist to display light beams. The fog fluid in cryogenic fog is water, and it quickly evaporates if heated or mixed with the general air. Thus, heating the fog to make it rise or blowing it upward with fans will do nothing but make the fog disappear and raise the humidity in the room. Cryogenic burst effects, however, can achieve very impressive fog effects high in the air.

Because liquid nitrogen and liquid synthetic air are extremely cold and stored under pressure, their use normally is limited to professional applications.

Water accumulation can be a problem with cryogenic fogs, particularly with dry ice fogs. The violent agitation of the water in the dry ice fog machine creates large as well as small droplets. The large droplets readily fall out of the air and can create a wet floor in front of the fog delivery hose. These large droplets can be minimized by running the dry ice fog machine with the water no hotter than necessary to produce the volume of fog needed, and also by putting a u-shaped bend in the fog delivery hose. Water from the larger droplets will collect in the bottom of the bend. The bend must be drained periodically, or the hose will become blocked with water.

Safety Guidelines

Handle cryogens carefully. The cryogens are extremely cold and should be handled with caution. Directly exposing your skin to cryogens can cause severe frostbite. Consult the manufacturers’ safety recommendations for proper handling procedures.

Allow stored cryogens to vent. It is very difficult to keep cryogens at their extremely cold temperatures. As solid and liquid cryogens warm, they become gases. You must allow these gases to vent. If you store a cryogen in a sealed container and prevent the gas from venting, the container will eventually rupture. Store dry ice in an ice chest with a loose seal. Store liquid nitrogen in a properly constructed dewar or bulk storage tank.

Beware of oxygen deprivation, especially in low-lying places. Both carbon dioxide (dry ice) and nitrogen gases tend to dilute the oxygen in the air that the fog enters. Also, carbon dioxide in sufficient concentration is toxic. Usually, these properties present no problems. However, considerable care is required if large volumes of cryogenic fog are being used or cryogenic fog is being used in a confined area.

If a performer or technician does not get enough oxygen in the air he breathes, the first symptom will be that he becomes faint, fatigued, or light-headed. If this happens, he must quickly receive fresh air. Also, these gases (especially carbon dioxide, which is heavier than air) tend to accumulate in low-lying places. Never allow a person to lie down in a fog created by a cryogenic method. Be sure the orchestra pit, any other low-lying areas, and any cryogen storage areas have adequate ventilation.

Look out for moisture accumulation, particularly with dry ice fog. It’s hard to keep water droplets suspended in air. The droplets may evaporate, in which case the fog disappears. Alternatively, the water droplets may fall out of the air and collect on surfaces, in which case you may have puddles on the floor. Check your fog-making situation carefully to be sure that there is no moisture accumulation that could become a hazard, or prepare the floor area with non slip material. Check this before every performance. Slight changes in the humidity in the venue or changes in the ways the machines are operated can produce great changes in accumulation rates. In addition to testing the fog system before performances, the stage manager should ask performers to report any accumulation they detect while on stage.

Maintain the fog-making equipment. Water, particularly moving water, is abrasive and can cause significant wear on fog machine components. Tap water contains minerals and can leave scale when the water evaporates. This makes regular inspection of fog machines imperative to insure that all parts are in safe, efficient operating condition. Learn the maintenance schedule for your fog-making equipment and follow it.

Carbon dioxide dissolves in water to form a weak acid. It is less corrosive than soda pop, but it is still hard on the fog-making machinery. You should change the water frequently in a dry ice fog-maker and check for signs of corrosion.

Toxicity: Safe environmental concentrations for nitrogen and carbon dioxide have been established by the Occupational Safety and Health Administration (OSHA) in the United States and the Health and Safety Commission (HSC) in the United Kingdom. The Health and Safety Executive in the UK also publishes guidelines for workplace safety, and there is legislation in the UK that applies to the atmospheres of specific work places.

Nitrogen: Since nitrogen is not bioactive (that is, it is inert insofar as your body is concerned), safe concentrations of nitrogen are stated in terms of remaining concentrations of atmospheric oxygen. The atmosphere is normally about 21% oxygen (O_2). Nitrogen can be added to the atmosphere until the oxygen level falls to 19.5%, according to OSHA regulations in the U.S., or to 18% according to HSE guidelines in the U.K. HSE also notes that the Mines and Quarries Act of 1954 requires that oxygen levels never be allowed to fall below 19% by volume.

This is obviously a more conservative level than that imposed on general industry, but is not so conservative as the levels set by OSHA. Breathing air with reduced levels of oxygen causes impaired coordination and judgment, so these minimum levels are set to avoid accidents in their respective industries. Lower levels of oxygen, besides increasing the risk of accident, can lead to unconsciousness. Extremely low oxygen levels can cause death. Both automated and inexpensive hand-held O_2 monitoring equipment are available. Safety data sheet (SDS) information is available from your industrial gas supplier or by the Internet at http://hazard.com and many other sites.

Carbon dioxide: Carbon dioxide is bioactive, affecting respiration and the transfer of oxygen to the bloodstream through the lungs. The OSHA permissible exposure limit (PEL) time-weighted average (TWA) for acceptable exposure over an 8-hour workday and the HSC occupational exposure standard (OES) for CO_2 is 5000 parts per million, or 0.5%. In the U.S. CO_2 also has a short term exposure limit (STEL) for no more than 15 minutes of 30,000 ppm (3%), while the HSC short term limit is half that. Carbon dioxide is weakly narcotic at 3%, causing reduced hearing acuity and increased pulse rate and blood pressure. Levels above 7% can cause unconsciousness in a few minutes. High carbon dioxide levels can cause death. Both automated and hand-held CO2 monitoring equipment are available. MSDS information is available from your industrial gas supplier or by the Internet at http://hazard.com.

Liquid synthetic air: Liquid synthetic air (LSA) is a homogeneous mixture of liquid nitrogen and liquid oxygen which can be used as a cryogen in fog effects in place of LN2 (liquid nitrogen). Because the concentration of oxygen (O_2) in the gas produced by the mixture is between 19.5% and 22%, LSA can be added to the atmosphere in unlimited quantities.

NOTE: Oxygen concentrations in LSA must be monitored frequently. Monitoring should address two concerns: (1) the longer the liquid remains in its container, the higher the O2 concentration will be; and (2) whenever LSA is allowed to pool outside of its cryogenic container the O2 concentration will rise above 23.5% very quickly. OSHA considers atmospheric oxygen levels above this hazardous because of the increased fire danger. Caution must be exercised to insure safe usage.

Heated Fogs

There are two heat-based methods for making fog—pump-propelled glycol and gas-propelled fluid. Both methods propel a fluid into a heat exchanger and produce an opaque aerosol (fog). The glycol system propels a solution of one or more glycols or glycerin and water with a mechanical pump or compressed air.

The gas-propelled systems use a non-flammable gas as the propellant for either high-grade mineral oil or a fluid composed of one or more glycols or glycerin and water.

Pump-propelled glycol fog systems were developed by Günther Schaidt for opera companies in Germany, based on a new fog fluid concept. He introduced the idea to the United States in 1979. The innovation was such an improvement that it received an Academy Award in 1984. The system uses a series of glycols of low molecular weight diluted in water.

The glycol in glycol fog droplets helps keep them from evaporating and disappearing in the air. Glycol changes the refractive index of the vapor in a way that helps make the glycol fog visible. Highly efficient glycol fog machines can be designed to occupy a very small space, often no bigger than a bread box and sometimes as small as a pack of cigarettes, and produce a long-lasting fog. These factors account for the high popularity of glycol fog systems.

Gas-propelled fluid fog-making systems were also developed in the 1970s. The fluid used is either a high-grade mineral oil or a solution of one or more glycols and water. The heated fluid process produces a fog or haze composed of small droplets, which can remain suspended in the air for a long time.

How They Work

Pump-propelled glycol machines use a fog fluid containing a mixture of one or more glycols and water that is moved from a reservoir (usually either a bottle or an on-board tank) into a heat exchanger by a pump. The heat exchanger has been heated to the point at which the fluid will vaporize, usually less than 644°F (340°C). The fluid’s own expansion into vapor forces the heated material out the front of the machine where, when it mixes with cooler air, it forms an aerosol of tiny droplets. These droplets reflect the light, which is what gives this type of fog its characteristic white coloring. Some machines use variable speed pumps so the output of the machine can be varied.

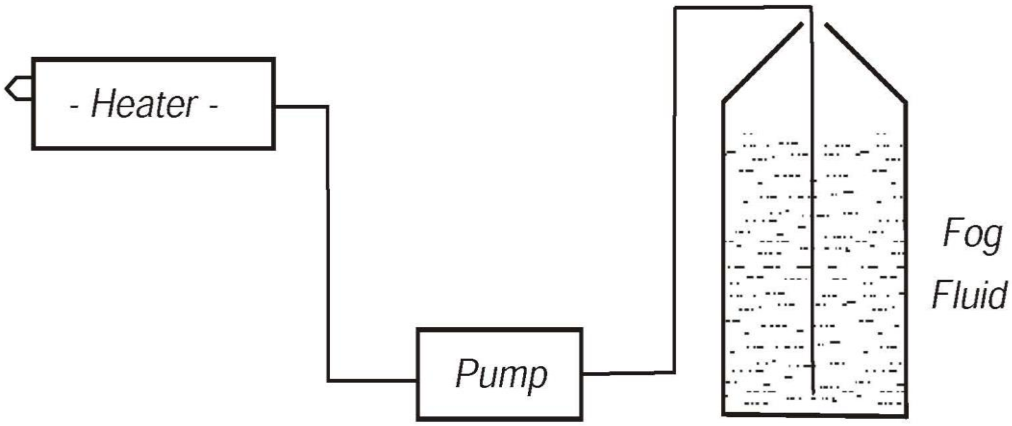

Figure 3. Pump-propelled machine

Warning: Never use mineral oil in a pump-propelled glycol fog machine because this can create a fire hazard.

Gas-propelled machines use a fluid (high-grade mineral oil or a solution of one or more glycols and water) that is stored in an on-board tank and is mixed with a non-flammable gas, either carbon dioxide (CO_2) or nitrogen (N_2), from a standard pressurized gas bottle. Usually, the gas bottle is contained in the fog machine, but the gas bottle can be located remotely and connected to the machine by a hose or tubing. The fluid/gas mixture is propelled into a heat exchanger. The heat exchanger is preheated to the boiling temperature of the fluid, which is different for mineral oil and each of the possible glycol solutions. The boiling fluid's expansion into vapor and the pressurizing gas forces the vapor out the front of the machine, where it condenses into an aerosol. The result is a fog containing droplets with a diameter of between 0.5 and 4 microns. The size of the droplets is sometimes controllable by varying the amount of non-flammable gas mixed with the fluid. In some cases, the pressurized gas also is used for purging purposes. The volume of fog produced is controlled by the regulator valve on the pressurized non-flammable gas bottle.

