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# THE USE OF WATER TO PROTECT BUILDINGS FROM RADIATED HEAT

by

P. H. Thomas

## Summary

The feasibility of using water to protect buildings from heat radiated from an adjacent fire is examined. Two means of applying the water are discussed, one as a radiation water spray, and the other as a film on those parts of the surfaces of the buildings which require protection. It is shown that for equivalent protection, the surface film theoretically requires less water than the radiation curtain. The reason for this is that the falling velocity of films are controlled by the flow of water itself, whereas the falling velocity of a spray depends on the drop diameter which cannot be reduced to a value low enough for efficient use in this application.

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Fire Research Station,
Boreham Wood,
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# THE USE OF WATER TO PROTECT BUILDINGS FROM RADIATED HEAT

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## Introduction

This report consists of the theoretical treatment of two problems. In the first the use of water spray as a curtain against radiation is discussed and in the second the protection afforded by a thin film of liquid on a vertical surface is evaluated for different conditions of application. The water required for these two means of protecting buildings from the heat of a fire are then compared with that used in practice to contain the fire emitting the radiation.

## I - Water spray

The transmission of heat radiation through water sprays of the kind obtained from fire-fighting appliances has been investigated theoretically (1) and experimentally (2) at the Joint Fire Research Organization. In this note, this information is used in making an estimate of the efficiencies of radiation curtains of different droplet sizes, widths and heights.

### Theory of water spray curtain

The transmission of heat radiation through a water spray is determined mainly by the surface area of water in a unit section of the curtain. Thus in Figure 1, if the radiating panel 'A' and the screen 'B' are of infinite extent and the intensities of radiation and concentrations of water are uniform over a plane 'C', the ratio of the incident $I_o$ to the transmitted intensity of radiation $I$, depends on the surface area of water in a volume 'D' such as is shown in Figure 1. For simplicity, we shall think of the spray as consisting of drops of one size only. The amount of water in the volume 'D' is then proportional to the product of the flow of water into the spray curtain and the time it takes to pass through that volume. If the water is released at some point at a height 'H' and falls through the curtain, the drop velocity is made up of two components, namely, the velocity relative to the air, and the absolute velocity of the air entrained in the spray. The velocity of the drop relative to the air at some distance below the point of release is the terminal velocity and this can be expressed in terms of the properties of air and water and the drop diameter. The velocity of the entrained air cannot be accurately determined but we can make an estimate by regarding the curtain as a negative chimney. That is, the weight of the moving water spray is transferred to the air and this generates the downdraught of air.

We can calculate the time a drop is in suspension if we assume that there is no loss of size due to evaporation. The time for the spray to completely evaporate may also be estimated. Provided the suspension time is not too large a fraction of the evaporation time, the ratio of these times is the same as the ratio of the flow of water needed to absorb the heat and the flow actually applied. We can, therefore, evaluate approximately the efficiency in terms of water consumption. The actual equations and calculations are given in the Appendix.

Figure 2 shows the flow of water required in a water screen of various drop sizes. Four conditions are considered, viz. curtain heights of 40 ft and 100 ft and intensity reduction ratios of 40 : 1 and 4 : 1. The width of the curtain is taken as 15 ft. Values of the evaporation time and the suspension time are given in Figure 3 while in Figure 4 the flow of water required for different incident and transmitted intensities is given for a drop diameter of $^1/20$ cm since mean drop sizes less than $^1/20$ cm may be difficult to produce.

The maximum transmitted intensity that can be tolerated is governed by the minimum intensities of radiation required to ignite a material such as wood. 0·10 cal $cm^{-2}$ $sec^{-1}$ is the critical intensity for the surface ignition of wood and this intensity produces physical discomfort if one's skin is exposed to it for about 10 seconds. Half this intensity produces discomfort in about 30 seconds. The curves are drawn, therefore, for a transmission of 0·05, 0·10 and 0·20 cal $cm^{-2}$ $sec^{-1}$, and show the effect of increasing the allowed transmission.

The average intensity of radiation about 50 ft from a severe fire in a large building can be over 1·0 cal $cm^{-2}$ $sec^{-1}$, and very close to the building it can be as much as 3·5 cal $cm^{-2}$ sec. Values of water flow necessary are given for incident intensities up to the higher value. The efficiency in terms of the actual to a minimum necessary quantity of water is given in Figure 5.

This minimum quantity which is shown in Figure 6 is that theoretically necessary to absorb by complete evaporation the heat radiated. Figure 2 shows that the flows of water necessary increase markedly with the drop size, while from the relation between $T_H$ and $T_s$ shown in Figure 3 it appears that the drop size at which these are equal, and at which, therefore, the water is most gainfully used, increases with the height of the curtain. It follows that, for a particular drop size, sprays are more efficiently used when the height to be protected is large. For example a reduction in the height from 100 ft to 40 ft reduces the amount of heat radiated in the same ratio 100 : 40 but the flow necessary is reduced only in the ratio 100 : 70.

We have assumed the spray to be formed by allowing water drops to fall from a height comparable with the building height. If the spray were projected upward and then allowed to fall both upward and downward parts could contribute to the reduction in intensity. They would, however, not contribute equally since the drop will ascend more quickly than it will descend. A maximum estimate of the usefulness of this practice would be that it changes the necessary reduction in intensity from a factor R to 1 to $\sqrt{R}$ to 1 for each part of the spray. In practice it would not be possible to achieve curtains of much height since the range of sprays is not very great and is rarely more than 30 ft in the horizontal for normal pressures.

