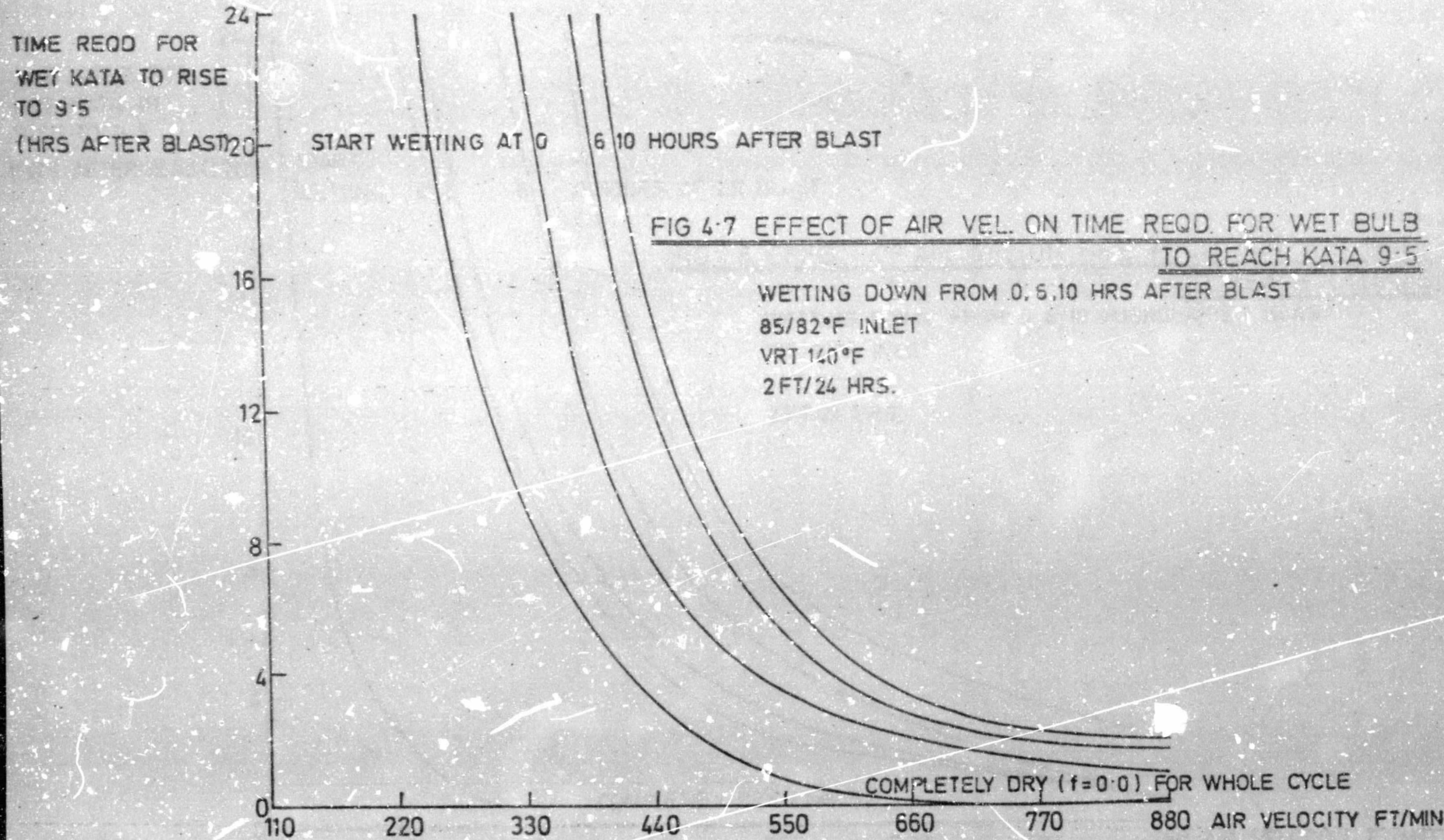



FIG 4·7 EFFECT OF AIR VEL. ON TIME REQD. FOR WET BULB TO REACH KATA 9·5

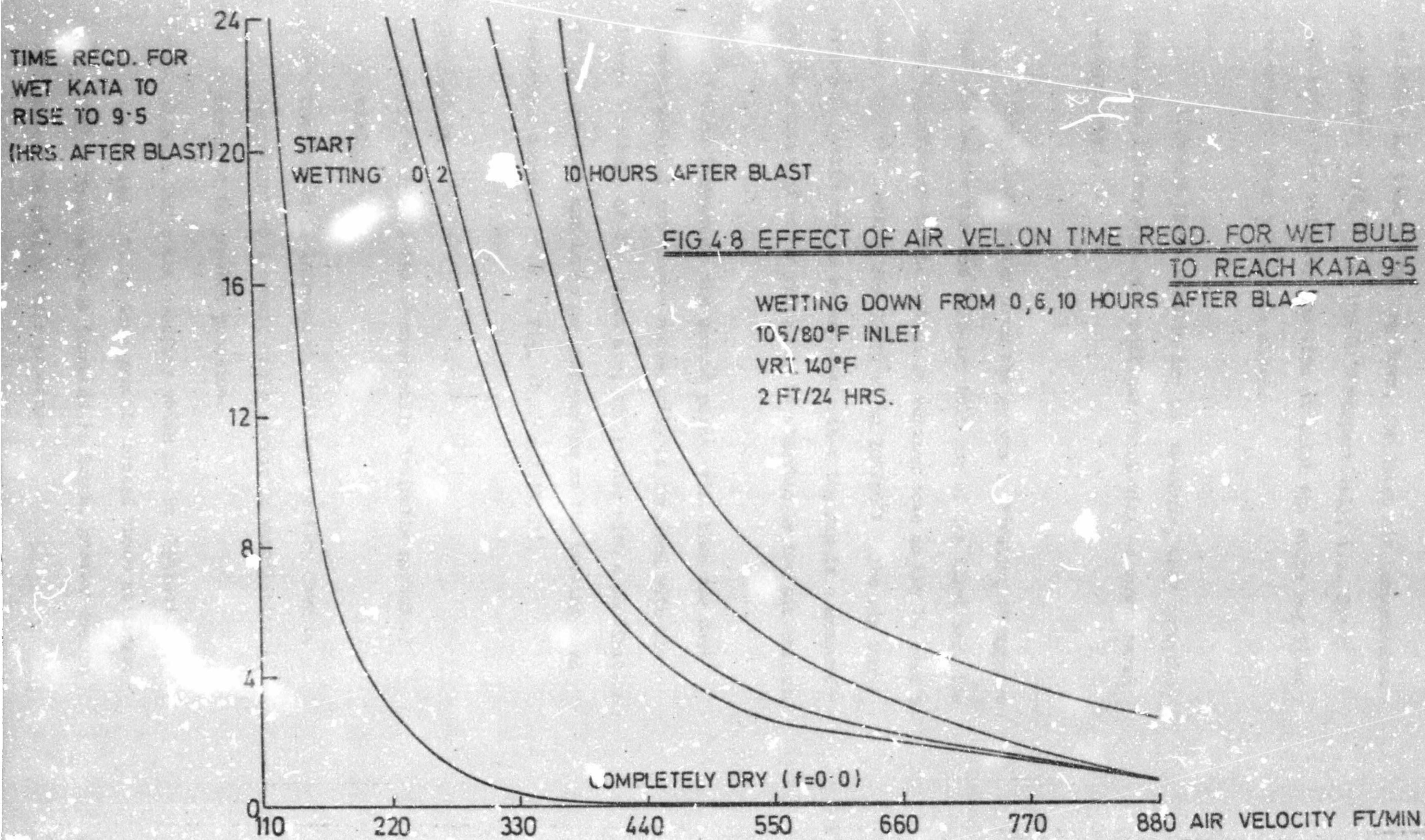



FIG 4·8 EFFECT OF AIR VEL. ON TIME REQD. FOR WET BULB TO REACH KATA 9·5 velocity and time of wetting down, for inlet air temperatures of 75/75°F, 85/82°F and 105/80°F respectively, i.e. for a particular air velocity the time at which the stope may first be entered after a blast is shown.

Although these results are not absolute, they nevertheless give indications of conditions which will be encountered at high VRT's.

Two points emerge from the graphs : Firstly, it appears that the larger the wet bulb-dry bulb gap of the inlet air, the more significant is the method of wetting down as may be seen by comparing the results for 75/75°F and 105/80°F inlet air temperature. This was to be expected since the gap is a measure of the amount of water which can be absorbed by the air stream.