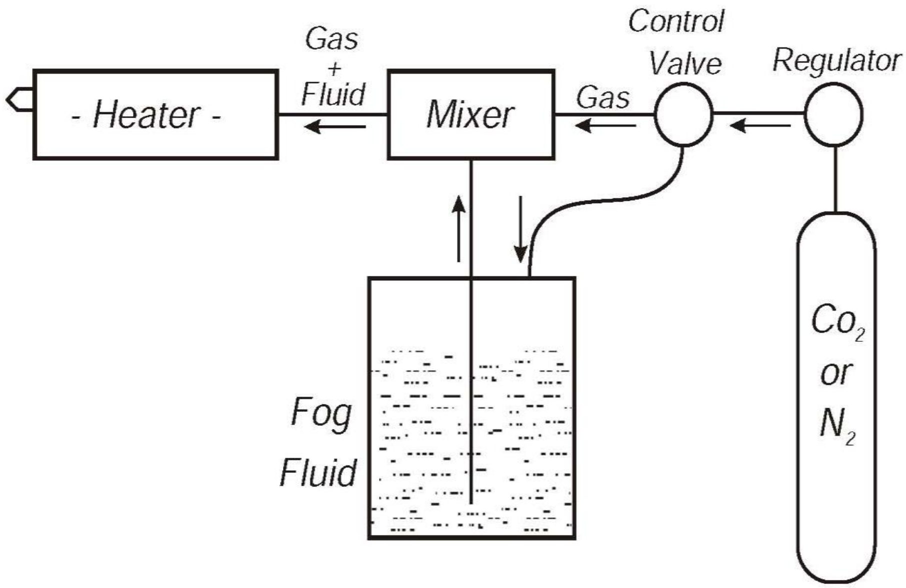

Figure 4. Gas-propelled machine

Warning: Never use compressed air if an inert gas is specified for use in a gas-propelled machine.

Effective Use

Heated fog technology is capable of delivering anything from a wisp to billowing clouds of fog by simply varying the pump flow rate or the pressurized gas flow rate. Variable output is a feature on all but the least expensive of the heated fog machines, and adds to their versatility. A light use of fog lends a texture to the air so beams of light can be seen, which is a very popular effect with moving lights. A moderate use of fog allows for dramatic effects like the battle scenes in *Les Miserables*. A heavy use of fog can cause a character to disappear in a cloud of "smoke," such as the Wicked Witch of the West in *The Wizard of Oz*. This range of effects is available from one machine if it has a provision for varying the output.

All heated fog machines convert fluid (glycol/water solution or mineral oil) to fog very efficiently. The machines are designed so that a light haze can be maintained for an entire performance without replenishing the fluid supply. When more fluid is needed, refilling a machine is a quick, simple task. Many manufacturers also offer automated systems for permanent installations that supply the fog fluid to individual machines from a central source.

Several accessories expand the usefulness of these technologies. If the fog is chilled after leaving the machine, the result is a low-lying fog effect similar to the traditional dry ice fog effect. Some manufacturers make chiller accessories that use cryogenic materials such as liquid carbon dioxide. See the section on cryogenic fogs for information on how to use these cold materials safely and effectively. Most manufacturers now sell timers and remote controls for their equipment. Some fog machine manufacturers offer devices to allow their machines to be controlled by DMX512 or analog lighting controllers.

Safety Guidelines

Consult the equipment manufacturer’s specifications and requirements to insure that the proper fluid is used in the equipment. Although manufacturers of fog systems and fluids may use some of the same components in their fluids, they do not necessarily have the same formulas. Likewise, each machine is designed to heat or vaporize the specific formula or formulas that the manufacturer recommends. The relationship between fog fluid composition and temperature settings and other internal features of the fog-making equipment is critical.

The relationship between machine and fluid is important since the under-heating of a specific fluid may lead to a wet fog that will leave a slippery residue on the floor in front of the machine, and the over-heating of the fluid can lead to fluid decomposition. This decomposition or burning of the fog fluid may create harmful byproducts. Using the wrong fluid may also ruin the fog machine.

Do not modify or bypass the thermostat. Most fog machines are designed with thermostats that maintain the tight range of temperatures needed to achieve optimum fog production without over- or under-heating the fluid. In choosing a fog machine, make sure that it is equipped with a thermal cut-off device that will prevent overheating if the primary thermostat fails.

Never alter the contents of a fog fluid. People frequently ask if it is possible to make the fog appear colored by adding pigment or dye to the fog fluid. The answer is, "No." The heated adulterants may be unsafe to breathe. Also, adulterants could clog or damage the machine. Fog looks white because it reflects the light shining on it. If the light is white, the fog will reflect white. If the light is colored, the fog will be colored.

Never add perfumes or other scents to the fog fluid, unless recommended by the manufacturer. If you wish to have a scent present in conjunction with a fog effect, you should consult the manufacturer of your machine for recommendations.

Do not use contaminated fluids. If your fluid contains foreign substances, the contaminants may clog or damage the machine, and may be propelled into the air. The heated contaminants may be unsafe to breathe.

Beware of slippery residues. The use of fog machines can lead to a slow build up of slippery residue that is particularly noticeable on metal surfaces and sealed concrete floors. Care should be taken to insure that dangerous build-up does not occur on trusses, catwalks, stairways, or anywhere else where there is a slipping hazard. The residue may collect in air filters and clog them.

Beware of effects on asthmatics. Persons suffering from asthma or allergic sensitivity may experience irritation, discomfort, or allergic symptoms when exposed to any aerosol such as heated fog effects. Accordingly, manufacturers' literature should be consulted for specific health cautions before using equipment and fluids.

Provide for quick access to all fog machines. The small size of heated fog machines may tempt you to build one into scenery. If you do so, be sure that the machine can be quickly accessed in an emergency. Remember that some components in the fog machine get hot and adequate ventilation must be provided to prevent overheating. Normal fire safety precautions must be observed.

Use a clean machine. Most heated fog machines require periodic cleaning. If such cleaning is recommended in your owner's manual, follow the manufacturer's instructions.

Limit exposure. There are exposure standards for the fluids used in most fog fluids. Do not exceed those exposure standards. There are also standards for the maximum amount of carbon dioxide permissible in the air and for the minimum amount of oxygen. Do not go beyond those limits.

Toxicity: The chemicals used to make heated fogs have fairly low toxicity, but there are recognized exposure limits for them. One of the most important standards setting limits for theatrical fog is ANSI E1.5, Entertainment Technology — Theatrical Fog Made With Aqueous Solutions Of Di- And Trihydric Alcohols, which draws on studies of the effects of fogs on Broadway performers. It is designed to protect performers from even slight irritation effects, and sets exposure limits for theatrical fogs made with fluids containing triethylene glycol, monopropylene glycol, diethylene glycol, dipropylene glycol, 1,2-butylene glycol, 1,3-butylene glycol, or glycerin. The exposure limits in E1.5 for all the glycols is a peak exposure limit of 40 milligrams per cubic meter of air (mg/m^3) and a time-weighted exposure limit (TWA) for an eight-hour day of 10 mg/m^3. "Peak exposure" means that the level is never supposed to go above this level, not even for a short period of time. Glycerin has a peak exposure limit of 50 mg/m^3 and a TWA limit of 10 mg/m^3.

In addition to the ANSI E1.5 standard for theatrical fogs, there are exposure standards for some of the chemicals based on their use in general industry. In the United Kingdom, propylene glycol has an Occupational Exposure Standard (OES) of 470 mg/m^3 total, with a limit of 10 mg/m^3 for the particulate component. Diethylene glycol has an exposure standard of 100 mg/m^3 , and for glycerin the standard is 10 mg/m^3 . In the US, OSHA has set a Permissible Exposure Limit (PEL) for glycerin of 10 mg/m^3 . Highly refined mineral oil in both the UK and US has an exposure limit of 5 mg/m^3. These limits are time-weighted averages over an eight-hour workday. Normal, healthy workers can be expected to work in atmospheres up to these limits without ill effects. Many Actors' Equity contracts in the United States also specify a peak exposure limit of 25 mg/m^3 for mineral oil.

To comply with any of these exposure standards, you need to know what is in the fog fluid you are using. The easiest way to find out what is in a fog fluid is to consult the Safety Data Sheets (formerly known as Material Safety Data Sheets or MSDSs). You should always ask for an SDS when you buy any product containing chemicals. If you receive one, you should read it, and keep a copy handy. If you do not receive an SDS and are told that one is not required because the product contains no hazardous chemicals, do not be alarmed because this may be true. However, you should be very wary of any dealer or manufacturer that does not know what an SDS is, that gives some other explanation for why one is not available if one is not, or that belittles your request for one. If an SDS is not available, ask for other documentation that identifies what is in the fog fluid. It is impossible to be sure that you comply with any exposure standards without this information.

Mechanical Fogs

There are four mechanical methods for making fog: pressurized water, crackers, sprayers, and ultrasonic. All these methods have the common theme that heating or cooling is not used and that some mechanical process is used to break the fluid into small droplets in the air.

Pressurized water fog generation was originally developed by Tom Mee II (a cloud physicist) in 1969 to create a permanent cloud for the Pavilion of the Clouds at the Expo ’70 World’s Fair in Osaka, Japan. This technology has been enhanced since then into a commercial product with applications in many industries besides the entertainment industry. It is used in many situations where humidity, static electricity, and temperature must be controlled. There are now many companies offering pressurized water systems.

Cracker fog technology was developed in the 1960s as an improvement over previous fog-making techniques based on mineral oil. Previously, mineral oil haze had been generated by dropping the oil on a hot plate, which heated the oil to just below its flash point. The development of the cracker method was considered to be a vast improvement because it uses no heat at all.

In chemistry, cracking a compound means to decompose (break down or reduce) that compound using heat. In the petroleum industry, cracking is the name given to specific parts of the oil refining process. For theatrical fogs, cracker does not describe a chemical process. These crackers work more like cracking a dinner plate; they break the fluid into small droplets.

