EFFECTS OF TEMPERATURE AND WIND VELOCITY ON TIME OF PERSISTENCE OF VESICANTS

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ABSTRACT

The time of persistence of a vesicant at a given temperature and wind velocity may be obtained by the expression

$$T = \frac{4\sigma}{\mu^4}\left[\frac{(\mu\sqrt{r_o})^3}{3} - \frac{(\mu\sqrt{r_o})^2}{2} + (\mu\sqrt{r_o}) - log(1+\mu\sqrt{r_o})\right]$$

where r_o is the radius of the vesicant drops.

Tables for the variation of σ and μ with temperature and wind velocity have been given so that the time of persistence of a vesicant under given conditions can be readily obtained.

Introduction

Persistence is in general an expression for the period for which a chemical agent remains and exerts its influence on the place, where it has been released. It is determined mainly by the physical properties of the agent.

In case of solid and liquid chemical agents, used in Gas Warfare, the persistence varies greatly according to the specific properties of the substances. Most of the materials of this kind are liquids, which on the explosion of the shell in which they are placed are sprayed over the terrain in large or small drops, whence they are evaporated into air. As long as there is liquid chemical material on the ground, it is a constant source of replacement for the evaporated portion of the material which has been thinned down or carried away by the air currents.

For tactical considerations it is of decisive importance to know the period for which the chemical agent is present in the liquid state. The effect of temperature on the persistence has been discussed by Prentiss [10] and others. In this paper the authors propose to discuss the effect of wind velocity on this important quantity.

Evaporation of a Drop

The evaporation of a single drop at rest with respect to the surrounding air has been studied theoretically by Maxwell[7] and Langmuir[6] who find for the steady state the relations—

$$\frac{dm}{dt} = \frac{-4\pi DMp}{RT}.r \quad \quad (1)$$

where m is the mass of the drop,
t is the time,
D is the coefficient of Diffusion,
M is the Molecular weight of the evaporating substance,
p is the vapour pressure of the liquid,

T is the absolute temperature,
r is the radius of the drop,
and R is the Universal Gas Constant

Putting $m = \frac{4}{3} \pi r^3 \rho$ where ρ is the density of the liquid Eqn. (1) can be written as—

$$-\frac{dr}{dr} = \frac{DMp}{RT} \cdot \frac{1}{r} \quad .. \quad .. \quad (1A)$$

This equation has been experimentally verified by Morse [8], Namekawa and Takahashi [9] and recently by Ranz and Marshall [11].

The most complete theoretical and experimental investigation of evaporation from a drop in moving air seems to have originated with Frossling ([2]). After noting that the velocity of air increases the evaporation, Frossling takes as the starting relation—

$$\left(\frac{dr}{dt}\right)_u = f\left(\frac{dr}{dt}\right)_o$$

$$\text{or } -\frac{dr}{dt} = f. \frac{DMp}{\rho RT} \cdot \frac{1}{r} \quad .. \quad .. \quad (2)$$

After a good deal of discussion Frossling evaluates f empirically as:—

$$f = 1+0\cdot276(Sc)^{\frac{1}{3}} (Re)^{\frac{1}{2}} \quad .. \quad .. \quad (3)$$

Where Sc and Re are the Schmidt and Reynold's numbers respectively given by

$Sc = \frac{\nu}{D}$, D being the coefficient of diffusion, ν the kinematic viscosity of air

and $Re = \frac{2Ur}{\nu}$ U being the velocity of the air relative to the drop.

From Eqn. (2) we have—

$$\int_0^T dt = -\sigma \int_{r_0}^{0} \frac{2rdr}{1+\mu\sqrt{r}}$$

where $\sigma = \frac{\rho RT}{2DM}$ & $\mu = 0\cdot276 \left(\frac{\nu}{D}\right)^{\frac{1}{3}} \left(\frac{2u}{\nu}\right)^{\frac{1}{2}}$.