This introduces the second point, viz. that the best conditions will not always necessarily be obtained with the lowest wet bulb of the inlet air, but rather with a combination of low wet bulb and large gap, depending on the wetting down technique adopted. (c.f. Fig. (4.6) and (4.8)).

## 4.3 Conclusions

(i) Dry mining is the theoretically desirable method of mining.

(ii) Once water is introduced, judicious wetting down is equivalent to a considerable saving in ventilation compared to present practice.

(iii) At high VRT's the benefits which may be obtained by controlled wetting down greatly exceed those at lesser VRT's. Thus as mines increase in depth, greater regard should be paid to this process.

## CHAPTER 5

### Insulation of airways

The advantage to be gained by insulating an airway with polyurethene foam was examined by using the mathematical airway computer model designed by Starfield. This model calculates wet and dry bulb increases in airways using the same basic principles as the stope program, except that

(i) radial heat flow is assumed;

(ii) the dimensionless temperature is calculated from Goch-Patterson tables[1] for radial heat flow into a tunnel (which assumes an infinite heat transfer coefficient) and the finite strip method described by Starfield[8].

Heat flow in a direction parallel to the length of the airway is ignored. This assumption is unlikely to affect the validity of the model as heat flow in that direction is extremely small.

### 5.1 Description of the model

An airway of radius 6½ ft surrounded by rock at VRT's of 100°F, 120°F and 140°F was considered. The temperature of the air entering the tunnel was 85/82°F and the rate of air flow was 170,000 c.f.m. (1280 ft/min).

Insulation thicknesses of ½", 1" and 2" were simulated by using an equivalent value of the heat transfer coefficient H. (See Carslaw and Jaeger p. 322)[26]. The heat capacity of the foam film was neglected. It was assumed that insulation could be applied over the entire surface area of the airway.

In practice it would probably not be feasible to insulate the footwall. Also, the surface of the insulation was assumed to be dry, i.e. no evaporation took place into the ventilating air.

The wet and dry bulb temperatures of the air were then calculated at a point 2000 ft along the airway for a period of 500 days after holing, before which it was assumed to have been unventilated.

These results were compared with those obtained for the same airway without insulation, and having various degrees of overall wetness, viz. $f = 0$ (completely dry), $f = 1/10$, $f = 1/2$ and $f = 1$ (completely wet). In the light of subsequent work by Starfield and Dickson[13], it is probable that $f = 1/10$ most nearly represents the case of a damp footwall with dry side and hangingwalls. This is a typical underground condition.

The computer model assumes that the airway appears instantaneously, i.e. the development of the airway is neglected. Thus for very short periods of time after holing the model is inaccurate, but for the period considered above it is unlikely that this factor will be significant. As in the case of the stope, the results are not intended to be absolute but rather a comparison of conditions which will yield useful information for future planning.

The parameters used were as follows :-

(i) Thermal conductivity of rock $k = 3.0$ BTU/ft$^2$ hr ($^\circ$F/ft).

(ii) Thermal diffusivity of rock $D = 0.10$ ft$^2$/hr.

(iii) Thermal conductivity of foam = 0.013 BTU/ft$^2$ hr ($^\circ$F/ft).

(iv) Thermal diffusivity of foam = 0.004 ft$^2$/hr.

(v) Surface heat transfer coefficient H = 4.5 BTU/ft$^2$ hr $^\circ$F.

(vi) Mass transfer coefficient E = 0.4 lb/ft$^2$ hr in. Hg.

## 5.2 Results

The results are presented in Fig. (5.1)(VRT = 100$^\circ$F), Fig. (5.2)(120$^\circ$F) and Fig. (5.3)(140$^\circ$F).

The thickness of the insulating layer does not appear to be critical as the 2" layer does not give greatly increased benefits compared to the ½" layer.

The wet bulb temperature in the wet airways is not particularly sensitive to the wetness factor f. This serves to confirm that if "dry mining" is de[illegible]le, the surface must not have any trace of moisture at all, [illegible] a small amount of water has almost the same effect as a completely wet surface.