The fluid used in crackers is usually high-grade mineral oil. The main advantage of mineral oil is its extremely low rate of evaporation, which results in a persistent fog. Mineral oil also has the advantage that it produces an odorless, pure white fog. There also are so-called “water crackers” that use the same methodology, but crack a glycol-based fluid instead of mineral oil.

Sprayer fog technology is another technology that uses high-grade mineral oil or pure glycol to produce a very fine haze. Jim Gill was considered for a Technical Achievement Award for this process by the Academy of Motion Picture Arts and Sciences. The machines are compact and self-contained, and are among the most popular forms of haze machines.

Ultrasonic fog generation is the latest invention in fog technologies. For several years, the use of ultrasonic transducers working at very high frequencies (around 2 MHz) to throw off tiny water droplets has been well-known as a technique for room humidifiers. Around 1994, this technique was adapted to work with a glycol and water fluid formula, thus producing a fog that does not evaporate quickly.

How They Work

Pressurized water machines force water at high pressure (typically over 1,000 psi) through a tiny nozzle. In most systems this nozzle directs the water against the blunt end of a small rod. The water’s impact on the rod end breaks the stream into tiny droplets. The droplet size, and hence the way the fog floats in the air, can be controlled to some extent by varying the size of the nozzle opening and the water pressure. Usually the droplets produced are a wide variety of sizes. Those that are large enough to be categorized as a mist usually fall to the floor or ground below the nozzle while the smaller droplets float away as fog. Because of the mist that is produced by most systems, pressurized water systems are usually used where the wetness caused by the water will not be a problem. Examples of such applications are ice shows and equestrian events. In the latter case, the moisture is a positive benefit because it helps control dust from the dirt covered arena.

Crackers use a high-pressure air compressor that is attached to a dispersion system—for example, some brass fittings with tiny holes in the end— which is then placed in a tank of fog fluid. When the air comes out of these holes and breaks the surface of the fluid, tiny droplets are dispersed into the air. The aerosol produced is composed of droplets of varying sizes. Usually a haze is the desired result, so only the smallest droplets are wanted. The cracker usually has a long exit path for the haze, which often looks like a stovepipe. The larger droplets fall out of the air along this path and run back to the tank, leaving only the smallest droplets to emerge from the machine.

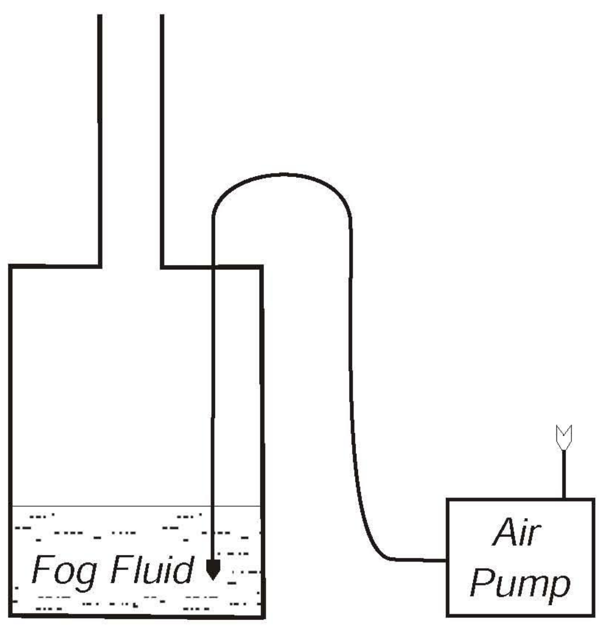

Figure 5. Cracker machine

Sprayers are small, self-contained machines that may use highly refined mineral oil or a pure glycol as the fog fluid. The fluid is mixed with air and sprayed through a very fine nozzle into a chamber. An aerosol with droplets of varying sizes is produced in the chamber. The aerosol moves from the chamber through a labyrinth in which the larger droplets tend to fall out of the air, leaving only the smallest droplets. What emerges from the machine is a fine haze. The droplets that are trapped in the labyrinth drain back into the fluid storage tank.

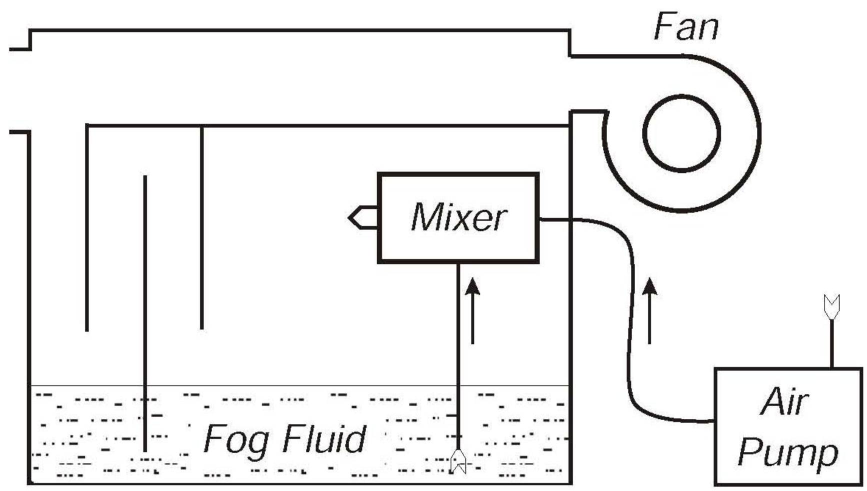

Figure 6. Sprayer machine

Ultrasonic machines use an array of ultrasonic transducers submerged just under the surface of a weak mixture of glycol and water (typically 10% to 20% glycol). The transducers break-up the fluid into tiny (1 to 10 micron) droplets that drift in the air above the fluid. The droplets are then moved out of the machine by a fan. The fog produced by this method comes out of the machine as a fine haze rather than as a dense fog.

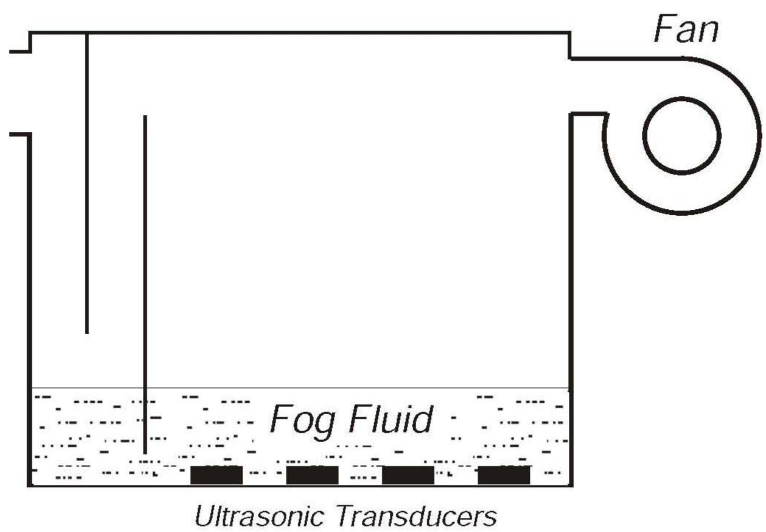

Figure 7. Ultrasonic machine

Effective Use

Fog generated by pressurized water evaporates quickly, but it easily can be made in great quantities. This has made it suitable for such diverse purposes as crop protection from frost and cooling patrons waiting in lines at summer theme parks.

Crackers, sprayers, and ultrasonic fog machines normally are used to create a fine, almost invisible, haze to enhance light beams and add dramatic atmosphere. A high-grade mineral oil or a low evaporation-rate glycol is normally used in the fluid to give the haze a long hang-time. The machines are often left running continuously during a production, set to an appropriate output level to give a constant level of haze.

Safety Guidelines

Pressurized water machines require maintenance. The water pressurization hardware may require periodic maintenance; check your owner's manual. The nozzle will be eroded by the water and must be replaced. Water, particularly moving water is abrasive and can cause significant wear on fog machine components. This makes regular inspection of fog machines imperative to insure that all parts are in safe, efficient operating condition. Learn the maintenance schedule for your fog-making equipment and follow it.

Beware of slippery residues. The use of fog machines with slow-evaporating or non-evaporating fluids can lead to a slow build up of slippery residue that is particularly noticeable on metal surfaces and sealed concrete floors. Care should be taken to insure that dangerous build-up does not occur on trusses, catwalks, stairways, or anywhere else where there is a slipping hazard. The residue also may collect in air filters and clog them. Long lasting fluids may also spread beyond the immediate stage area and may be drawn into the air filters of electronic equipment and clog them. It should be noted that newer machines are much more controlled and restrict their output to very small droplets, which helps minimize this problem.

Consult the equipment manufacturer's specifications to insure that the proper fluid is used. There are many different types of mineral oil or glycol solution, but only some are suitable for use in fog-making equipment. Your manufacturer's specifications and requirements are your best guide to obtaining the proper, safe mineral oil (or glycol solution) for your fog machine.

Do not use contaminated fluids. If your fluid is contaminated, it will make contaminated fog.

Do not add coloring agents to any fog fluid. Fog looks white because it reflects the light shining on it. If the light is white, the fog will appear white. Use colored light to create colored fog.

Limit exposure. There are exposure standards for the fluids used in most fog fluids. Do not exceed those exposure standards. There are also standards for the maximum amount of carbon dioxide permissible in the air and for the minimum amount of oxygen. Do not exceed those limits.

Toxicity: The chemicals used to make mechanical fogs have fairly low toxicity, but there are recognized exposure limits for them. One of the most important standards setting limits for theatrical fog is ANSI E1.5, Entertainment Technology — Theatrical Fog Made With Aqueous Solutions Of Di- And Trihydric Alcohols, which draws on studies of the effects of fogs on Broadway performers. It is designed to protect performers from even slight irritation effects, and sets exposure limits for theatrical fogs made with fluids containing triethylene glycol, monopropylene glycol, diethylene glycol, dipropylene glycol, 1,2-butylene glycol, 1,3-butylene glycol, or glycerin. The exposure limits in E1.5 for all the glycols is a peak exposure limit of 40 milligrams per cubic meter of air (mg/m^3) and a time-weighted exposure limit (TWA) for an eight-hour day of 10 mg/m^3. "Peak exposure" means that the level is never supposed to go above this level, not even for a short period of time. Glycerin has a peak exposure limit of 50 mg/m^3 and a TWA limit of 10 mg/m^3.