Hence the time of evaporation is given by

$$T = \frac{4\sigma}{\mu^4}\left[\frac{(\mu\sqrt{r_o})^3}{3} - \frac{(\mu\sqrt{r_o})^2}{2} + (\mu\sqrt{r_o}) - \log(1+\mu\sqrt{r_o})\right] \quad .. \quad (4)$$

It is easy to see that $\lim_{u \to o} T = \lim_{\mu \to o} T = \sigma r_o^2$

Hence σ is a useful quantity which we may call persistivity whose product with the square of the radius of the drop gives the life of the drop in still atmosphere.

Thus we see that the life of a drop or the time of persistence of a chemical war agent is a function of the radius of the drop, persistivity and μ. Hence it is useful from the operational point of view to have tables for the variation of σ with temperature and μ with temperature and wind velocity for commonly used war gases so that the time of persistence of the agent under given battle conditions can be readily obtained by Eqn. (4). In this paper the authors propose to construct the tables for the three common vesicants—Mustard Gas, Chloropicrin and phosgene.

Variation of vapour pressure with temperature

The vapour pressure in mms of mercury at any temperature T°K of Chloropicrin and Phosgene [12] and Mustard Gas [1] is given by—

a table for mustard Gas

$$\text{and } \log_{10} p = 8\cdot2424 - \frac{2045\cdot1}{T} \text{ for Chloropicrin}$$

$$\log_{10} p = 7\cdot5595 - \frac{1326}{T} \text{ for Phosgene}$$

Table I gives the vapour pressure in mms of mercury of the three vesicants at various temperatures—

TABLE I

Vapour pressure of vesicants in mms of murcury

Temperature	Mustard Gas	Chloropicrin	Phosgene*
—10°C	0·003	2·927	330·0
—5°C	0·004	4·078	408·8
0°C	0·008	5·641	505·3
5°C	0·015	7·681	617·3
10°C	0·026	10·390	..*
20°C	0·072	18·34	..*
30°C	0·162	31·08	..*
40°C	0·351	51·10	..*
50°C	0·716	81·55	..*

*Boils at 8°C.

Variation of Diffusion Coefficient D With Temperature

The coefficient of diffusion of a vapour into air at any temperature (International Critical Tables Vol 5, 62, 1929) is given by

$$D = D_0 \, T^2/T_0^2$$

where D_0 is its value at temperature T_0.

The values of D_0 and T_0 for the three vesicants are listed in Table II.

TABLE II

Values of D_0 and T_0 for the three vesicants

Vesicant	D_0 in cm^2 secs	T_0 in °K.	Reference
Mustard Gas	0·06	298	Ford Moore [1]
Chloropicrin	0·088	298	Jost [4]
Phosgene	0·095	273	Jost [4]

Table III gives the values of the coefficient of diffusions for the three vesicants at different temperatures.

TABLE III

Values of coefficient of diffusions of the three vesicants in cm^2 secs.

Temperature	Mustard Gas	Chloropicrin	Phosgene*
—10°C	0·047	0·069	0·088
—5°C	0·049	0·071	0·092
0°C	0·050	0·074	0·095
5°C	0·052	0·077	0·098
10°C	0·054	0·079	..
20°C	0·058	0·085	..
30°C	0·062	0·091	..
40°C	0·066	0·097	..
50°C	0·071	0·103	..

* Boils at 8°C.

Variation of Kinematic Viscosity of air with Temperature

In Table IV the values of viscosity η of air have been taken from International Critical Tables[3] and the values of density ρ are those given by Lange[5].

TABLE IV

Viscosity and density of air

Temperature	$\eta \times 10^7$ in poises	$\rho \times 10^4$ in gms/c.c.	$\log_{10} \rho/\eta$	$1/6 \log_{10}\rho/\eta$	$\nu^{-\frac{1}{6}}$
—10°C ..	1658	13·424	0·9081	0·1514	1·417
—5°C	1684	13·173	0·8932	0·1489	1·409
0°C	1709	12·931	0·8790	0·1465	1·402
5°C	1734	12·697	0·8648	0·1441	1·393
10°C	1759	12·472	0·8506	0·1418	1·387
20°C	1808	12·046	0·8237	0·1373	1·372
30°C	1856	11·647	0·7978	0·1330	1·358
40°C	1904	11·274	0·7721	0·1287	1·345
50°C	1951	10·924	0·7480	0·1247	1·332

Variation of Persistivity with Temperature

The mean relative densities and molecular weights of the three vesicants are shown in Table V.

