THE UTILIZATION OF FOG AS A THERAPEUTIC AGENT

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Humidification has long been recognized as a beneficial factor in the therapy of certain types of infections of the respiratory tract, particularly in children. The steam kettle of an earlier day provided only erratic and varying degrees of humidity, and was replaced in many hospitals by the use of a steam room which would provide more certain, and to some extent, more controllable degrees of humidity for the treatment of such respiratory disorders as laryngo-tracheo-bronchitis. Steam humidification, however, is associated with certain fundamental disadvantages, in that it may raise the environmental temperatures so high that the patient becomes not only uncomfortable, but actually embarrassed in the physiological sense when hyperthermia is already a fundamental aspect of the syndrome being treated. The high humidity oxygen tent was developed in an attempt to provide high moisture content at controlled temperatures, and it has proven to be a decided step forward in making possible the combination of humidification, oxygen therapy, and patient comfort, within a single unit (1). Its major disadvantages have been the disturbing, and at times intolerable, sense of confinement that is inevitable in a tent or a box, and the difficulty of providing adequate nursing care without at the same time disturbing both the patient and the internal environment of the patient's tent. Some of these difficulties have been overcome by the application of "cold" humidification to room-sized patient areas (2). Such units have been employed at the Hartford Hospital for the past year and a half, to provide extremely high degrees of humidification for prolonged periods of treatment without disturbance of either the patient's comfort or adequate nursing care.

These units for the therapy of disorders of the respiratory tract have been constructed by the installation of a natural fog generator in a full-sized patient room, and for these reasons have come to be known as "fog rooms." Fog consists of finely divided water droplets existing in air which is supersaturated, and is formed by the condensation of these very small air-borne droplets from the vapor state. Fog therefore differs from mists, the only other visible form of humidity, in that violent action is usually necessary to create a mist of very small droplet size from a liquid, by atomizing, by spraying, or by the escape of a dissolved gas upon release of pressure. The extremely small particle size of a fog is of some considerable clinical significance in the

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treatment of respiratory tract disorders, inasmuch as the size of the droplets determines the part of the lung they reach (3–7). Droplets that are more than 30 microns in diameter are baffled out in the trachea. Particles between 10 and 30 microns reach the terminal bronchioles, and those from 0.5 to 3 microns in diameter penetrate to the alveoli themselves. Particles that are smaller than 0.5 microns tend to enter

![Psychometric chart depicting conditions at 760 mm. Hg atmospheric pressure.](image)

the air sacs but, because of their extreme lightness, many tend to be expired at once, to no useful purpose. It must be understood that droplet size is changing constantly, becoming larger through agglomeration as the vapor is cooled, or disrupting to submicroscopic size and eventually reaching the vapor phase as the droplets are warmed.

A second aspect of fog which has great clinical importance is the fact that it is a supersaturated atmosphere, and is capable of provid-
ing more moisture in terms of grains of water per pound of dry air, than other methods of humidification in common clinical use. The term "relative humidity" has little real meaning as concerns actual moisture content, since the relative humidity of air will vary with changes of both temperature and pressure. Absolute humidity, however, expresses the number of grains by weight of water per pound of dry air, and is a figure which can remain constant despite variations in the temperature or pressure of the air; a grain of moisture being defined as a weight equal to 1/7,000 pound of water, and a pound of dry air having a specific volume of 13.33 cubic feet. A glance at the psychrometric chart (fig. 1) will serve as a graphic depiction of the differences between the moisture content of air at varying temperatures, and relative and absolute humidities at standard atmospheric pressure (8–10). The abscissa, or bottom horizontal line, represents the dry bulb temperatures as obtained by reading any standard thermometer. The total amount of moisture actually in the air is marked off on the right hand ordinate as the water content in the air in terms of grains of moisture per pound of dry air, while the saturation curve is marked off in wet bulb temperatures on the left hand ordinate. The curved lines parallel to the saturation curve are the "per cent relative humidity lines," and it can be seen that the actual moisture content of the air can vary greatly at a given relative humidity depending upon the dry bulb temperature. The same thing will be seen to be true for a saturated atmosphere, as represented by the saturation curve: a saturated atmosphere at 70 F. will hold 111 grains of moisture per pound of dry air, while it would require 290 grains of moisture per pound of dry air to produce a saturated atmosphere at body temperature. Finally, it can be seen by looking to the shaded area to the left of the saturation curve, which is the fog, or supersaturated area, that again, the actual amount of moisture in the air in terms of grains of moisture per pound of dry air, will vary in relationship to the dry bulb Fahrenheit temperature; and that the degree of supersaturation which is 100 per cent relative humidity plus moisture held in suspension, can be increased by removing heat from the air.

