PROPYLENE GLYCOL VAPOUR AS AN AIR DISINFECTANT—I

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Introduction

The work of Robertson et al. (1942 a and b) has indicated that propylene glycol vapour may prove to be a suitable agent for the routine air disinfection of occupied premises with a view to preventing transmissible respiratory tract infections. The vapour, in concentrations of from 0.02 gm. to 0.5 gm. per million ml. of air, was found in a test tank to have a marked bactericidal effect upon atomised suspensions of various respiratory pathogens; the higher concentrations produced almost immediate and complete disinfection of the air. The glycol was found to be non-toxic to rats, even on inhalation of the vapour for many months, and treated atmospheres were invisible, odourless and non-irritating.

The object of the present work was to investigate further the air disinfecting action of propylene glycol (1:2 dihydroxy propane) vapour in empty and in occupied rooms, particularly under conditions resembling those of crowded premises with poor ventilation, where, presumably, air disinfection would be most desirable. As it is to be expected that the activity and rate of inactivation of the disinfectant will be affected by the degree of ventilation, crowding, temperature and humidity, the more important tests were carried out in a crowded and practically unventilated room.

The susceptibility to disinfecting agents of air-borne organisms may differ considerably according to whether they are dust-borne, carried in saliva droplets produced by mouth-spray, or contained in droplets atomised from culture suspensions. Tests of the glycol were therefore made against naturally produced air infection, both dust-borne and droplet-spray-borne, in addition to the preliminary tests made against artificial air infection produced by atomising bacterial suspensions. Particular attention was paid throughout to the persistence of disinfecting action. In order to maintain the bacterial content of the air of occupied premises at a low level, in spite of the rapid and continuous reinfection produced by the normal mouth-spray and dust-raising activities of the occupants, it is necessary that the disinfecting process should be continuous. The disinfectant must be introduced into the air either continuously, or in single doses repeated at intervals, the length of which is determined by the time during which each dose remains effective. Tests were always made, therefore, in the presence of continuous reinfection of the air, whether this was natural or artificial. Measurements were made of the extents and durations of
disinfection following the rapid introduction into the air of single doses of different sizes. Measurements were also made of the extent of the reduction in the bacterial content of the air which was maintained by continuous vaporisation of the glycol at different rates. An attempt was made to discover the most effective and practicable dosage rate for routine use.

This work follows the investigation of air disinfection by hypochlorites carried out by Challinor (1943), and the same room was used.

**Experiments with Air Infection produced by Atomising Suspensions of *B. prodigiosum* in a Room empty except for One Person**

The room was practically unventilated and small in size—15 ft. by 14 ft. by 8 ft., that is 1700 cub. ft. in capacity. Its floor and furniture were wooden. Before each experiment it was thoroughly aired with door and window open. The air of the room was infected by continuous atomisation from an electrically driven atomiser, the "Dynalysor," of dilute suspensions, in nutrient broth, physiological saline, or distilled water, of 24-hour cultures of *B. prodigiosum*.

The bacterial content of the air was measured at intervals of two-and-a-half, five or ten minutes throughout the experiment by sampling the air, usually in 1 cub. ft. amounts, with the Bourdillon slit sampler, using nutrient agar plates, but with a slit-plate distance of 3 mm. The sampler was sited near the centre of the room with its intake 3 ft. 4 in. above the floor, and at 7 ft. from both the glycol vaporiser and the air infector, which were also 7 ft. from each other; in some experiments the instruments were rather closer. After exposure, the plates were incubated aerobically for twenty-two hours, and the number of colonies of *B. prodigiosum* on each was counted. The contamination found in each air sample is expressed in this paper as the number of bacteria-carrying particles per cubic foot of air.

The glycol was vaporised into the air directly by heat, from a metal or porcelain dish containing a little sand and heated cautiously over a naked flame. Where a single dose was put into the air, its size is expressed as the number of ml. vaporised per million ml. of air. Where continuous or intermittent dosage was carried out, the dosage rate is expressed as the number of ml. of the glycol vaporised per million ml. of air per hour.