As the VRT increases so the insulation becomes more effective. The greatest benefit from insulating is obtained during the early life of the airway and this benefit decreases with age. This is due to the fact that the heat flux into the airway is greatest immediately after holing. This implies that insulation should be applied as soon as the rock becomes exposed in order to obtain the maximum benefit. It is also expected that if a portion of the airway remains uninsulated (e.g. the footwall), the advantages to be gained from insulation will be greatly reduced. (A subsequent more general analysis by Harrison, Whillier and Cook[27] using a resistance paper analogue provides an indication of this reduction.)

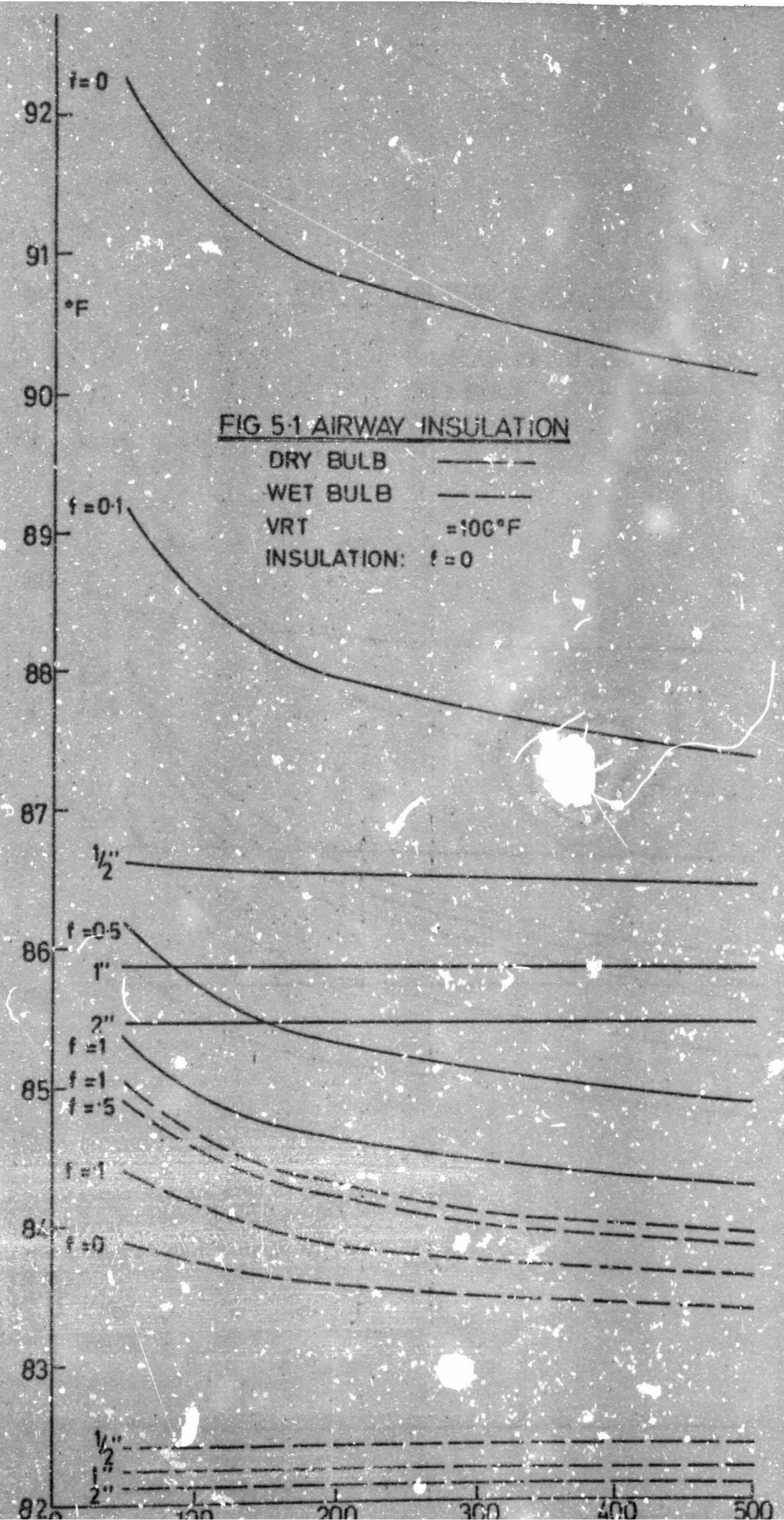


FIG 5·1 AIRWAY INSULATION
DRY BULB
WET BULB
VRT =100°F
INSULATION: f = 0
°F
f = 0
f = 0·1
f = 0·5
f = 1
f = ·5
½"
1"
2"
92
91
90
89
88
87
86
85
84
83
82
100
200
300
400
500