Therapeutic humidification by the utilization of fog thus has the important advantages that it consists of superfine particles of moisture and that it contains more actual moisture than other forms of high humidity therapy. When the fog is produced by a natural fog generator installed in a full-sized patient room, there is the additional advantage that the need of enclosing the patient in a canopy is eliminated, thus lessening the tendency toward claustrophobia and permitting nursing care without interruption of therapy. The natural fog generator (fig. 2) has harnessed steam in a new and different way by cooling, blending, and injecting it into the room atmosphere in such a manner that the objectionable heat is either removed or used to control room temperature as desired. This is accomplished by a refrigerant
circuit which consists of an over-sized copper coil with closely spaced aluminum fins. As Freon-12 circulates through this coil, controlled by a multiloulet expansion valve, it changes state from a liquid under pressure to a gas at 34 F., and, therefore, absorbs the latent heat of vaporization. This reduces the return air temperature to 50 F. and condenses its entrained moisture. The cooled return air, saturated to 100 per cent relative humidity at 50 F., discharges into the room through a plenum, where it mixes intimately with live steam at approximately ten pounds pressure, supplied through a dead-end, pressure-

Fig. 2. Functional diagram of the natural fog generator showing the distribution of air, steam, and condensate.

reducing valve. Heavy particles formed by the mixing air stream are drained away, and the remaining fine droplets are blended with the room atmosphere to create a fog of the required density. The resultant superfine particles of moisture are recirculated at the rate of one air change per minute before being swept from the room and precipitated by the cooling coil. There is not time for agglomeration and subsequent precipitation to take place within the room, and the droplets remain in the range of therapeutically useful particle size. One air change per minute has proven to be sufficient to keep larger particles entrained and the ceiling, walls, and floor dry.
The air is cooled in the evaporator coil to 50 F. and delivered in a saturated state containing 53 grains of moisture per pound of dry air in sufficient quantities to cool the room to 68 F. in the upper mixing chamber. Live sterile steam at 212 F. is added in amounts necessary to reheat the room to 75 F. In so doing, the room moisture content reaches 166 grains of moisture per pound of dry air, and a dense fog exists within the room, since, of this total moisture content of 166 grains per pound of dry air, 132 grains are in a vapor state in the air and 34 grains or 25 per cent of the 132 grains are in suspension in the air in the form of fog. Thus, the atmosphere may be said to be 25 per cent supersaturated; this is a theoretical figure, however, and, because of several factors influencing heat gained, 10 per cent excess moisture, or supersaturation, is the average obtained in the "fog room." For all practical purposes, the limit of visibility has been reached at a 10 per cent supersaturation in the temperature range of 70-75 F., and a denser fog would be undesirable since visibility would be decreased to the point at which the nursing personnel could not see the patient.

**TABLE 1**

Types of Patients Treated in "Fog Room"

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laryngo-tracheo-bronchitis</td>
<td>63</td>
</tr>
<tr>
<td>Poliomyelitis</td>
<td>20</td>
</tr>
<tr>
<td>Midbrain injury</td>
<td>5</td>
</tr>
<tr>
<td>Bronchitis or asthmatic bronchitis</td>
<td>2</td>
</tr>
<tr>
<td>Pneumonitis</td>
<td>3</td>
</tr>
<tr>
<td>Edema of larynx</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>95</td>
</tr>
</tbody>
</table>

The utilization of fog as a therapeutic agent at the Hartford Hospital has continued since February of 1955. During that time, 95 patients have been treated for varying periods of time ranging from less than a day to almost a month (table 1). The diseases treated have varied greatly with the time of year, reflecting the incidence of those diseases at certain seasons. During the summer of 1955, and into the early fall, the great majority of patients who were treated were suffering from poliomyelitis, and were placed in a respirator after a tracheotomy had been established. During the fall and winter months of last year, laryngo-tracheo-bronchitis was almost epidemic in the Hartford area, and the great majority of patients treated in the supersaturated atmosphere were children suffering from croup. Other pathological processes, which have occurred without relation to a seasonal incidence and which have been treated in the "fog room," have included tracheal edema following the removal of foreign bodies, pneumonitis, edema of the vocal cords following endotracheal anesthesia, asthmatic bronchitis, and hyperthermia owing to midbrain damage as
the result of traumatic head injury, encephalitis, or surgical intracranial intervention.