In most experiments the glycol vapour and the bacterial particles were distributed throughout the room only by diffusion and by the air currents produced by the warm radiator in a corner of the room and by the movements of the operator. This apparently resulted in reasonably thorough mixing, for the glycol vapour in visible clouds could be seen to pass from the vaporiser and disperse throughout the room. In a few experiments an electric fan, operating continuously and blowing diagonally up through the room, was employed to ascertain if different results would be obtained with more thorough
mixing. There was indeed a more prompt disinfection at the start of vaporisation, and a more prompt reinfection afterwards, but the difference was not great.

Atomisation of the bacterial suspension was started at the beginning of each experiment, and continued throughout. The bacterial content of the air increased rapidly in the first few minutes, but soon reached an "equilibrium level"; thereafter, in the absence of disinfection, it remained about this level indefinitely, or diverged from it only slowly. Tests were made with air infection at levels ranging, in different experiments, from 20 to 950 bacterial particles per cubic foot. No propylene glycol was introduced into the air for the first twenty to

### Table I

*To show the Reductions in Air Infection (due to Continuous Atomisation of *B. prodigiosum*) which were produced by Single Vaporisations of Different Amounts of Propylene Glycol*

| Dose | Fluid | Fan | R.H. Per Cent. | Air Infection before Vaporisation | Air Infection after Vaporisation | Maximum Percentage Reduction | Duration of near Maximum Percentage Reduction |
|------|-------|-----|----------------|-----------------------------------|----------------------------------|-----------------------------|-----------------------------------------------|
| 0·02 | B     | 57  | 446            | 348                               | 22                               | 7                           |
| 0·02 | B     | 59  | 150            | 113                               | 25                               | 7                           |
| 0·02 | B     | 64  | 950            | 662                               | 75                               | 8                           |
| 0·02 | S     | 62  | 917            | 229                               | 75                               | 10                          |
| 0·02 | S     | 62  | 166            | 28                                | 83                               | 4                           |
| 0·02 | D     | 67  | 342            | 152                               | 56                               | 7                           |
| 0·02 | D     | 61  | 629            | 200                               | 68                               | 4                           |
| 0·02 | D     | 63  | 370            | 122                               | 79                               | 7                           |
| 0·05 | B     | 70  | 442            | 87                                | 85                               | 4                           |
| 0·05 | S     | 61  | 229            | 18                                | 92                               | 9                           |
| 0·05 | D     | 63  | 121            | 1                                 | 99                               | 14                          |
| 0·1  | B     | 65  | 235            | 11                                | 95                               | 7                           |
| 0·1  | B     | 58  | 182            | 1                                 | 99                               | 9                           |
| 0·1  | S     | 52  | 148            | 16                                | 89                               | 7                           |
| 0·1  | S     | 52  | 80             | 1                                 | 99                               | 10                          |
| 0·1  | S     | 69  | 20             | 0                                 | 100                              | 13                          |
| 0·1  | S     | 62  | 72             | 0                                 | 100                              | 7                           |
| 0·1  | S     | 60  | 221            | 5                                 | 98                               | 2                           |
| 0·1  | D     | 58  | 425            | 1                                 | 99                               | 14                          |
| 0·1  | D     | 57  | 412            | 6                                 | 99                               | 7                           |
| 0·2  | S     | 66  | 725            | 20                                | 97                               | 12                          |
| 0·2  | S     | 59  | 287            | 0                                 | 100                              | 13                          |
| 0·4  | S     | 55  | 134            | 1                                 | 99                               | 33                          |

Column 1: Dose expressed in number of ml. of the glycol vapourised per million ml. of air space.

Column 2: Fluid of bacterial suspension: B = broth; S = saline; D = distilled water.

"3": F signifies experiments in which electric fan was employed.

"4": R.H. signifies approximate relative humidity.

Columns 5 and 6: The degree of air infection is expressed as the number of bacterial particles per cubic foot of air.

Column 5: Average air infection during five minutes preceding vaporisation.

"6": Air infection found in least contaminated sample after vaporisation.

"7": The maximum reduction, thus found, expressed as a percentage of the value for air infection found before vaporisation.