In addition to the ANSI E1.5 standard for theatrical fogs, there are exposure standards for some of the chemicals based on their use in general industry. In the United Kingdom, propylene glycol has an Occupational Exposure Standard (OES) of 470 mg/m^3 total, with a limit of 10 mg/m^3 for the particulate component. Diethylene glycol has an exposure standard of 100 mg/m^3, and for glycerin the standard is 10 mg/m^3. In the US, OSHA has set a Permissible Exposure Limit (PEL) for glycerin of 10 mg/m^3. Highly refined mineral oil in both the UK and US has an exposure limit of 5 mg/m^3. These limits are time-weighted averages over an eight-hour workday. Normal, healthy workers can be expected to work in atmospheres up to these limits without ill effects. Many Actors' Equity contracts in the United States also specify a peak exposure limit of 25 mg/m^3 for mineral oil.

To comply with any of these exposure standards, you need to know what is in the fog fluid you are using. The easiest way to find out what is in a fog fluid is to consult the Safety Data Sheet (formerly known as the Material Safety Data Sheet) for that fluid. You should always ask for an SDS when you buy any product containing chemicals. If you receive one, you should read it, and keep a copy handy. If you do not receive an SDS and are told that one is not required because the product contains no hazardous chemicals, do not be alarmed because this may be true. However, you should be very wary of any dealer or manufacturer that does not know what an SDS is, that gives some other explanation for why one is not available if one is not, or that belittles your request for one. If an SDS is not available, ask for other documentation that identifies what is in the fog fluid. It is impossible to be sure that you comply with any exposure standards without this information.

Beware of effects on asthmatics. Persons suffering from asthma or allergic sensitivity may experience irritation, discomfort, or allergic symptoms when exposed to any aerosol such as some mechanical fog effects. Accordingly, manufacturers' literature should be consulted for specific health cautions before using equipment and fluids.

Working with Fog

In order to work with fog effectively you have to understand how it interacts with light and how it moves in the air.

Lighting Fog

Fog is visible because it scatters light. However, it does not scatter light equally in all directions. When a beam of light hits a fog droplet, most of the light is scattered in a forward direction. That is, it continues in the direction it was going, but it is spread out in a wider angle than it would have been if the fog were not there. A lesser amount of the light is scattered backwards, back toward the source of the light. The angle of scatter in the backward direction is very narrow, however, so you generally don't see it unless you are almost looking straight down the path of the light beam. Little light is scattered to the sides perpendicular to the direction of travel of the light beam.

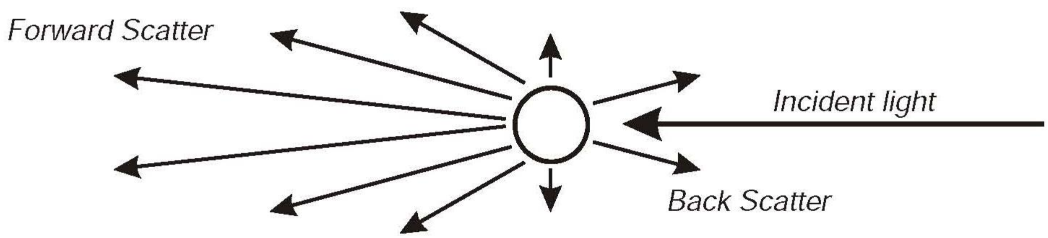

Figure 8. Fog droplet with scattering

What this means is that fog can be quite visible or almost invisible depending on the angle at which you light it. Backlight, particularly low backlight, does the most to make fog visible. Steep front light, or normal 45-degree McCandless acting area light, will not show the fog very well at all. Low front light from a footlight or balcony rail position might be useful, but it may light the fog effectively for people seated only in some parts of the theatre.

The color of the background behind the fog, and how well that background is illuminated, also can have an effect on the visibility of the fog. For example, sidelight is not a particularly good angle for lighting the fog; the audience or camera will be looking at the fog at exactly the angle at which the fog scatters the light the least. However, if the sidelighting leaves the background in darkness, the fog will show up quite well.

In any case, by working with the lighting designer to light the fog at the optimal angles, you can get the maximum effect for the minimum amount of fog. You can also use the lighting to make the fog almost disappear when it is not wanted in succeeding scenes.

Always keep in mind that you must also consider the performers and what they see as well as what the audience or camera sees. Fog is an obscurant, and you never want to use it in such a way that the performers cannot see hazards. For example, low sidelight normally makes it difficult for a performer to see where he is going when exiting the stage; fog in the air may make it completely impossible. Work with the production team to identify any potential low visibility problems and to find ways to fix them. Perhaps the fog or the lighting needs to be adjusted, or perhaps any tripping hazards immediately offstage need to be eliminated. Perhaps little LED guide lights will help the performer see the safe path. There are innumerable ways to deal with low visibility problems, but it is always good to deal with them before a performer walks into a wall or off the edge of the stage.

Note that you will find subtle differences in how fog looks under light, depending on the type of fog fluid and the type of machine used. Fog machines and fogs are not all the same. The amount of light scattering and the direction is dependent on the composition of the fog fluid, the size of the droplets, and the density of the fog. The scattering is also somewhat dependent on the color of the light. You will find that some fogs look slightly bluish when lit with white light and viewed from certain angles, and will look slightly brownish when observed from some other angles. The color differences are subtle, but they may be important for some productions. There is no substitute for experimentation and experience in picking the right fog for a particular application.

Location of Fog

Different kinds of fogs move differently in the air, and where the fog is located as opposed to where it is not located is as much a part of a fog effect as the amount of fog or how it is lighted.

Cryogenic fogs, because they are cold, produce a low-lying effect that covers the floor and usually fill no more than the bottom three feet or so of the performance space. Cryogenic fog effects can be simulated by chilling the output of a thermal machine. Many manufacturers make accessories that use dry ice, liquid carbon dioxide, or refrigeration units to cool the output of thermal machines. When the intention is to simulate dry ice or liquid nitrogen fog, a fast dissipating glycol-type fluid is used so that, as it warms and starts to rise, it disappears. Longer lasting fluids also can be used, but the effect will be different. If a longer lasting fluid is used, the fog will be discharged from the machine cold and follow the floor, but as it warms it will slowly rise. The top surface of the clouds along the floor becomes lighter with wisps of fog reaching up into the air. It's an entirely different effect but appropriate for some applications.

Note: Only use fog fluids in a machine that are approved by the fog machine manufacturer. Do not use fluid designed for one machine in another. If you need to use a particular fluid to achieve an effect, get a machine that is appropriate for that fluid.

Most heated fogs tend to rise as they leave the fog machine because they are warmer than the ambient air. As they come to room temperature, the fogs will either stay close to whatever height it has achieved, or if the droplets are large, it will start to fall. Fogs that have essentially neutral buoyancy in the air can be used to create interesting stratified effects if the air currents in the venue are carefully controlled. It is possible to discharge some heated fogs into the air several feet above the stage or studio floor and have the fog hang there like a cloud ceiling over the action below. As is the case with fog and light, there is no substitute for experimentation and experience in putting a fog in just the right place in a performance space and getting it to stay there.

A surprisingly small amount of air movement can have a dramatic effect on fog movement. Some professional special effects designers have discovered that a couple of standard window fans can clear all the fog off a stage in a matter of seconds. Small equipment cooling fans are also useful, although their effects on fog are more limited because they are smaller. In *Les Miserables*, the performers whip a fine haze into a whirling cloud simply by running around the stage in a circle.

You must pay careful attention to the air-handling system in the venue. Even though you cannot feel the presence of an air circulation system, it may be capable of pulling all the fog off the stage and into the house. Be sure to test your fog effects with the heating and cooling system running in the same way that it will be when an audience is present. You may have to add cues to turn off and restart the house air handlers.

Be aware of the effects created by patrons. Sometimes their body heat can change the building air currents and your fog effects. If at all possible, make sure that you develop your effects with an audience present, perhaps at a preview performance or at an open rehearsal. It is also useful to have someone in the house watching the fog effects so that settings backstage can be changed to compensate for the effects of the audience. The changes needed for this problem are usually minor.

Stage doors also can be a problem. The breeze from an open stage door, no matter how small, can destroy your carefully planned fog effect. Make sure everyone working on the show knows this and that you have someone who can close a door if one is accidentally left open.

Cryogenic fogs have the particular problem that they run along the floor and, in a theatre, fall off the front edge of the stage into the first row of the audience or into the orchestra pit, where they are rarely welcome. However, cryogenic fog can be kept where needed with small barriers. In a theatre, pop-up footlights can work as a dam to help keep the fog on stage and out of the pit. Scenery, such as a garland of flowers or greenery, can be laid across the front edge of the stage to create a barrier. Almost any obstruction will be a great improvement over a flat floor for keeping cryogenic fog where it is needed, and out of areas where it is not needed or not wanted.

Distribution of Fog

You may know where you want the fog to be, but you have to put it there somehow. Obviously the most efficient way to do this is to make the fog right where you need it. Sometimes this is difficult. There may not be enough room for a fog machine to be placed where the fog is needed but out of sight. Many heated fog machine manufacturers now make remote heat-exchanger heads, which can be tucked into a small space, while leaving the pump, gas bottle, fluid reservoir, and other components someplace else.

Remote heads are not always a solution, however. Sometimes these remote heads are still too large to be hidden, or the concentrated jet of fog coming from the head is not what you want the audience or camera to see. Dry ice and liquid nitrogen machines are by nature fairly large and do not lend themselves to miniaturization or separation into components.

When fog cannot be made where you need it, some kind of distribution system is required. Usually this is done by coupling a hose or duct to the output port of the fog machine. This is standard practice with dry ice and liquid nitrogen machines, and their output ports are usually designed to accept a hose. These machines also expel the fog with enough force to carry it a long way down a hose.

With heated fog machines, adding a distribution system is not so simple. For short distances a simple hose will do. However, the hose must not be put flush against the front of the machine. You must leave an air space between the hose and the machine that is about two inches (5 cm) wide so the jet of fog can pull in some cool air. If you don't leave this gap, you will get no fog out of the other end of the hose. All you will get is a hose with hot fog fluid in it. Also, the front of the machine is often hot. It is not a good idea to let a hose that might melt touch the hot machine surface.