TABLE V

Mean Specific Gravity and Molecular Weight of Vesicants.

War Gas	Molecular Weight	Specific Gravity
Mustard Gas	159	1·3
Chloropicrin	164·5	1·6
Phosgene	99	1·8

Using Tables I, III and V and the value $R = 8{\cdot}315 \times 10^7$ ergs deg^{-1}, mole^{-1} we can compute the values of the persistivity σ at various temperatures. The values are given in Table VI.

TABLE VI

Variation of persistivity σ in secs/cm² with temperature for the three vesicants

Temperature	Mustard Gas	Chloropicrin	Phosgene*
—10°C	4732×10^5	3950×10^2	5133
— 5°C	3467×10^5	2805×10^2	4041
0°C	1731×10^5	1983×10^2	3225
5°C	9038×10^4	1424×10^2	2607
10°C	5112×10^4	1046×10^2	..
20°C	1780×10^4	5699×10	..
30°C	7650×10^3	3248×10	..
40°C	3427×10^3	1914×10	..
50°C	1612×10^3	1166×10	..

*Boils at 8°C.

Variation of μ with Temperature and Wind Velocity

We have:—

$$\mu = 0{\cdot}276\,(\nu/D)^{\frac{1}{3}}\;(2u/\nu)^{\frac{1}{2}} = 0{\cdot}276\sqrt{2}\,D^{-\frac{1}{3}}\,\nu^{-\frac{1}{6}}\sqrt{u}$$

Table VII, VIII and IX give the values of μ at various temperatures and wind velocities. The values have been obtained by the use of Tables III and IV.

TABLE VII

Variation of μ with wind velocity and Temperature for Mustard Gas

Velocity in cms/sec. / Temperature	0	25	64	100	400	900	1600	2500
—10°C ..	0	7·660	12·256	15·32	30·64	45·96	61·28	76·60
— 5°C ..	0	7·515	12·024	15·03	30·06	45·09	60·12	75·15
0°C ..	0	7·425	11·880	14·85	29·70	44·55	59·40	74·25
5°C ..	0	7·320	11·712	14·64	29·28	43·92	58·56	73·20
10°C ..	0	7·155	11·448	14·31	28·62	42·93	57·24	71·55
20°C ..	0	6·915	11·064	13·83	27·86	41·49	55·32	69·15
30°C ..	0	6·700	10·720	13·40	26·80	40·20	53·60	67·00
40°C ..	0	6·495	10·392	12·99	25·98	38·97	51·96	64·95
50°C ..	0	6·280	10·040	12·56	25·12	37·68	50·24	62·80

TABLE VIII

Variation of μ with wind velocity and temperature for chloropicrin

Velocity cms/sec. / Temperature	0	25	64	100	400	900	1600	2500
—10°C ..	0	6·745	10·792	13·49	26·98	40·47	53·96	67·45
—5°C ..	0	6·640	10·624	13·28	26·56	39·84	53.12	66·40
0°C ..	0	6·510	10·416	13·02	26·04	39·06	52·08	65·10
5°C ..	0	6·420	10·272	12·84	25·68	38·52	51·36	64·20
10°C ..	0	6·305	10·088	12·61	25·22	37·83	50·44	63·05
20°C ..	0	6·090	9·744	12·18	24·36	36·54	48·72	60·90
30°C ..	0	5·895	9·432	11·79	23·58	35·37	47·16	58·95
40°C ..	0	5·710	9·136	11·42	22·84	34·26	45·68	57·10
50°C ..	0	5·550	8·880	11·10	22·20	33·30	44·40	55·50

TABLE IX

*Variation of μ with wind velocity and Temperature for Phosgene**

Velocity in cms/sec. / Temperature	0	25	64	100	400	900	1600	2500
—10°C ..	0	6·220	9·952	12·44	24·88	37·32	49·76	62·20
5°C ..	0	6·090	9·744	12·18	24·36	36·54	48·72	60·09
0°C ..	0	5·995	9·592	11·99	23·98	35·97	47·96	59·95
5°C ..		5·925	9·480	11·85	23·70	35·55	47·40	59·25

* Boils at 8°C.