## II - Direct wetting of the exposed building

If a surface exposed to radiant heat is wetted by a film of water the surface temperature cannot exceed 100°C indefinitely. Also the heat that passes through the film and enters the solid cannot exceed that entering a semi-infinite solid whose surface temperature is raised suddenly to 100°C. After a minute the flow of heat in such circumstances would be less than 0·1 cal $cm^{-2}$ $sec^{-1}$ for a wooden body and after four minutes it would be half this value.

It is thus reasonable to regard a surface protected by a film of water for a long time from radiation of intensity of over 1 cal $cm^{-2}$ $sec^{-1}$ as absorbing no heat itself, heat not absorbed by the water being reflected. The proportions of heat absorbed and reflected by a water film depend primarily on the geometry of the radiating and the exposed surfaces of the film thickness and only if the two surfaces are very near is the whole of the incident radiation absorbed, irrespective of the film thickness. Even if the surfaces are a long way apart so that radiation is not reflected back to the radiator and then back again a film $2 \times 10^{-2}$ cm would be expected to absorb about three-quarters of the radiation emitted by a source at a temperature of 1000°C. It is therefore reasonable to assume that water used in this way can be used almost to its full capacity as an absorber of heat.

The limitations to this method in practice are those incurred in dispersing the water over the area to be protected. This dispersal is affected by the presence or absence of obstacles to the flow of water and when the film becomes thin disruptive effects of surface tension may well be a limiting factor.

Unlike the spray, the water required to protect an area by direct wetting would be expected to increase approximately in proportion to the height wetted.

## III - Partial protection

If it is desired to protect only part of the exposed building, the windows say, there are choices between a spray curtain and direct wetting and between a cover extending over all windows above each other and separate protection for each window; this protection augmenting that provided for the lower windows.

It has been shown above that the use of spray becomes increasingly more wasteful the smaller the height to be protected, while the efficiency of direct application should not be affected.

## IV - Water used in practice

Apart from estimating the efficiency of the curtain relative to a complete evaporation of water we can compare the flows necessary with those used in practice to contain fires. The number of jets commonly used is approximately that given by spacing of 10 ft to 60 ft with a mean value of about 25 ft. If we take 1 gal $\mathrm{min}^{-1}$ as the flow from a typical jet the rate of application is 5 to 30 gals $\mathrm{min}^{-1}\ \mathrm{yd}^{-1}$ with a most probable figure of about 10 gal $\mathrm{min}^{-1}\ \mathrm{yd}^{-1}$. It is perhaps significant that this is of the same magnitude as that necessary in a screen designed solely to prevent spread and which contributes nothing directly to extinguishing the fire.

## V - Conclusions

Theory shows radiation curtains formed by sprays from conventional nozzles to be unduly wasteful of water if the height to be protected is less than 100 ft or if the intensity of radiation is less than 3 or 4 cals $\mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$. From the point of view of economy of water protection of exposed areas is better achieved by a direct application of water. If there is a 'run-off' from a spray curtain, reduction in the flow reduces the degree of protection. If there is a 'run-off' from direct application a reduction in flow, unless it reduces the wetted area, does not reduce the protection but only the 'run-off'.

## References

(1) "Absorption and scattering of radiation by water sprays of large drops". P. H. Thomas. Brit. J. Appl. Phys. 1952, 3 (12) 385.

(2) "The use of water sprays as protection against radiant heat". P. M. T. Smart. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization. F.R. Note 66/1951.

## Appendix

Let $I_o$ and $I_1$ be incident and transmitted intensities

$Q$ be water flow rate per unit length of curtain

$w$ be air velocity

$V_t$ be terminal velocity of drop

$\eta_{a,w}$ be air and water viscosities

$\rho_{a,w}$ be air and water densities

$p$ be air pressure

$T_s$ be time drop is suspended in curtain

$T_e$ be time of complete evaporation of spray

$R$ be ratio of incident to emergent intensity

$H, J$ be height and width of spray

$D$ be drop diameter

$c$ be concentration vol/vol of water in spray

$t$ be film thickness

$k$. be attenuation per cm of thermal radiation in water

$L, \Lambda$ be the latent and total heats of steam at 100°C

## Analysis of protection by water spray

We have from the Lambert-Beer law of transmission

$$R = \exp \frac{(3d.1.)}{D} \qquad \ldots\ldots (1)$$

for a spray of totally absorbing drops.

When $D$ is small we have from Stokes' Law

$$V_t = aD^2. \qquad \ldots\ldots (2)$$

where

$$a = \frac{g.\rho_w}{18\,\eta_a} \qquad \ldots\ldots (3)$$

$$= 3\cdot7 \times 10^3 \text{ sec}^{-1}$$

For large values of $D$ we have

$$V_t = b.D \qquad \ldots\ldots (4)$$

where

$$b = \left(\frac{g\,\rho_w}{9\,\rho_a^{1/3}\,\eta_a^{1/3}}\right)^{2/3} = 3 \times 10^{-5} \text{ cm}^{-1} \text{ sec}^{-1} \qquad \ldots\ldots (5)$$