Experiences gained in the use of "cold" humidification as treatment for acute laryngo-tracheobronchitis have been particularly satisfactory, since it has been possible with this form of therapy to prevent secretions from drying, becoming tenacious, and further obstructing respiration. Furthermore, it has seemed probable that in a number of instances it has been possible to avoid performance of tracheotomy because of the therapeutic results obtained in the "fog room." The following report is illustrative:

A four-year-old white boy had been hospitalized seven times with the diagnosis of acute laryngo-tracheobronchitis since the age of two. On two of these admissions, respiratory impairment had been sufficiently severe to require the performance of tracheotomy. Early in the morning of the day of the present admission, noisy, expirational barking, and difficulty in breathing developed suddenly. Upon admission to the hospital, the patient had moaning respiration with occasional barking, the throat was moderately injected, the throat culture revealed hemolytic Staphylococcus aureus, Streptococcus viridans, pneumococci, and H. influenzae. The white blood cell count was 16,000, with 82 per cent polymorphonuclear cells. The patient was immediately placed in the "fog room," and after eighteen hours of therapy in the supersaturated atmosphere he was entirely without symptoms. Therapy was continued in the same manner for a subsequent twenty-four hour period and the patient was discharged cured two days later.

The contribution of humidification to such a satisfactory result is, of course, difficult to determine; but a number of similar experiences have served to suggest that the remarkable clinical improvements in the presence of laryngo-tracheitis are more than merely coincidental.

The importance of humidification for the patient with a tracheotomy has been impressively emphasized by the group of patients with poliomyelitis requiring care in a respirator located in the "fog room." Under normal circumstances, inspired air breathed through the nose is warmed and humidified when it reaches the bifurcation of the trachea. Its temperature is approximately 36 C. (96.8 F.) and it is 98 per cent saturated with moisture. Air breathed through a tracheotomy when it reaches the bifurcation has much the same temperature and humidity as room air. In consequence, the air takes up moisture in the bronchi and the mucous membranes become dry and the secretions become tenacious. This may be a disastrous handicap to the patient with poliomyelitis whose power to cough is impaired and in whom the crusting of secretions in the air passages may become a sinister complication. Therapy of a supersaturated atmosphere can help to prevent the formation of inerupted secretions and subsequent blockage of the bronchi.

A five-and-one-half-year-old boy was admitted to the Hartford Hospital following a four day illness owing to mild upper respiratory infection. The night prior to hospi-
talization, he complained that his ears hurt and that he had difficulty in swallowing. At the time of admission to the hospital, there was rigidity and spasm of the back muscles, the "tripod position" on sitting, and hyperactive reflexes. Rectal temperature was 101 F. Lumbar puncture revealed crystal-clear fluid containing 397 white blood cells per cubic centimeter, with 98 per cent polymorphonuclear cells. The disease progressed rapidly. Within twenty-four hours his neck muscles, particularly the sternocleidomastoids, appeared weak. On the second hospital day, the patient experienced further difficulty in swallowing, a right sided facial paralysis appeared and the knee jerks became negative. Ocular ataxia, nystagmus, and profound weakness of the neck muscles were apparent. Spotty weakness of the lower extremities and abdominal muscles developed. By the third hospital day, the patient was regurgitating fluids through his nose, all the extremities were flaccid and the patient was excessively lethargic and somnolent. Within the next few hours, neurological findings indicated rapidly shifting involvement of higher centers, in addition to the spinal weaknesses. Since respirations were becoming shallow, high tracheotomy was performed and the patient was placed in a respirator in the fog room. The use of the supersaturated atmosphere was supplemented by the injection of 5 cc. of saline into the tracheotomy tube prior to hourly suction to control the viscosity of the secretions in the trachea and bronchi. The child's progress was remarkable. The temperature returned rapidly to normal, and on the fourteenth hospital day weaning out of the respirator was begun. By the twenty-ninth hospital day, the patient had been removed from the respirator entirely. Two days later the tracheotomy tube was removed and ten days later he was transferred to an orthopedic hospital for further physiotherapy and rehabilitation.

