### Infra-red Energy

The invisible energy nearest the violet end of the visible spectrum is called 'Ultra-violet'. At the other end of the visible spectrum just beyond the red light is another band of 'invisible energy'. This is called 'Infra-red' and in common with other radiant energy it has one most useful property - whenever it is absorbed the energy is transformed into heat. Infra-red lamps were developed to make use of this property by the process of radiant heating.

### Heating Process

Infra-red lamps differ from other types of radiant heaters such as bar-fires and steam radiators in that they generate the shorter wave length Infra-red energy. This energy passes through the intervening air with little or no absorption and is converted to heat in the receiving material itself. More conventional radiators generate longer wave Infra-red which is absorbed to a large extent by the intervening air. Therefore heating with such radiators involves a double transfer i.e. from the radiator to the air and from the air to the receiving material - a less efficient process.

Infra-red energy like light can be absorbed, reflected, refracted and transmitted according to wavelength and the physical characteristics of the material receiving it. All this can take place in one medium. For example, in paint baking on metal the radiated energy is partly absorbed by the paint thus raising its temperature and partly transmitted through the film. The part transmitted strikes the underlying metal which will reflect, absorb and transmit the energy in proportion to its characteristics. The temperature of the metal is thus raised and the paint temperature increased again by the process of radiation and conduction.

It can be seen from this that most of the heat is generated in the paint itself and explains why Infra-red has been described as 'heating from the inside out'.

### LAMPS

Ordinary Infra-red lamps are similar in construction to conventional tungsten filament lamps in that they comprise a glass envelope containing an inert gas and in which a filament is mounted. However, since their prime purpose is to generate heat and not light, the filament operates at a lower temperature than that in a GLS lamp. The result is that much more heat is generated with less light and the life of the lamp is increased considerably.

### Which lamp to use?

Technical details of Infra-red lamps are given in our Lamp Data Sheets but the following indicates their uses. Three types of Infra-red lamps are in use at present.

(a) pear shape bulb.
(b) Internal reflector type.
(c) Quartz Tubular type.

(1) Pear shape bulbs

These lamps were the first produced and were used with gold plated spun copper or aluminium reflectors. The lampholders were adjustable with respect to the reflectors so that dispersive or concentrating distributions could be obtained. However, due to the bulky arrangement of lamp plus reflector and the speed with which the reflectors could be fouled by dust or paint they were superseded by the internal reflector type lamps. They are seldom used for new Infra-red installations today.

(2) Reflector type lamps

These are the most popular types for the majority of industrial applications. They have the advantages of:

(1) Accurate control of energy by a properly shaped bulb contour and internal aluminizing of the lamp.
(2) Ease of cleaning.
(3) Less glare than from pear shape bulbs due to the 'cut-off' provided by the internal reflector.
(4) Fairly high intensities can be achieved as the lamps can be spaced close together (diameter of bulb 5"). The density range which can be achieved is up to 10 watts per sq. in.

(3) Quartz Infra-red lamps

As the popularity of Infra-red lamps grew the need for a source of higher energy output became apparent. This has been achieved by the use of quartz for the lamp envelope. The major advantages of quartz are :

(1) High melting point.
(2) Low thermal inertia.
(3) Low co-efficient of expansion.

The high melting point (3000°F as opposed to 840°F for ordinary glass bulbs) has enabled large wattages to be concentrated in lamps of small physical dimensions-the average tube diameter is $\frac{3}{8}$"-and so lamps can be spaced more closely to give high density distributions.

A single 1 kW Quartz Infra-red lamp in a suitably designed reflector will give a density of 50-100 watts/sq.in. over a limited area. By using multiple arrays of lamps and reflectors it is possible to obtain densities of up to 50 kW per sq. ft.

Due to the low thermal inertia the lamps achieve full operating temperature almost instantly and when switched off lose 80% of their maximum intensity in two seconds. The 'warming up' period often required by more conventional heating methods such as steam heated ovens is due to the intrinsic difference of heating the air to heat the objects as opposed to direct infra-red irradiation of the objects. This is, of course, equally true for any form of Infra-red heating including the internal reflector type lamp, and for that matter, gas-fired Infra-red heaters.