We assume that

(1) the spray is of uniform drop size
(2) the drops move at their terminal velocity relative to the air which itself moves at constant speed
(3) the degree of absorbtion and the water in the spray etc. can be calculated on the assumption of no loss of water due to evaporation.
This approximation becomes increasingly worse as the ratio $T_s/T_H$ increases

We have then

$$T_s = \frac{H}{w + v_t} \qquad \ldots\ldots (6)$$

and

$$c.l. = \frac{Q}{w + v_t} \qquad \ldots\ldots (7)$$

From (1) and (7) we have

$$\frac{\text{Log}R}{3} \cdot D \cdot = \frac{Q}{w + v_t} \qquad \ldots\ldots (8)$$

The pressure gradient in the spray due to the weight of spray is given by

$$\frac{dp}{dh} = \frac{\rho_w Q g}{(w + v_t) l} \qquad \ldots\ldots (9)$$

so that if we neglect upward circulation of air around the down stream we have

$$w = \sqrt{2gH \cdot \frac{\rho_w}{\rho_a} \frac{Q}{(w+v_t) l}} \qquad \ldots\ldots (10)$$

for the air velocity calculated from the inertia forces

From (8) and (10) we have

$$w = \sqrt{2gH \frac{\rho_w}{\rho_a} \frac{\text{Log } R}{3.1.}} \qquad \ldots\ldots (11)$$

The solution of these equations gives,

for $v_t \propto D$

$$Q = \frac{\text{Log}\,R}{3} \cdot D \left\{ aD + \left( \frac{2}{3} \text{Log}\,R \cdot \frac{gH\rho_w}{\rho_a} \frac{D}{l} \right)^{1/2} \right\} \qquad \ldots\ldots (12)$$

and for $v_t \propto D^2$

$$Q = \frac{\text{Log}\,R}{3} D \left\{ bD^2 + \left( \frac{2}{3} \text{Log}\,R \cdot \frac{gH\rho_w}{\rho_a} \frac{D}{l} \right)^{1/2} \right\} \qquad \ldots\ldots (13)$$

We take 1 ≐ 15'.

and H, 40' or 100'.

Equations (12) and (13) do not give very different results in the range considered here. We shall, therefore, confine our attention to equation (12) which gives slightly lower values of $Q$ for drops larger than $\frac{1}{50}$ cm.

The curves of Q-v-D are plotted in Figure 2 for H equal to 40' and 100' and R equal to 4 and 40.

We can combine (6) and (8) to obtain

$$T_s = \frac{\text{Log } R}{3} \frac{HD}{Q} \qquad \text{......(14)}$$

This is also shown in Figure 2 for H = 40' and 100' and R = 4 and 40.

The time of evaporation $T_H$ is obtained as follows. The drops are assumed to be totally absorbing, so that the total radiation absorbed is $I_o (1 - {}^1/R)$. It is further assumed that this does not vary with height. Since the drops do decrease in size as they fall, the protection does in fact become less near ground level. With complete evaporation of the water there is of course negligible protection at the bottom of the curtain.

We have

$$I_o (1 - {}^1/R)\, T_H = \frac{Q\, A}{w + v} \qquad \text{......(15)}$$

$$\therefore \quad T_H = \frac{\text{Log } R}{3} \frac{D}{I_o} \frac{A}{(1 - {}^1/R)} \qquad \text{......(16)}$$

This is also shown in Figure 2 for $I_o$ = 2·0 cals $cm^{-2}$ $sec^{-1}$ and I = 0·05 and 0·5 cals $cm^{-2}$ $sec^{-1}$.

We also have

$$\frac{T_s}{T_H} = \frac{I_o}{AQ} H(1 - {}^1/R) \qquad \text{......(17)}$$

This is equal to the ratio of the minimum flow of water that need be used to absorb the heat to that actually used. It is thus a measure of the efficiency of application relative to the minimum quantity that need be used if all of it is turned to steam. This minimum quantity, does not of course refer exclusively to water curtains but to any mode of application, e.g. the application of water in a film to the surface to be protected.