The control of temperature provided in the fog room has proven to be a significant asset in the management of poliomyelitis, particularly when the hyperthermia inherent to the pathologic process is accentuated by high environmental temperature occurring during summer months when the disease is prevalent. The lower ambient temperature pertaining in this form of "cold" humidification facilitates loss of heat from the body. In addition, there is further loss of heat because of the flashing of extremely small particles of fog into vapor in the trachea, bronchi, and lungs, a process that requires heat of vaporization which is taken from the body.

The following clinical history serves as a dramatic example of the effectiveness of the "fog room" in combating hyperpyrexia:

A 25-year-old office worker was admitted to the hospital with a diagnosis of acute anterior poliomyelitis. On the third hospital day, because of difficulty in breathing and in swallowing, tracheotomy was performed, the patient was placed in a tank respirator and treatment was begun in the supersaturated atmosphere. The patient ran an extremely febrile course and at the time that she was placed in the "fog room" her temperature had reached 105 F. Within twenty-four hours after being placed in the "fog room" set for a temperature of 75 F., her temperature was 100 F. The patient's temperature remained in the range of 100 F. for another day, at which time, in order to make room for another extremely ill patient, she was moved out of the fog room. A dramatic change occurred in the patient's course. Within two hours her temperature had risen 2 degrees, the patient's face became deeply flushed, and she became disoriented. The patient was immediately moved back into the "fog room." During the course of the next six hours, her condition improved considerably, and her temperature fell progressively to reach 99.4 F. Her subsequent course was one of gradual but uneventful improvement and she was eventually transferred to another hospital for long-term rehabilitation.
This latter experience has been the basis for a most interesting, and unanticipated use of the "fog room." The natural fog generator can be regulated to produce a cold, relatively dry atmosphere. It has been utilized to combat hyperthermia and to produce a moderate hypothermia in neurosurgical patients suffering from midbrain damage owing to head injury, the postoperative effects of surgical intervention, and, in one instance, encephalitis of unknown etiology. The rationale has been based upon the hope that with the prevention of hyperthermia the demand for oxygen would not be increased in the presence of cerebral edema. Prolongation of life might thereby be effected and the regeneration of cerebral tissue permitted. Unfortunately, such therapy has not always proven to be life-saving; but the results to date have suggested that prolongation of life has been facilitated in several instances. This form of treatment is warranted for comatose patients, the aim being to tide them over the period of their cerebral edema during which tissue damage would be maximal if hyperpyrexia were not controlled. For this purpose the fog room provides an environmental temperature of 60 to 65°F., the hope being to reduce the patient's temperature, in conjunction with the use of chlorpromazine, to 91–92°F.

Small numbers of patients suffering from pneumonia, from bronchitis, and from asthmatic bronchitis have been treated with good results in the supersaturated atmosphere. Of particular interest to anesthesiologists, will be the use of the "fog room" in the therapy of edema of the larynx following the use of endotracheal anesthesia.

A one-year-old boy with bilateral equinovarus was admitted to the hospital for bilateral heel-cord lengthening and posterior capsulotomy. Anesthesia was induced with open drop Vinethene and ether, and, following endotracheal intubation with a no. 2 Portex endotracheal catheter, the patient was turned into the prone position and anesthesia was maintained with nitrous oxide-oxygen-ether through a Stephen-Slater non-rebreathing valve system for the duration of the one and one-half hour operation. Early in the postoperative period, about three hours after anesthesia had been terminated, evidence of laryngeal edema became apparent in the form of a croup-like cough. The patient was immediately moved into the "fog room," and during the course of the next twenty-four hours there was a gradual cessation of cough, stridor, and hoarseness. The remainder of the postoperative course was uneventful, and the patient was discharged at the end of the fifth hospital day. It was thought that the need for a tracheotomy had been obviated.