The low coefficient of expansion enables lamps to be used in situations where other lamps would crack or break due to thermal shock, as quartz expands or contracts very little with temperature changes. To demonstrate this a cigarette could be lit from the hot quartz envelope, yet the latter would not crack if touched with a piece of ice. For this reason the lamps are suitable in processes where they are likely to be splashed by liquids or subject to violent temperature changes.

## APPLICATIONS

Infra-red lamps are used for the following main applications:

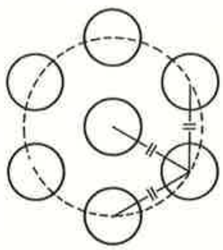
(1) Heating e.g. to expand or soften materials or to prepare them for other processing.

(2) Drying e.g. to evaporate liquids.

(3) Baking e.g. curing paint finishes either by evaporation for lacquers or polymerisation for Enamels. Varnishes, Japans and House paints are cured by oxidation and the application of heat does little to assist this process.

### Suitability of Infra-red Method

The suitability of Infra-red lamps for a particular application can be judged best by a small scale installation which can be adjusted to meet the specific conditions. It is suggested that 7 Reflector type lamps would be a suitable number for experimental trials as shown below.



As a preliminary step the number of lamps required can be calculated mathematically or by graphical methods. From this an estimate of costs can be made and the economics of the system assessed.

This sheet gives sufficient data to enable such calculations to be made.

## METHODS OF APPLICATION

### DRYING UNITS

Detailed information on the design of drying units is beyond the scope of this data sheet but the following indicates the most popular types of drying units and their use.

Flat Banks are most suitable for flat sheet steel, wood parts, paper, fabric, etc.

Portable Units. These are small banks which can be taken to the work i.e. for drying synthetic enamel on cars after being touched up.

I.R. Tunnels and Ovens. These are best used for all 3 dimensional objects and are usually of the conveyor type. The cross section of the tunnel will depend on the largest dimension of the object to be passed through. The length in feet of the I.R. Tunnel of a conveyor type of oven is the product of the time taken to complete the drying process in minutes and the speed of the conveyor in feet per minute.

The efficiency of the tunnel used will depend on:

(1) Its shape. Cylindrical tunnels are most efficient but not always practicable.

(2) Reflection factor of internal surfaces. Anodized aluminium has a high reflection factor to Infra-red. Specular or slightly diffuse etched anodized aluminium is commonly used to back banks of internal-reflector and quartz lamps to redirect otherwise wasted energy back on to the articles passing through the tunnel.

(3) Thermal insulation of outside walls. This factor is not so important in the I.R. oven as it is with conventional ovens.

### Length of Tunnel

As mentioned above under 'Tunnels', the length of a tunnel for any given job is a function of the time required for drying and the production rate in feet per minute. Thus if the time required to complete the drying process is 't' minutes and the movement of the conveyor is 'm' ft. per minute then the length of the tunnel is 't' x 'm' ft. It depends on the space required for lamps and reflectors.

## GENERAL CONSIDERATIONS

Before proceeding with the calculations for the applications the following queries and points should be noted.

(1) Can Infra-red lamps be applied to the particular heat problem without damage to the materials involved?

(2) Can the process be more readily and quickly performed by the use of Infra-red lamps?