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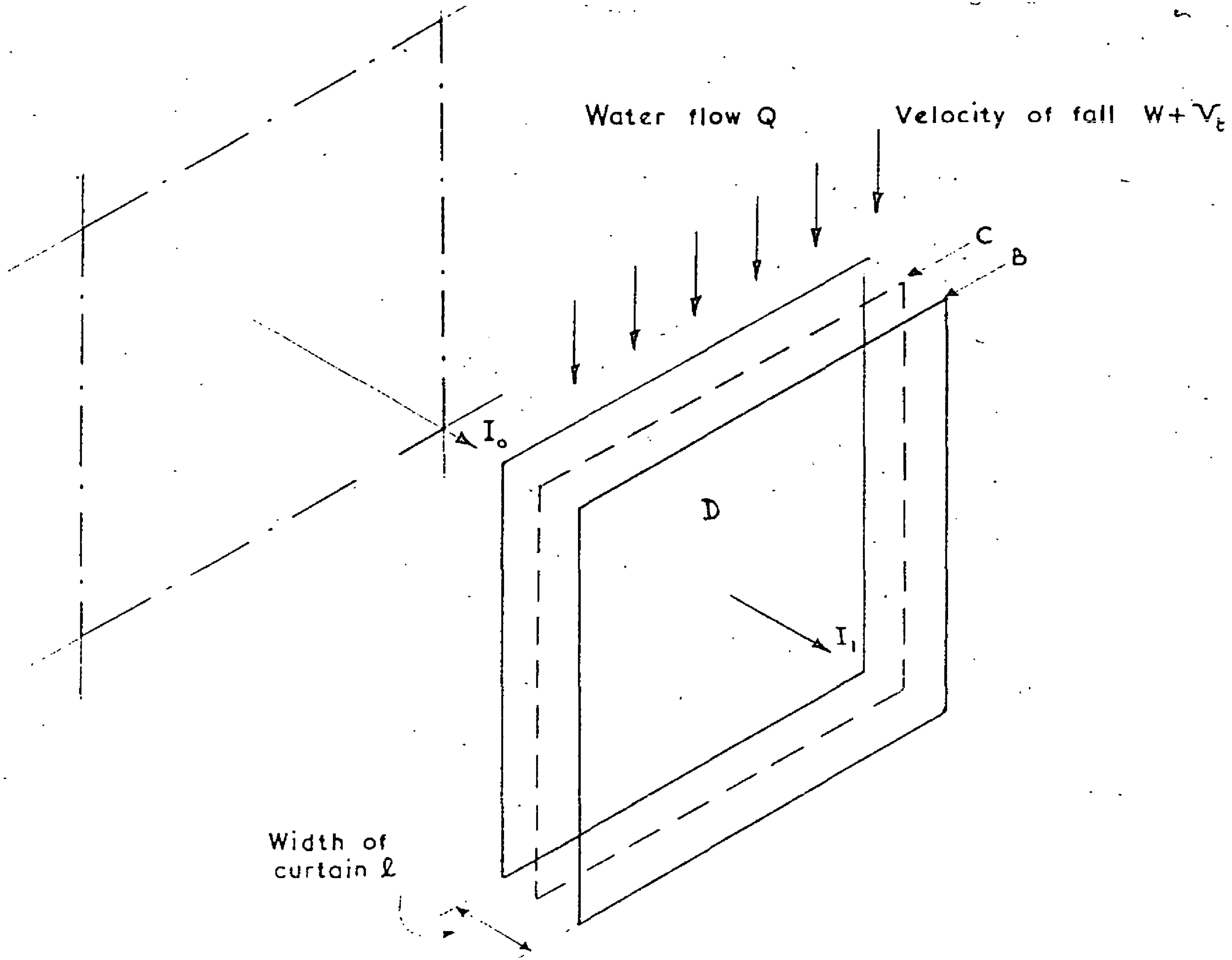
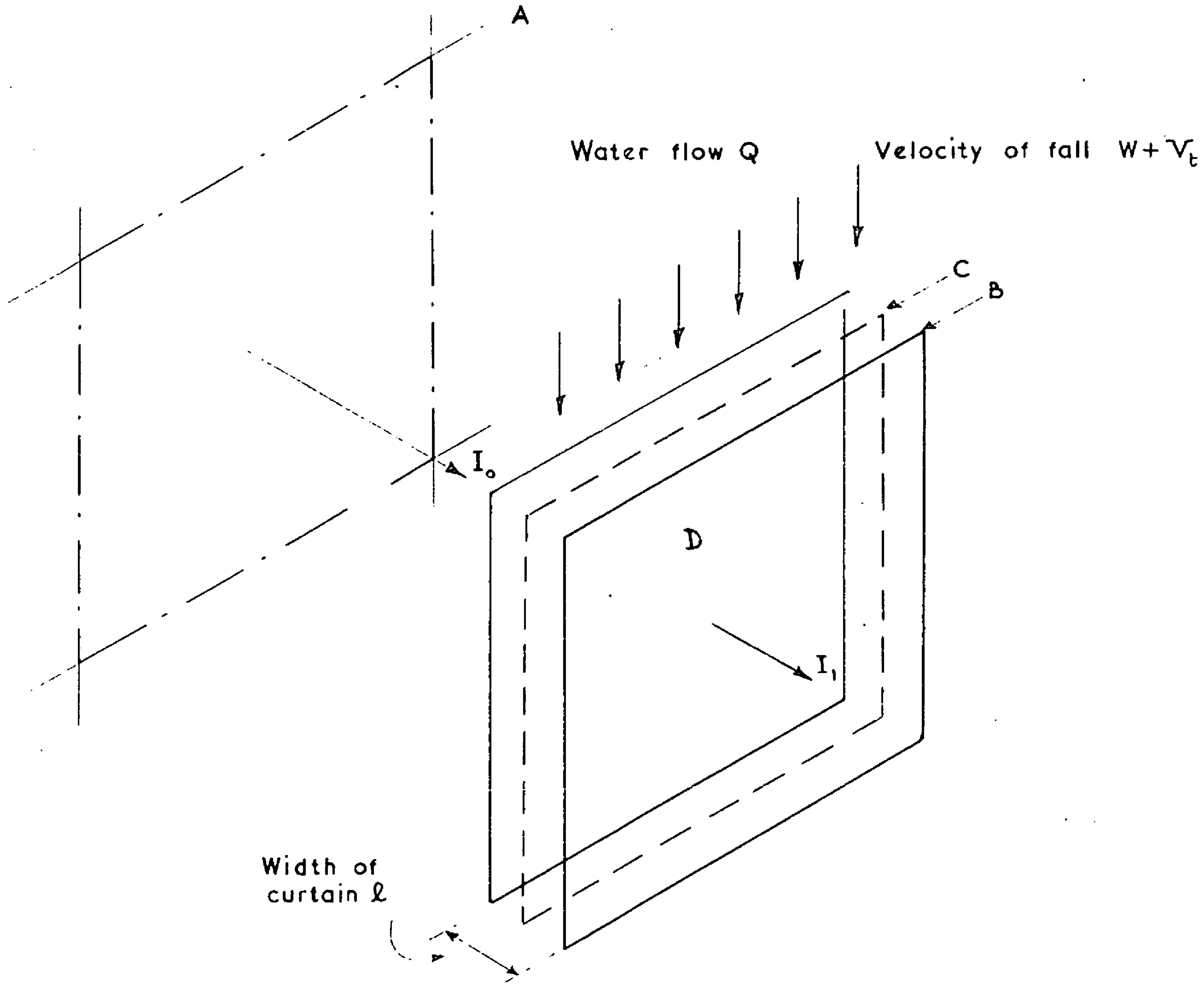