Column 8: The duration in minutes for which a reduction, of an extent at least 80 per cent. that of the maximum, was maintained.
thirty minutes of an experiment in order that the initial rapid increase in air infection might be completed, and that the relatively stabilised level of air infection might be measured during five or ten minutes before disinfection for comparison with the subsequent reduced levels of air infection. Air sampling was continued during disinfection and after disinfection, to show how soon reinfection occurred. Wet and dry bulb thermometer readings were taken at intervals to ascertain approximately the relative humidity, for it has been shown (Wells and Zappasodi, 1943) that the humidity may greatly affect the activity of the glycol, disinfection being most apparent at relative humidities between 40 and 70 per cent. The values recorded for relative humidity are probably too high, as the thermometer readings were made in the absence of sufficient movement of the air (Challinor, 1943).

I. Tests of Single Rapid Vaporisations of the Glycol.—Doses ranging between 0·02 ml. and 0·4 ml. of the glycol per million ml. of air were completely vaporised within a period of, depending on their size, from one to four minutes. The results of some representative experiments are recorded in Table I. This shows the extent of the maximum reduction in air infection which followed vaporisation of each dose, expressed as a percentage of the average value for air infection in the five minutes preceding vaporisation. To indicate how long the disinfecting action persisted, the table also shows the time for which maximum reduction was maintained, or nearly maintained, that is, the duration of at least 80 per cent. of maximum reduction. Two of the experiments are illustrated in Fig. 1.

The results show that a single vaporisation of the glycol was followed by an immediate but transient reduction of air infection.
Maximum reduction usually occurred within five minutes after vaporisation was complete. Its extent varied from about 100 per cent. with the larger doses to about 50 per cent. with the smaller—rather more when atomised suspensions of the test organism in saline or distilled water were used than when suspensions in broth were used. A reduction as great, or nearly as great, as the maximum was seldom maintained for more than ten minutes after vaporisation of 0.1 ml. of the glycol per million ml. of air, or of smaller amounts. Disinfection, however, persisted somewhat longer after vaporisation of larger amounts, but this was accompanied by misting of the room to an extent which interfered with visibility in an objectionable manner.

It should be noted that the above findings relate to single vaporisations of the glycol completed within one to four minutes, and must not be confused with those which relate to the continuous vaporisation of the glycol at various rates over a relatively long period of time.

**TABLE II**

*To show the Reductions in Air Infection (due to Continuous Atomisation of B. prodigiosum Suspensions) which were maintained by Continuous or Intermittent Vaporisation of Propylene Glycol at Different Rates*

| Vaporisation. | 4. | 5. | 6. | 7. |
|---------------|----|----|----|----|
| 1. Rate.      | 2. Method. | 3. Period. | Average Air Infection during Ten Minutes preceding Vaporisation. | Average Air Infection during Period of Vaporisation. | Average Percentage Reduction maintained for Period of Vaporisation. |
| 0.25 | continuously | | | | |
| 0.3 | 0.1 ml./20 mins. | 1 hr. | 66 | 260 | 131 | 50 |
| 0.3 | 0.05 ml./10 mins. | 40 mins. | 64 | 373 | 106 | 72 |
| 0.6 | 0.1 ml./10 mins. | 40 mins. | 64 | 261 | 17 | 88 |
| 0.6 | 0.1 ml./10 mins. | 1 hr. | 64 | 611 | 30 | 93 |
| 0.8 | continuously | 11/10 mins. | 120 | | 3 | 94 |

Column 1: As number of ml. glycol vaporised per million ml. air per hour.

2: Where vaporisation was intermittent the size of each dose (as the number of ml. vaporised per million ml. air) and the interval between doses are given. Each single dose was completely vaporised within two to three minutes.

Columns 6 and 7: Values for air infection obtained during the first ten minutes of the period of vaporisation were omitted from the calculation of the average, because where vaporisation was continuous several minutes elapsed, after the start of vaporisation, before full reduction was obtained. (See also note 7, Table I.)

Saline suspensions of B. prodigiosum were used in each experiment, except the first quoted above where a broth suspension was used.