For longer distances some kind of forced-air assistance is needed. Few manufacturers make such devices, but they can be fabricated easily. One popular design is called a "stuffer box" (Figure 9). One can be made by simply building a box with one side open and a hose or duct coupling on the other side. Rig an electric fan inside the box to blow into the hose. A squirrel cage blower or equipment cooling fan will do. Set the fog machine so that the output discharges into the open side of the box. The fan will suck the fog in and blow it down the hose or duct. Note that some of the fog will be lost as droplets hit the fan blades. An air amplifier can be used to avoid this loss. This is a device that uses a jet of compressed air to move a larger volume of air. This will require an external compressed air source however, and may not be quiet enough for some applications. A forced-air assistance device also can be used with a mechanical fog machine.

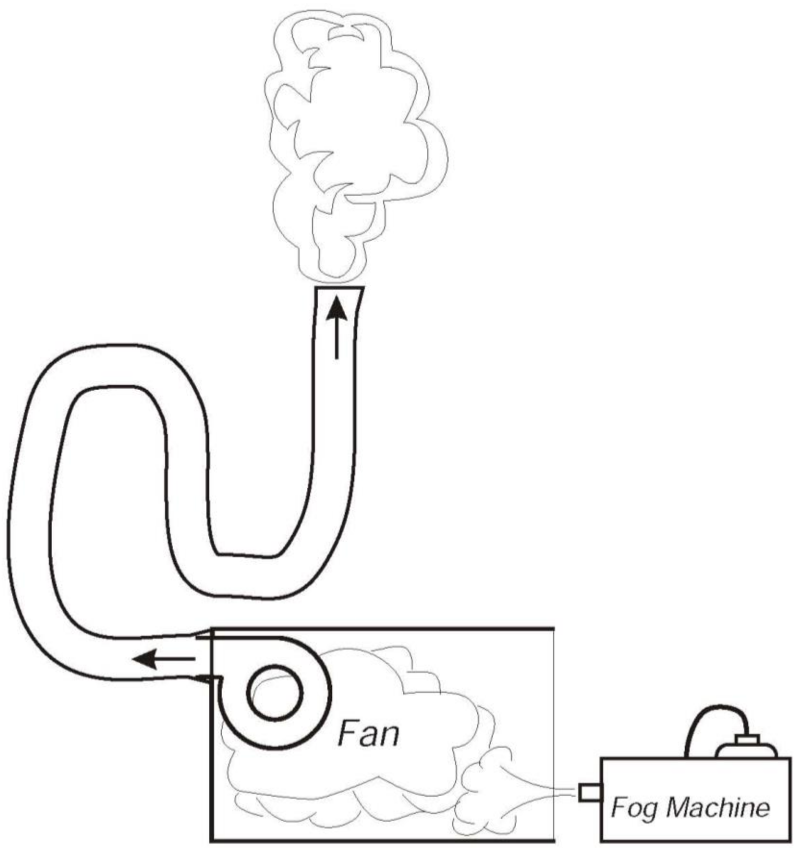

Figure 9. "Stuffer box" forced-air assistance system

Note that no fog distribution system is going to be as efficient as a fog system in which the fog is discharged directly into the space where it is needed. Some fog is going to be lost along the way. This is not a problem as long as you allow for it. You will have to make more fog than you need to allow for the loss, and you will have to deal with the fog fluid that is lost in the system. Fluid will collect on the inside of the hoses or ducting, particularly in the bottom of U-shaped bends. The accumulation is slow, but if not cleaned up or drained out you can eventually have a big mess and possibly a blocked duct.

The loss of fog fluid in a distribution system can be minimized in three ways:

- Use as smooth a ducting or hose system as possible.
- Use as straight a ducting or hose system as possible.
- Use ducts and hoses that are as large as possible.

Four-inch (10 cm) dryer hose is often used because it is cheap and readily available. Unfortunately, its wall is not smooth. The ridges in the wall make it more likely that the fog droplets will bump into the wall. When they do, they are likely to stick and make the inside of the hose wet. Whatever fluid is in the hose is lost fog. Use ridged hose as little as possible. Use smooth-walled pipe or ducting instead.

Bends in the ducting also make it more likely that the fog droplets will touch the wall and accumulate. Use as few bends as possible, and make them as gentle as possible. In particular, avoid sharp bends immediately in front of the output of the fog machine or the assistance fan. Try to make the first several feet of the ducting smooth and straight.

Use a large duct. Four-inch hose or pipe should be considered the minimum size to use. Six-inch (15 cm) or 8" (20 cm) would be better. Eight-inch ducting has twice the circumference but four times the cross-sectional area of 4" ducting. Much less fog will contact the walls and be lost.

Larger ducting also helps preserve the quality of the fog because the fog moves through the hose at a lower velocity with less turbulence. If the fog is violently agitated, the droplets are likely to touch each other and to condense into fewer, larger droplets. The fog will lose its visual density, and will float for a shorter time in the air.

Anticipate some accumulation in the ducting and plan for it. All ducting systems will accumulate some fluid, even when used with what people call "dry fog" systems. The only fog that is truly dry isn't fog at all. It's smoke.

Working with Fire Alarms

Before fog effects are used or tested, it should be determined if there are smoke detectors in the facility. Note that they are often not self-evident and may be located inside the air handling system. If they are present, personnel monitoring the system, such as a building engineer, alarm company, or fire department, must be notified. Many uses of theatrical fog will not trigger these systems but it is essential to determine this with air handling equipment in performance conditions to avoid public panic or disrupting a show. In no event should smoke detection be bypassed without following proper procedures such as those outlined in ANSI/NFPA 1126 - 2016, sections 6.4.3, 8.1.6, 8.7.6 and their subclauses.

A Little Can Go a Long Way

While there is a body of scientific research that shows that reasonable concentrations of fog are not hazardous, it is prudent to minimize exposures by such means as relocating fog machines to avoid exposing people to direct, concentrated release of fog and minimizing the amount of fog necessary for a production. Even if the fog is absolutely safe, if it annoys or distracts the performers, or if it makes it difficult for the performers to see what they are doing, it hurts the show. In any case, performers moving through the fog discharges can push the fog in directions you do not want it to go, making the job of controlling the fog's location more difficult. Position the fog machine outlets so that they do not blow directly onto performers or onto sensitive equipment.

If all you want is to make the light beams visible, a very light fog of the correct type in the right place is sufficient. Although managing the air movement in a venue might seem like a lot of work, doing the work can have substantial benefits. If you can hold a small amount of fog in place for one scene, then clearing the fog for the next fog-free scene will be much simpler. If a little bit of fog is good, a lot of fog is not necessarily better.

Controlling Exposure

There are situations in which the strategy of using as little fog as will achieve the desired effect is simply not precise enough. Examples of some of these situations would include:

- when people are exposed to the fog repeatedly over a long period of time, as staff working a theme park attraction might.
- when you have a contractual obligation to limit people's exposure, as you probably will have when doing a show under an Actors' Equity contract.

- when you have a performer or technician who is particularly sensitive to the fog—or is simply very worried about it.

In any of these cases and others, it is prudent to take steps to keep the fog exposure below whatever maximum level is permissible for the situation, and to do this in a way that can be documented and explained to others.

Types of limits

There are three different types of limits:

- Peak or ceiling limit. This is not to be exceeded, not even for a moment.
- STEL: Short Term Exposure Limit. The maximum exposure level averaged over a short term, generally 15 minutes.
- TWA Limits. Time Weighted Average exposure averaged over period of time, generally an 8-hour period.

TWA Limits are normally given for an eight-hour work-day in a 40 hour work-week. That is, the limits are set assuming that a person will be exposed to the fog for no more than eight hours a day, leaving the other 16 hours of the day fog-free. Likewise with the work-week limit: the assumption is that the fog exposure will be no more than 40 hours out of a 168-hour week. Usually people working on theatrical shows that have opened and are running will not exceed these time limits, but they might during long technical rehearsals. People working in motion picture production are more likely to exceed these time limits because motion pictures are often shot over a few very long work-days.

In any case, where a person's exposure time is more than eight hours a day or more than 40 hours a week, the TWA Limit given for an eight-hour day must be adjusted. If someone is exposed to the fog for longer than that, for example for 12 hours during the work-day, the TWA limits would have to be reduced to half their eight-hour values. The calculations are simple, or a table can be used. The calculations and table for adjusting TWA Limits for longer exposures can be found in “Adjusting TWAs for Long Shifts” available on the ESTA Technical Standards Program website (http://tsp.esta.org/) by clicking “Fog Testing Protocols” under QUICK LINKS in the lower right of the TSP homepage.

Monitoring exposures

The two limits most often of concern for the fog droplets and that need monitoring are the peak or ceiling limits, and TWA (long-term exposure) limits. The limits most often of concern with effects that use nitrogen or carbon dioxide are the STEL and TWA Limits.

There are basically three ways of monitoring fog exposure:

1. Time and distance guidelines
2. Meters
3. Calculation

All three work for exposure to the chemicals in fog droplets. The second works for monitoring gas levels and identifying excessive carbon dioxide exposure or oxygen deficiency.

Time and distance guidelines

Time and distance guidelines are a simple way to make sure that people are not exposed to fog above the peak or ceiling limits. They essentially say that for a given fluid in a given machine, if a person is more than a certain distance away from the machine's nozzle, the person will not be exposed to levels above the peak or ceiling limits. The method does not tell you what the actual exposure is; it is simply a tool to help you make sure the exposure is not above the limit.

A table might look like this (note that this is an example only, and should not be used):

Summary of Time-and-Distance Guidelines for Fog Generation with Way-Cool Fogger and Way-Cool Glycol Fog Fluid							
Release Duration (secs)	Fan Speed	Output Setting	Time (in sec) after Which Air Concentrations are Below Guidance Level (40 mg/m^3)				
			5 ft	10 ft	15 ft	20 ft	25 ft
30	100	100	10	10	0	0	0
60	100	100	20	20	0	0	0
120	100	100	30	30	30	30	30
30	100	65	20	20	0	0	0
60	100	65	20	20	0	0	0
120	100	65	30	30	30	0	0

The 40 mg/m^3 is the ceiling limit for glycol fog written into Equity contracts—and it is the peak limit written into ANSI E1.5, which has broader application than the Equity contracts. Other ceiling limits embodied in these tables are 50 mg/m^3 for glycerin fogs (which also is the same as in ANSI E1.5), and 25 mg/m^3 for mineral oil fogs.

This table says that if you have a performer standing 15 feet away from the machine that releases a 30-second fog blast, the performer will not be exposed to levels above the 40 mg/m^3 ceiling. If the fog blast lasts 120 seconds, the fog will have dissipated enough 30 seconds after the end of the blast that the performer can stand 15 feet in front—but not until 30 seconds have passed. The table does not tell you what the exposure will be, only that it will not be too high.