(1) Suitability

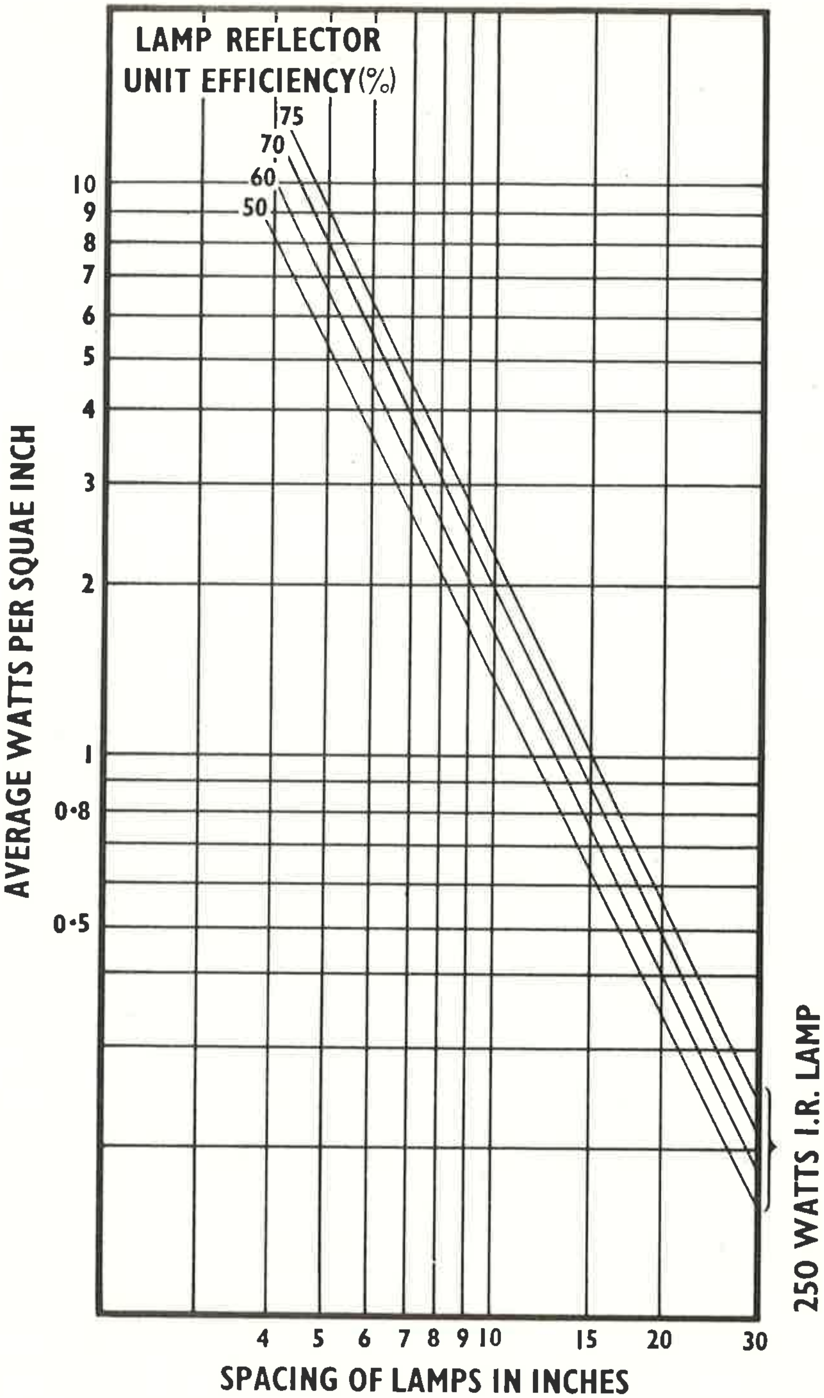
Is the material suitable for heating by the Infra-red process? Materials which absorb infra-red well are best suited and information on this point can usually be obtained from the manufacturers of the particular material.

(2) Temperature

What is the maximum safe working temperature for the materials? There is usually a maximum temperature which some materials or finishes will withstand. In others the rate of temperature rise is the prime factor. Again the total amount of heat absorbed is the most important consideration with other materials. Measurements are usually made with thermocouples and results judged by the appearance and quality of the material after treatment.

Safety

What are the safety precautions necessary for the installation? Adequate air circulation must be provided to remove inflammable volatiles but for maximum heating efficiency air circulation should




**APPROXIMATE SPACING OF DRYING LAMP UNITS FOR OBTAINING DESIRED CONCENTRATION OF RADIANT ENERGY**

be kept to a minimum. Natural air circulation might be adequate but where there is doubt the factory inspector or other appropriate authority should be consulted.

Only quartz Infra-red lamps and reflector lamps with heat resistant bulbs will withstand the splashing of liquids. Lamps should be suitably protected to avoid mechanical breakage. Ceramic lampholders are needed usually to withstand oven temperatures.