2. *Tests of Intermittent or Continuous Vaporisation over Longer Periods.*—In view of the transitory nature of the disinfection produced by a single vaporisation of the glycol, an attempt was made in the following experiments to demonstrate the possibility of maintaining disinfection by continuous vaporisation or by the repeated vaporisation of single doses at short intervals. The results of six experiments are recorded in Table II, which shows for each rate of vaporisation the average reduction of air infection maintained during the period of vaporisation; this reduction is expressed as a percentage of the
average air infection found during the 10-minute period preceding vaporisation. Fig. 2 illustrates one of the tests, and the course of air infection in a control experiment where no vaporisation was carried out.

It was found possible by vaporisation of 0.6 ml. of the glycol per million ml. of air per hour to maintain a reduction of about 95 per cent. in the artificially produced air infection. Vaporisation at this rate did not produce objectionable misting. Where single vaporisations were carried out at 20-minute intervals, considerable reinfection of the air occurred between doses. Vaporisations repeated at 10-minute intervals, on the other hand, appeared as effective as continuous vaporisation in maintaining reduction in air infection. Continuous vaporisation, however, was found more convenient.

Experiments on the Air Infection (largely Dust-borne) present naturally in a Crowded Room

The practically unventilated room used in the previous experiments was occupied by fifteen men and the operator. The occupants remained in their chairs at the sides of the room for two-and-a-half hours. There was practically no sneezing or coughing, and little talking. Very few (only 2 to 4 per cent.) of the organisms found in the air gave α-haemolysis on blood agar. Mouth-spray-produced air infection includes a much higher proportion of α-haemolytic organisms, e.g. 15 to 50 per cent. in our later experiments (see also Wells et al., 1939).
Therefore the low percentage of a-hæmolytic organisms recorded above was taken as indicating that, under such circumstances, only a small part of the air infection consisted of droplet-spray-borne organisms derived from the upper respiratory tracts of the occupants. It was concluded, therefore, that the majority of the organisms were dust-borne, having been liberated by movements of the occupants, from their clothes and from the furnishings of the room.

The bacterial content of the air was measured at intervals of two-and-a-half or five minutes throughout the experiment by sampling the air in 1, 2 or 4 cub. ft. amounts, as described previously. Here, however, 5 per cent. horse blood agar plates were used, and after aerobic incubation for twenty-two hours, the number of colonies present was counted with the aid of a plate microscope. In the absence of disinfection it was found that the level of air infection rose to a maximum (35 to 85 bacterial particles/cubic feet) within a minute or two after entry of the occupants, presumably because of considerable dust-raising occasioned by the movements of entry and of finding seats. After ten to twenty minutes the air infection was reduced to a level of somewhere between 20 and 50 bacterial particles/cubic feet, and it remained about this level until the occupants rose to leave at the end of the experiment.

Accordingly, no propylene glycol was vaporised during an initial period (usually of thirty minutes or more) in order that the degree of air infection might be measured in several samples after it had become relatively stabilised. The glycol was then vaporised for one-half to two hours, and the average reduction maintained for the period of vaporisation (disregarding the first ten minutes of this) was then calculated from the numerous measurements made of the air infection.

The results of seven experiments carried out in this manner are recorded in Table III, which shows, for each rate of vaporisation, the

### Table III

| Rate | Method | Period | 3. | 4. Average Air Infection during Ten Minutes preceding Vaporisation. | 5. Average Air Infection during Period of Vaporisation. | 6. Average Percentage Reduction maintained for Period of Vaporisation. |
|------|--------|--------|---|-------------------------------------------------|-----------------------------------------------|--------------------------------------------------|
| 0·6  | continuously | 1 hr. | 69 | 29 | 27 | 7 |
| 0·6  | ,       | 1½ hrs | 59 | 19 | 15 | 21 |
| 0·6  | 0·1 ml./10 mins. | , | 73 | 31 | 23 | 19 |
| 0·8  | 0·2 ml./15 mins. | 2 hrs. | 68 | 42 | 8 | 81 |
| 1·0  | continuously | 1 hr. | 65 | 22 | 3 | 86 |
| 1·6  | 0·4 ml./15 mins. | 2 hrs. | 70 | 47 | 4·5 | 90 |