Time and distance guidelines document can be found on the Actors' Equity website (https://www.actorsequity.org/). Look for it under “Resources,” “Resources for Producers,” 'Safe & Sanitary Workplaces,” “Theatrical Smoke and Haze Regulations.” The guidelines are offered as a tool to help producers meet their contractual obligations. Sometimes people look at the guidelines as an “Equity approved” list. It's not. Actors' Equity does not approve fog machines and fog fluids, but they do try to help people to take care of Equity's members; the time and distance guidelines are a tool to help.

Limitations of time and distance guidelines

These guidelines are easy to follow and work for simple fog effects, such as a “puff of smoke” for a magic trick. However, they assume that the air is clear before the fog effect and that there will be time for the air to clear after it, before the next fog effect; the method doesn't work if there are multiple fog effects or atmospheric haze.

The time and distance guidelines are relevant to making sure that ceiling or peak limits are not exceeded. They do not address concerns about TWA exposures over several hours. Furthermore, the guidelines are for particular machines with particular fluids. Many machine-fluid combinations are not listed. This limitation is not unique to the time and distance guidelines, but the time and distance guidelines are a particularly limited list.

Aerosol meters

Another method to monitor glycol, glycerin, and mineral oil exposure is to use portable aerosol meters. Meters are good tools when there are multiple sources of fog or the fog tends to stay in the air from one fog cue to the next. An aerosol meter will give a real-time reading of the concentration of the fog droplets in the air—good for monitoring ceiling limits—and will give a time-weighted average reading over the time period that the meter is turned on and taking readings. Those are useful for making sure that long-term, TWA limits are not exceeded. Meters give you real measurements, not simply an okay/not okay verdict.

An aerosol meter measures the chemical concentrations in the air by measuring the light scattering caused by the fog; it gives the readings in milligrams per cubic meter, assuming that the fog in the air is a standardized kind of dust. Fog isn't dust, of course, so the readings must be multiplied by a calibration factor that is specific to the fog machine and fluid being used.

A table of calibration factors recognized by Actors' Equity for use with a 1000 pDR AN aerosol meter is available on the Actors' Equity website (https://www.actorsequity.org/) on the “Theatrical Smoke and Haze Regulations” page. A table of calibration factors for the 1000 pDR AN and instructions for taking the measurements with that meter is available on the ESTA Technical Standards Program website (http://tsp.esta.org/) by clicking “Fog Testing Protocols” under QUICK LINKS in the lower right of the homepage.

Limitations of aerosol meters

Calibration factors are available for many machine/fluid combinations on the market, but not all of them. If you have a machine/fluid for which there is no calibration factor, you cannot take a meaningful reading with a meter. Doing the testing needed to arrive at an appropriate calibration factor is neither cheap nor easy, so calibration factors do not exist for all machine/fluid combinations.

The calibration factors that are widely published are for use with the 1000 pDR AN aerosol meter. This has been a standard meter in the industrial hygiene industry for years, but it is no longer state-of-the-art. Newer meters are available and are being used by industrial hygienists with theatrical fog. Calibration factors for them are being developed, but they have not yet been published. Also, Actors' Equity Contracts do not accept readings from other meters yet. The Fog Testing Protocols page on the ESTA TSP website will be updated when those calibration factors are available.

Calculations based on fluid consumption and space

According to ANSI E1.23, Entertainment Technology - Design and Execution of Theatrical Fog Effects, calculating time-weighted average exposure levels from the quantity of fluid used over an interval of time and the volume of the venue is permissible if the fog effect is an evenly distributed fog or haze and no one is ever in the visible plume from the fog effect machine. That is, this method is not appropriate for any fog effect where there is a cloud produced where there are people, but it is appropriate when a haze machine is positioned out of the way, perhaps up on a catwalk, and the haze is evenly distributed before it enters the playing space or auditorium.

The method is simple. Generally with haze effects, after the haze machine is turned on, the haze builds and then stabilizes at some visible level. The milligrams of glycol, glycerin, or mineral oil in the fluid used to achieve that level divided by the volume of the venue in cubic meters will give an average milligrams per cubic meter concentration.

For example, assume a black box theatre, 52 feet square and 26 feet tall inside, for a volume of 70,304 cubic feet, which is 1,991 cubic meters. Assume a haze machine will fill this space with an evenly distributed haze in about 20 minutes, and in the process consume 125 ml of haze fluid. Also assume that the haze fluid used is 6% glycerin and 94% water, so the amount of glycerin used in 20 minutes is 7.5 ml, which with a glycerin density of 1.26 g/ml, is 9,450 milligrams.

$$\text{Concentration} = 9{,}450 \text{ mg} / 1{,}991 \text{ m}^3$$
$$\text{Concentration} = 4.75 \text{ mg/m}^3$$

The actual concentration will be lower than this because some of the haze droplets will have disappeared out doors and become stuck on people, walls, curtains, floor, and furniture. However the calculations tell us that the concentration cannot be above this because only this much glycerin was put into the room. The calculated 4.75 mg/m^3 is well below the 50 mg/m^3 ceiling limit for glycerin and less than half the TWA Limit. We don't know exactly what the exposure would be for people within this space, but we know it is within safe limits.

Limitations of the calculations method

The method is simple, requiring only some measurements and simple math. However, it has limitations:

- It is only effective for haze or fog that is evenly distributed throughout a venue. It does not tell you what the concentration is in the fog plume coming out of the machine, so it doesn't help you protect anyone in that plume.
- You have to know the composition of the fluid you are using—not simply what chemicals are in it, but also the proportions. That is often proprietary information. The mixture used above in the example, is only an example, and is not necessarily representative of the composition of real haze fluids.

Monitoring gas exposure

Portable meters are used to measure carbon dioxide and oxygen levels in fog effects that add carbon dioxide or nitrogen to the air in a performance space—the latter possibly diluting the air to the point where oxygen levels are too low.

Carbon dioxide

The OSHA permissible exposure limit (PEL) time-weighted average (TWA) for acceptable exposure over an 8-hour workday and the HSC occupational exposure standard (OES) for CO_2 is 5000 parts per million, or 0.5%. Rarely is there an 8-hour dry ice or other carbon dioxide fog effect, although this limit can be important in places where dry ice or dewars of carbon dioxide are stored, and where show personnel are under the stage. Carbon dioxide is heavier than air and will collect in low-lying areas, such as trap rooms and orchestra pits.

Fog effects more often bump against the STEL for carbon dioxide. In the U.S. CO_2 also has a STEL for no more than 15 minutes of 30,000 ppm (3%), while the short term limit in the U.K. is 1.5%. Carbon dioxide is weakly narcotic at 3%, causing reduced hearing acuity, increased pulse rate and blood pressure, and impaired coordination and judgment. Levels above 7% can cause unconsciousness in a few minutes. High carbon dioxide levels can cause death.

Oxygen

The atmosphere is normally about 21% oxygen (O_2). Nitrogen can be added to the atmosphere until the oxygen level falls to 19.5%, according to OSHA regulations in the U.S., or to 18% according to HSE guidelines in the U.K. Breathing air with reduced levels of oxygen causes impaired coordination and judgment, so these minimum levels are set to avoid accidents. Lower levels of oxygen, besides increasing the risk of accident, can lead to unconsciousness. Extremely low oxygen levels can cause death.

Using meters

Portable meters are available for measuring carbon dioxide and oxygen levels. They are not particularly expensive and are not difficult to use. Carbon dioxide meters are particularly easy to obtain, since carbon dioxide is a byproduct of many industries, such as beer and wine brewing, and carbon dioxide is sometimes used as an indicator of indoor air quality.

Testing protocols for carbon dioxide and oxygen meters can be found on the ESTA Technical Standards Program website (http://tsp.esta.org/) on the "Fog Testing Protocols" page. Click the link on the lower right of the homepage.

Limitations of gas meters

They are simple to use, but there are a few caveats when selecting a meter.

For a **carbon dioxide meter**, use one that will read well above the 3% STEL. Many meters are made to help keep a workplace to within the 0.5% TWA limit and do not read much higher. A low-lying dry ice fog effect is likely to exceed 0.5% by a wide margin; the meter is useless if it maxes out before it can give you a real reading.

Oxygen meters often use sensing elements that have a finite life when exposed to oxygen—and they are exposed to oxygen all the time, unless you store the meters in an inert atmosphere. Check the meter to make sure it is working before you need it. If you buy a meter, plan to replace the sensor at regular intervals—or plan to simply rent a meter when you need it.

Technology summary table

A quick review of the fog-making technologies described in this book:

Machine type	Key ingredients	Typical uses	Cautions: Adverse conditions that may occur in certain situations	See pages
Cracker	Mineral oil	Haze-accentuated light beams	Slippery residue with prolonged use. Residue build-up in air filters.	22
Cracker	Glycol with water	Haze-accentuated light beams	Slippery residue with prolonged use. Possible irritation reactions. Residue build-up in air filters.	22
Cryogenic burst	Liquid nitrogen or liquid carbon dioxide	Varied	Oxygen deficiency. Cryogen handling.	13
Dry ice & hot water	Dry ice	Ground cover	Slick. Liquid accumulation at output. Oxygen deficiency. Cryogen handling. CO2 toxicity.	10-12
Heated, pressurized gas	Glycol with water or mineral oil alone	Varied	Slick. Liquid accumulation at output. Possible irritation reactions.	17-18
Heated, pump or compressed air	Glycol with water	Varied	Slick. Liquid accumulation at output. Possible irritation reactions.	16-17
High pressure water	Water	Varied	Wetness from large droplets. Fallout. Liquid accumulation.	22
Liquid nitrogen & hot water	Liquid nitrogen	Ground cover	Slick. Liquid accumulation at output. Oxygen deficiency. Cryogen handling.	10, 12-13
Liquid synthetic air & hot water	Liquid synthetic air	Ground cover	Slick. Liquid accumulation at output. Cryogen handling.	10
Sprayer	Mineral oil	Haze-accentuated light beams	Slippery residue with prolonged use. Residue build-up in air filters.	23-25
Sprayer	Glycol	Haze-accentuated light beams	Slippery residue with prolonged use. Possible irritation reactions. Residue build-up in air filters.	23-25
Ultrasonic	Water with glycol	Haze-accentuated light beams	Slick. Liquid accumulation at output. Possible irritation reactions.	25

Glossary

Aerosol: a suspension of fine droplets or particles in a gas.