## HEATING

All calculations are based on the conversion into watts of the B.Th.U. required to raise and/or maintain the temperature. The amount of heat required largely depends on time available for the process.

Temperature rise is the important thing, the increase depending on the specific heat of the material being heated.

The material should have a good infra-red absorption factor, a high ratio of surface area to volume and be a good conductor of heat.

As much of the surface as possible should be irradiated to ensure quick and even heating.

Having established the total watts needed, the choice of lamps and spacing depends upon the rate of warm-up desired, conveyor speed and other factors. Length of oven depends on area needed for lamps and reflectors.

Total lamp watts required:

$$= \frac{\text{lb. of material per hour} \times \text{sp. heat} \times \text{required temp. rise } (0^{o}\text{F})}{3413 \times \text{lamp and reflector efficiency} \times \text{Abs. factor} \times \text{space factor}}$$

| Typical Lamp and Reflector Efficiencies |
|---|
| (a) Reflector lamps 0.75 |
| (b) Pear shape bulb and reflectors 0.68-0.80 |
| (c) Quartz Infra-red lamps and reflectors 0.75 |

Absorption factor = the percentage of the radiant density falling on the material and absorbed by it. Factors for common reflector materials and colours are shown in the table.

Space factor = the ratio of energy arriving at the working plane to that which is interrupted by the work. With a good oven design having a good infra-red reflecting surface and for flat bank work the factor is about 0.9.

| Approx. Infra-red absorption factors | |
|---|---|
| Specular Metal | 0.05-0.10 |
| Aluminium | 0.15 |
| Steel | 0.20 |
| Copper | 0.25 |
| White | 0.35-0.40 |
| Cream | 0.45 |
| Light Green | 0.55 |
| Chrome Yellow | 0.55 |
| Red | 0.65 |
| Green, Brown, Blue | 0.65-0.75 |
| Light Grey | 0.65-0.75 |
| Black | 0.90 |

| Approx. specific Heat of materials (with temperature at $212^{o}$F unless otherwise stated.) | |
|---|---|
| Air | 0.24 |
| Aluminium | 0.23 |
| Asbestos | 0.20 |
| Brass | 0.09 |
| Bronze | 0.09 |
| Carbon, Graphite (at $185^{o}$F) | 0.18 |
| Cellulose, Dry | 0.37 |
| Cement, Powder | 0.20 |
| Chalk | 0.21 |
| Charcoal (at $50^{o}$F) | 0.16 |
| Clay, Dry | 0.22 |
| Copper | 0.09 |
| Ebonite | 0.4 |
| Glass | 0.12-0.2 |
| Granite | 0.19 |
| Ice (at $14^{o}$F) | 0.53 |
| Ind. Rubber | 0.48 |
| Iron | 0.12 |
| Lead | 0.03 |
| Leather, Dry | 0.36 |
| Marble | 0.21 |
| Nickel | 0.11 |
| Porcelain | 0.26 |
| Steam | 0.48 |
| Steel | 0.12 |
| Water | 1.00 |
| Wood | 0.42 |
| Zinc | 0.10 |

### Lamp Spacing

Heating and Drying processes - having found the total watts needed the choice of lamps and spacing will depend on:

(1) Rate of warm-up required.

(2) Conveyor speed.