FIG. I. DIAGRAMMATIC VIEW OF UNIT SECTION OF SPRAY CURTAIN


A
Water flow Q
Velocity of fall $W+V_t$
C
B
$I_o$
D
$I_1$
Width of curtain $\ell$

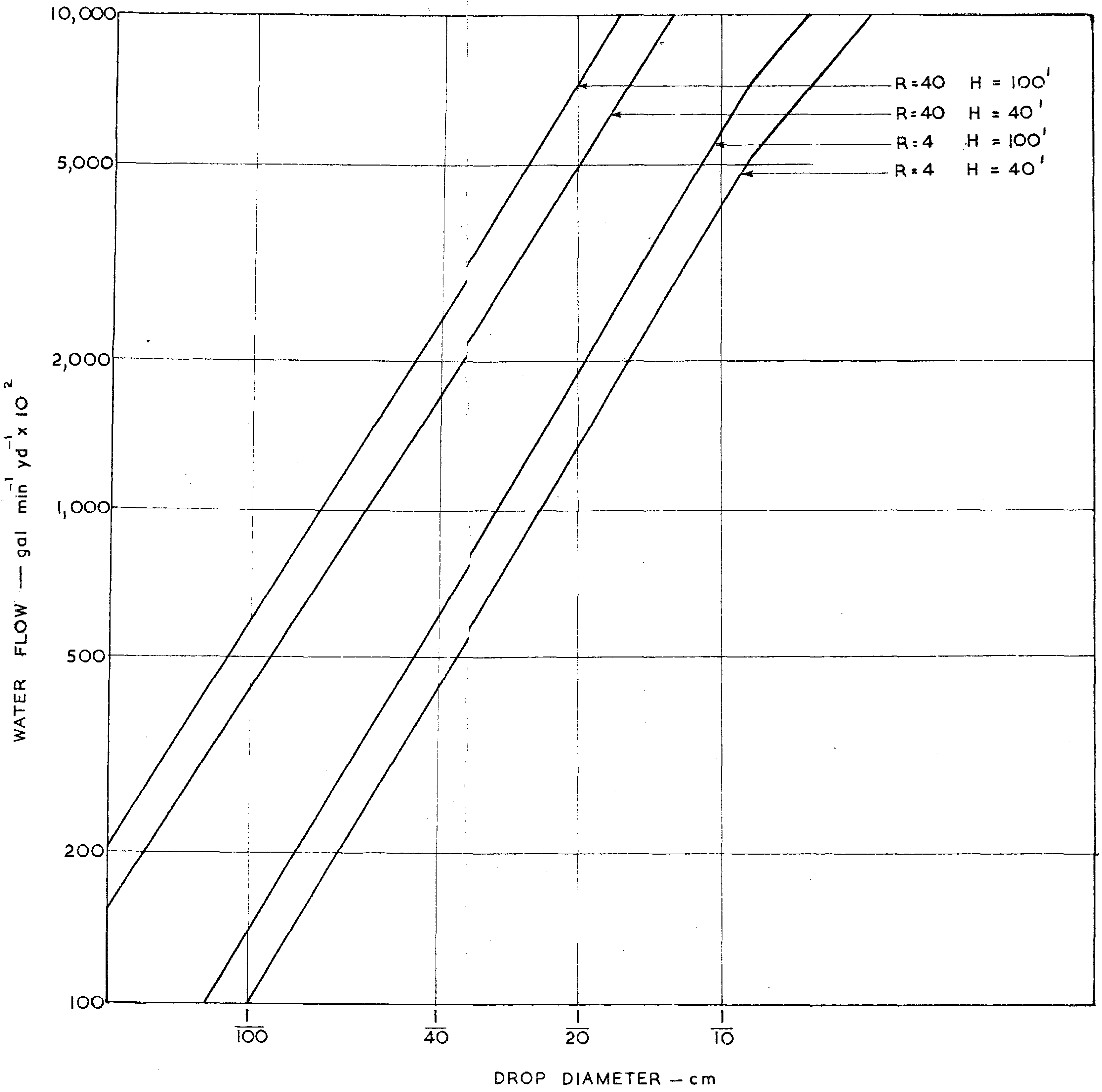