Carbon dioxide: a colorless, odorless, non-flammable gas that is present in air and produced by human breathing. In solid form, carbon dioxide is called dry ice.

Cracker: a fog machine that generates a haze by blowing pressurized air through an open vessel of fog fluid, typically mineral oil or a glycol/water mixture.

Cryogen: a substance for producing low temperatures.

Dry ice: frozen carbon dioxide (nominal temperature –80°C), an effective cryogen.

Fog: a mixture of liquid droplets in air that reduces visibility and reflects light.

Fume: a suspension of particles in a gas.

Glycerin: An alcohol composed of a chain of three carbon atoms, with each carbon atom linked to one hydroxyl group.

Glycol: an alcohol with a molecular structure having two hydroxyl groups. Common grain and wood alcohols have one hydroxyl group, while glycerin has three.

HSC: Health and Safety Commission, the organization in the UK that sets occupational exposure limits for certain chemicals.

HSE: Health and Safety Executive, the governmental organization in the UK that develops health and safety laws and standards, and enforces them.

Hang-time: the length of time that a fog stays in the air without dissipating.

Haze: an accumulation in the atmosphere of very fine, widely dispersed, solid or liquid particles giving the air an opalescent appearance.

Hydroxyl group: a molecular group containing one hydrogen and one oxygen atom.

Liquid synthetic air: a homogeneous mixture of liquid nitrogen and liquid oxygen that produces a gaseous mixture with a ratio of nitrogen and oxygen identical to the ratio in the atmosphere.

MHz: megahertz, one million cycles per second.

Mist: fine droplets of moisture in the air, not as dense as fog, but often of larger size.

MSDS: A Material Safety Data Sheet is a printed document that alerts anyone handling or using a product to the presence of any hazardous chemicals in the product and tells them of any specific cautions concerning the chemicals. Now called a "Safety Data Sheet."

Nitrogen: a colorless, odorless, non-flammable, gaseous element that constitutes about 78% of the volume of the atmosphere. When cooled to –198°C, it becomes a liquid and an effective cryogen.

OES: Occupational Exposure Standards, are exposure limits set in the United Kingdom by the Health and Safety Commission. They are similar in purpose to the standards set by OSHA, and are also limits based on a time-weighted average over an 8-hour workday.

OSHA: The Occupational Safety and Health Administration, a division of the United States Department of Labor, that is responsible for workplace safety.

Oxygen: Oxygen is a colorless, odorless element, which constitutes about 21% of the atmosphere by volume. Oxygen is a gas above -198□ C and is necessary for human respiration. Oxygen is also primarily responsible for combustion or burning. In the US, required oxygen concentration levels are set by OSHA to be above 19.5%.

PEL: Permissible Exposure Limit, an exposure limit set by the Occupational Safety and Health Administration in the United States. PELs are normally time-weighted averages, based on an 8-hour workday. They are exposure levels that a worker can be exposed to for up to eight hours a day, every workday, and not be expected to become ill from the exposure.

SDS: A Safety Data Sheet is a printed document that alerts anyone handling or using a product to the presence of any hazardous chemicals in the product and tells them of any specific cautions concerning the chemicals. Formerly called "Material Data Sheet."

Smoke: small, solid particles produced by burning and dispersed in the air. In the context of atmospheric effects, "smoke" is used to refer to any aerosol made of solid particles rather than liquid droplets.

STEL: Short Term Exposure Limit. The maximum exposure level averaged over a short term, generally 15 minutes.

TLV-TWA: (Threshold Limit Value-Time Weighted Average) This is a standard means for stating acceptable exposure to a chemical over an 8-hour workday, 40 hours a week. TLVs are set by the American Conference of Governmental Industrial Hygienists, Inc.

TWA: Time Weighted Average. Exposure level averaged over period of time, generally an 8-hour period.

Toxic: acting as or having the effect of a substance with an inherent property that tends to destroy life or impair health.

Transducer: a device that transfers power from one system to another system, usually in another form. In the context of ultrasonic fog-making machines, a transducer is the device in the machine that converts electricity in the machine's circuitry to ultrasonic waves in the fog fluid.

Ultrasonic: frequencies that are beyond the normal human auditory limit, that is, above 20,000 Hz.

Vapor: a substance in a gaseous state as opposed to a liquid or solid state. In common speech, "vapor" is often used to describe any smoke or fog. However, in the context of atmospheric effects, where it is important to distinguish between fogs, fumes, smokes, and gases, it is important to limit the meaning to the more restrictive definition of the term.

Vaporize: to cause to change into a vapor (fog, mist, steam, or visible exhalation).

Other Reading

Basic texts:

ANSI E1.5, Entertainment Technology — Theatrical Fog Made With Aqueous Solutions Of Di- And Trihydric Alcohols (current edition)

ANSI E1.14, Entertainment Technology — Recommendations for Inclusions in Fog Equipment Manuals (current edition)

ANSI E1.23, Entertainment Technology - Design and Execution of Theatrical Fog Effects (current edition)

Moline, J. M., Golden, A. L., Highland, J. H., Wilmarth, K. R., and Kao, A. S. Health Effects Evaluation Of Theatrical Smoke, Haze, And Pyrotechnics. Equity-League Pension and Health Trust Funds. June 2000. Available at http://www.equityleague.org/health/health_smokehaze.html

ANSI/NFPA 1126, Pyrotechnics Before a Proximate Audience (current edition)

Thompson, G.C. Report on Investigation into Safety of Smoke Machines. The Professional Lighting and Sound Association. November 1990.

Thompson, George. "Smoke and Fog Machines." Focal Guide to Safety in Live Performance. Butterworth-Heinemann Ltd., 1993. ISBN 0-240-51319-3.

United States National Institute for Occupational Safety and Health. Health Hazard Evaluation Report. HETA 90-355-2449. 1994.

Walne, Graham, and Joe Aveline, John Leonard and Esquire Jauchem. Effects for the Theatre. A & C Black Ltd. and Drama Book Publishers, 1995. ISBN 0-89676-136-3.

More advanced texts:

"Monograph title/HSN #: 492 for Glycerol." Revision: 960722. National Library of Medicine. Electronic. Hazardous Substances Data Bank.

"Glycerin Mist." Federal Register 54 No. 12. Rules and Regulations. January 19, 1989. 2593.

"Monograph title/HSN #:1112 for 1,4-Butanediol." Revision: 970225. National Library of Medicine. Electronic. Hazardous Substances Data Bank.

"Monograph title/HSN #:174 for Propylene Glycol." Revision: 970311. National Library of Medicine. Electronic. Hazardous Substances Data Bank.

"Monograph title/HSN #:2854 for Dipropylene Glycol." Revision: 960124. National Library of Medicine. Electronic. Hazardous Substances Data Bank.

"Monograph title/HSN #:69 for Diethylene Glycol." Revision: 970324. National Library of Medicine. Electronic. Hazardous Substances Data Bank.

"Monograph title/HSN #:898 for Triethylene Glycol." Revision: 970124. National Library of Medicine. Electronic. Hazardous Substances Data Bank.

"The Registry of Toxic Effects of Chemical Substances." U.S. Department of Health and Human Services. Electronic. National Institute for Occupational Safety and Health.

"Commercial Exploitation of Glycol Vaporizers." American Journal of Public Health 39. February 1949. 222.

ACGIH. Industrial Ventilation, A Manual of Recommended Practice. 21st edition. American Conference of Governmental Industrial Hygienists. Ohio, 1992.

ACGIH. Documentation of the Threshold Limit Values and Biologic Exposure Indices. Sixth Edition. American Conference of Governmental Industrial Hygienists, Inc. Ohio, 1991.

American Conference of Governmental Industrial Hygienist. Documentation of Threshold Limit Values and Biological Exposure Indices for Glycerin Mist. 6th edition. 1992. 705-706.

American Industrial Hygiene Association. Workplace Environmental Exposure Level Guide - Diethylene Glycol. Virginia, 1985.

American Industrial Hygiene Association. Workplace Environmental Exposure Level Guide - Propylene Glycol. Virginia, 1985.

Bartsch, W., G. Sponer, K. Dietmann, and G. Fuchs. "Acute Toxicity of Various Solvents in the Mouse and Rat." Arzneim-Forsch 26. 1976. 1581.

Browning, E. Toxicity and Metabolism of Industrial Solvents. New York: American Elsevier, 1965. 628, 654, 666 & 667.

Burr, G.A., R. Driscoll, and T.G. Wilcox. Health Hazard Evaluation Report No. HETA-90-0355-2449. Hazard Evaluations and Technical Assistance Branch, NIOSH, U.S. Department of Health and Human Services. 1994.

Center for Chemical Hazard Assessment. Information on Potential Occupational Hazards: Glycols. Contract No. 210-79-0030. Syracuse Research Corporation, prepared for NIOSH. February 1982.

Clayton , G.D. and F.E., ed. Patty's Industrial Hygiene and Toxicology. Volume 2F, 4th edition. New York: John Wiley & Sons, 1994. 4645-4719.

Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area. List of MAK and BAT Values 1996. Report No. 32. Deutsche Forschungsgemeinschaft. New York: VCH Publishers, Inc. 1996.

Consultech Engineering Co. Health Effects of Glycol Based Fog Used in Theatrical Productions. Prepared for Actors' Equity Association, 1995.

Crook, J.W. et al. The Acute Toxicity of Polyethylene Glycol 200 in Laboratory Animals. Chemical Systems Laboratory Report ARCSL-TR-81058. U.S. Army Armament Research and Development Command, Aberdeen Proving Ground. Maryland, October 1981.

Crook, J.W. et al. The Subchronic Inhalation Toxicity of Polyethylene Glycol 200 in the Rat and Mouse. Chemical Systems Laboratory Report ARCSL-TR-81051. U.S. Army Armament Research and Development Command, Aberdeen Proving Ground. Maryland, December 1981.

Deichmann, W. "Glycerol -- Behavior in the Animal Organism (A review of the Literature)" Industrial Medicine. 9. 1940. 58-67.

Desai, L.S. Effect of Inhalation Exposure using Atmospheres' Fluid. Toxicon Report 90G-0161. Toxicon. Performed for High End Systems, Inc. MA., February 1990.

Ellenhorn, M.J. and D. G. Barceloux. Medical Toxicology. 1st edition. New York: Elsevier, 1988.