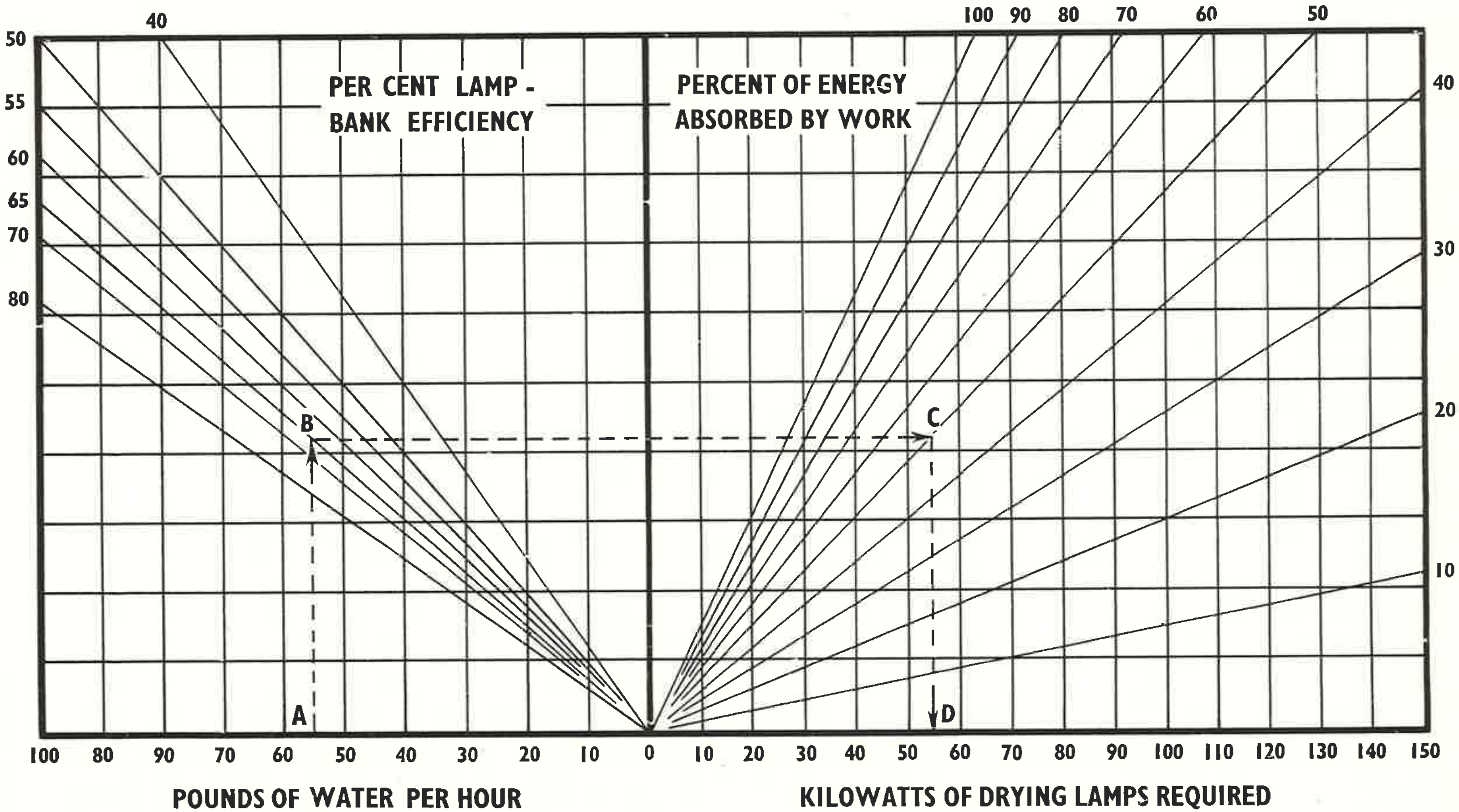
(3) Other factors - see (Which lamps to use; Safety).

### Time period to complete process

Where it is desired to alter the time period to complete the process the quotient of the heating or drying formula must be multiplied by $\frac{1}{T}$ where T is the time in hours to complete the process.

If the watts required is increased (i.e. the time required is less than 1 hour) care must be taken to ensure that the safe working temperature for the material concerned is not exceeded.

For determination of approximate kilowatts of drying lamps required for water heating and evaporating. Starting with a given weight of water (for example 55 pounds per hour at A) proceed clockwise to the lamp-bank efficiency (for example 65% at B). Then to absorption per cent (for example 50% at C). Then to final answer D (in this case 55 kilowatts). This chart is based on an initial water temperature of 70° F.



## Drying

The purpose of the Infra-red heating is to supply enough heat to:

(a) raise the temperature of the liquid-bearing material from its initial temperature to the vapourization temperature of the liquid it contains.

(b) raise the temperature of the liquid contained in the material from its initial temperature to its vapourization temperature.