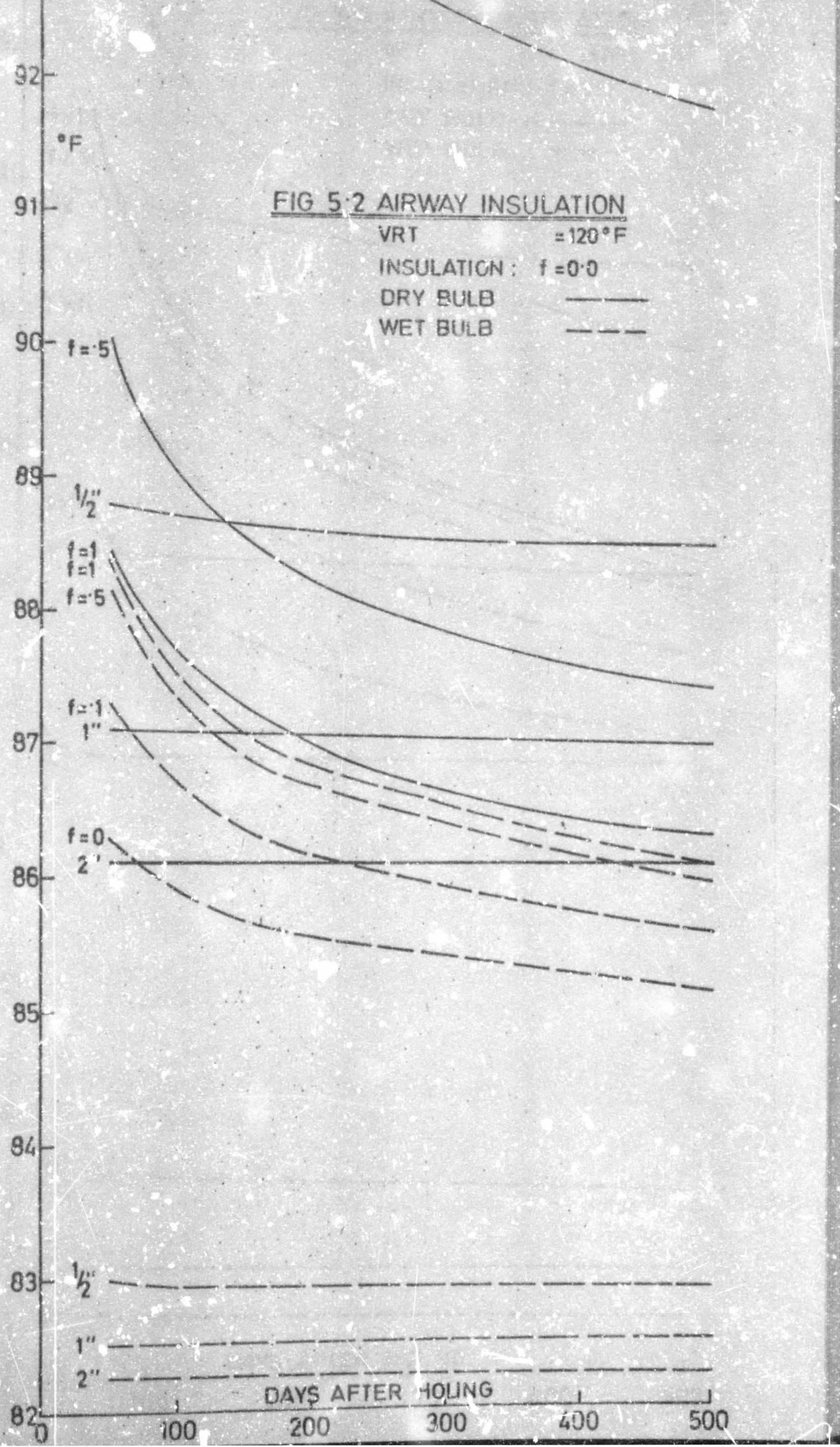


FIG 5·2 AIRWAY INSULATION
VRT = 120°F
INSULATION : f = 0·0
DRY BULB
WET BULB
°F
92
91
90
89
88
87
86
85
84
83
82
f = ·5
1/2"
f = 1
f = 1
f = ·5
f = ·1
1"
f = 0
2"
1/2"
1"
2"
DAYS AFTER HOLING
0
100
200
300
400
500