FIG. 2. THE REQUIRED WATER FLOW AS A FUNCTION OF DROP SIZE

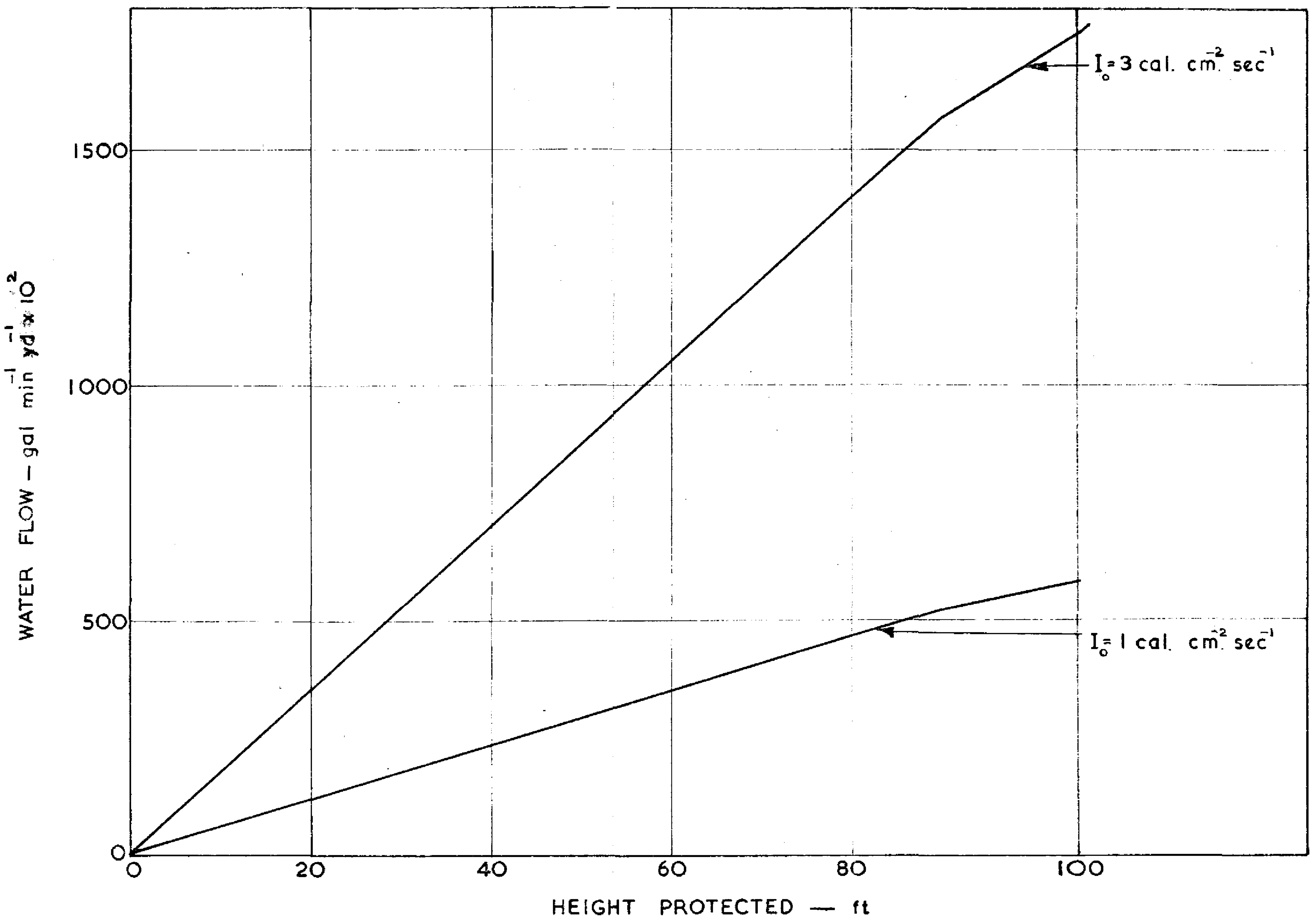


FIG. 6. THE MINIMUM THEORETICAL FLOW NECESSARY TO PROTECT A CERTAIN HEIGHT FROM RADIATION