(c) vapourize the liquid either completely, or so that the material reaches a certain degree of dryness as required by the user.

The liquid may be water, in which case the vapourization at normal atmospheric pressure is 212°F. The vapourization temperature of some other liquids is given in the following table.

Energy level, i.e. watts per square inch, and temperature are to some extent interlocked. Temperature is a result of energy level which is adjusted by controlling the watts/sq.in. on the work. The watts per sq.in. are in turn controlled by the lamp size and spacing and the operating characteristics of the Infra-red equipment used. It should be noted that the temperature of a particular material under a certain intensity for a particular time will vary depending on the relative absorption of the I.R. This in turn depends on the overall efficiency of the oven.

The drying process comprises:

(1) Heating the liquid bearing materials and surrounding air.

(2) Reducing the humidity of the air flowing over it.

(3) Increasing the air flow.

Infra-red drying is concerned with the first stage only, though all three are necessary.

In assessing the total wattage required 3 quantities have to be determined.

(1) The B.Th.U. required to raise the temperature of the material containing the liquid to the vapourizing temperature of the liquid in one hour = temperature rise in °F x lb. of material per hour x sp. heat (material).

(2) The B.Th.U. to raise the liquid from initial to vapourizing temperature in 1 hour.
= Temperature rise in °F x lb. of liquid per hour x sp. heat of liquid.

(3) The B.Th.U. to vapourize the liquid at vapourizing temperature = Heat of vapourization (B.Th.U. per lb.) x lb. of liquid per hour.

Total watts required

$$= \frac{(1) + (2) + (3)}{3413 \times \text{lamp \& reflector efficiency} \times \text{abs. factor} \times \text{space factor}}$$

| | Vapourization Temperature °F | Heat of Vapourization B.Th.U./hour |
|---|---|---|
| Acetone | 133 | 224 |
| Amyl. Alcohol | 268 | 216 |
| Benzene | 176 | 710 |
| Carbon Disulphide | 115 | 152 |
| Carbon Tetrachloride | 170 | 84 |
| Ethyl Acetate | 32 | 184 |
| Ethyl Alcohol | 173 | 368 |
| Methyl Acetate | 32 | 205 |
| Methyl Alcohol | 133 | 177 |
| Water | 212 | 970 |

## Baking or Stoving

In paint baking the temperature to which the paint should rise without damage is determined by its ingredients and should be specified by the paint manufacturer. The specification calls for a certain temperature to be held for a certain length of time and the oven should be designed to provide these specified conditions. This temperature is the one at which the energy radiated by and/or convected or conducted from the work is equal to the energy received from the heat source. As long as this condition exists the work will maintain this maximum temperature. If the manufacturer specifies that a paint should be baked for 10 minutes at 275°F then 275°F is the maximum maintained temperature to which the oven must bring the work.

The density level (i.e. watts/sq.in.) required to obtain a given temperature depends on the nature, mass, and absorption characteristics of the material and the flow of air through the oven.

Approximate figures can be obtained from the accompanying chart. For more accurate information the intensity necessary for a particular application should be found by experiment.

## Lamp Spacing

Having found the watts per sq.inch required the lamp spacing can be found by the following formula.

Area per lamp =

$$\frac{\text{watts per lamp} \times \text{lamp and reflector efficiency}}{\text{watts per sq.inch}}$$

From the above if lamps are spaced at 6" x 6" centres each lamp will cover an area of 36 sq.in.