An Example

Table X and Fig. 1 give the variation of life of a drop of mustard gas of radius 1/9 cms at 20°C with wind velocity. The values have been obtained by using Tables VI, VII and Eqn. (4)

TABLE X

Variation of life of a drop of mustard gas of radius 1/9 cms at 20°C with wind velocity.

u in cm/sec.	0	25	64	100	400	900	1600	2500
t/t_0 ..	1·00	0·36	0·26	0·22	0·13	0·088	0·067	0·054

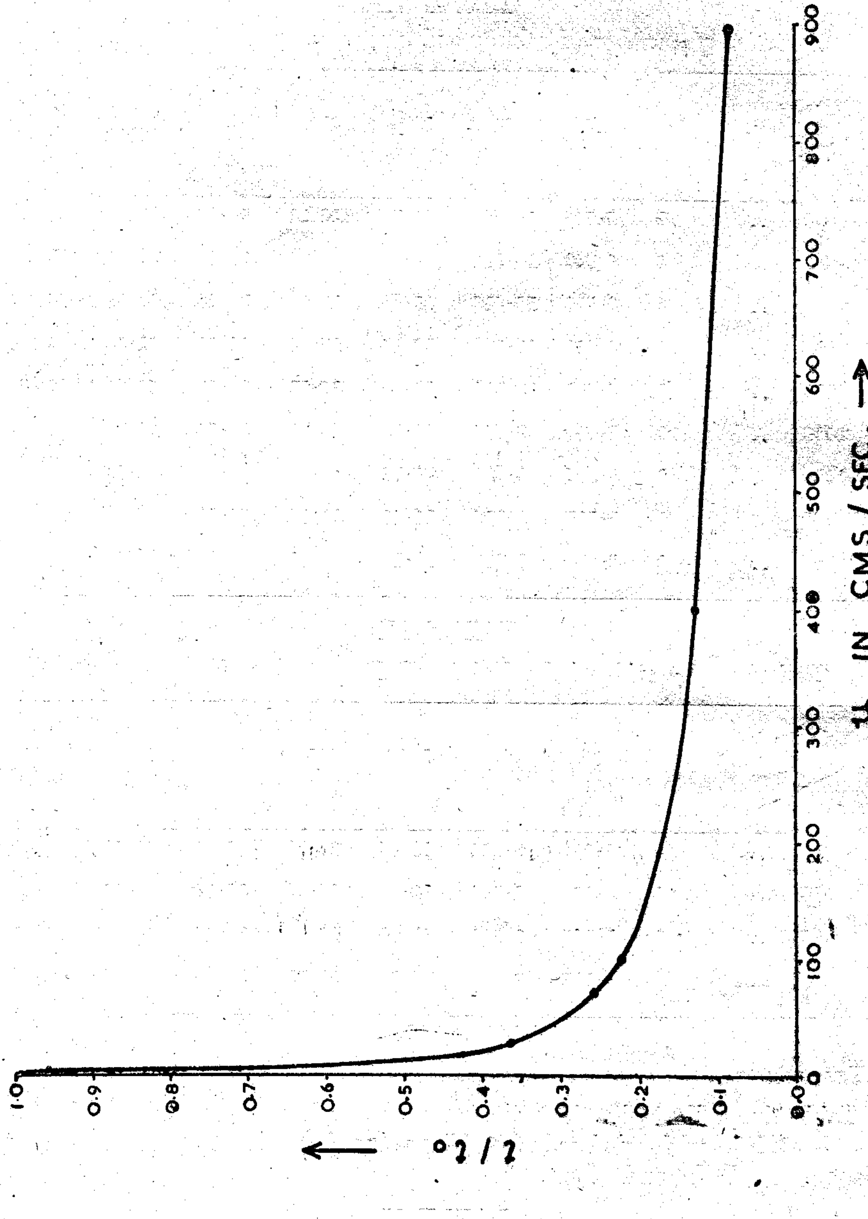

FIG. 1—Variation of t/t_0 with wind velocity u of a mustard gas drop of radius 1/9 cms at 20°C

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