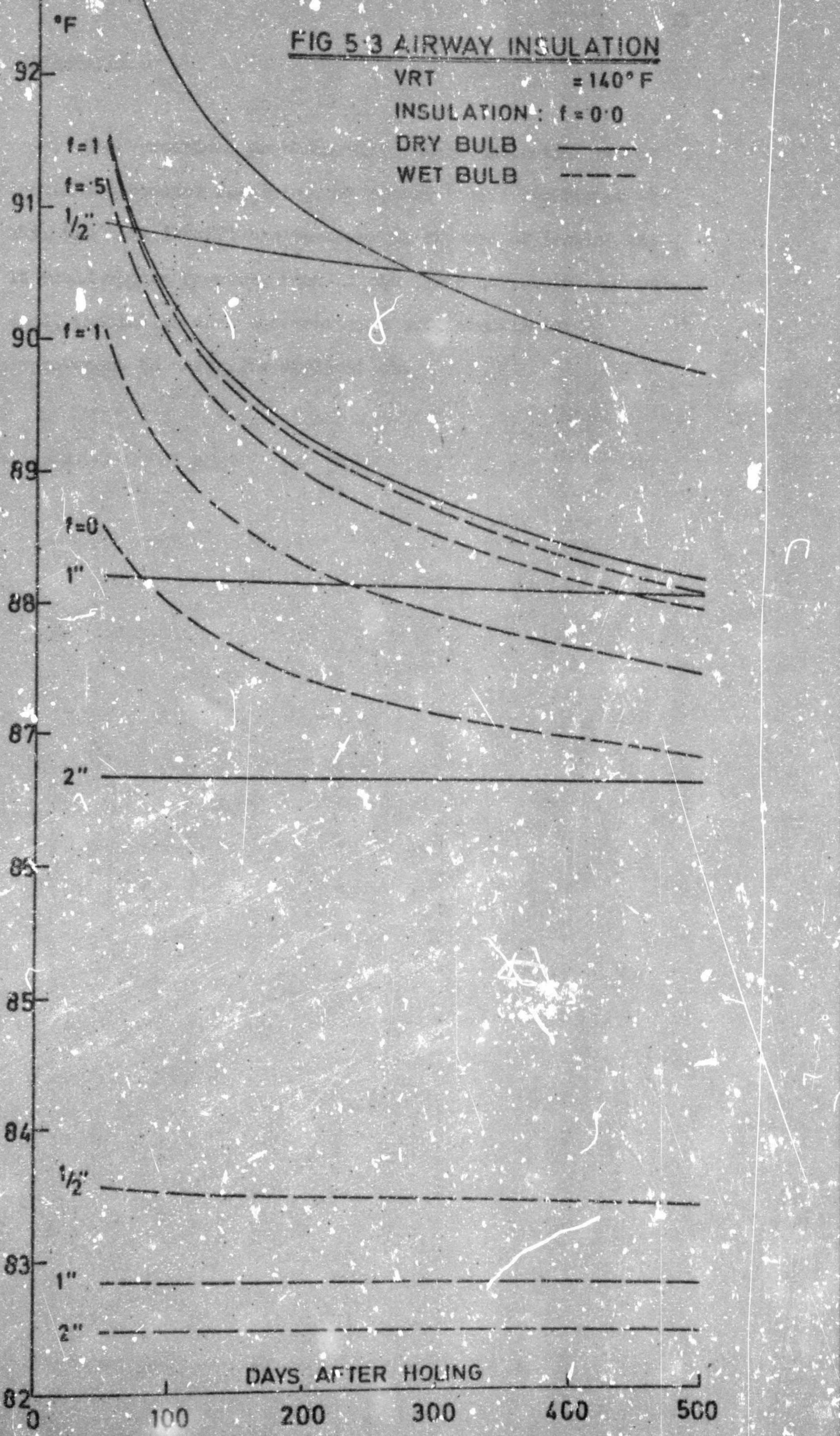


FIG 5·3 AIRWAY INSULATION
VRT = 140° F
INSULATION : f = 0·0
DRY BULB
WET BULB
°F
92
91
90
89
88
87
86
85
84
83
82
f=1
f=·5
1/2"
f=·1
f=0
1"
2"
1/2"
1"
2"
DAYS AFTER HOLING
0
100
200
300
400
500

## 5.3 Conclusions

Many practical problems will require attention before insulation becomes feasible, but theoretically the higher the VRT, the more justifiable becomes the expense of insulating. It would appear however, that at the VRT's at present encountered, insulation does not provide a sufficiently large improvement to merit its application.