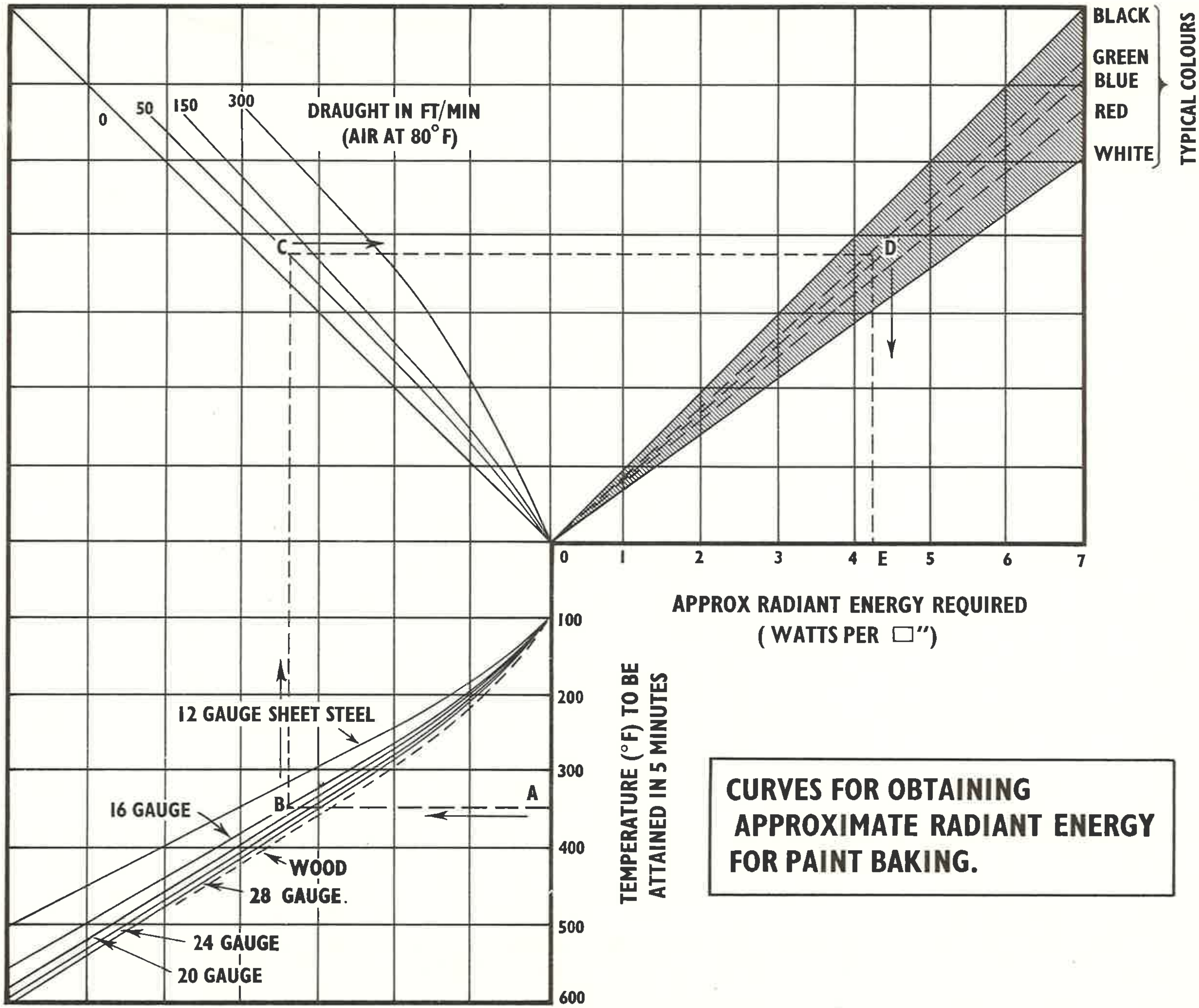
The spacing of 250-watt Reflector lamps to give the concentration of radiant energy required can be found from the attached graph Note that the graph is for diagonal and not rectangular spacing of lamps as shown on the graph.