The advantages of "fog room" therapy have been numerous, but such treatment is not a panacea. The high humidity tent also is capable of producing a supersaturated atmosphere, can provide a cool environment adjustable to the patient's comfort, and in addition permits therapy with high concentrations of oxygen. Oxygen therapy in the "fog room," on the other hand, is limited to the catheter method, either intranasal or directly into the trachea in patients with tracheotomies. However, therapy in a high humidity tent is very apt to cause frightening claustrophobia in certain patients, particularly chil-
dren, and makes nursing care difficult. If the tent must be frequently opened the desired atmospheric condition is lost, and therapy is interrupted. When patients begin to improve they are intolerant of confinement in such an enclosed space. In spite of these objections the high humidity tent has its place in our therapeutic armamentarium.

The advantages of the use of the "fog room" have appeared to be fourfold. First and foremost, of course, has been the increased amount of moisture, in grains per pound of dry air, that is available for therapeutic purposes in the supersaturated atmosphere. It should be emphasized that even a supersaturated air containing 166 grains of moisture at 75 F., if allowed to reach equilibrium in the lung, has only a 58 per cent relative humidity at body temperature. In this sense, therefore, it is not that moisture is being added, so much as it is that moisture is being conserved. However, such equilibrium is not entirely reached, and many free moisture droplets are actually deposited by contact on the mucous membranes and thus saturate and soften mucous secretions. Herein lies the clinical utility of fog as a therapeutic tool.

The second great advantage of the "fog room" is the production of such high degrees of humidity at a temperature that is comfortable to the patient; the machine may be set normally for temperatures from 68–80 F. Tolerance of high humidity is increased many fold in comparison to that prevailing in an old-fashioned steam room. Furthermore, from a physiological point of view, metabolism within the organism is lower than when the room ambient temperature is as high as is necessary in the average steam room. The comfort of the patient permits continuous therapy at high humidity which could not be tolerated by the patient if it were necessary to maintain the temperature beyond the range of the comfort curve.

A third advantage of the natural fog generator has been the facilitation of nursing care. The familiar dripping walls, the puddled floor, the soaked bed clothes, and the "drowned rat" appearance of nursing personnel in a steam room are problems that are greatly minimized, and often entirely removed, with the use of the "fog room." There are still complaints from nurses that their uniforms become soggy, that their hair stiffens, and that they catch cold, but the complaints are fewer in comparison with those from persons working in steam rooms.

Finally, the air conditioning facilities which are inherent in the design of the natural fog generator as applied to a full-sized patient room, have proven to be ideal for the production of low environmental temperatures in the therapy, on a prolonged basis, of hyperthermia irrespective of cause. Such therapy constitutes a modified form of hypothermia. This use of the "fog room" was not anticipated when the apparatus was installed. Some engineering modifications were advised. The necessary changes were made for its facilitation, to provide a room temperature of 60 F. The fog room regulated at a temperature within the range of 60 to 65 F. has proven to be of value when
moderate reduction of body temperature (to as low as 92 to 93 F.) was necessary for a period of several days or more.

**Summary**

The installation of a natural fog generator in a full-sized patient room has permitted the use of a form of humidification in the therapy of certain pathologic respiratory conditions that has definite advantages over other types of therapeutic humidity. Such units, or "fog rooms," can provide a supersaturated atmosphere, at comfortable and controllable temperatures, in an area that is large enough to permit adequate nursing care and to prevent the development of a sense of claustrophobia in the patient.

Ninety-five patients have been treated, for varying periods of time ranging from less than a day to almost a month, with most promising results in terms of the beneficial effects upon reactions, inflammatory processes, or both. Sixty-three of these patients were suffering from acute laryngo-tracheo-bronchitis, 20 were poliomyelitis patients with tracheotomies, and 7 patients had miscellaneous diagnoses which included bronchitis, asthmatic bronchitis, pneumonia, and edema of the larynx.

A most interesting, and unanticipated, use of the "fog room" has been to combat hyperthermia and to produce a moderate hypothermia (91–92 F.) in 5 neurosurgical patients suffering from midbrain damage owing to head injury, the postoperative effects of surgical intervention, and, in one instance, encephalitis of unknown etiology.

**References**