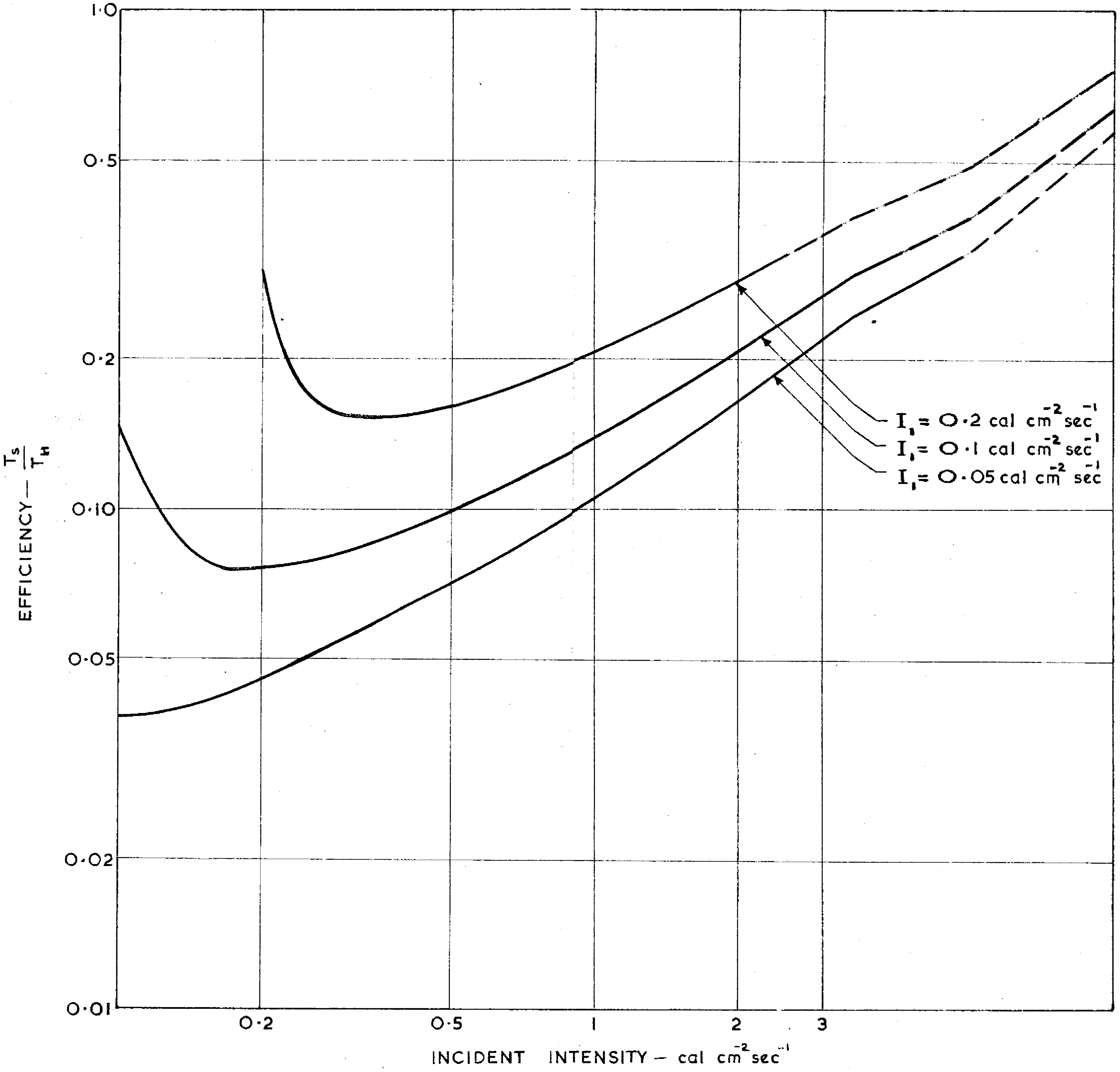


FIG. 5. THE FRACTION OF THE TOTAL COOLING CAPACITY OF **WATER** USED AS A FUNCTION OF INCIDENT INTENSITY

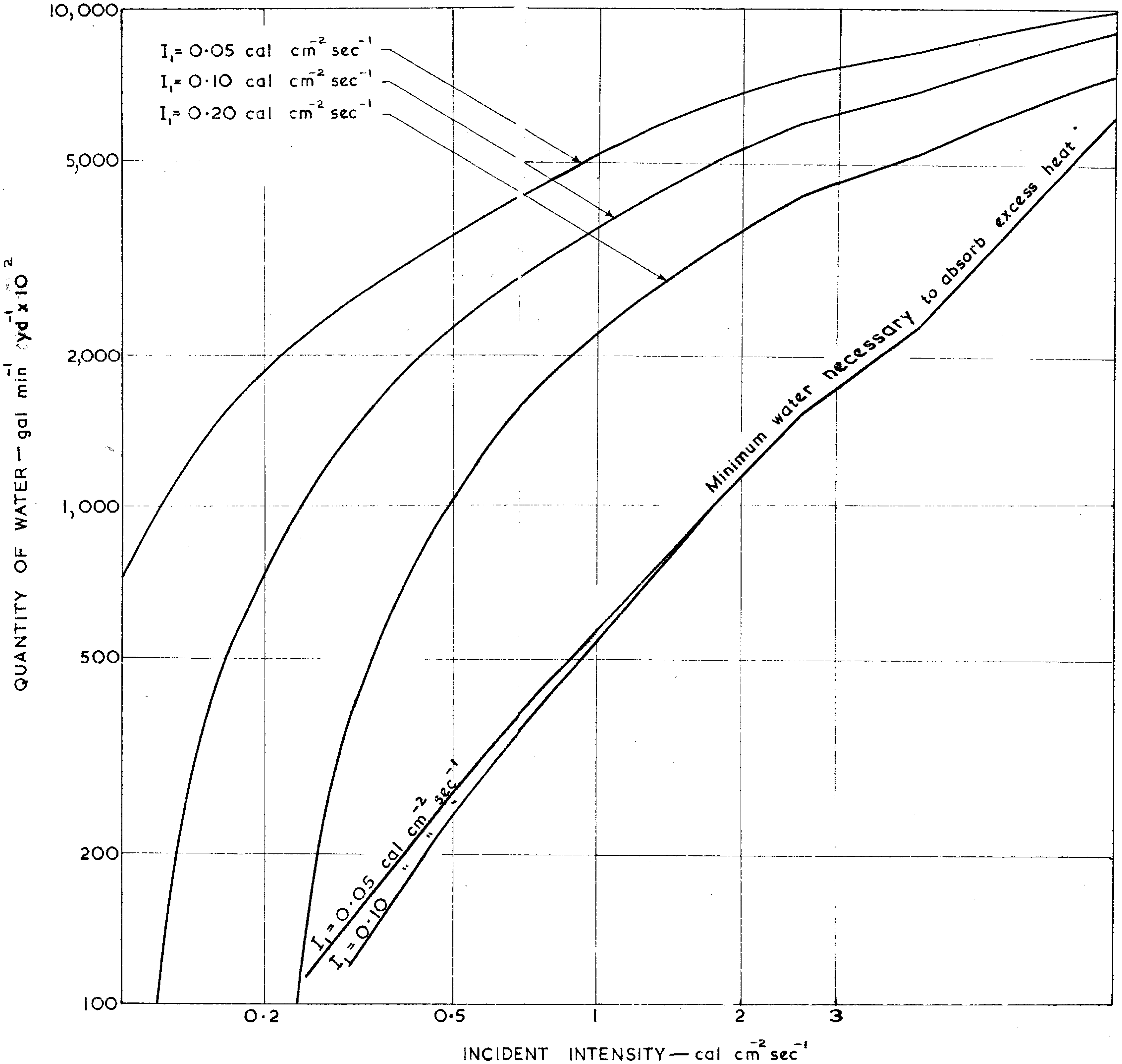