# PART II

# CHAPTER 6

## Heat flow into an advancing stope - The solution of the two dimensional diffusion equation by Saul'ev's method

The solution of the diffusion equation in two dimensions has applications in many different fields. It forms the basis to an understanding of heat flow into underground excavations, and a solution of this equation is required before any comprehensive picture of wet and dry bulb temperature changes can be obtained.

In the case of an underground airway, heat flow is assumed to be radial and a one dimensional solution suffices.[8] Heat flow in a direction parallel to the direction of the airway is considered to be negligible. The main source of error in Starfield's mathematical model of a tunnel[9] is that the heat flow during the time the tunnel is being developed is ignored. However, an airway generally requires a long term solution and as the airway ages so the model becomes more accurate.

The stope on the other hand involves short term changes so that an exact simulation is desirable. While Starfield's quasi-analytic one dimensional model has the advantage of containing closed expressions for temperature and flux, it does involve approximations, the most severe of which is the neglect of the heat flow from the face to the hangingwall and footwall. (For a full discussion of Starfield's method see "Heat flow into the advancing stope"[28]).

### 6.1 Statement of the problem

The complete problem of heat flow into a stope may be

/illustrated

illustrated diagramatically as in Fig. (6[illegible]

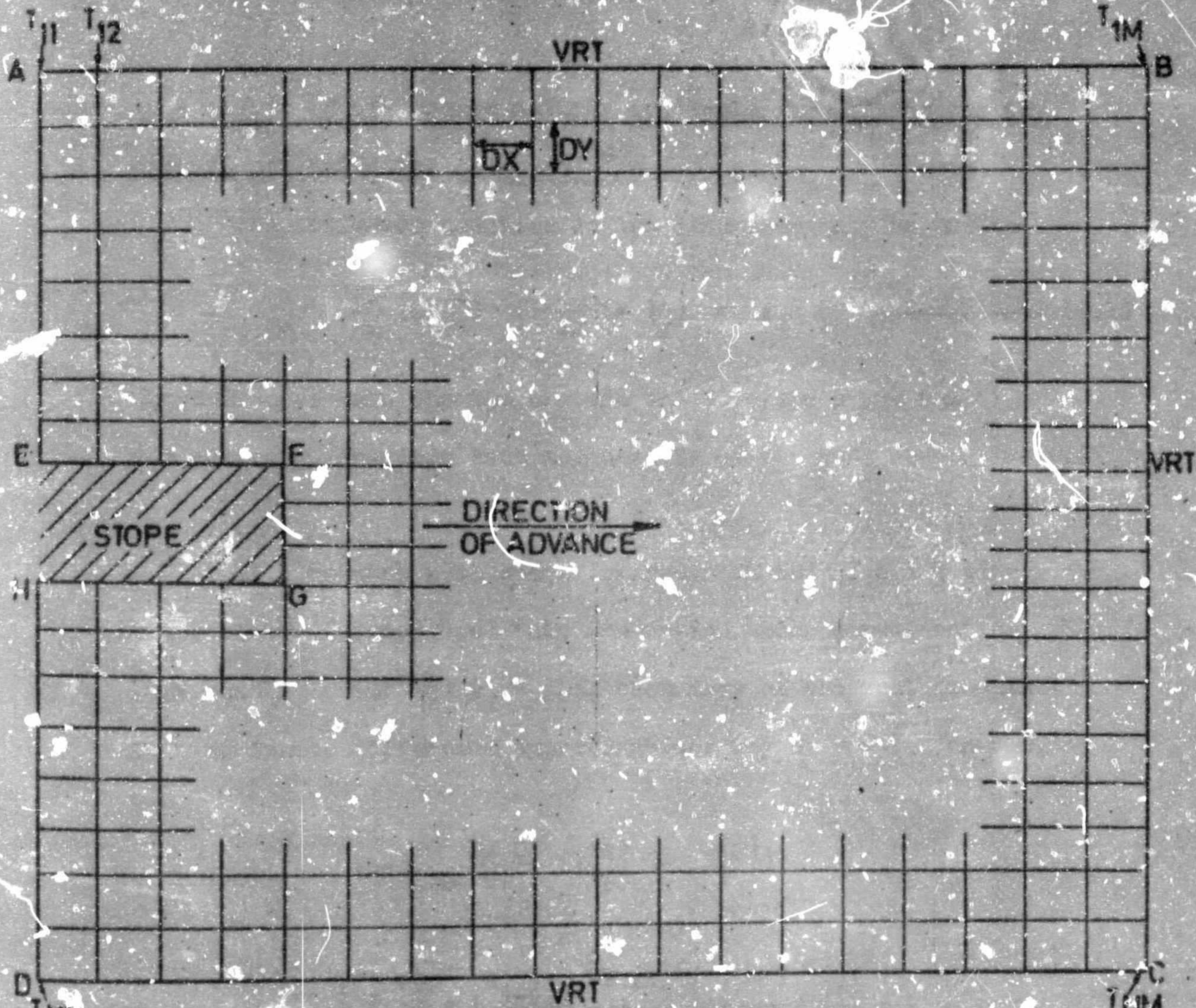
EFGH represents an advancing stope, where AB, BC and CD are assumed to be at VRT. The stope advances in discrete steps at each blast, cools for the remainder of the cycle and then advances again by another discrete step. After several such blasts a recurring state, in which temperature-time profiles remain the same for each cycle, is reached.