Column legends as in footnote to Table II.
average percentage reduction in air infection maintained during the period of vaporisation. Fig. 3 illustrates an experiment in which a reduction of about 85 per cent. was maintained on average for two hours by the continuous vaporisation of propylene glycol at the rate of 1 ml./million ml./hour; the course of air infection in a control experiment, where no vaporisation was carried out, is shown in the same figure for comparison. The vaporisation of the glycol at the rate of 1 ml./million ml./hour resulted, in the above experiment, in some mist formation throughout the room. Vaporisation at the rate of 0.6 ml./million ml./hour was not found to cause significant misting, but the average percentage reductions maintained during such vaporisation in three experiments were approximately only 7, 21 and 19 per cent. At the intermediate rate of 0.8 ml./million ml./hour reductions of the order of 80 per cent. were obtained, but the glycol was introduced in single doses repeated at 15-minute intervals, each of which caused objectionable misting, and up to the present time continuous vaporisation at this rate has not been carried out.

Discussion of Results

Were propylene glycol to be used for routine air disinfection of occupied premises, the upper limit to the rate at which it might be vaporised would probably be determined by the mist formation and sweet taste which occur at high vaporisation rates, and by the cost of the glycol. The highest practicable vaporisation rate cannot now be defined precisely. The point at which misting and sweet taste of the air become objectionable is a matter of personal and thus variable opinion. Moreover, it is probable that these manifestations vary with such factors as temperature, humidity and mode of vaporisation. It
was always found, however, that vaporisation at the rate of 0.5 ml./million ml./hour was quite unobjectionable, and this rate can be safely recommended for preliminary trial in practice. In this series of experiments, vaporisation at the rate of 1 ml./million ml./hour was found slightly objectionable because of mist formation, and vaporisation at higher rates was definitely objectionable. In experiments carried out in a different season of the year and with a different instrument for vaporisation (see Personnel of Naval Laboratory Research Unit No. 1, 1943), it was found that vaporisation could be increased to the rate of 1.5 ml./million ml./hour before even slight misting occurred; at this latter rate the air, when inhaled through the mouth, had a definite sweet taste but no smell.

It has been shown above that by continued vaporisation of propylene glycol at a sufficiently high rate (e.g. 1 ml./million ml./hour) it is possible to maintain a considerable reduction (85 per cent. approximately) in the air infection naturally present in an occupied room. It is doubtful, however, whether continuous vaporisation at this rate could be carried out in practice because of possible misting and the large quantities of glycol which would be required. In this connection it may be pointed out that continuous vaporisation of glycol at half this rate, namely, 0.5 ml./million ml./hour for fifteen hours per day during one month in a hospital ward of 40,000 cub. ft. would require about 50 gallons of the glycol. Vaporisation at the more practicable rate of 0.6 ml./million ml./hour was found to produce only small reductions in the aerial flora of the occupied room. As this, however, consists largely of saprophytes in a partially dry state, and perhaps protected to some extent by dust material, the small reduction observed may be no measure of the destruction, which might occur, of respiratory pathogens in newly exhaled salivary droplets. Experiments were, therefore, initiated to measure the reductions produced by propylene glycol vapour in mouth-spray infection; these are described in a further paper. It must be remembered that there is evidence to suggest that some respiratory infections can be transmitted by infected dust, which may become air-borne; the activity of an air disinfectant on dust-borne air infection is, therefore, not without importance.

Summary

1. The efficiency of propylene glycol vapour as an air disinfectant has been tested (a) in air continuously infected by atomisation of suspensions of B. prodigiosum, and (b) in a crowded room with its natural, largely dust-borne, air infection.

2. The effect of single vaporisations of the glycol was found to be transient.

3. Reduction of air infection could be maintained by continuous vaporisation of the glycol, or by single vaporisations repeated at short intervals of about ten minutes.
4. Vaporisation at the rate of 1 ml. glycol/million ml. air/hour produced a considerable reduction (about 85 per cent.) in the naturally present air infection of a crowded room during the period of vaporisation; perceptible mist formation, which might be found objectionable in practice, occurred at this dosage rate. Vaporisation at lower rates did not result in mist formation, but produced only small reductions in the air infection.

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