## Uniformity of Distribution

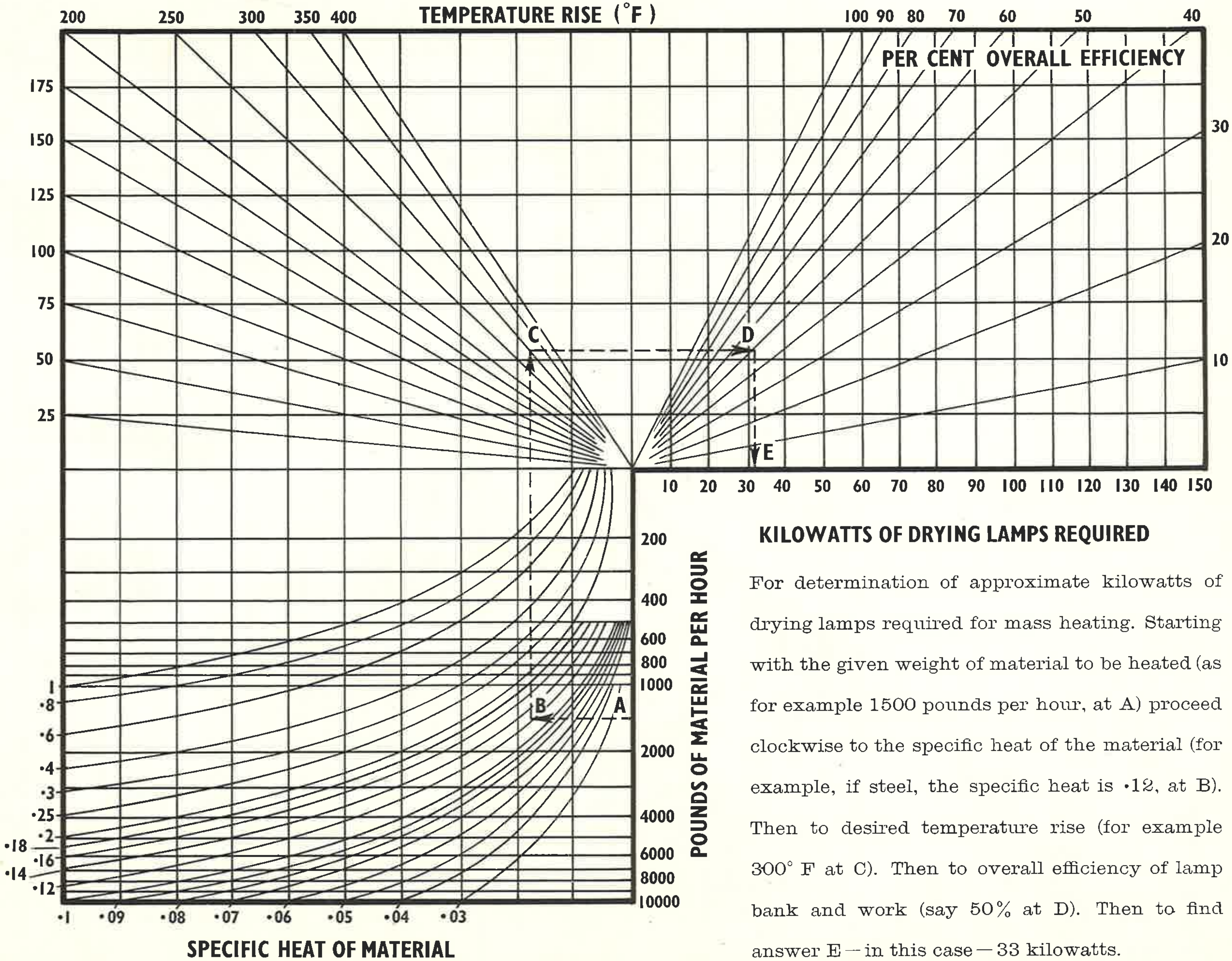
To provide uniform distribution, and in order to keep the energy utilization high, the distance between the heat source and the material to be treated should be:-

For pear shape bulbs, reflector lamps and reflectors - not less than 8" - 10" and not more than 15".

Spacing should not be less than 1.6 x distance from material.




**CURVES FOR OBTAINING APPROXIMATE RADIANT ENERGY FOR PAINT BAKING.**




## KILOWATTS OF DRYING LAMPS REQUIRED

For determination of approximate kilowatts of drying lamps required for mass heating. Starting with the given weight of material to be heated (as for example 1500 pounds per hour, at A) proceed clockwise to the specific heat of the material (for example, if steel, the specific heat is ·12, at B). Then to desired temperature rise (for example 300° F at C). Then to overall efficiency of lamp bank and work (say 50% at D). Then to find answer E — in this case — 33 kilowatts.