In order to solve this problem certain assumptions regarding boundary conditions are made. A condition of zero conduction is [illegible] across AH and [illegible]. From physical considerations [illegible] may be seen [illegible] assumption since the heat flow [illegible] point, [illegible] considerable time to reach [illegible] will be [illegible] that at the face and will take place [illegible] through the hangingwall and footwall with very little [illegible] the stope.

EF, FG and GH are either at a constant temperature or subject to a forced convection type boundary condition. The forced convection boundary condition is generally accepted as being applicable at a rock-air interface. [illegible] is the scatter-wall which is assumed to advance with the stope face.

As an initial condition it is assumed that the stope suddenly appears in rock at VRT. Taking the rate of advance to be DL ft every KDT hours, the rock around the stope cools for KDT hours after blast, where DT is a time step and K is the number of such steps. The stope then advances by a step of DL ft [illegible] the rock cools for KDT hours etc.

FIG 6.1 DIAGRAMMATIC REPRESENTATION OF A STOPE



The problem is to determine the temperature distribution in the rock for all time.

The problem may be solved by dividing ABCD into a mesh and applying a finite difference technique. Until recently the solution of large two dimensional grids by difference methods has proved unfeasible due to the slowness or instability of the various methods available.

## 6.2 An analysis of difference methods available for solving the two dimensional diffusion equation(29)

The diffusion equation in two dimensions may be written

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) = \rho c\frac{\partial T}{\partial t} \qquad (6.1)$$

where T represents the temperature and k, c and $\rho$ are the conductivity, specific heat and density of the rock respectively.

If a network with space intervals DX and DY and a time interval DT is introduced into the region under consideration such that $x_i$ = iDX and $y_i$ = jDY, then many of the most frequently used finite difference approximations may be written in the form,

$$(\rho c)_{i,j}\frac{DX\ DY}{DT}\left(T^{(q)}_{i,j} - T^{(p)}_{i,j}\right)$$

$$= \sum_r \beta^{(r)}_{i-\frac{1}{2},j}\left\{\frac{k_{i-\frac{1}{2},j}\ DY\ \left(T^{(r)}_{i-1,j} - T^{(r)}_{i,j}\right)}{DX}\right\}$$

$$+ \sum_r \beta^{(r)}_{i+\frac{1}{2},j}\left\{\frac{k_{i+\frac{1}{2},j}\ DY\ \left(T^{(r)}_{i+1,j} - T^{(r)}_{i,j}\right)}{DX}\right\}$$

$$+ \sum_r \beta^{(r)}_{i,j-\frac{1}{2}}\left\{\frac{k_{i,j-\frac{1}{2}}\ DX\ \left(T^{(r)}_{i,j-1} - T^{(r)}_{i,j}\right)}{DY}\right\}$$

+ / ...