FIG. 4. THE REQUIRED WATER FLOW AS A FUNCTION OF INCIDENT INTENSITY AND TOLERATED TRANSMITTED INTENSITY

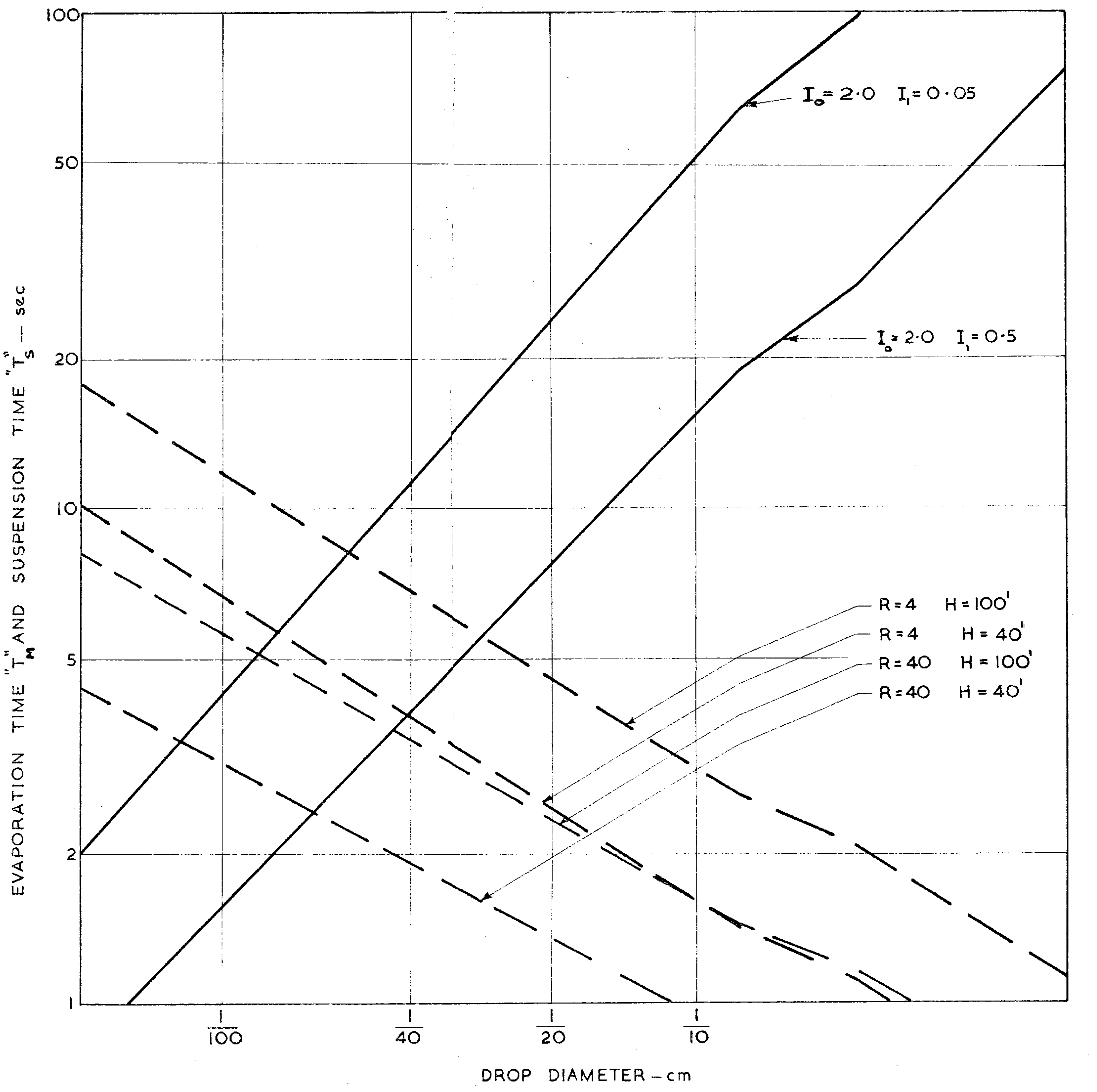


FIG. 3. THE TIME TO EVAPORATE THE SPRAY & THE TIME OF SUSPENSION IN THE CURTAIN