Ellenhorn, M.J. Editor. Ellenhorn's Medical Toxicology: Diagnosis and Treatment of Human Poisoning. Williams and Wilkins, 1997. 1157-59.

Fitzhugh, O.G. and A.A. Nelson. Comparison of the Chronic Toxicity of Triethylene Glycol With That Of Diethylene Glycol. 1946. 28, 40-43.

Gaunt, I.F., and Carpanini, F.M.B. "Long-term Toxicity of Propylene Glycol in Rats." Food and Cosmetic Toxicology 10. 1972. 151-162.

Gosselin, R.E., R.P. Smith, and H.C. Hodge. Clinical Toxicology of Commercial Products. 5th edition. Williams and Wilkins, 1984. 178.

Gosselin, R.E., R.P. Smith, H.C. Hodge and M.N. Gleason. Clinical Toxicology of Commercial Products. 4th edition. Williams and Wilkins, 1976. 119 and 147.

Grant, W.M., and J.S. Schuman, ed. Toxicology of the Eye. 4th edition. Springfield: Charles C. Thomas, 1993. 551, 1209 and 1460.

Grant, W.M. Toxicology of the Eye. 3rd edition. Charles C. Thomas, 1986. 162, 769 and 945.

Hamburger Jr., M.; T.T. Puck; T. Theodore; and O.H. Robertson. "The Effect of Triethylene Glycol Vapor on Air-borne Beta Hemolytic Streptococci in Hospital Wards. " Journal of Infectious Diseases. 76. 1945. 208-215.

Hamburger Jr., M.; V. Hurst;O.H. Robertson; and T.T. Puck. “The Effect of Triethylene Glycol Vapor on Air-borne Beta Hemolytic Streptococci in Hospital Wards, III.” Journal of Infectious Disease 77. 1945. 177.

Hanzlik, P.J., H.W. Newman, W. Van Winkle Jr., A.J. Lehman, and N.K. Kennedy. Toxicity, Fats and Excretion of Propylene Glycol and Some other Glycols.

Hardman,J.G. and L.E. Limbird ed. Goodman and Gilman's, The Pharmacological Basis of Therapeutics. 9th edition. McGraw-Hill, 1996. 1682-83.

Hendricks, N.V. et al. “A Review of Exposures to Oil Mist.” Arch. Env. Hlth 4. 1962. 139.

High End Systems, Inc. and Lightwave Research. Material Safety Data Sheet for Atmospheres HQ Light Enhancement Fluid. Texas, 1 July 1995.

International Agency for Research on Cancer. Monograph on the Evaluation of the Carcinogenic Risk of Chemicals to Man: Some Monomers, Plastics and Synthetic Elastomers, and Acrolein. Volume 19. France: World Health Organization, 1979. 579-594

International Labour Office. Encyclopedia of Occupational Health and Safety. Geneva: International Labour Office, 1983. 975

International Labour Office. Encyclopedia of Occupational Health and Safety. New York: McGraw-Hill, 1971. 620.

Kaassen , C.D. , ed. Cassarett and Doull's Toxicology, The Basic Science of Poisons. 5th ed. New York: McGraw Hill, 1996.

Kinney, L.A., B.A. Burgess, E.F. Stula, and G.L. Kennedy Jr. "Inhalation Toxicology of 1,4-Butanediol." Inhalation Toxicology 3. 1991. 379-388.

Lewis, Richard J., Sr. Sax's Dangerous Properties of Industrial Materials. 9th Edition. Van Nostrand Reinhold. 1996.

Loosli, C.G. et al. "Control of Cross-Infections in Infants' Wards by the Use of Triethylene Glycol Vapor." American Journal of Public Health 37. 1947. 1387.

Loosli, C.G., M.H.D Smith, R.L. Gauld, O.H. Robertson, and T.T. Puck. "Control of Cross-Infections in Infants' Wards by the Use of Triethylene Glycol Vapor." American Journal of Public Health 37. 1947. 1383-98.

Lynn. S.P. Hemolysis Test-Direct Contact with Rabbit Blood using Atmospheres' Fluid. Toxicon Report 90G-0059. Toxicon. Performed for High End Systems, Inc. MA., February 1990.

Lynn. S.P. Tissue Culture-Agar Overlay Test with Atmospheres' Fluid. Toxicon Report 90G-0058. Toxicon. Performed for High End Systems, Inc. MA., February 1990.

Marks, J.G. Jr., and DeLeo. Contact and Occupational Dermatology. 2nd edition. V.A. , 1996. 156-157.

McEvoy, G.K. editor. AHFS Drug Information. 1997.

Muhly, R.L. Programmatic Life Cycle Environmental Assessment for Smoke/Obscurants - Volume 1: Fog Oil, Diesel Fuels, and Polyethylene Glycol. Environmental Assessment ARCSL-EA-83001. U.S. Army, Chemical Research & Development Center, Environmental Technology Division, Aberdeen Proving Ground. Maryland, July 1983.

National Institute for Occupational Safety and Health. NIOSH Health Hazard Evaluation Report HETA 90-0355-2449. U.S. Department of Health and Human Services. August 1994.

National Institute for Occupational Safety and Health. NIOSH Hazard Evaluation and Technical Assistance Report HETA 88-117-0000. U.S. Department of Health and Human Services. November 1988.

National Institute for Occupational Safety and Health. NIOSH Health Hazard Evaluation Report HETA 94-0130. U.S. Department of Health and Human Services. January 24, 1994.

National Institute for Occupational Safety and Health. Testimony of NIOSH on the Occupational Safety and Health Administration's Proposed Rule on Air Contaminants: 29 CFR Part 1910, Docket No. H-020. August 1, 1988. Table N2.

Ontario Ministry of Labour, Health and Safety Support Services Branch. Circular for 1,2-Propylene Glycol. Issue 5-9-84. Updated: 5-29-91.

Opdyke, D.L.J. "Triethylene Glycol." Food and Cosmetic Toxicology 17. 1979. 913-16.

Palmer, W.G. Exposure Standard for Fog Oil. U.S. Army Biomedical Research & Development Laboratory Technical Report 9010. U.S. Army Medical Research & Development Command, Fort Detrick. Maryland, November 1990.

Pasternak , G. and L. Goldfrank, eds. Case Studies in Environmental Medicine for Ethylene and Propylene Glycol Toxicity # 30. Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services. September 1993.

Patil, A., R.J. Corwell. Health Hazard Evaluation Determination. Report No. MHETA 82-006- 9002. U.S. Department of Health and Human Services, Center for Disease Control, NIOSH. August 1992.

Poldrugo, F. and O.C. Snead,. "1,4 Butanediol, Gamma-Hydroxybutyric Acid and Ethanol: Relationships and Interactions." Neuropharmacology 23, No. 1. 1984. 109-113.

Puck, T.T., M. Hamburger Jr., O.H. Robertson, and V. Hurst. "The Effect of Triethylene glycol Vapor on Airborne Beta Hemolytic Streptococci in Hospital Wards." Journal of Infectious Disease. 76. 1945. 217-26.

R.J. Lewis, ed. Hawley's Condensed Chemical Dictionary. 12th ed. New York: Van Nostrand Reinhold Co, 1993.

Reynolds, J.E.F. Martindale's, The Extra Pharmacopeia 30th edition. 1993.

Robertson, O.H., C.G. Loosli, T.T. Puck, H. Wise, H.M. Lemon, and W. Lester Jr. "Tests for the Chronic Toxicity of Propylene Glycol and Triethylene Glycol on Monkeys and Rats by Vapor Inhalation and Oral Administration." J of Pharmaceutical and Experimental Therapeutics 91. 1947. 52-76.

Sax, N.I. Dangerous Properties of Industrial Materials. 6th edition. New York: Van Nostrand Reinhold, 1984. 547.

Sax, N.I. Dangerous Properties of Industrial Materials. 5th edition. New York: Van Nostrand Reinhold, 1984. 627.

Smith, G.D. Report on Health and Safety Aspects of Smoke Generator Machines- J.E.M. Limited. Report No. GH/O311/GS/DL. NOHS. September 30, 1993.

State of California. General Industry Safety Order 5155, Airborne Contaminants. Title 8, California Code of Regulation.

Suber, R.L., R. Deskin, I. Nikiforov, X. Fouillet, and C.R.E. Goggins. "Subchronic Nose-Only Inhalation Study of Propylene Glycol in Sprague-Dawley Rats." Food and Cosmetic Toxicology 27: No. 9. 1989. 573-583.

Thienes, C., and T.J. Haley. Clinical Toxicology. 5th edition. Philadelphia : Lea and Febinger, 1972. 161.

U.S. Department of Labor. 29 CFR Part 1910, "Air Contaminants; Final Rule." Occupational Safety and Health Administration. Federal Register 54. January 19, 1989. 2462.

Von-Oettingen, W.F. "The Aliphatic Alcohols: Their Toxicity and Potential Dangers in Relation to Their Chemical Constitution and Their Fate in Metabolism." Public Health Bulletin No. 281. 1943.

Weil, G.S., M.D. Woodside, H.F. Smyth, and C.P. Carpenter. "Results of Feeding Propylene Glycol in the Diet to Dogs for Two Years." Food and Cosmetic Toxicology 9. 1971. 479-490.

Wiebe, J.P., K.J. Barr, and K.D. Buckingham "Sustained Azoospermia in Squirrel Monkey, Salmir Schureus Resulting from a Single Intratesticular Glycerol Injection." Contraception 39, No. 4. 1989. 447-457.

Wikinson, D.P. "Diethylene Glycol Poisoning." Medical Journal of Australia. August 26, 1967. 463-464.

Williams, J., J.R. Reel, J.D. George, and J.C. Lamb. “Reproductive Effects of Diethylene Glycol and Diethylene Glycol Monoethylether in Swiss CD-1 Mice Assessed by a Continuous Breeding Protocol.” Fundamental Applied Tox. 14. April, 1990. 622.

Willis, C.M., C.J.M. Stephens, and J.D. Wilkinson. "Epidermal Damage Induced by Irritants in Man: A Light and Electron Microscopic Study." Investigative Dermatology 93. 1989. 695-699.

Wills, J.H. et al. “Inhalation of Aerosolized Ethylene Glycol by Man.” Clinical Toxicology 7. 1974. 463.

Investors in Innovation

The Technical Standard Program is supported by companies and individuals who make undirected donations to the TSP. The "Investors in Innovation" at the time this edition was published include these companies and individuals:
