Industrial Application of Infrared Technology

Paul W. Gaussorgues

HALTEC

B. A.

Industrial Applications of Infrared Spectroscopy

H. A. Willis
J. H. van der Maas
R. G. J. Miller

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APPLICATIONS

of

INFRARED

The quality of the materials used in the manufacture of this book is governed by continued postwar shortages.

Industrial
APPLICATIONS
of
INFRARED

By JAMES DOYLE HALL

Advisory Engineer

Lamp Division, Westinghouse

Electric Corporation

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INDUSTRIAL APPLICATIONS OF INFRARED

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To

ISABELLE

and

DAVID HALL

PREFACE

Since November, 1938, when general publicity first was given to the Ford Motor Company's process for drying finishes on automobile bodies with infrared tunnels, there has been widespread and ever-increasing interest in infrared radiation for an almost endless number and variety of heat applications. This interest, which has caused a continuous, unabated flow of inquiries on the use of infrared lamps, has prompted this effort at preparing a nontechnical source of reference which, it is hoped, will anticipate many of the questions on the subject.

Although heat formulas and theoretical calculations are useful in considering the application of radiant heat, in many cases data obtained from actual tests or from the experience of others are more valuable in quickly reaching the final and complete solution of a given problem. With this latter thought in mind, emphasis has been placed on the practical rather than the theoretical aspects of the subject. Simple test procedures are outlined, and data obtained from a number of sources are used. The variety of infrared installations photographically recorded and described should be of assistance not only in the solution of specific problems but also in suggesting additional uses of radiant heat to the reader.

The author freely acknowledges the use of information acquired by the effort and the experience of others; in fact, he prefers to consider this book largely as a compilation of existing data rather than an original treatise on the subject. Without the help received from many sources, the undertaking would not have been possible. Appreciation is due especially to friends in The Fostoria Pressed Steel Corporation, C. M. Hall Lamp Company, *Electrified Industry*, Commonwealth Edison Company, and The Cleveland Electric Illuminating Company for their invaluable assistance in obtaining installation data and photographs.

Within his own company, the author is indebted particularly to Priscilla Presbrey, Ralph Brady, and Robin Adair for their criticisms and help in the composition of the text and to all members of the department who assisted in the mechanical preparation of the manuscript.

JAMES DOYLE HALL

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Industrial

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CHAPTER I

INTRODUCTION

The desire of the human mind to explain phenomena in terms of the obvious created the "ether" as the medium by which light is transmitted. Similarly, the concept of heat could be explained in the scientific mind of 200 years ago only by a weightless fluid known as "caloric," the presence or the absence of which determined the thermal condition of a body.

Heat

Heat is a form of energy—related to but different from all other forms of energy. In the modern atomic theory of matter, it is associated with the energy of motion of the particles of which such matter is composed. When no physical change occurs in a body, the usual indication of a change in heat is an increase or decrease in the temperature, probably as a result of changes in speed and friction within the atomic orbits.

Temperature

Temperature is the obvious indication of heat. If an object feels warm, or becomes warm, as a result of some treatment, it is assumed that direct heat has been applied or that there has been an absorption of some other form of energy which by its effect on the atomic structure produces the same results as directly applied heat. Regardless of our scale of measurement—Fahrenheit, centigrade, absolute, or others—temperature is merely a measure of the *intensity* of heat. But more than intensity must be considered since heat is related to the total amount of energy involved in producing a given temperature.

Heat Quantity

As against temperature as a measure of heat intensity, the calorie has been established as a quantitative measure of heat—a calorie being the amount of heat required to raise 1 gram of

water 1°C in temperature. Likewise, the British thermal unit, also a quantitative measure of heat, is the amount of heat required to raise 1 lb of water 1°F in temperature.

Specific Heat

The ability of a material to absorb heat, or in other words its thermal capacity, is expressed in terms of "specific heat." The specific heat of a material is merely a mathematical expression of its ability to absorb heat as compared with water having a specific heat of 1.00. Thus, a material having a specific heat of 0.10 requires one-tenth as much heat to increase its temperature 1 degree as is required by a similar weight of water.

Changes Effected by Heat

It is important to recognize that heat does far more than change the temperature of a body. In many industrial-heating applications these other considerations are paramount. The most obvious change is in physical state—from solid to liquid, or from liquid to gas. Because of the different characteristics of matter in the various states, many industrial techniques are built on converting materials from one state to another, effecting a desirable alteration, and then returning them to their original state.

Another important change is that of volume; in fact, all standard thermometers are based on the uniform expansion of some material. In the case of a gas, the change of volume is not often permitted because the gas is usually confined; in such cases an increase in pressure results. Obviously, this also is possible with liquids and solids.

Many chemical reactions are accelerated or made possible by increased temperatures, probably as a result of the increased activity within the atomic orbit that permits or creates a breakdown of the normal limits of such atomic travel. This is especially true where the material is a relatively unstable compound created by special conditions.

Since electricity is a form of energy transfer from one atom to another, it is to be expected that heat affects the degree of electrical conductivity of most materials. Furthermore, electromagnetic radiations—the basis of so many energy forms—directly

result in heat. In the most common example of an electromagnetic radiator, the incandescent lamp, the tungsten filament is inert at room temperatures in so far as radiations are concerned. Heat applied by means of passage of electric current, or by any other means, is radiated largely in the form of infrared and visible light.

Even the element of comfort to the human body is a function of heat transfer. With the body, self-regulated at 98.6°F under normal conditions of good health, there is a discharge of heat into the air—the result of energy produced by air and food combustion within the body.

Heat as Related to Industrial Operations

With so many ramifications of the effect of heat, it is not strange that heat technology is a fundamental part of many industrial operations and of many purely human everyday living activities. And since heat can be provided in so many ways, many engineering analyses have gone into the study of the related problems. Obviously, the first requirement is the ability to achieve the particular heating result desired. Secondarily, however, there are problems of economics, of practical working comfort, and many other considerations. In fact, in many industrial problems, these secondary considerations become primary, since many methods of heating will produce the desired result.

Electricity, not in its direct form of merely creating a rise in temperature, but in its indirect form of creating electromagnetic infrared radiations as most commonly associated with the incandescent lamp, has opened an entirely new practical field of industrial heating. This is usually termed "infrared", or "radiant", heating. By its indirect nature it presents different aspects of control and application, many in a form not readily secured by any other form of heating. It is the purpose of this book to review these aspects in order to assist in a better understanding of the factors involved in this new field.

Electromagnetic Radiations

The great field of electromagnetic radiations (Fig. 1–1) is familiar through its manifestation as light, as a means of radio

communication and as X rays. These are, however, but a small part of this family—all showing definite similarities, yet all radically different with respect to results achieved by their use.

Approximately at the center of this group are the wave lengths (4,000 to 7,600 A[1]) that cause the sensation of light, and immediately adjacent (beyond 7,600A) the wave lengths that are known as "infrared." Both these groups cause the sensation of heat and are a direct result of the atomic disturbance due to the heating of matter. In fact, the main difference is not in the radiations themselves but in the fact that animals possess optic nerves that

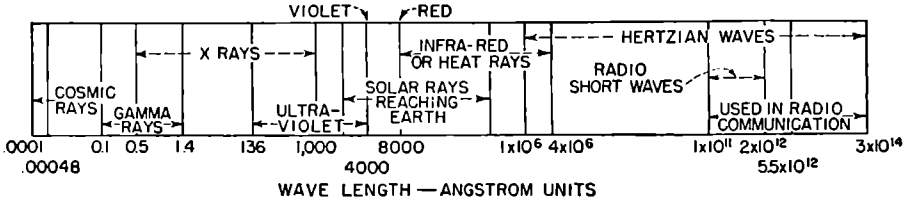

FIG. 1–1.—The electromagnetic spectrum showing relative position of infrared portion.

are capable of reacting to a very narrow portion of this radiation in producing sight. Most materials react exactly the same to radiations immediately on each side of the 7,600 A point, but as the wave lengths increase or decrease, characteristics such as reflection, absorption, and transmission tend to alter. It is because of this similarity and because of their very practical nature in regard to size, operation, and convenience that incandescent lamps are the standard form of infrared generators. The inherent difference causing change in wave length characteristics is temperature of filament operation—the higher the temperature, the greater the shift of peak energy radiation to the shorter wave lengths (Fig. 1–2). This is enough of a shift so that ultraviolet radiations in minute quantities are produced below the 4,000 A region with incandescent solids. However, it is important to note that even in the most efficient incandescent lamp commercially made—the photoflood lamp—the amount of visible radiation does not exceed 20 per cent while the infrared radiation exceeds 70 per cent of the total energy consumed by the lamp.

All electromagnetic radiations travel at the rate of 186,000 miles per sec. Therefore, there is no problem of timing involved

[1] The angstrom is a physical unit of length equal to 3.937 billionths of an inch.

in the actual transfer of energy by infrared generators in industrial applications. Naturally, time is a factor in the process itself, since the conversion of such energy into heat as evidenced by a temperature rise or change in state of the material irradiated does not proceed at a rate that may be measured by a similar scale of speed.

Furthermore, electromagnetic radiations do not need a "carrier" —as does convected or conducted heat. This makes possible the

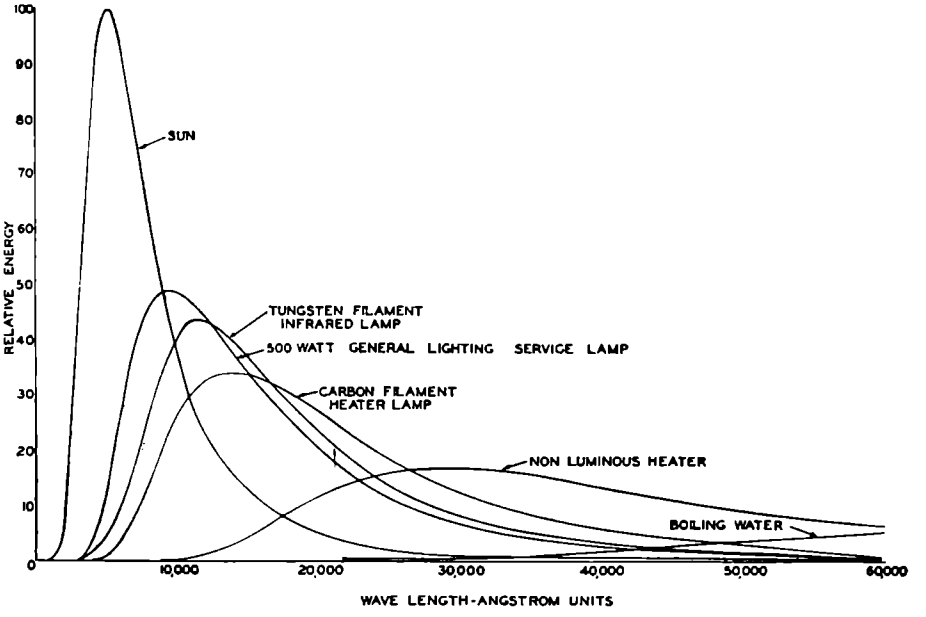

FIG. 1–2.—Comparison of distribution of energy radiated by various sources.

use of infrared in evacuated containers and eliminates any interference that might result from ventilation procedures made necessary by fumes or vapors generated from the heating process.

And, finally, electromagnetic radiations can be reflected and otherwise redirected so that high concentrations of energy may result in local areas even though the total energy input may be relatively small. This is well illustrated by the ordinary searchlight. Within the limitations of source size, and commercial reflecting surfaces, there is no essential difference between light direction and infrared direction.

Heat Transfer

Although the use of infrared involves the transfer of heat by radiation, no practical heat problem can overlook the association

of conduction and convection. Therefore, a brief review of these fundamentals of heat transfer without particular reference to any source is important.

Conduction

Heat transfer by the atomic or molecular action within a body, or from one body to another, is called "conduction." Such a transfer, by definition, requires the physical presence of material. Furthermore, because only solids have relatively fixed boundaries of mass, conduction is seldom associated with gases or liquids.

When a body is heated, it tends to reach a uniform temperature (or heat distribution) within itself. This is seldom possible because it simultaneously tends to reach a uniform temperature with adjacent surfaces, and these adjacent surfaces with still other adjacent surfaces. Heat is not static; it is continuously in a state of flow, of transfer of energy from a hotter to a colder body. It is therefore not surprising that the initial scientific concept was of a weightless fluid. Actually, many believed in two fluids—a cold flow as well as a hot flow.

While in theory a uniform temperature is impossible, for all practical purposes this can be achieved in a material by surrounding it with surfaces that resist the transfer of heat. Such materials are called "insulators." Every material is a partial conductor and a partial insulator; the predominance of one characteristic establishes its classification. Even this is not absolute, since at temperature extremes a conductor may become an insulator, or vice versa. The actual theory of heat conduction is not fixed, but it is felt that it is due to the transfer of free electrons normally moving within a fixed orbit but ejected by some exterior force or internal collision. Materials that are good conductors have either a low *electron* surface tension or weak nuclear attraction for such free electrons; materials that are good insulators have the reverse characteristics.

As before indicated, an approach to uniform temperature may be attained if heat equilibrium is established by completely surrounding a material with insulators. The degree to which these insulators approach perfection establishes the temperature gradi-

ent within the material under consideration. To maintain such a temperature, it is necessary to compensate for the conduction (or other losses) by the addition of energy; if a greater amount is added, the temperature rises; if a lesser amount, the temperature drops.

A simple example of heat transfer by molecular action occurring within a body, or by conduction, is that of a rod of metal, which, having a flame applied to one end, soon becomes heated beyond the area in direct contact with the flame. In like manner, regardless of whether heat is applied to the surface of a mass of metal by convection, conduction, or radiation, the interior of the mass gradually increases in temperature owing to heat transmitted by conduction.

Convection

Both gases and liquids are fluids that within normal limits have such low surface tensions (not *electron* surface tensions) as to permit ready changes in form due to any applied force or energy. Thus, it is characteristic of both that, when heat is applied, an immediate expansion of volume occurs with consequent lowering in density. There is only a slight tendency toward heat equilibrium because most gases or fluids are essentially poor conductors. Nevertheless, heat does tend to distribute because the lowered density particles rise, carrying the absorbed heat to the top of the mass of material. This action is called "convection." It is the only form of heat transfer that is to some extent visible—not, of course, in the sense of actually seeing the heat, but in the sense of seeing the disturbance in the medium due to the flow of particles.

In the home, the pipeless hot-air heater is an example of heat transfer by convection. Also, the so-called steam "radiator" used for heating building interiors really *radiates* only a small part of the energy supplied to it by steam from a central heating plant. Actually, it accomplishes its purpose by heating the air that flows over and comes in contact with its surface. Thus, it is seen that a steam radiator might be described more properly as a steam "convection heater." Likewise, industrial ovens using

steam coils, gas, or open electric coils transmit heat by air to the object being heated.

Radiation

In the previous discussion of infrared radiation, the essential factors of heat transfer by this method were considered. In fact, there is little to distinguish between the energy and its transfer. When infrared energy is present, it is transferred regardless of intervening media or lack of them. It is, however, important to realize that all electromagnetic transfers of energy to some degree or another result in heat, a fact that emphasizes its inherent association with behavior within the atomic orbit. Even fluorescence, the phenomenon of electromagnetic conversion from short wave lengths to longer ones, is inefficient to the degree that some of the original energy is absorbed in a thermal change.

Just as insulators in effect reject heat transfer by conduction, many materials reject heat transfer by radiation. A body that is perfect in its acceptance of incident radiation is called a "blackbody"—a theoretical concept that does not exist, especially with respect to the whole range of electromagnetic radiations. This acceptance of all radiations is a direct indication of its ability to emit all radiations. It is characteristic of a perfect blackbody that the spectral distribution of the radiated energy varies directly with—and only with—its temperature. In the design of infrared generators and light sources, this factor is of fundamental importance. Energy, as supplied by electricity, gas, or any other method, results in a rise of temperature. Depending on the variation from a true blackbody of the radiating body—usually a tungsten or carbon filament—the spectral distribution is directly dependent on the temperature (Fig. 1–2). Thus, infrared generators are simply practical means of creating radiant energy with a peak in the desired range.

The rejection of heat transfer by radiation is called "reflection" and is absolutely similar to the same phenomenon with light waves. No surface is a perfect reflector, and therefore there is some heat loss or absorption. Furthermore, all surfaces vary in their selectivity of reflection, and the spectral distribution of the reflected energy may be quite different from that of the incident

energy. Many materials that are good reflectors of visible light—for example, ordinary lead-base paint—are extremely poor reflectors of infrared energy even though light and infrared radiation are in adjacent portions of the energy spectrum. Similarly, relatively poor reflectors (for example, gold) for visible light may be among the best for infrared. Such considerations are fundamental in the design of control equipment for infrared generators.

Early Use of Infrared Heat

When prehistoric man discovered fire, "man-made" infrared, or radiant, heat was born. Probably its first use was for warmth when man stood before an open fire and exposed his body to the radiated heat. He soon learned that the part of his body not directly exposed to or nearest the fire was not warmed, thus discovering that infrared does not heat the surrounding air and thereby heat the body but that direct exposure to the fire is necessary.

In modern times infrared, or radiant, heat, although not generally recognized as such, long has been used for many purposes, particularly for home or domestic applications. Barbecued meat, for example, is prepared by exposing it to radiant heat from red-hot embers. Likewise, glowing charcoal provides the infrared energy for charcoal grilling of steak. Food placed under the flames in the oven of the kitchen range is broiled or cooked largely by the action of infrared rays. Open-element electric radiant heaters, a useful source of supplemental heat in the bathroom or dressing room on chilly mornings, impart heat to the human body by infrared energy projected directly on the body rather than by heating the air in the room. The electric toaster browns bread by the combined action of radiated and convected heat generated by open elements.

Soon after Edison perfected the carbon-filament incandescent lamp designed primarily for lighting purposes, the lamp was recognized as an especially suitable and convenient means of supplying local heat for therapeutic treatments. Thus, the carbon-filament "infrared" lamp came into being. The tungsten-filament incandescent lamp subsequently developed made little or no effort to invade the therapeutic field except for the fact that

1,000- and 1,500-watt general-lighting-service lamps were employed by physicians and hospitals for treatment of larger areas than possible with the lower wattage carbon-filament lamp.

Industrial Application of Radiant Energy

Records are not clear as to who should be accorded the distinction of having first used radiant heat for industrial application, but it appears that infrared really emerged from the class of a domestic servant to the position of a worth-while tool of industry during the thirties. The Ford Motor Company was the first to have received widespread publicity on large-scale application of this new tool.

The adoption of radiant heat as a drying agent in the automotive industry can be ascribed largely to the change from lacquer to enamel body finishes. Although the use of enamel was a great forward step in the body-finishing field, the change incurred the necessity for increased baking facilities, which were achieved by means of steam-heated ovens in which the finished bodies were baked at 250°F for some seventy minutes. Following this baking operation came the upholstering and the mounting of the instruments, glass, hardware, etc. Despite the use of great care in these latter operations, it was inevitable that damage should result to the finish on some of the bodies. In this event it was necessary to remove the fittings, refinish the body, and then repeat the baking operation. The increased cost and the added time necessary for these repeat operations are obvious. This situation led Ford engineers to the investigation and adoption of infrared heat to replace the steam-heated ovens. This new method made it possible to apply heat locally to damaged or scratched areas without the necessity for removal of all the fittings. Incidental, and of great importance, was the added fact that baking time was decreased from seventy to some five to ten minutes. Out of this grew the widely publicized Ford infrared "tunnels" (Fig. 1–3) now used for the complete body-baking operation and which very largely have been responsible for making the industrial user of heat infrared-conscious.

The long-standing prior usage of the carbon-filament infrared lamp made it the obvious and natural selection as a means for

applying radiant heat to industrial purposes. Hence, the carbon lamp was used widely in the early, and is still being used in many of the subsequent, industrial applications.

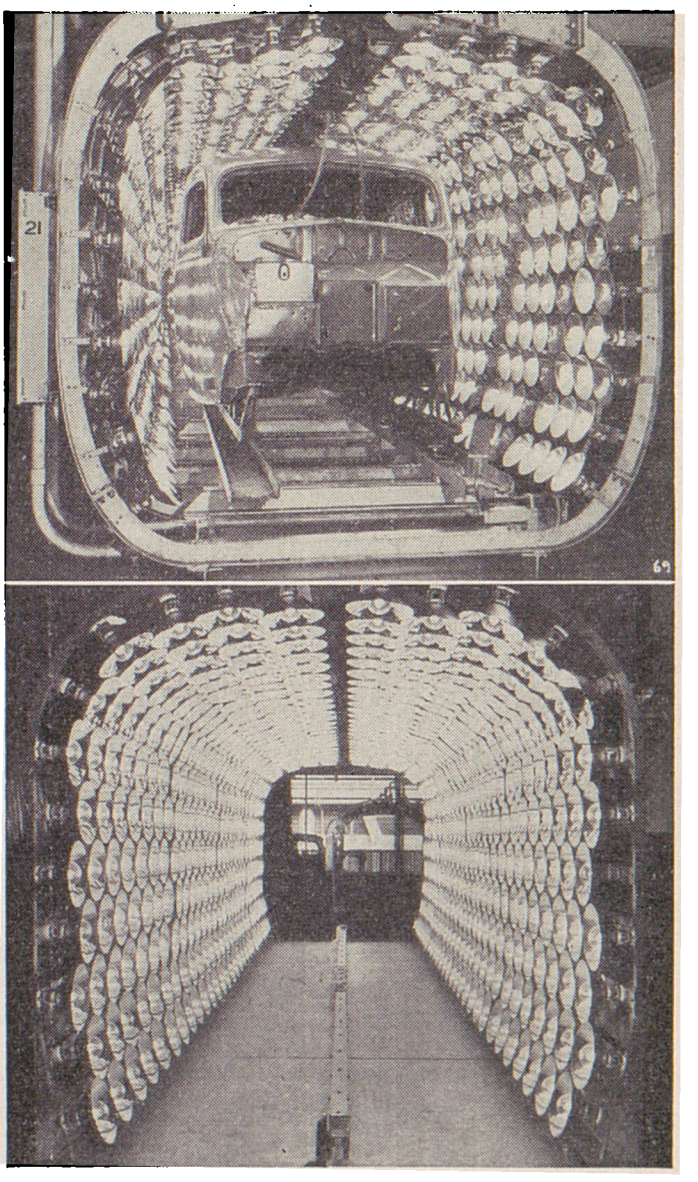

FIG. 1–3.—Original infrared tunnels used by the Ford Motor Company for the drying of automobile bodies.

Like light, infrared for efficient utilization requires equipment for reflection and redirection. Since gold not only is an efficient reflector of infrared but also is resistant to oxidation, it was a

natural choice as a metal for the plating of infrared reflectors. Largely for these reasons Ford's ovens or tunnels consisted of large continuous banks of carbon-filament lamps and gold-plated metal reflectors made from Ford headlights.

CHAPTER II

ADVANTAGES OF INFRARED HEAT

Radiant heat does not invalidate any of the well-known laws relating to energy requirements such as, for instance, the law which states that 970 Btu are required for evaporating 1 lb of water at 212°F or that each kilowatt-hour is equivalent to 3413 Btu. Also, it should be recognized that radiant heat is not a cure-all, nor is it best suited or most economical for all heating and drying purposes. The nature and condition of the material to be heated, the relative cost of the various types of energy (steam, gas, electricity) available, space requirements, quality of results produced, etc., are some of the factors to be considered in reaching a choice of the method to be used for a given heating or drying problem.

However, radiant heat does have certain inherent advantages. The prospective user must determine for himself whether or not these advantages, some of which are summarized herewith, are of sufficient worth in his particular problem to warrant the use of infrared heat in preference to other heating methods.

Speed

As a whole, speed is the most important of all advantages of radiant heat over other forms of energy transmission for many industrial purposes. This is true particularly of the curing or drying of synthetic surface finishes (Fig. 2–1) where speediest results are accomplished by bringing the finish up to the required temperature in the least time. The ability of radiant heat to accomplish this more rapidly than other means of heat transmission widely used is not due to any mystic penetrating power. Although infrared will penetrate thin paint films and transparent material such as glass, it does not penetrate solids such as wood or metals. The temperature rise inside of a mass of such latter material is due solely to heat conducted from its surface.

We refer to the laws of heat transfer as related to convected or conducted heat to find the secret of the speed of infrared or radiant energy. In effect, these laws state that, in the transfer of heat from one medium or object to another, the rate of transfer

FIG. 2–1.—The superintendent of a large building having 4,500 doors to maintain solved the problem of refinishing by using two portable racks of 250-watt infrared lamps and reflectors arranged as shown. Synthetic enamel used for this refinishing dries in 12 min at 50 per cent of the former cost and with better quality. With air drying formerly used, 16 hr were required.

is relatively high when the temperature differential between the two is relatively great. The rate of energy transfer falls off rapidly as the temperature of the object being heated approaches that of the source of heat. This is due to the increased molecular action within the object, which tends to repel the absorption of additional energy as supplied by convection or conduction.

These laws, however, do not apply to transfer of heat by infrared radiation wherein there is no dependence upon solids or gases to conduct the heat from the source to the object being heated. Infrared heat, like light, is projected at a speed of 186,000 miles per sec without being absorbed or obstructed by the atmosphere through which it passes. The rate of *energy transfer* is constant throughout an infrared heating process. The rate of *temperature rise* of an object being radiated is not constant only because of the cooling effect of convection currents flowing around the object and because the object itself, when heated, reradiates part of the energy absorbed.

Simplicity of Construction and Operation: Flexibility of Control

Sudden or unexpected requirements of increased production may be bottlenecked by lack of proper heating or baking facilities or inability to increase the speed of the equipment. Construction and installation of conventional equipment usually require time much in excess of that necessary for the usual infrared equipment. The simplicity of the latter assures the possibility of speedy installation. In contrast with convection- or conduction-heating equipment, an infrared oven when once adjusted for a given operation seldom requires subsequent adjustment. This minimizes the need for experienced or skilled labor.

A radiant-heat installation may be wired or constructed to permit any desired degree of flexibility of control. Where material of varying widths passes under a bank of lamps, rows of lamps along the length of the bank may be turned off or on so that the width of the bank conforms with that of the material. Likewise, when materials of varying thickness, moisture content, or color are to be dried or heated, the desired variation in energy required may be obtained by varying the voltage applied to the lamps, by turning on or off lamps in rows perpendicular to the direction of travel of the material, or by changing the speed of the material passing through the oven.

Ready-built as well as made-to-order radiant-heat equipment may be so designed as to make changes in contour of the lamp banks to accommodate varying conditions, such as size and shape of

the material being heated. Bringing about these changes is merely a matter of loosening thumbscrews and rearranging the reflector supports. This design assures the most economical use of the oven.

In contrast, steam cans or convection ovens have no flexibility with respect to variations in dimensions and shapes of materials being processed. For example, a steam cylinder or can is always heated to its full width regardless of the width of the material passing over it. The resultant energy waste when the material does not cover the full width of the can is obvious. Although variations in heat or temperature with steam cans or convection ovens are possible, there is always a lag in the change, due to the latent heat, with resultant delays in production. In contrast, immediate changes in temperature or energy requirements are possible with radiant heat.

Instant Starting and Stopping

A convection oven or a conduction heater such as a steam drum requires skilled attention for an appreciable time prior to each starting period, such as in the morning and after the lunch hour, to assure readiness of the equipment for the regular production run. Unlike these heating methods, radiant heat requires no "warm-up" period. It may be made ready for use on an instant's notice merely by the throwing of the power switch. Likewise, there is no lag with radiant heat—turning off the electric circuit discontinues the heating process almost immediately. The savings in labor and power costs during the starting and stopping periods alone may prove to be sufficient to merit the choice of radiant heat.

Uniformity of Results

Uniformity of results is essential in many of today's heating jobs. This uniformity usually can be assured only by application of heat at a uniform rate. Normal variations in the pressure of steam or gas used for convection heating may be sufficient to cause serious nonuniformity of results produced. This can be prevented only by constant attention or by the use of elaborate control apparatus.

When once adjusted, radiant heat applies energy at a constant rate, little or no control or attention being necessary. The

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normal voltage variations in the usual power or lighting circuit generally are too small to affect seriously the power input and hence the output of the lamps.

Cleanliness and Improved Working Conditions

One has merely to visit any manufacturing plant where steam-heated rolls or cans are used for heating purposes to visualize the improvement in cleanliness and working conditions that might be provided by the substitution of infrared heat. Floors covered with water, and an atmosphere of high temperature saturated with moisture by steam escaping from leaky valves and connections serve to present an untidy appearance and create unsatisfactory working conditions. The use of radiant heat would serve not only to improve appearances very greatly but also to provide more satisfactory working conditions by making the operation possible in an atmosphere of reduced temperature and humidity. Experience shows that tidy and orderly surroundings tend to promote the same desirable characteristics in the workmen. The resulting effects on the quality and cost of the material being processed can be only positive.

Low Initial and Maintenance Costs

Usually the cost of radiant-heat equipment required for a given purpose is appreciably less than that of corresponding convection or conduction equipment (Fig. 2–2). This is due to its outright simplicity, the lower cost of installation, and the elimination of expensive insulated ovens. In some cases it is necessary to provide and operate boilers for the sole purpose of supplying steam for a heating process. Where it is possible to eliminate such equipment by using radiant heat, the savings may be of considerable magnitude even though the cost of electric power may be higher than that of the steam.

Maintenance of convection ovens, steam cans, etc., is expensive —often involving the service of mechanics, plumbers, steamfitters, and others. Further, in case of breakdowns it sometimes is necessary to allow the equipment to cool for long periods before repairs can be made. In comparison, maintenance of radiant-heat equipment consists principally of infrequent replacement of broken or

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burned-out lamps and occasional cleaning of lamps and reflectors. Repairs may be made almost immediately because there is little or no latent heat in infrared-oven equipment. Thus, a great saving in time and loss of production is effected.

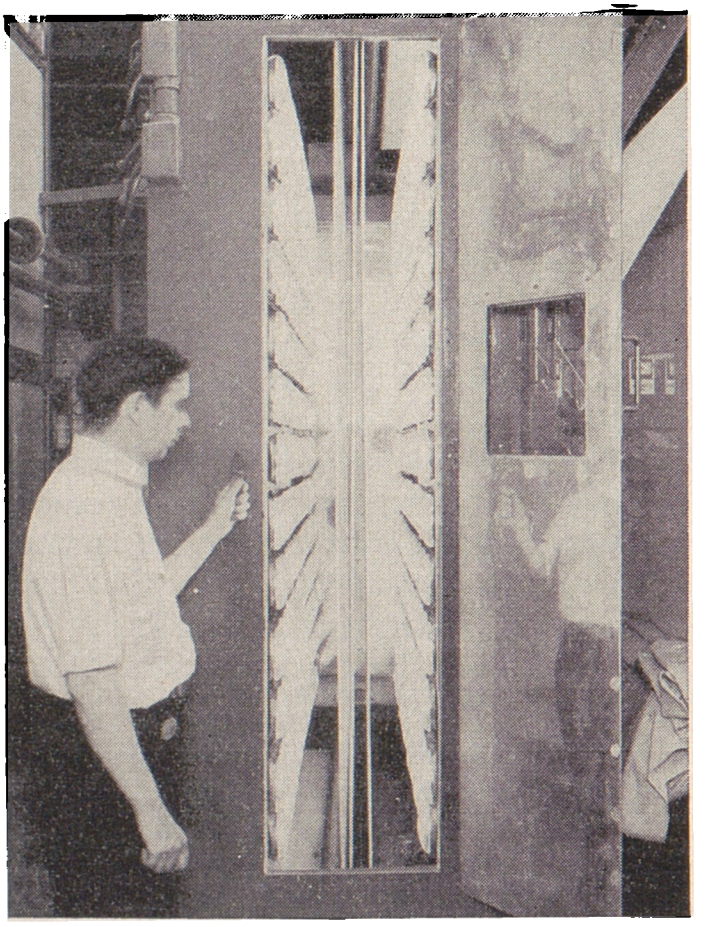


FIG. 2–2.—Following drying by means of conventional convection oven, woolen cloth (16–03 Navy melton) is carbonized in this infrared oven using one hundred seventy-five 250-watt reflector-type lamps arranged in two parallel banks approximately 12 in. apart, at a rate of 25 yd per min. Of interest is the fact that the cost (approximately $1,000) of the infrared carbonizer is from one-tenth to one-sixth of that of a conventional carbonizer, while the floor space occupied is about one-eighth that necessary for steam-heated equipment of the same capacity.

Reduced Space Requirements

Owing to the possibility of application of a greater amount of energy per unit area with radiant heat, the installation usually occupies less space than conventional heating and drying equipment required for the same process (Fig. 2–2). Being of relatively

light weight, infrared lamps and their auxiliary equipment may be suspended from and mounted near to the ceiling, thereby conserving the floor space below for other purposes (Fig. 2–3). This ability to concentrate energy in small areas makes radiant heat particularly useful as a supplementary source of heat where

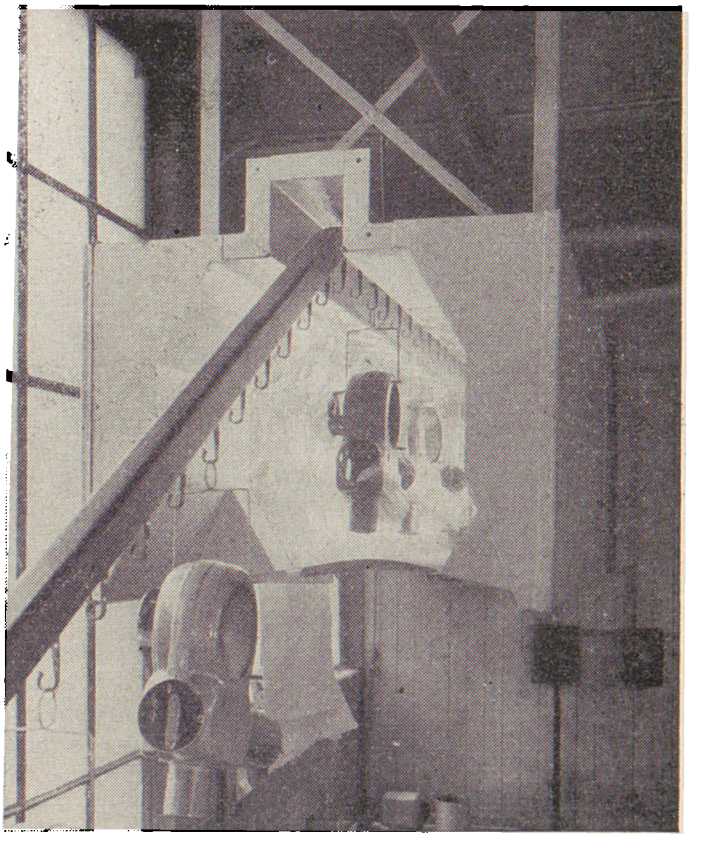


FIG. 2–3.—This infrared oven, suspended from the ceiling, uses sixty 250-watt lamps and dries the finish on oil burners made of gray iron castings (8 min) and sheet steel (5 min). It replaces air drying which required several hours and has effected a 30 per cent saving in floor space.

increased production is desired but where available space is insufficient or other conditions prevent enlarging the existing equipment. In some cases infrared units are mounted within the confines of existing equipment, thereby to all intents and purposes occupying no additional and otherwise usable space (Fig. 2–4).

Safety

There are certain elements of danger inherent in any type of oven used for processing materials wherein the volatiles driven

off are of a highly inflammable or explosive nature. The degree of danger present in an oven, of course, depends partly upon the concentration of the volatiles. Even though ventilation equipment is used, this concentration is liable to be greater in enclosed convection ovens than in open infrared ovens.

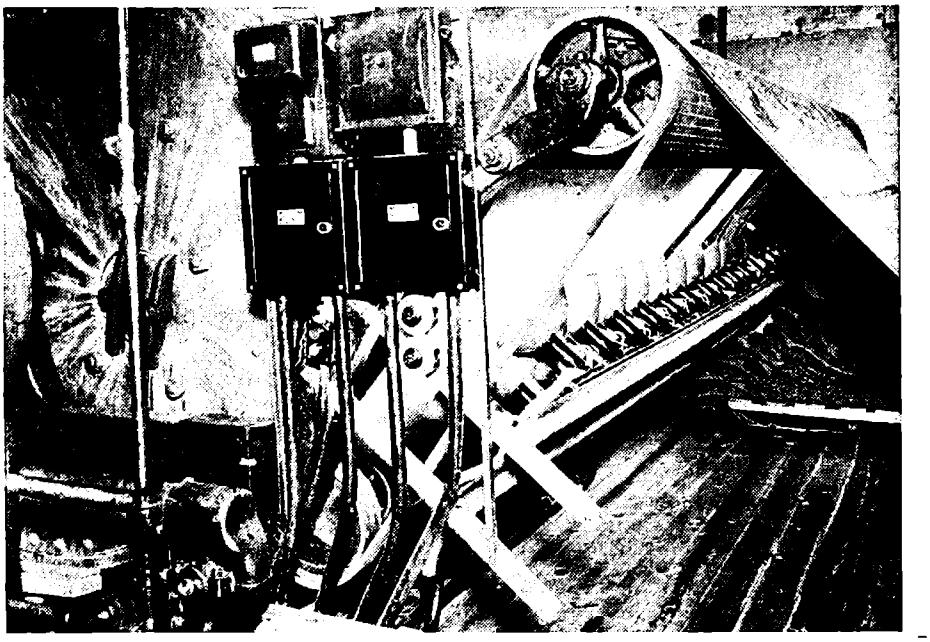


FIG. 2–4.—Twenty-eight 250-watt lamps with gold-plated reflectors were used to eliminate a bottleneck in drying Wilton rugs and carpets after they had been given a final steaming through the back to open up pile tufts closed or matted in previous operations. Prior to utilization of radiant heat, all drying was done by passing the rolls of carpet face up over a large steam-heated drying drum. Production of the dryer was such that, in order to keep up with weaving production, the steaming and drying unit frequently had to be operated overtime. Installation of infrared lamps as supplemental drying equipment made possible a 25 per cent increase in speed on heavy goods and as much as a 30 to 35 per cent increase on lighter materials. The installation was achieved with little or no change in or alteration of existing equipment.

Where hazards exist with the usual type of enclosed convection oven, the danger of fire or explosion can be minimized by the use of nonenclosed infrared equipment. In open infrared ovens, natural convection currents usually are sufficient to keep the concentration of volatiles below the danger point. Even though ignition of the fumes should occur, the results are not liable to be nearly so serious as those attending the ignition of explosive vapors within a confined space.

As described in Chap. VI, it is possible to design an infrared oven so that the lamps are located outside of the vaporous atmosphere; thereby, an added safety factor not possible with other conventional heating methods is provided.

Improved Quality of Product

There are numerous reports of improvement in the quality of the finished product where infrared has replaced other heating methods. In some cases the reason for the improvement is evident while in others it has not been explained. In the manufacture of some materials involving a series of operations, the results obtained in one of the operations may greatly influence the cost, speed, and quality of succeeding operations. For example, textile manufacturers agree that an improvement in the quality of the work produced in the slasher operation so greatly improves quality and simplifies the final weaving operation that, in order to obtain the improvement in slashing, a considerable increase in cost of this operation may be justified. These conditions apply to many other manufacturing operations. Hence, when the use of infrared heat is contemplated where the power cost may be greater than the cost of other heating methods, the possible *over-all* effects on costs and quality should be considered.

Visibility of Material in Process

Inasmuch as infrared ovens generally are not totally enclosed, it is possible to inspect material at any stage during its passage through an infrared tunnel. This inspection is facilitated by the light from the lamps. In contrast, inspection of material being processed in totally enclosed convection ovens is difficult and sometimes impossible.

Reduction in Spoilage

Owing to the presence of latent heat in convection ovens, steam drums, or cans, etc., spoilage of material resulting from unexpected stoppages due to breakdown may be appreciable. Material passing through a convection oven or over steam drums must remain stationary while necessary repairs are being made. This may result in excessive baking, overcuring, or scorching of the material

being processed. Radiant heat being projected directly from the source to the material being heated, air and metal with their capacity for storage of heat are not factors to be dealt with in the infrared oven. By interlocking of the electric circuits, discontinuance of the application of radiant heat can be made to coincide

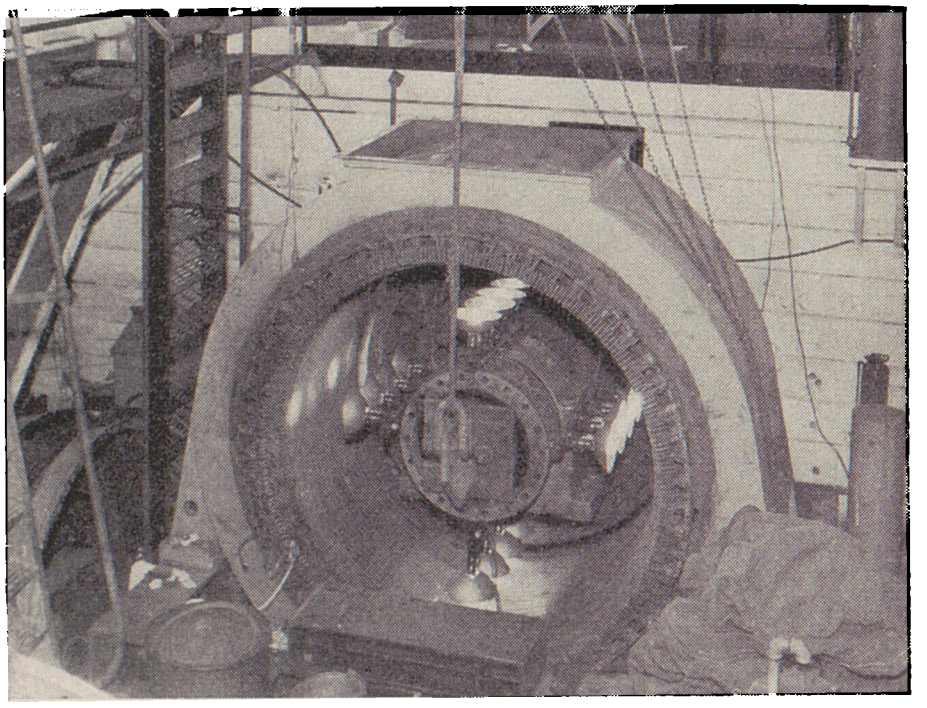


FIG. 2–5.—This 350-hp synchronous motor after having been submerged 60 days in salt water was washed continuously with fresh water for 3 days and then completely dried with sixteen 250-watt infrared lamps in 72 hr. Then the windings were varnished and baked for 8 hr. Finally, glyptol was applied and then baked for 4 hr. The cost of removing the motor from the dredge on which it was installed to a suitable convection oven would have been prohibitive while the total time required to place the motor back into service would have been greatly increased.

with the stoppage of the driving motors. Likewise, application at its maximum efficiency may be continued immediately on starting of the motors. This feature of infrared equipment assures a minimum spoilage due to unexpected interruptions in the orderly flow of material being processed.

Portability

In some manufacturing plants a single oven may serve for heating or drying material being intermittently processed at various

locations. When the usual type of convection oven located in a fixed position is used, the cost of cartage to and from the oven may be considerable. The equipment composing an infrared oven being of relatively light weight, the smaller installations can be so constructed that they may be moved from place to place as needed.

Portable infrared equipment also is found useful in the application of heat to heavy equipment, as in the drying out of water-soaked motors that could be moved to a fixed oven only with difficulty if at all (Fig. 2–5).

Suitability for Vertical Ovens

The nature of a process or space limitations sometimes necessitate the use of vertical ovens. When convected heat is used, difficulty may be experienced because of inability to maintain a uniform temperature at both the top and the bottom of the oven. Owing to the rising convection currents, the temperature at the top of the oven may prove to be excessively greater than at the bottom. Air not being a medium of transmission in the infrared oven, rising convection currents are not such a great factor. For this reason, greater uniformity of application of heat in a vertical oven is possible when radiant heat is used.

CHAPTER III

THE INCANDESCENT LAMP AS A SOURCE OF INFRARED RADIATION

Terms Applied to Infrared Lamps

Whether incandescent lamps for heating purposes are known as "infrared," "heat," "drying," "radiant heat," or any one of a number of trade names, they are all essentially the same in that, like the incandescent lamps used for lighting, they function by virtue of an electrically heated filament operating in a vacuum or in an inert gas enclosed by a glass bulb.

Operating Characteristics of Incandescent Lamps

For a better understanding of the factors involved in the design of infrared or radiant-heat lamps, it might be well to review the operating characteristics of the general-lighting-service incandescent lamp of which the modern infrared lamp is a modification.

The passage of sufficient electric current through a wire causes it to become heated to incandescence and expend its energy input largely in the form of light and heat. In the incandescent lamp, the filament wire is operated in a vacuum or in an atmosphere of inert gas to protect it from oxygen in the air; thus its useful life is greatly prolonged.

During operation, the filament wire in a lamp gradually evaporates or sublimates and settles on the inner surface of the bulb in the form of a brownish-black deposit. This action continues until the wire becomes so thin that it fuses or breaks, or, as we commonly say, the lamp "burns out."

All other factors remaining constant, the life of a lamp and the amount of light it produces depend upon the operating temperature of its filament. The higher the temperature of the filament, the more light is produced per watt of power input. At the same time, however, the higher its temperature the faster the filament evaporates, and, consequently, the shorter its life. A lamp can

be designed to operate at a low temperature, for a long life and a relatively small light output, or it can be designed to operate at a high temperature, with a shorter life and a much greater light output. In other words, the life and the light output of an incandescent lamp are interdependent, and either can be increased at the expense of the other (Fig. 3–1).

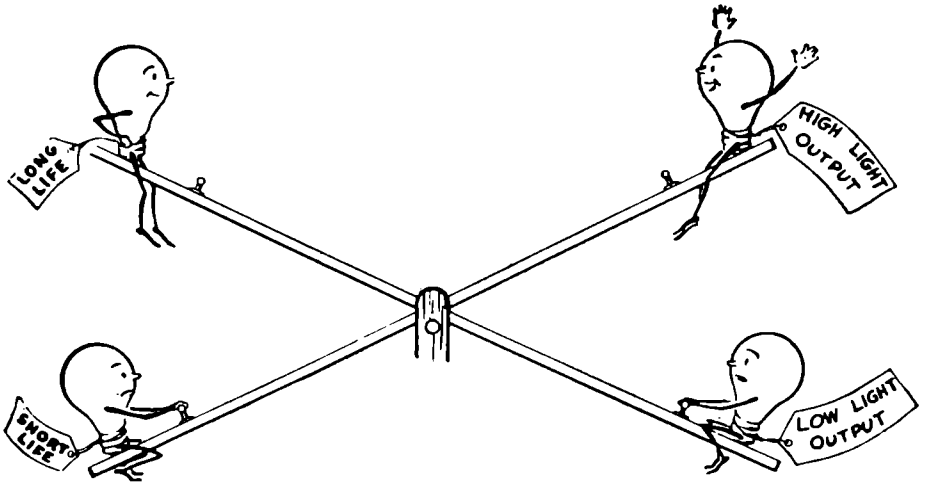


FIG. 3–1.—Relation between life and light output of an incandescent lamp. If the light output of a lamp of a given type is relatively high, the lamp is of relatively short life. Conversely, if the light output is low, the life is long.

Factors Affecting Design of General-lighting-service Lamps

General-lighting-service lamps are designed with a view to converting the maximum of the electric energy into light by operating the filament at the highest temperature consistent with satisfactory life of the lamp. The conditions under which a lamp is used determine what constitutes "satisfactory life." In motion-picture projection, for example, in order to illuminate the screen properly, it is necessary to provide a lamp having a filament of intense brilliance and high light output. This is accomplished by the use of a lamp whose filament is designed to operate at a temperature only a few hundred degrees below the melting point of tungsten. Projection lamps may be designed for a life as short as 10 hr. In contrast with projection service, lamps for street-lighting purposes may be designed for a life of 3,000 hr. In this latter service, extreme brilliance of the light source is not necessary, the need being rather for a lamp of relatively long life because of

the high cost of labor required for replacing burned-out lamps in remote locations.

Factors Affecting Design of Infrared Lamps

From the standpoint of infrared output alone, either the projection or the street-lighting lamp would serve satisfactorily, for even lamps of these types whose filaments operate at the higher temperatures radiate only some 10 to 15 per cent of their energy as visible light. The rest of the energy is converted largely into heat, most of which is dissipated by radiation. The economic relationship between light output and life that governs the design of lamps for lighting service does not exist in the design of lamps for heating purposes. Since the incandescent lamp is inherently an efficient generator of infrared radiation, the principal factor to be considered in the design of a "heat" or infrared lamp is that of life. The amount of light produced is not important, and, therefore, it is possible to reduce the filament temperature and greatly increase the life without decreasing the effectiveness of the lamp. Actually, the effectiveness of the lamp is increased somewhat, because some of the energy that was formerly converted into light is now radiated in the form of heat. However, in this connection it should be remembered that light and infrared are the same form of energy, differing only in wave length, and that they behave in exactly the same way. When electromagnetic radiation of any wave length falls upon any surface, part of the energy is reflected and part is absorbed, and the portion that is absorbed tends to create heat. In this sense, all radiations are "heat rays." Materials are affected differently by radiation because they differ greatly in their spectral absorption curves. Some absorb much more infrared than others, and there are differences in the infrared wave lengths that they absorb most completely. Light-colored objects absorb very little light, whereas very dark objects, such as black velvet, for example, absorb almost all the light that strikes them. The temperature rise of an irradiated object depends as much on the absorption characteristics of its surface as on the nature of the radiation. Therefore it is quite possible, especially in the case of dark-colored objects, that light may be almost as effective for heating purposes as infrared radiation. An advantage of designing infrared lamps

to produce little light is not only that the amount of infrared radiation is increased, but also that glare, which in large banks of lamps arranged in an open installation may be objectionable, is reduced.

Life of Infrared Lamps

Since it is not necessary to give principal consideration to the amount of light produced, an infrared lamp having a relatively long life (in excess of 5,000 hr) is practical. This is accomplished by designing the lamp to operate at a reduced filament temperature. For example, a 300-watt lamp for general-lighting purposes has a filament temperature of some 4800°F, while that of the infrared lamp is approximately 4000°F. As a result of its lower temperature, the latter produces less light and consequently less glare.

Solely on the basis of normal failure or burnout of general-lighting-service lamps, that is, failure due to evaporation or sublimation of the filament, the tungsten-filament infrared lamp could be rated at a life much in excess of the published life. However, lamps of such long life may fail to function from causes other than filament burnout (bulb breakage, vibration, shock, corrosion of lead-in wires, etc.). Hence a conservative life rating of about 5,000 hr usually is assigned to tungsten-filament radiant-heat or infrared lamps. Actually, adverse operating conditions, such as shock or vibration, may result in a life of much less than 5,000 hr.

Carbon-filament versus Tungsten-filament Infrared Lamps

There are available two general classes of lamps for industrial heating and drying purposes, one using a carbon filament, and the other a tungsten filament, as a source of radiated heat. Claims concerning the advantages of each are in some respects controversial and conflicting. That each type has merits is indicated by the fact that both are being used. Nevertheless, there are definite advantages and disadvantages associated with each class. In general, the advantages of the carbon-filament lamps are as follows:

1. **Lower Operating Brilliancy.**—This is desirable where the lamps are in the line of vision and where annoying glare is a factor

to be considered. Tungsten-filament lamps of the same or even lower filament brightness are feasible, but a decrease in the operating temperature of a tungsten filament to that of a carbon filament of comparable wattage and voltage requires an appreciable increase in the length of the tungsten-filament wire. This increases the cost of manufacture owing to complications in design and construction.

2. Greater Uniformity of Beam Pattern.—From the standpoint of control and redirection of radiant energy, infrared is similar to light in that the generator, or filament, should be concentrated; preferably it should approach a theoretical point source. The filament wire in a carbon lamp of a given wattage and voltage is shorter than that of a corresponding tungsten lamp, and this, plus other characteristics of carbon, makes concentration more feasible and less costly than similar concentration of the source in a tungsten-filament lamp. The resulting greater uniformity of heat distribution attainable with carbon-filament lamps is of little advantage where the material or surface to be irradiated is moving on a conveyor past the lamps. Where, however, the irradiated surface is stationary with respect to the lamps, nonuniform application of heat may in some cases result in the development of an undesirable temperature gradient, especially if the material involved is a poor conductor of heat, such as wood.

The principal advantages of the tungsten-filament lamps are as follows:

1. Longer and More Uniform Life.—The filament of a tungsten lamp evaporates or sublimates more slowly than that of a carbon lamp even though it is operated at a higher temperature. As a result, the theoretical life of the tungsten-filament lamp is longer, and, in addition, experience has shown that service life likewise generally is longer. Maintenance of rating and quality control of the tungsten lamp on the whole have developed to a higher degree, resulting in more uniform performance. These factors are of importance in considering lamp costs and the cost of labor for replacing burned-out lamps.

2. Higher Radiant-energy Output per Watt throughout Life.—The sublimation or evaporation of the filament of any lamp begins as soon as the lamp is lighted and continues as long as it

is burning. As previously mentioned, the sublimated material forms a black deposit on the inside of the lamp bulb that increases

DATA ON TUNGSTEN-FILAMENT INFRARED LAMPS

Watts	Bulb	Base	Nominal bulb diameter, inches	Maximum over-all length, inches
100	A-23	Medium screw	2⅞	6 1/16
250	R-40	Medium screw	5	7¼
250	PS-30	Medium screw	3¾	8 1/16
250	G-30	Medium screw	3¾	7⅛
375	G-30	Medium screw	3¾	7⅛
375	R-40	Medium screw	5	7¼
500	T-40	Medium bipost	5	7¼
1,000	T-40	Medium bipost	5	7¼

in density as the lamp burns. This deposit obstructs the radiated energy—both light and infrared—and, consequently, progressively decreases the output of the lamp. The decrease in the vis-

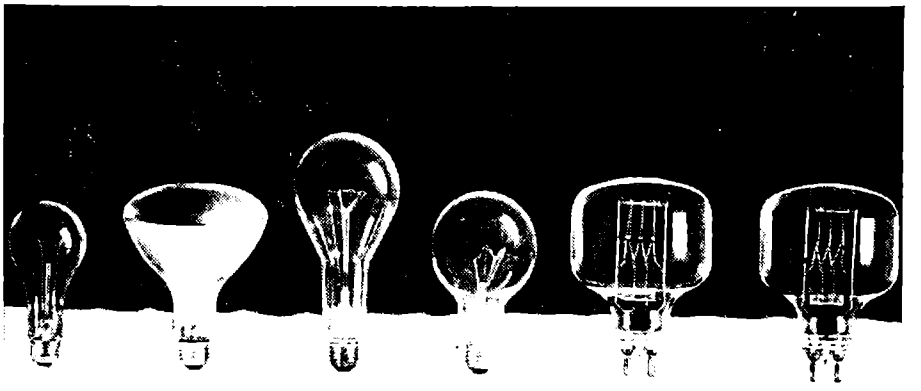


FIG. 3–2.—Typical tungsten-filament infrared lamps. From left to right, 100-watt A-23 bulb, 250- and 375-watt R-40 bulb, 250-watt PS-30 bulb, 250- and 375-watt G-30 bulb, 500-watt T-40 bulb, and 1,000-watt T-40 bulb. The 100-, 250-, and 375-watt lamps may be used with standard medium-screw porcelain sockets, while the 500-watt and 1,000-watt lamps require medium bipost sockets.

ible light is readily apparent to the eye, but the decrease in the invisible infrared radiation is not so easily detected. Since the rate of bulb blackening of the tungsten lamp is much slower than

that of the carbon lamp, the rate of depreciation in radiant-energy output of the former is less.

Carbon-filament lamps are available in a variety of wattages, while the tungsten-filament types so far have been confined

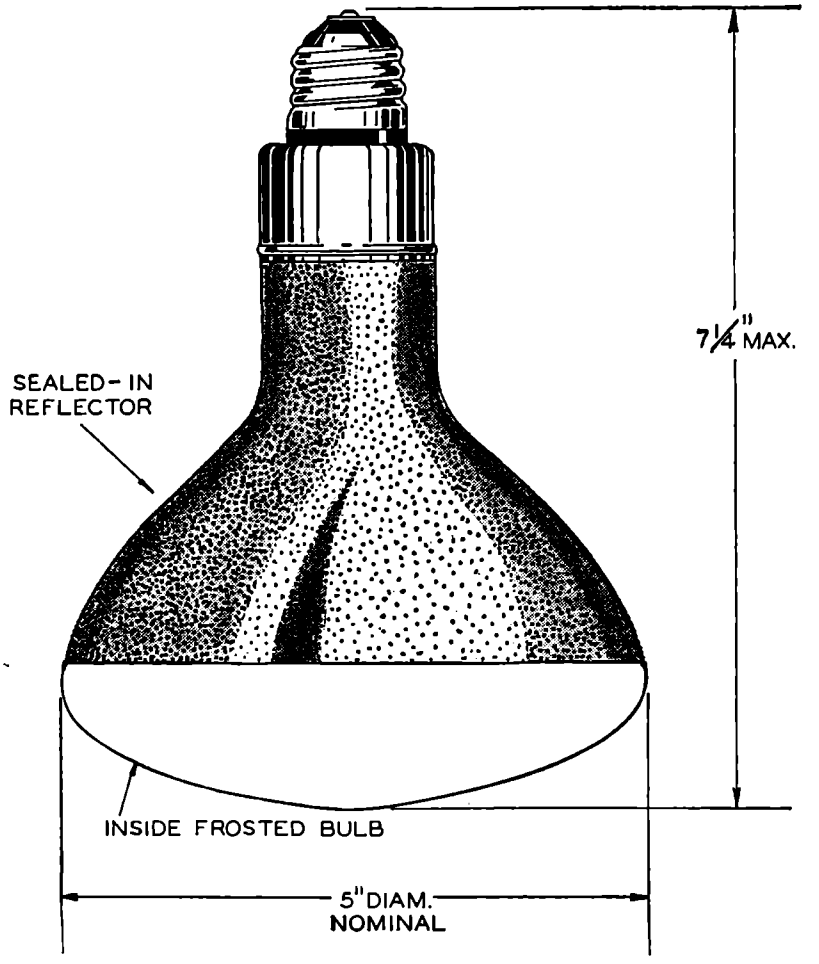


FIG. 3–3.—A typical reflector-type infrared lamp. The sealed-in reflector consists of a coating of vaporized aluminum or silver deposited on the inner surface of the bulb. The end of the bulb is frosted to provide greater uniformity of application of the infrared rays.

largely to the 100-, 250-, 375-, 500-, and 1,000-watt sizes (Fig. 3–2), of which the 250- and 375-watt types are by far the most popular. There are two broad general types of lamp, one requiring a separate reflector, and the other having its own self-contained sealed-in reflector (Fig. 3–3). At present, the latter type is generally available only in the 250- and 375-watt ranges,

but increased use of radiant heat may warrant and require the future development of additional wattages.

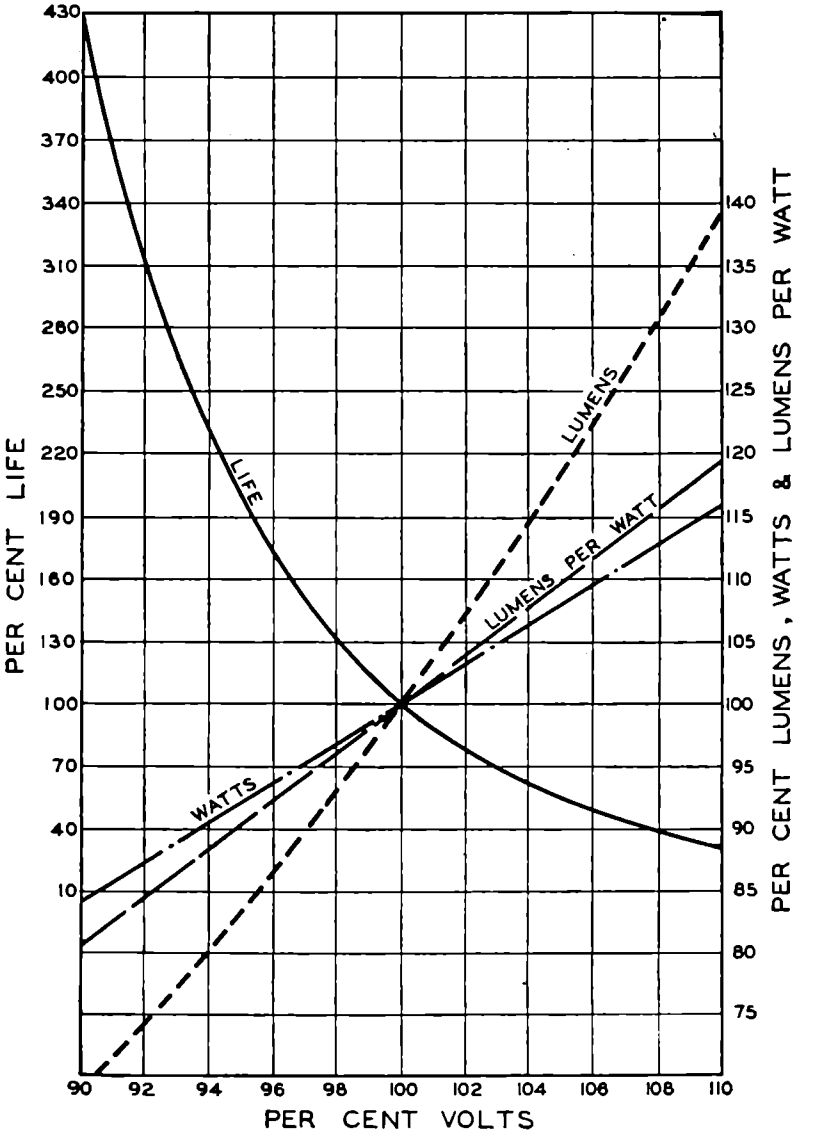


FIG. 3–4.—Tungsten-filament-lamp characteristic curves. Operation of an incandescent lamp at other than its rated voltage affects its performance as indicated in these typical characteristic curves.

Effect of Voltage Variation on Lamp Performance

For most efficient performance and satisfactory life, a general-lighting-service incandescent lamp should be operated on a circuit whose voltage corresponds with the labeled voltage of the

lamp. For this reason, lamps for lighting service are available in several voltages in the 100–130 volt range. Operation of any filament-type lamp at other than its rated voltage affects its life, radiant-energy output (light and infrared), and wattage consumption (Fig. 3–4). Overvoltage operation decreases the life and increases both the energy output and the wattage consumption. Conversely, undervoltage burning increases the life and decreases the wattage consumption and the energy output.

Since the life of a lamp is affected by voltage variations, overvoltage operation of general-lighting-service lamps is usually to be avoided because of their relatively short design life. Likewise, undervoltage burning is not desirable because of the reduction in light output. As has been pointed out, the light output of an infrared lamp is not an important factor in its design and functioning. This leaves only life, wattage, and infrared output as the factors to be considered. The theoretical life of an infrared lamp is so great in comparison with its actual life that the reduction in theoretical life resulting from any reasonable overvoltage operation has no practical effect on lamp replacements. Hence, the effects of overvoltage or undervoltage operation on only radiant-energy output and wattage have to be taken into consideration; and since the output is almost directly proportional to the wattage, for all practical purposes it is necessary to give thought only to the effect of voltage variation on wattage (Fig. 3–5). In practice, undervoltage operation may necessitate an increase in the number of units or lamps in order to compensate for the reduction in output. Conversely, overvoltage operation may reduce the number of units or lamps required for a particular heat-application problem.

Use of Lamps on 230- and 440-volt Circuits

The length of the filament wire used in a lamp of a given wattage is approximately proportional to its voltage. For example, the length of uncoiled wire in a 60-volt lamp is about one-half that of the wire in a corresponding 120-volt lamp. Similarly, the length of the wire in a 230-volt lamp is approximately double that of a 115-volt lamp of the same wattage. As previously

mentioned, an appreciable increase in the filament length of a lamp of a given wattage complicates its design and increases its cost. The length of the filament wire used in an infrared lamp is much greater than that of a general-lighting lamp of the same rating. For this reason, tungsten-filament infrared lamps are not

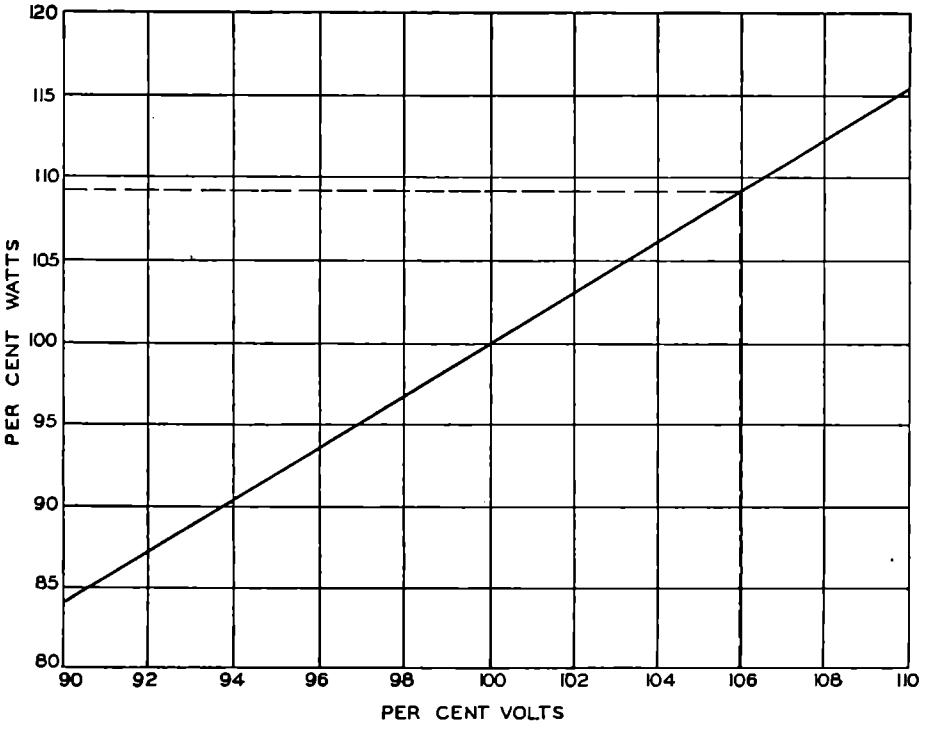


FIG. 3–5.—Effect of operation at various voltages on wattage consumption of infrared lamp. Inasmuch as the infrared output of a lamp is approximately proportional to its wattage consumption, knowledge of the effect on wattage of operating a given lamp at other than its rated voltage is of value. The broken lines in the above chart show an example wherein a 115-volt lamp is operated on a circuit having an average voltage of 122, or 106 per cent volts. Following the broken line vertically from 106 per cent volts to the curve and then horizontally to the left we find that the wattage would be approximately 109 per cent of that when the lamp is operated at 115 volts. If the average voltage of a circuit (measured at the lamp socket) is known, the approximate wattage consumed by a lamp of a given rating can be readily determined.

regularly available for use in multiple on 200–260 volt circuits. Where such circuits are involved, it is the common practice to operate 115-volt lamps in series of two. Likewise, series of four lamps are used on 440-volt circuits (Fig. 3–6). In any case, only lamps of a single wattage should be used in a series circuit; for

example, 100-watt lamps should not be mixed with 250-watt lamps on a four-in-series circuit.

Protection of Lamps from Vibration

The filament wire of a lamp is somewhat soft and pliable when operated at incandescence, and hence the filament coils are liable to become stretched and distorted if subjected to shock and

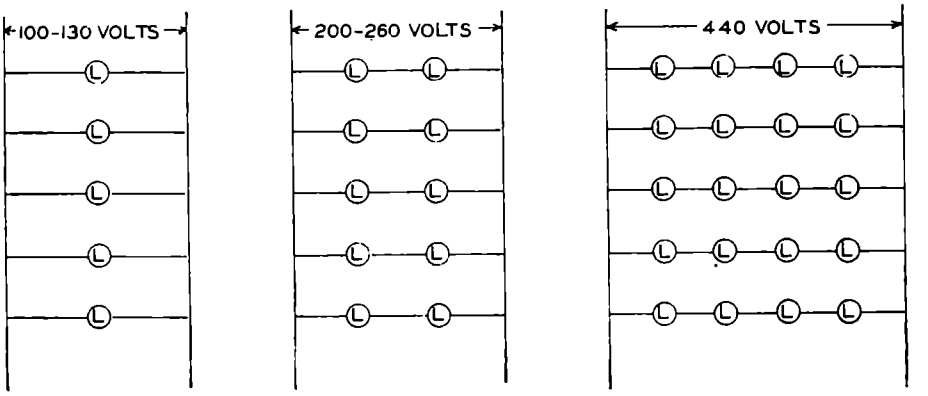


FIG. 3–6.—Methods of connecting infrared lamps on circuits of various voltages. As indicated, 115-volt infrared lamps may be used satisfactorily in multiple on 100–130 volt circuits. Two lamps in series may be used on 200–260 volt circuits while four lamps in series are used on 440-volt circuits. Lamps of different wattages should not be mixed on any single series circuit of two or four lamps.

vibration while the lamp is lighted (Fig. 3–7). This may cause a serious reduction in the life of the lamp. For this reason, care should be taken to avoid mounting lamp sockets where vibration from moving machinery, conveyors, etc., will be transmitted to the lamps. Such vibration may be of the high-frequency low-amplitude variety, not readily noticeable, but nonetheless harmful to the lamps. To avoid this condition, it may be desirable to mount lamp banks on the floor or suspend them from the ceiling. Where movable drying lamp stands are used, rubber-wheel casters should be provided. To minimize the possibility of damage to the filament coils, it is preferable to turn the lamps off while the stands are being moved.

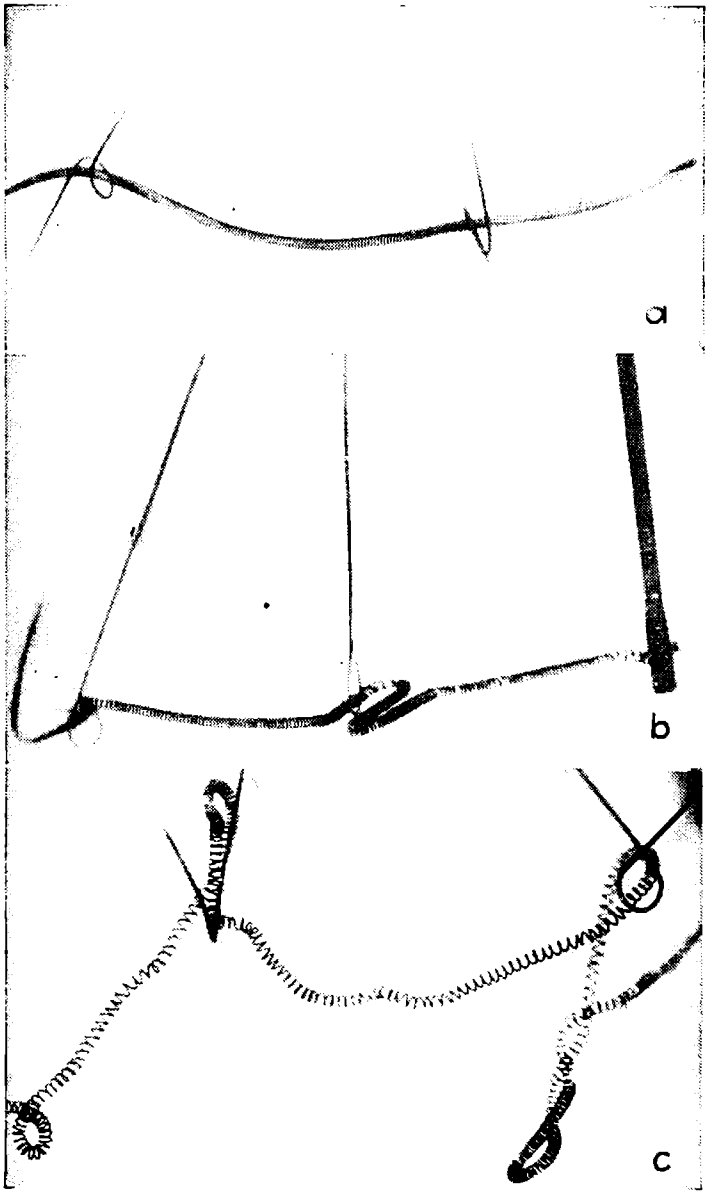


FIG. 3–7.—Effect of shock and vibration on lamp filament. (*a*) Appearance of lamp filament wherein failure occurred after normal life under conditions where shock and vibration were not present. (*b*) Condition of filament coil after the lamp had been subjected to severe vibration. Life of lamp was short. (*c*) Severe shocks and vibration caused distortion of this filament coil with resultant extremely short lamp life.

CHAPTER IV

RADIANT-HEAT EQUIPMENT

Basis of Design of Infrared Reflectors

Invisible infrared radiation, having the same general characteristics as visible light radiation and being subject to the same laws of reflection, diffraction, and diffusion, is as easily controlled and redirected as light. This fact makes possible the design of radiant-heat reflectors based on known laws of physics relating to the control of visible light.

The design of general-lighting equipment varies with the wattage and the type of lamp used and with the application requirements it is to meet. Likewise, the design of infrared reflectors and equipment varies with the wattage and the type of lamp and with the many different kinds of jobs radiant heat is called upon to do.

In lighting practice, the problem may be to illuminate a small area to a very high intensity. This usually is accomplished by the use of a suitable lamp in a reflector, perhaps combined with a lens, designed to concentrate the light to the desired intensity. As against this, it may be wished to illuminate a relatively large area to a low intensity. Again, the required results may be attained by using a combination of the proper equipment and a suitable lamp.

In the application of radiant heat, the requirements may range from the use of a single lamp and a reflector to produce a high temperature over a small area (such as a special soldering operation) to the use of a bank of lamps for the drying of a large surface to which has been applied a finish containing a highly volatile material requiring a relatively low temperature for vaporization. The great variety of available lamps and reflector equipment plus the multiplicity of different possible arrangements of the equip-

ment makes it feasible to apply radiant heat successfully to a wide diversity of heating and drying problems.

Infrared-reflector Surfaces

Although the contour and general design of the radiant-heat reflector may be the counterpart of the light reflector, there is a

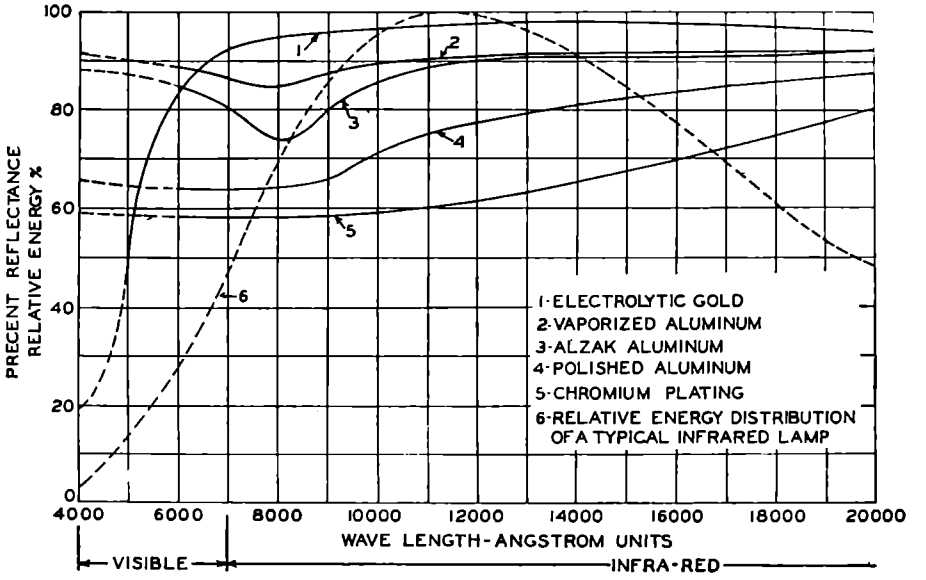


FIG. 4–1.—Relative infrared-reflection factors of various metals. The data may be considered as average. For a given plated surface such as 1, 2, or 5, the values shown may vary appreciably with individual reflectors depending upon the quality and the method of application of the coating. For example, comparative tests of specific samples of gold-plated versus vaporized-aluminum reflectors indicated the aluminum to be superior to the gold.

most important difference between the characteristics of the reflecting surface used for each. Surfaces or materials efficient for the reflection of light may be relatively inefficient reflectors of infrared. For example, porcelain-enameled and painted reflectors commonly used with commercial and industrial lighting equipment are unsuited for use as infrared reflectors because of their low infrared-reflection factors. Actually, no *painted* surface ranks sufficiently high in efficiency as an infrared reflector to justify its use for this purpose.

A reflector, whether it be used for light or for infrared, obviously should be efficient in redirection of the energy not only initially

but also throughout its life. A number of metals have high initial reflection factors (Fig. 4–1), but some are unsuited for open infrared reflectors, for when exposed to air they quickly depreciate in efficiency because of rapid oxidization or discoloration. Among the latter are silver and copper.

Gold, in the form of a thin electrolytic plating, is used almost exclusively for the reflecting surface of open-type infrared reflectors. Not only does gold have a high initial reflection factor but also, owing to the ability to resist oxidation, its maintenance factor is high. Open infrared reflectors of Alzak aluminum, although not as efficient as gold plated reflectors, are used occasionally. "Alzak" is a commercial term applied to aluminum, the surface of which has been subjected to a special treatment to provide resistance to oxidation.

Aluminum and silver are the commonly used metals for coating the inner surfaces of infrared reflector-type lamp bulbs. So far it has not been found feasible to use gold or copper for this purpose. The coating of aluminum or silver is deposited on the glass by means of a process wherein the metal is vaporized within the bulb that has been evacuated. In the finished lamp, the bulb is filled with an inert gas and hermetically sealed; hence, the metallic surface, which has a high initial reflection factor, suffers no depreciation because of oxidation or collection of dirt or dust from the air. The very small and gradual depreciation in the infrared output of reflector lamps is due largely to the vaporization of the tungsten filament which occurs as the lamp burns and which is a common characteristic of incandescent lamps of any type. The vaporized metal deposits on the inner surface of the bulb and absorbs light and infrared radiation in gradually increasing quantities. The rate of the vaporization and deposit, and hence of the absorption, is much slower in the infrared lamp than in the general-lighting-service lamp because the filament of the former operates at a lower temperature.

Sockets

In perhaps no other type of service are lamp sockets subjected to the severe treatment encountered in an infrared installation. Because of the usual close spacing of the units, the use of lamps

of relatively high wattage, and the long, continuous periods of operation, the temperature of lamp sockets in an infrared oven may be much in excess of that found in lighting-equipment sockets. Often, too, the nature of the work being done by the oven is such that the sockets operate in an atmosphere of high humidity. These conditions make it obvious that the usual type of brass shell socket is unsuited for this service.

Where screw-base lamps are involved, use of the best grade of porcelain shell sockets may avoid costly maintenance and loss of production due to equipment shutdowns caused by socket failures. The sockets preferably should be of the one-piece shell type; use of two-piece sockets such as are common with sign receptacles should be avoided. With the latter type, there is a tendency for the removable shell to loosen in use, especially if subjected to vibration. As a result, the porcelain shell may extend too far beyond the inner brass shell causing the former to come in contact with the bulb neck and thus scratch the glass. This condition may cause the glass bulb to break or crack and allow air to enter the lamp resulting in its failure. Lamps failing from this cause usually may be identified by the presence of a white or a yellow-white deposit on the inner surface of the bulb.

The commonly used higher wattage infrared lamps such as the 500- and 1,000-watt types are provided with medium bipost bases. Medium bipost sockets now available have not proved to be entirely satisfactory for use with infrared equipment because of the high temperatures to which they are subjected. Until a more suitable socket for this service is available, bipost-base infrared lamps are being used by the expedient of braided wires welded to the base posts and in turn connected to the power wiring. With this arrangement the "socket" used has no current-carrying parts but serves in the capacity of a lamp holder only (Fig. 4–2).

Conveyors

High-speed, continuous production of materials or objects in which the application of infrared heat is one of the manufacturing processes usually can be accomplished most conveniently and economically by providing some means of passing the product

through the infrared oven as it is manufactured. Batch ovens generally are used only where the production is of an intermittent nature and where the heating process will not impede the orderly flow of materials as produced.

The design of conveyor equipment used with infrared ovens involves so many factors which vary widely depending upon the particular job to be done that no attempt will be made herein to

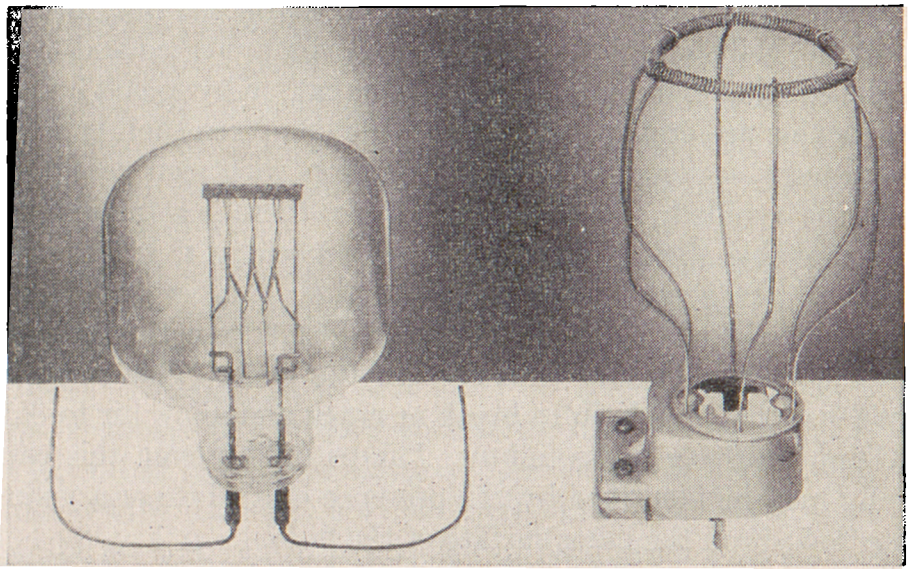


FIG. 4–2.—Thousand-watt T-40 bulb, medium bipost base infrared lamp with flexible connectors brazed to base posts. At right, lamp holder for use with bipost base lamps. It differs from the conventional socket in that it has no current-carrying parts, the lamp connectors being attached direct to the supply wires.

cover the many ramifications of the subject in detail. As is true of conveyors used for other purposes, infrared conveyor equipment can be placed in two general classifications, namely, that in which the material passes through the heat zone resting on some type of belt or other means of support, and that wherein the material or objects are suspended from above. In either case, as contrasted with conveyor equipment used with convection ovens, it often is possible and desirable to locate the moving parts of the mechanism outside the high-temperature zone, thereby minimizing lubrication and maintenance problems.

In considering the selection of conveyor equipment, it should be kept in mind that, for most uniform and satisfactory results, all surfaces of an object to be heated should be exposed, as far as

possible, to the direct rays from the infrared lamps. In many cases this means that the object should be rotated slowly as it passes through the heat zone. This rotation can be accomplished by means of a continuous series of revolving platforms or spindles supporting the objects or by means of revolving hooks from which the objects are suspended.

Conveyor Belting

The belt is the only part of the conveyor system that comes in contact with the load and hence is exposed to the most severe wear; therefore, its choice should be the subject of careful study and analysis. The factors to be considered in the design and selection of belting are (1) material from which it is to be made; (2) the size of the mesh, where mesh type is to be used; and (3) its construction.

The material from which belting is to be made depends upon a number of factors, among them being the nature of the product being handled; for example, foods, metal objects, etc., the chemical characteristics of the product, the type of atmosphere in which the belt must operate, and the temperature range encountered.

Belting mesh size is dependent upon the shape as well as the maximum and minimum sizes of the objects or material to be conveyed. Belt construction is dictated by the conveyor and oven design, belt speed, and loading conditions. Knowledge of these factors on the part of the belting manufacturer is necessary if he is to recommend and supply the type of belting best suited for the purpose in question.

Conveyor Drives

The conveyor drive for infrared equipment may be one of the many conventional types. However, it should be borne in mind that a somewhat greater flexibility in speed may be required when infrared heat is used than with the usual type of convection oven. Where, for example, painted objects or textiles of varying colors are processed from time to time, changes in the speed of the conveyor may be necessary to compensate for the variation in absorption of the radiated energy by the different colors (Fig. 7–2). Such changes in conveyor speed because of color differences are

unnecessary with convection ovens or steam-heated drums or cans.

As previously stated, in order to minimize damage to material being processed, conveyor drive equipment should be so interlocked with the infrared-lamp electric circuit that the latter is switched off whenever the conveyor stops for any reason (Fig. 4–3).

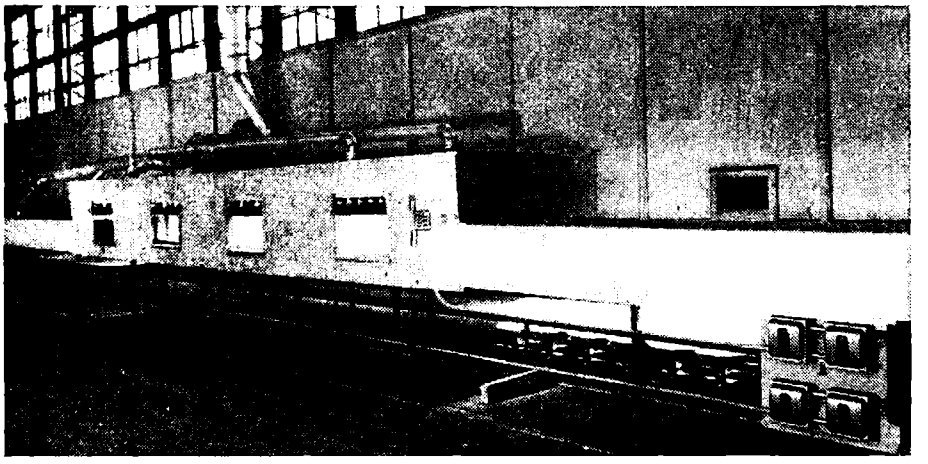


FIG. 4–3.—Completely enclosed tunnel of radiant energy installed to finish a special lacquer coating (Boydell Color Works Nitro and Scrap coating lacquer on a 100 auto trim board). The sheet board passes through the heat zone on a horizontal conveyor. Formerly 1,500 sq ft of board per hour were finished. By means of infrared heat this has been increased to 9,000 sq ft per hr. The local public utility tested this installation to determine the hazard from solvents in the lacquer. The mine safety meter registered only 0.025 although it is necessary to have a reading of 1.00 before a hazard is present. Installation approved by the state inspection bureau. Interlocking relay used on conveyor to turn off radiant energy when conveyor stops. Ten thousand cubic feet of fresh air per minute introduced into tunnel to remove solvents. One hundred 260-watt lamps and gold-plated reflectors are used.

Unlike other types of conventional heating and drying equipment, there is little latent heat in an infrared oven. Consequently, if the lamps are turned off concurrently with interruptions in the processing, stopping material in an infrared oven will cause no losses due to overbaking or scorching.

Transformers

Infrared lamps are regularly available in the 110–125 volt range only (Chap. III). Suitability of these lamps for operation in multiple on 110–125 volt circuits, in series of two on 220–260 volt circuits, or in series of four on 440-volt circuits eliminates the

need for a transformer. Where only the higher voltage circuits are available, series-lamp operation may be preferred because of the resulting lower cost of auxiliary equipment such as wiring, switches, circuit breakers, etc.

Despite the lower equipment cost possible with series-lamp operation, other factors may dictate the preference for multiple-lamp operation to be accomplished by means of a transformer to provide a circuit of 110–125 volt range. From the standpoint of replacement of burned-out lamps, multiple-lamp operation is the more desirable, because, as exemplified by Christmas-tree lamp strings, on failure of a single lamp in a series, the rest of the lamps become and remain inoperative until the burned-out lamp is replaced. Location and replacement of this lamp naturally require greater time than when lamps are operated singly in multiple.

Favoring the use of 110–125 volt circuits is another more important and perhaps the deciding factor—that of personal-safety hazard. Local or plant safety requirements may prohibit the use of high voltage on equipment such as that used for infrared drying and heating.

Where a single infrared oven is required to provide a wide range in temperatures, multiple-tap transformers are sometimes used as a means of varying the voltage and hence the wattage and heat output of the lamps (Fig. 4–4). Also, this method may be preferred to varying the speed of the conveyor, especially if a change in temperature, without a change in processing time or speed, is required.

Ventilation Equipment

By far the majority of radiant-heat installations are of the open type using no forced-ventilation equipment. When infrared ovens of this type are used, the natural convection currents are depended upon to remove vapors and discharge them into the surrounding air. If the oven is located in a confined space and the fumes from the processing are of a toxic or inflammable nature, ventilation equipment for discharging the fumes to the outside air may be necessary. Usually, a hood over the entire oven, connected to a stack, will suffice (Fig. 4–5). In most cases the natural draft of the stack serves to remove the vapors without the use of a motor-driven fan.

Where an enclosed infrared oven is used for processing of a nature such as to produce inflammable or explosive fumes, it is necessary to follow the same precautions relating to ventilation as are required for conventional types of convection ovens. This

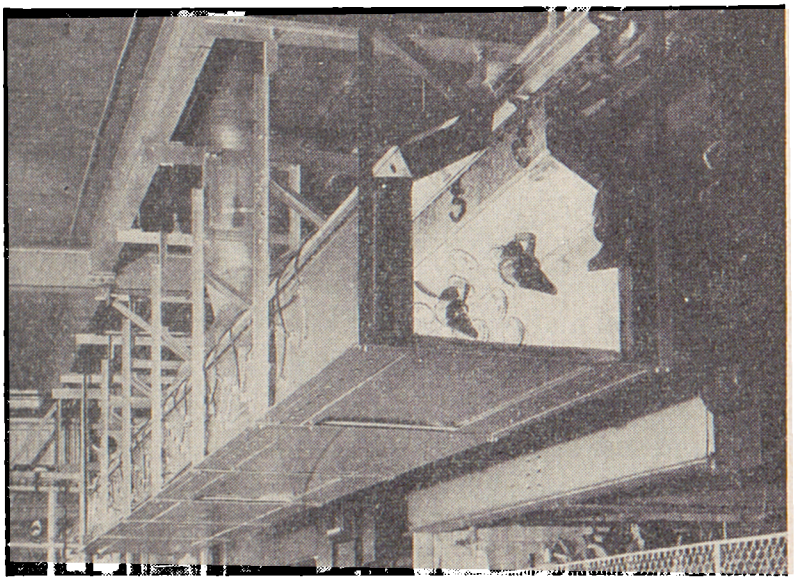


FIG. 4–4.—Household-appliance parts are baked at 350°F in this infrared tunnel in 15 per cent of the time required by a convection oven. The tunnel uses 200 250-watt reflector infrared lamps and is 31 ft long. It has a number of unique features, among them being ceiling suspension, thereby conserving floor space; lamps located on the sides and roof of tunnel wired in three separately controlled zones, each zone being connected to a transformer that provides 125 variations of heat control from 50 to 100 per cent power capacity; a variable-speed overhead conveyor that may be regulated to travel at rates of from 2 to 6 ft per minute; demountable trays for easy access to tunnel; sheet-metal enclosures in spaces between the lamps; air-convection currents in the space between the inner enclosure and outer enclosure on which sockets are mounted to keep the sockets and lamp bases cool; a hood sloping upward from each end of the tunnel to the center exhaust stack for removal of solvents.

ventilation must be such as to keep the concentration of the fumes below a point where they might cause a fire or explosion and as defined in local safety-precaution codes.

In addition to being used for safety or health requirements, forced ventilation or draft is desirable in many infrared applications involving water evaporation. Removal of water from the surface of a material as rapidly as it is vaporized greatly expedites and reduces the cost of the drying operation.

Where the material being dried is in a continuous piece such as cloth, the air movement preferably should be parallel to the plane of the material and in a direction perpendicular to the direction of movement of the material. Materials of relatively small particle size, for example, shredded codfish and broken tobacco stems, are sometimes dried by infrared heat applied from above, assisted

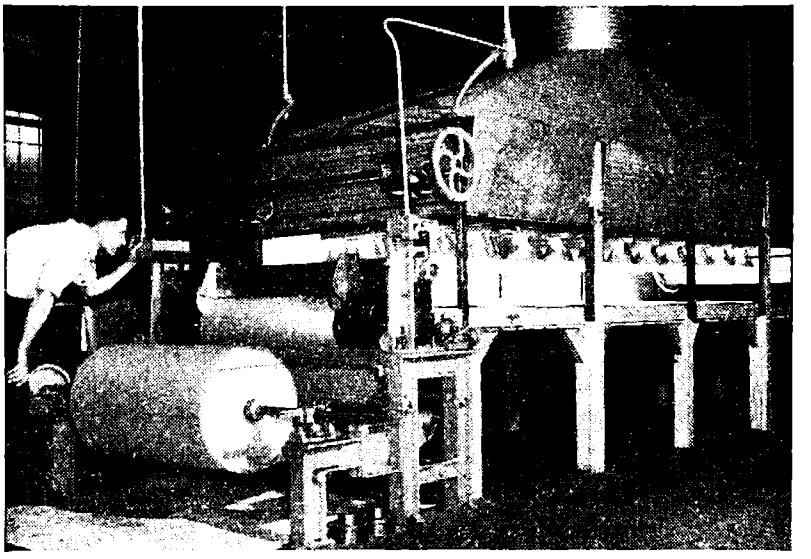


FIG. 4–5.—Drying of pressure-sensitive adhesives on paper by means of a bank of eighty-eight 250-watt lamps with Alzak aluminum reflectors. The drying is accomplished in 18 to 22 sec. The distance of the bank of lamps from the surface of the paper is adjustable. The canopy and stack serve to conduct the heat and fumes to the outside of the building.

by air blown from below through perforations in the conveyor belt. Where air is forced through particles of material in this manner, small particles or dust may arise and settle on the lamp bulbs as the material approaches the dry state and thereby adversely affect the performance of the lamps or cause a possible fire hazard. Under such conditions, frequent cleaning of the lamps may be necessary, as proved to be the case in an installation used for drying broken tobacco stems.

Where drying or vaporizing of water or a solvent is not involved in the application of radiant heat, draft or passage of air over the material or objects being heated should be held to a minimum to ensure the most economical use of the heat. An example is the preheating of metal or plastic sheets prior to processing. Any

passage of air over the sheets would serve only to increase the time required for them to reach the desired temperature.

Electrical Wiring and Equipment

Requirements of the National Electrical Code should govern the purchase, installation, and use of all electrical equipment required for an infrared oven. In this connection it should be noted that recent amendments to the Code clarify and authorize practices in the wiring of infrared ovens that may not be allowed in lighting-circuit wiring. These amendments consist principally of the following:

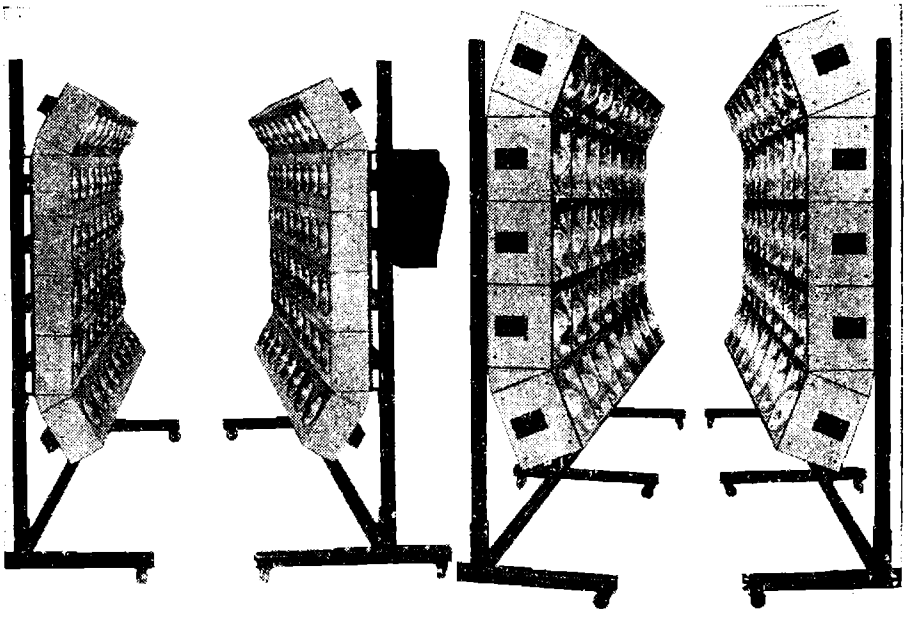
1. Lamps may be connected in series on circuits up to and including 550-volt rating.
2. Use of medium-screw-base lamps of a wattage as high as the socket wattage rating is permitted. In effect, this authorizes the use of 500-watt medium-screw-base lamps.
3. Circuits up to and including 50 amperes may be wired with a single fuse. Up to this current rating subfusing is unnecessary. This provision greatly simplifies the wiring of larger ovens where heavy current loads are involved.

Commercial Equipment and Ovens

Available infrared equipment ranges from wired channels with various socket spacings to finished ovens complete with conveyors, drive equipment, etc. From the standpoint of types of infrared lamps involved, there are two broad general classes of infrared equipment, one using lamps with self-contained reflectors and the other using lamps with separate gold-plated reflectors. Both classes are in widespread use.

No attempt will be made here to compare the merits of the various types of oven equipment offered by a number of manufacturers. Data on the characteristics and performance of infrared ovens may be obtained from these manufacturers. With this knowledge, the user should be able to choose the type of equipment best suited for his specific requirements.

The equipment illustrated on pages 47 to 53 is typical of that produced by several of the larger manufacturers. Other equipment differing slightly in details of design is also available.



(*a*) (*b*)

FIG. 4–6.—Infrared production-oven units using, (a) reflector-type lamps and (b) separate lamps and gold-plated reflectors. Units may be assembled to produce ovens of various cross-sectional contours and of any desired length.

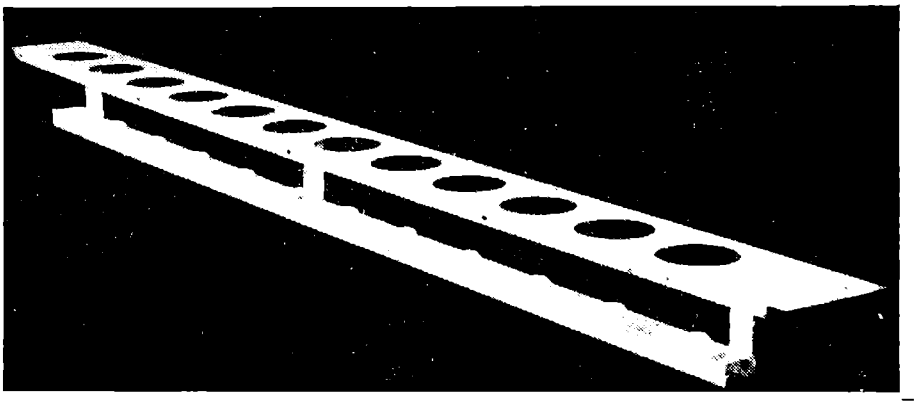


FIG. 4–7.—Oven part consisting of a wired channel attached to a section of oven wall with openings for R-40 bulb reflector-type lamps. The part is available with various socket spacings and with a variety of lengths with each spacing. It may be used in the construction of an oven of any size and length and of any desired contour.

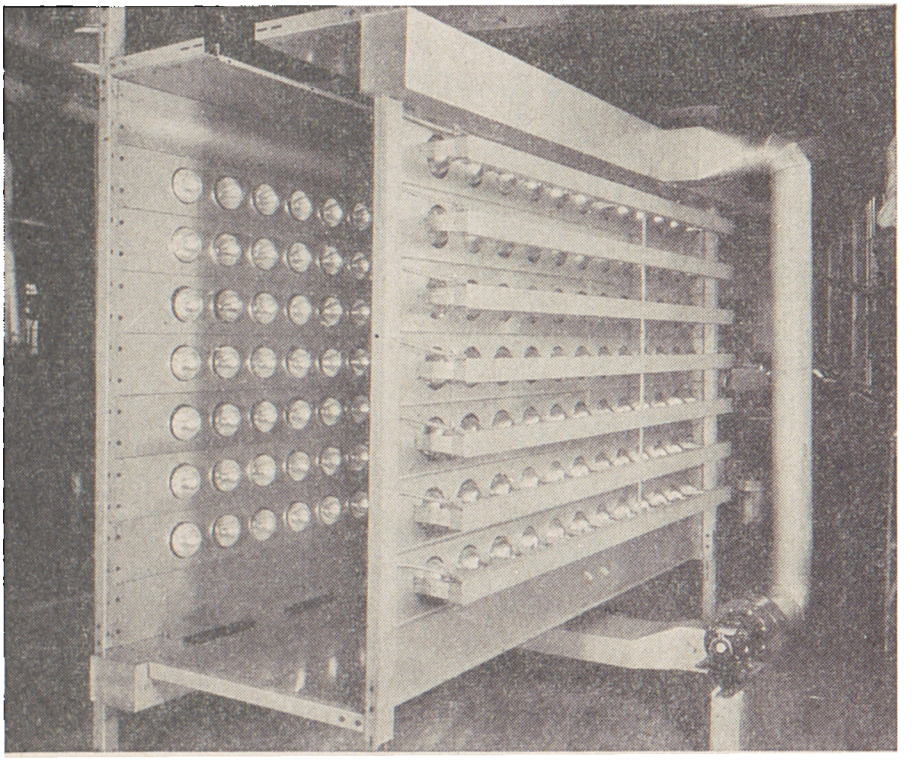


FIG. 4–8.—Finished section of conveyorized oven illustrating the use of the part shown in Fig. 4–7. A motor-driven fan provides the means of recirculation of the air in the oven. Sections may be assembled to provide an oven of any required length.

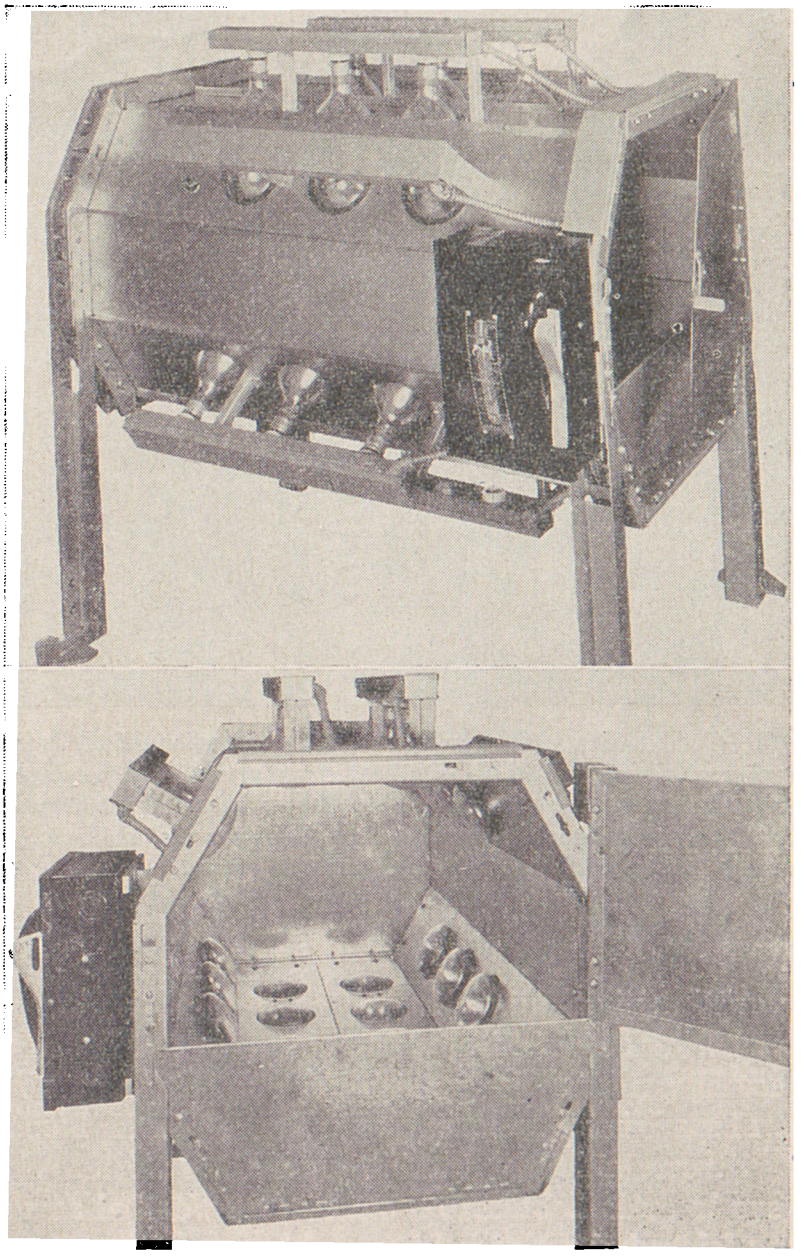


FIG. 4–9.—Batch-type oven—above, side view, below, end view. Note location of lamp bases and sockets outside of heat zone to provide favorable operating conditions.

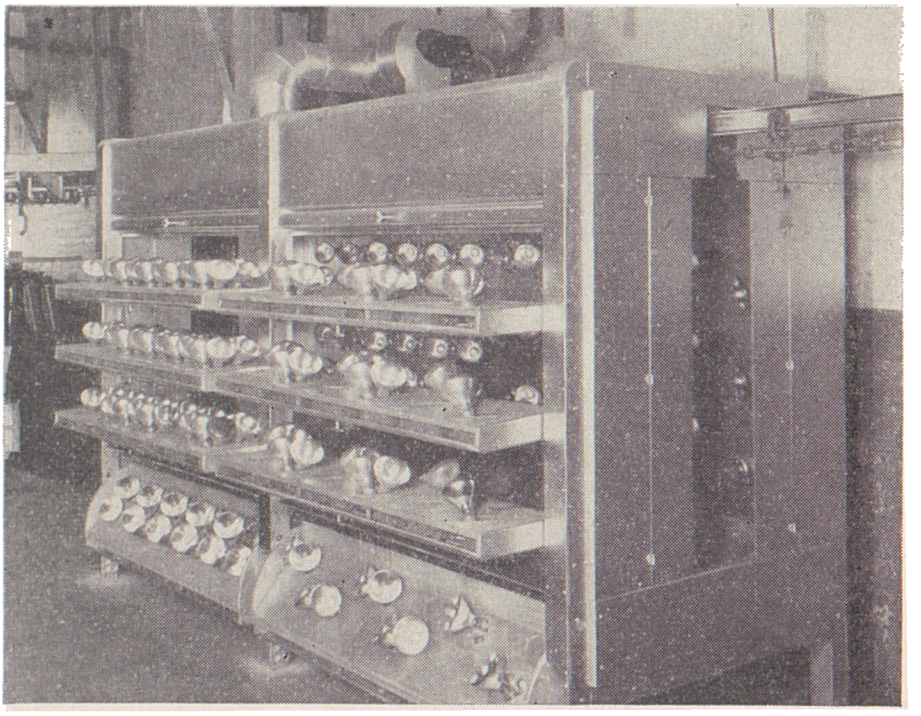


FIG. 4–10.—Combination infrared and convection oven using unique arrangement of lamps to provide more nearly uniform heat coverage in the processing of three-dimensional or irregularly shaped objects. The illustration shows the hinged sections opened for easy access to lamps. The various parts shown are available for assembly into an oven of any desired cross-sectional area and length.

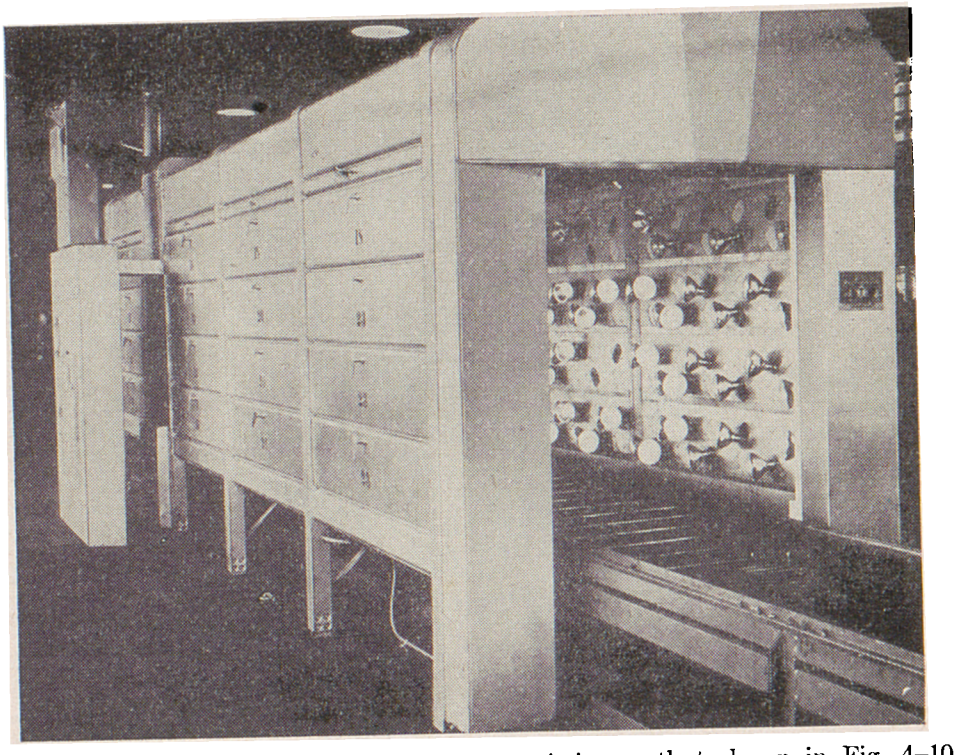


FIG. 4–11.—Oven of same general characteristics as that shown in Fig. 4–10. The hinged side sections are closed, with oven ready for operation.

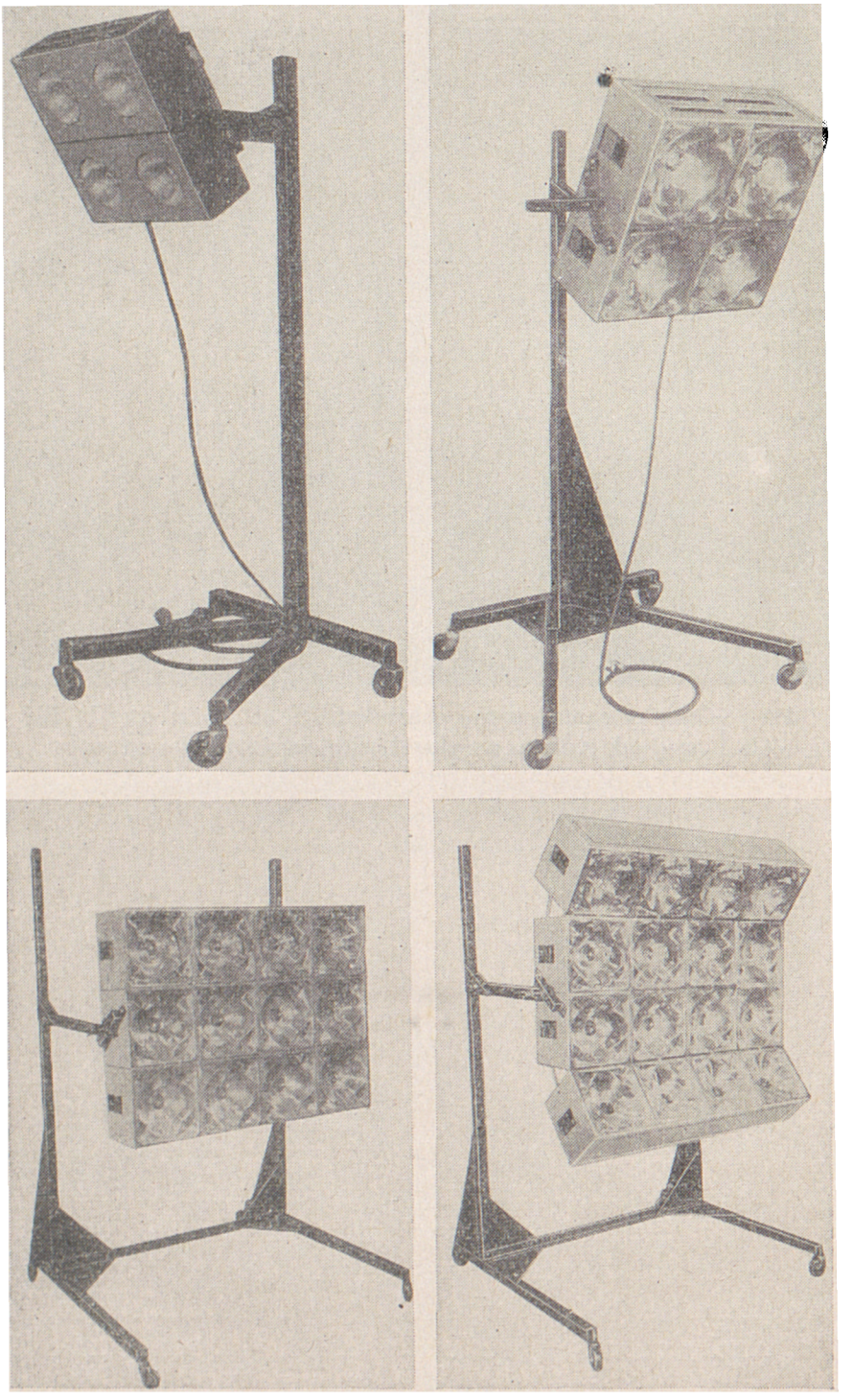


FIG. 4–12.—Small portable infrared units useful in the factory for various applications. The unit at the upper left uses reflector-type lamps, while the other three units use separate lamps and gold-plated reflectors.

FIG. 4–13.—Portable hand and work-bench infrared units consisting of separate lamps and gold-plated reflectors.

CHAPTER V

PLANNING AND DESIGN OF INFRARED INSTALLATIONS

When the use of radiant heat is being considered, calculations employing known heat formulas are of greatest value in determining the estimated power requirements. Knowing these requirements, it is possible to arrive at a decision as to the approximate power cost of infrared radiation for the purpose in question. The approximate number, type, and arrangement of infrared units and the time required for a specific drying or heating problem are most readily determined from data obtained from previous installations of the same character or by test.

Experience being gained from the ever-growing use of radiant heat for many varied purposes is making it increasingly easier for the user to determine in advance the general suitability of radiant heat and the approximate power load and equipment required for a proposed application. Subsequent illustrations and descriptions of infrared installations are offered as an aid in arriving at the correct answer to similar heating problems.

Heat-requirement Calculations

Inasmuch as many radiant-heat applications involve mass heating and liquid evaporation, the fundamental formulas for determining the heat requirements of the two are worthy of review.

Energy Requirements for Mass Heating

In calculating the requirements for mass heating, it is necessary only to know

(1) Pounds of material per hour to be treated
(2) The specific heat of the material
(3) The temperature rise required in degrees Fahrenheit

The above factors are used in the following formulas:

(4) (1) × (2) × (3) = Btu per hr

(5) $\frac{\text{Btu}}{3{,}413}$ = kw

Problem: Sheet brass is produced at the rate of 1,000 lb per hr. To facilitate punch-press operation it is desired to raise the brass from a temperature of 80 to 180°F, or a total of 100°F. Determine the approximate number of kilowatts required.

Since the specific heat of brass is 0.09, the data are substituted in the above formulas as follows:

(4) 1,000 × 0.09 × 100 = 9,000 Btu

(5) $\frac{9{,}000}{3{,}413}$ = 2.6 kw required

Calculation of Power Required for Liquid Evaporation

Two formulas are used for liquid evaporation. One of these for determining the energy required for raising the liquid to its vaporization temperature is the same as (4) above, in the use of which knowledge is required as to

(1) Pounds of liquid to be evaporated

(2) Specific heat of the liquid

(3) The degrees Fahrenheit temperature rise required to bring the liquid to its vaporization point.

The following formula (5) requires that

(4) The heat of vaporization of the liquid be known in order to determine the energy required to evaporate the liquid after it has reached its vaporization point

(5) (1) × (4) = Btu per hr

Since most liquid-evaporation problems involve removal of liquid on the surface or in the pores of some material, it is obvious that the material itself also must be heated to the vaporization point of the liquid. In such problems, naturally the total power requirements are determined by use of both the mass-heating and liquid-vaporization formulas.

Problem: Cloth weighing a total of 16 oz per yd, of which 13 oz is cotton and 3 oz moisture, is processed at the rate of 200 yd per min or 12,000 yd per hr. The cloth is at a temperature of

200°F when ready for drying. Determine the kilowatts necessary for drying.

This problem requires the evaporation of 2,250 lb $\left(\frac{12{,}000 \text{ yd} \times 3 \text{ oz per yd}}{16 \text{ oz per lb}} = 2{,}250 \text{ lb}\right)$ of water per hr from 9,750 lb $\left(\frac{12{,}000 \text{ yd} \times 13 \text{ oz per yd}}{16 \text{ oz per lb}} = 9{,}750 \text{ lb}\right)$ of cloth.

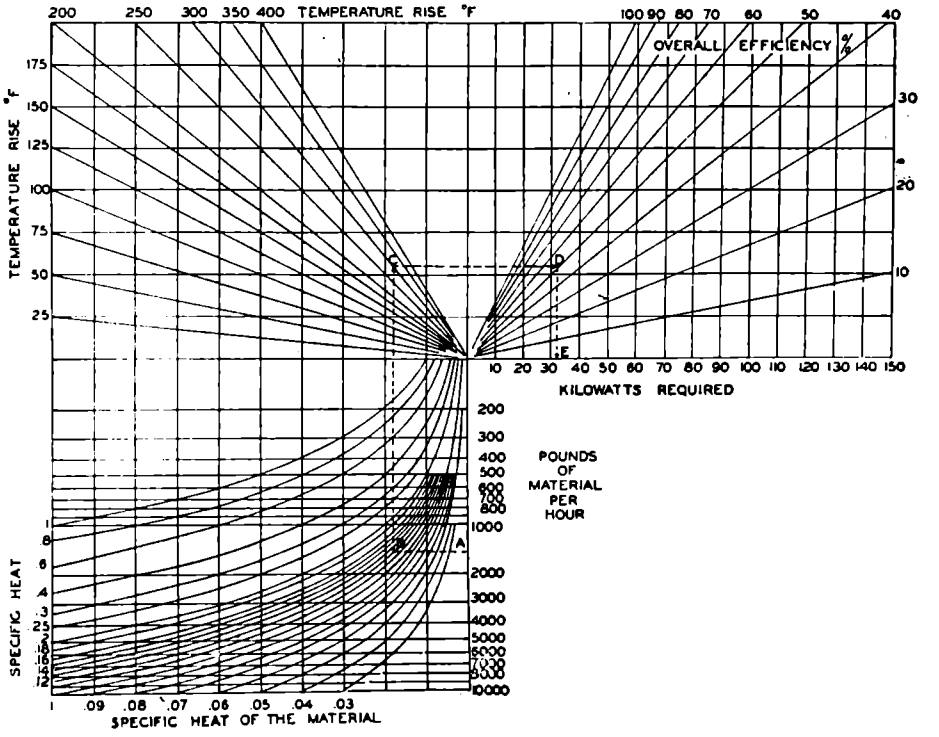


Fig. 5–1.—Chart for determination of approximate kilowatts of infrared lamps required for mass heating. Starting with the given weight of the material to be heated (for example, 1,500 lb per hr at *A*) proceed clockwise to the specific heat of the material (if steel, for example, the specific heat is 0.12 at *B*); then to the desired temperature rise (for example, 300°F at *C*); then to the over-all efficiency of lamp bank and work (say 50 per cent, at *D*); then to the final answer *E* (in this case 31.7 Kw). (*Courtesy of Howard Haynes, I.E.S. Transactions*, **36**, *p.* 61.)

The specific heat of cotton is 0.37 and of water 1.00. The heat of vaporization of water is 970. These data are substituted in the foregoing formula (4) as follows:

2,250 × 1.00 × 12 (212–200 = 12) = 27,000 Btu for raising the temperature of the water from 200 to 212°F.

9,750 × 0.37 × 12 = 43,290 Btu for raising the temperature of the cotton from 200 to 212°F.

Then substitute in formula (5) as follows:

2,250 × 970 = 2,182,500 Btu for evaporating the water.

The sum of the three is 2,252,790 Btu, or 660 kw.

Figures 5–1 and 5–2 may be used for estimating the power required in problems of mass heating and of water heating and

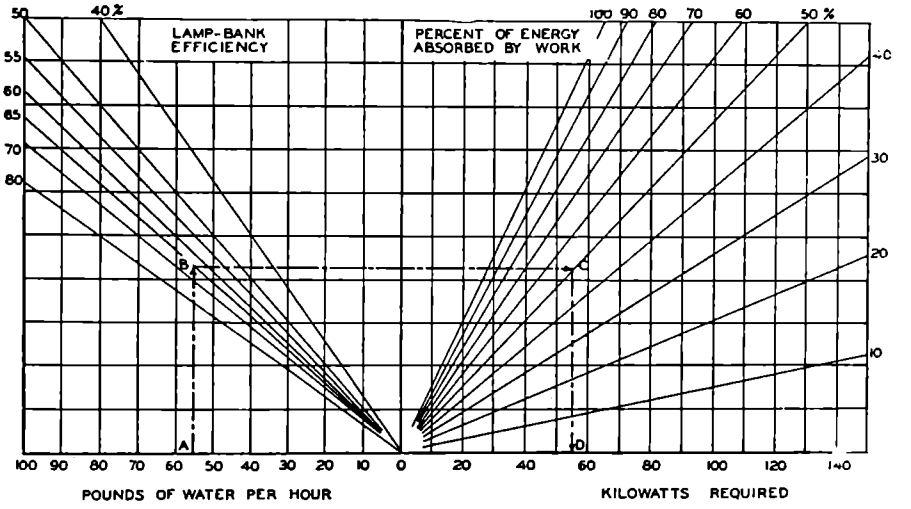


FIG. 5–2.—Chart for determination of approximate kilowatts of infrared lamps required for water heating and evaporating. Starting with a given weight of water (for example, 55 lb per hr at *A*) proceed clockwise to the lamp-bank efficiency (for example, 65 per cent at *B*); then to absorption per cent (for example 50 per cent at *C*); then to final answer, *D* (in this case, 55 kw). This chart is based on an initial water temperature of 70°F. (*Courtesy of Howard Haynes, I.E.S. Transactions*, **36**, *p.* 61.)

evaporation. The data obtained from the use of these graphs assume that all the radiant energy arriving at the working plane is intercepted by the material, as would be the case, for example, of canvas being passed continuously before a bank of lamps. If there are spaces between the material or objects or if there are holes in the material being passed through a lamp oven, the amount of energy required should be increased proportionately. For example, double the amount of energy per pound of material would be required for a given job of processing a sheet of metal perforated with holes occupying one-half of its area as compared with a sheet of the same net weight and thickness without the

perforations. In the former case one-half of the energy passes through the perforations and is not intercepted.

Comparison of results obtained in the typical problems shown with results determined from use of the formulas indicates that the actual load required for mass heating is approximately twice the theoretical. Likewise, in Fig 5–2 the power necessary is some three times the theoretical required as obtained by use of the formulas for the evaporation problem in question. From this it is evident that for general purposes of calculation, radiant heat may be considered some 50 per cent efficient for mass heating and 30 to 35 per cent efficient for water evaporation.

Some of the factors tending to decrease the efficiency of an infrared oven or tunnel follow: (1) The infrared lamps are not 100 per cent efficient as infrared generators, while the reflectors with which the lamps are used do not redirect all the infrared energy. The result is that the average unit is some 65 per cent efficient. (2) Not all the energy projected by the units is intercepted by the material being radiated. The actual amount intercepted depends on the design and operation of the oven. (3) There are heat losses due to convection currents and drafts. (4) Infrared is reflected by the material being heated. The amount reflected depends upon the character and color of the material. (5) There is loss of energy owing to reradiation. Any heated object or material is itself a secondary infrared generator. In an infrared oven much of this reradiated energy may be wasted.

Experimental Laboratories for Infrared Tests

Most infrared-heating-equipment manufacturers and some public utilities operate experimental laboratories where it is possible to determine not only the feasibility of radiant heat for a given process but also the amount, type, and cost of the essential equipment required. If the heating problem is involved and of considerable proportions, it usually is desirable to take advantage of the service offered by these laboratories.

If the proposed use of infrared requires that the equipment be adapted to and made a part of an already established process, it usually is preferable to conduct tests and investigations on the premises. In cases where the process is of a confidential nature

or where the use of infrared heat might appear to be a trade secret of value, it sometimes is considered desirable by the prospective user to conduct his own tests and subsequently construct the necessary equipment. The same may be true of applications requiring only a small amount of equipment that the user might wish to install without the delay incidental to formal laboratory tests at some distant point. For use of those desiring to conduct their own tests and install their equipment, certain fundamental application data are helpful.

Heat Produced by an Infrared Lamp

When the application of an internal-reflector lamp or a reflector-lamp combination for a given heating problem is being considered, it frequently occurs to the prospective user to inquire first, "How much heat will it produce?" When the wattage of the lamp and the efficiency of the unit as a radiant-heat reflector are known, it is a simple matter to calculate the amount of heat projected. For example, we know that the average unit reflects as radiant heat some 65 per cent of the total energy consumed. Therefore, determination of the radiant-heat output for a given time is merely a matter of

(1) Multiplying the consumption of the lamp expressed in kilowatts by the efficiency of the unit and in turn by the time expressed in hours.

(2) Multiplying the result by 3,413 (number of British thermal units per kilowatt-hour) to determine the total amount of infrared heat projected by the lamp as expressed in British thermal units. For example, four 250-watt lamps operated 10 hr consume 10,000 watt-hr, or 10 kwhr.

$$\frac{4 \text{ lamps} \times 250 \text{ watts per lamp} \times 10 \text{ hr}}{1{,}000 \text{ watt-hr per kwhr}} = 10 \text{ kwhr}$$

(1) 10×0.65 (lamp efficiency) $= 6.5$ kwhr

(2) 6.5 kwhr $\times$ 3,413 (btu per kwhr) $=$ 22,185 btu useful radiant-heat produced

Heat versus Temperature

It sometimes develops that the prospective user is interested not so much in the amount of heat produced as in the *temperature*

it is possible to achieve in a given object or material with a given infrared lamp. When he is told that the answer to this question depends upon many variables, the query as to why this temperature cannot be determined by use of a thermometer frequently follows.

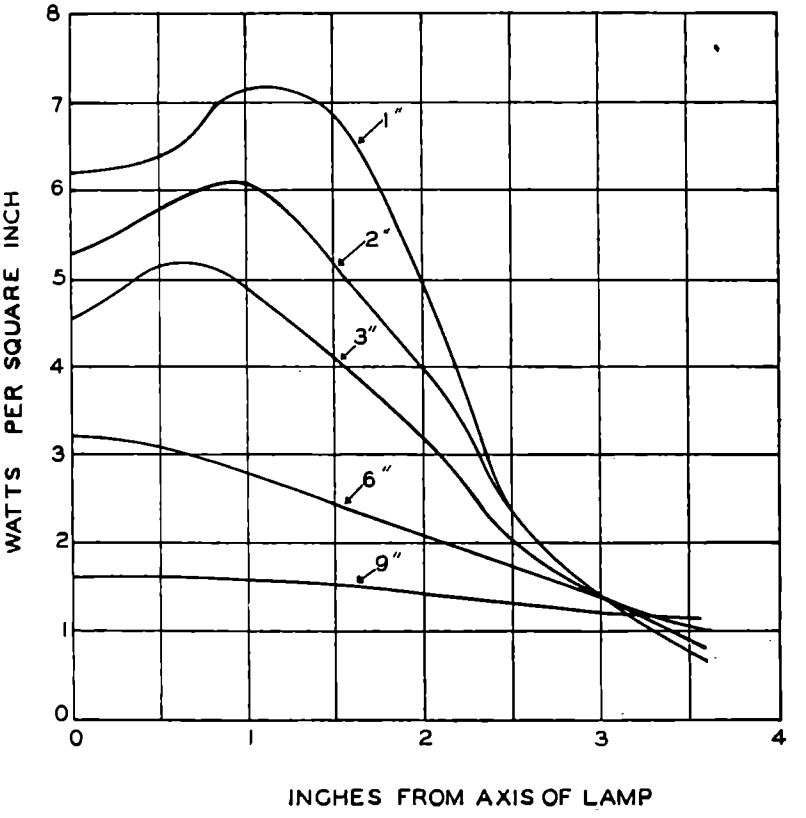


FIG. 5–3.—Radiant-energy distribution in a plane perpendicular to the axis of a 250-watt R-40 bulb reflector infrared lamp with the plane located at various distances (as shown) from the end of the lamp bulb.

The temperature produced by an infrared unit depends upon a number of factors independent of the characteristics of the unit itself. Among these are the distance of the unit from the surface being radiated (Figs. 5–3 and 5–4), the color and character (smooth or rough) of the surface, the nature of the material (wood, metal, etc.), and the thickness or mass of material.

A mercury thermometer placed in the infrared beam projected by a radiant-heat reflector would be worthless as a means of determining the temperature attained by a material or an object

located in the same position with respect to the reflector. Such use of a thermometer would serve only as an indication of the temperature reached at various positions in the beam by a globule of mercury of the same size as that in the thermometer. Since the infrared reflection and absorption characteristics of mercury are liable to differ widely from those of the object to be heated,

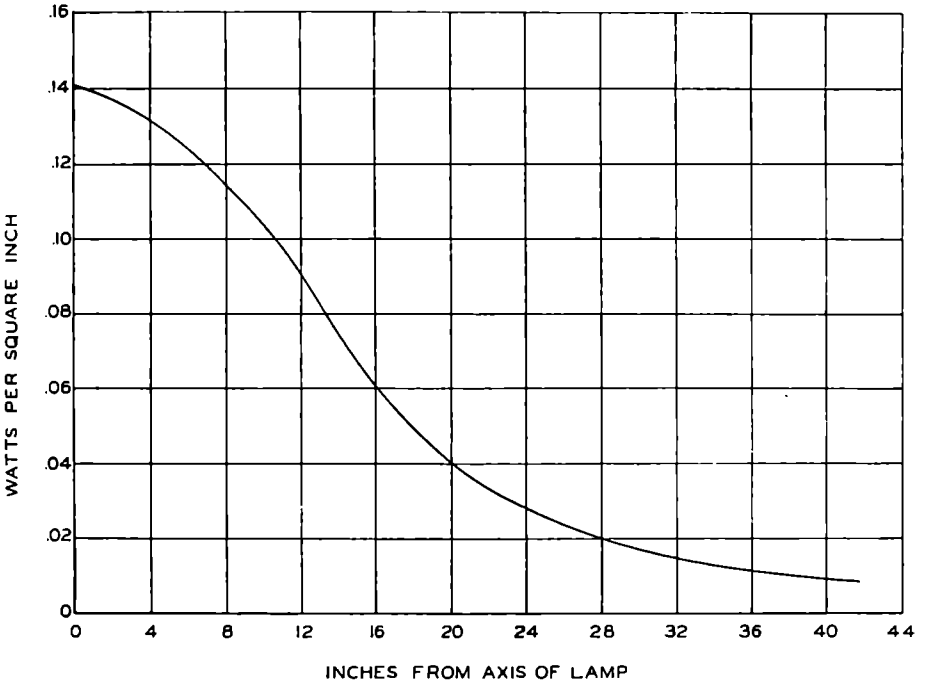


FIG. 5–4.—Radiant-energy distribution in a plane perpendicular to the axis of a 250-watt R-40 bulb reflector infrared lamp with the plane located at a distance of 36 in. from the end of the lamp bulb.

it is evident that any such temperature measurements are useless for the purpose of acquiring the desired information.

For determining the intensity of radiant energy delivered by an infrared generator to any given point in an infrared "beam," there is available a portable, lightweight (6 oz.), direct-reading radiation meter (Fig. 5–5), which may be used in the same manner as the well-known footcandle or light meter commonly applied to the measurement of light intensity.

The meter is sensitive to radiation of wave lengths from 3,000 to 35,000 A and is calibrated to read in gram calories per square centimeter per minute. By means of conversion factors supplied with the meter, readings may be converted into watts per square

inch, kilowatt-hours per square foot per hour, or British thermal units per square foot per hour.

Although the maximum capacity of the meter is lower than the intensity found in most industrial infrared applications, it can be used with satisfactory accuracy for measuring infrared intensities of the latter by providing a screen to absorb a portion of the radiation. If the absorption of the screen as determined by test with the meter is known, a multiplying factor for use in measuring the higher intensities may be determined.

FIG. 5–5.—Meter for measuring intensity of infrared radiation.

A screen suitable for the purpose should be of some loosely woven fabric, such as fine wire screening, which should be interposed between the energy source and the meter thermocouple. If we assume, for example, that the meter without the screen is placed at some arbitrary position and distance from any radiant-energy source so as to produce a scale reading of 2, and then the thermocouple is covered with the screen with a resultant reduction of the reading to 0.2, the meter with the screen could be used for direct readings at any desired position with respect to a given infrared source by using a multiplying factor of ten ($2/0.2 = 10$).

Obviously, the greater the difference between the intensity of the radiation to be measured and the normal maximum capacity of the meter, the finer the mesh of the screen required, and vice versa. A suitable mesh size can be determined by test.

Data on actual temperatures attained by a material being heated with infrared are determined most readily by the use of two thermocouple leads attached to the material and in turn connected to a millivoltmeter calibrated to read in degrees Fahrenheit or centigrade. If the material is of metal, the thermocouple leads may be attached with solder; if of some other material, such as glass or plastic, a sodium silicate paste may be

used. In either case, the amount should be the minimum required to accomplish the desired results satisfactorily. If too much is used, the readings on the meter may be inaccurate. The solder obviously should have a melting point in excess of the maximum temperature the material is expected to reach.

Commercially available lacquer, crayons, or pellets especially prepared for the purpose may be used for determining when a material or object has reached the de ired temperature. The lacquer, crayons, or pellets may be had for various temperatures over a wide range. When applied to a surface, they assume a characteristic change in appearance as soon as the surface reaches a temperature equivalent to that for which they are designed.

From the foregoing it is apparent that no specific statements are possible concerning the temperature produced by an infrared unit. The temperature rise in a given material being radiated under given conditions, if not known from previous experience, must be determined from actual tests. As before indicated, this temperature will vary with the character, color, thickness, mass, etc., of the material.

Use of Visible Light Produced by Infrared Lamp in Arrangement of Units

Inasmuch as infrared rays are reflected in the same manner as visible light, the infrared "beam" from a radiant-heat lamp or reflector has approximately the same shape and characteristics as the visible-light beam. For example, a surface or an object uniformly illuminated by a lamp or a bank of lamps likewise is uniformly radiated with infrared heat. Consequently, the visible light produced by an infrared lamp may be used as a guide in determining the relative distribution and intensity of radiant energy.

Just as in the case of visible light, an object placed in an infrared beam casts a "shadow" which, although invisible, coincides with the visible shadow cast by the light from the radiant-heat lamp. Hence, in order to obtain uniformity of heating of an object having irregular surfaces, lamps should be of such

number and so located and directed as to avoid visible shadows as far as possible.

Operating Position of Lamps

Infrared lamps may be operated in any position, that is, base down, base up, base horizontal, etc. This means that the units may be arranged and located in any manner necessary to conform

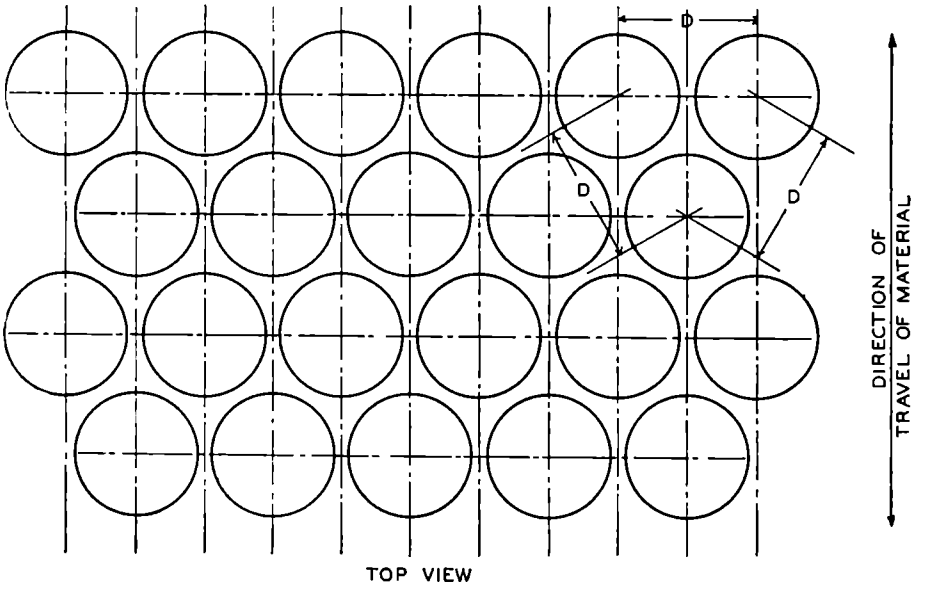


FIG. 5–6.—Arrangement of infrared units to produce greatest and most uniform concentration of energy. As will be noted, the center of each lamp is located at the same distance *D* from the center of each adjacent lamp. Where material is passing continuously (as on a conveyor) under a bank of lamps so positioned, the direction of travel should be as indicated for the most uniform application of the heat.

with the contour of the object being dried or heated, and that radiant energy may be applied to the top, bottom, and/or sides of any object.

Spacing and Arrangement of Infrared Units

The closer the lamp or the reflectors to the material being radiated, the greater the intensity of the energy per unit area of the surface being heated (Figs. 5–3 and 5–4). On the other hand, the shorter the distance between the two, the less the uniformity of the application. The greatest nonuniformity obviously would be experienced by the use of units relatively

widely spaced and located in close proximity to the material being heated. Maximum uniformity would be had by means of closely spaced units located at a distance from the material. Usually, it is possible to reach a satisfactory compromise between the two. In common practice banks of infrared units generally are arranged in one of two ways (Figs. 5–6 and 5–7). Of these two possible methods, that shown in Fig. 5–6 is to be preferred where a rela-

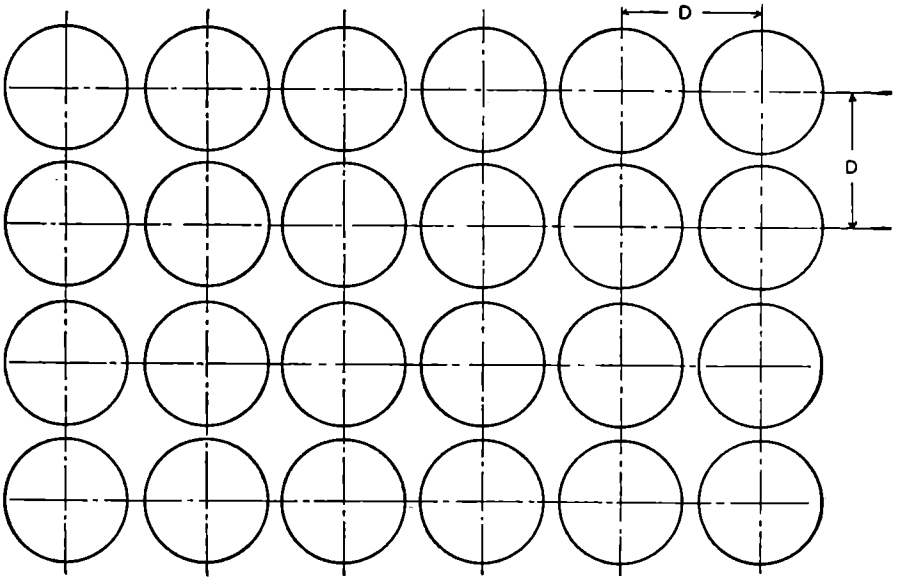


FIG. 5–7.—Top view of arrangement of infrared units frequently used in installations where uniform and maximum concentration of energy is not required. Wiring and installation problems with this method are somewhat simpler than with the arrangement shown in Fig. 5–6.

tively uniform heat coverage is desired. This arrangement also permits a greater concentration of energy per unit area for those applications requiring higher temperatures. The arrangement shown in Fig. 5–7 facilitates wiring and installation and is found in many infrared ovens where the process does not require the higher uniformity and concentration possible with the arrangement shown in Fig. 5–6.

Test Equipment

The type of infrared lamp and equipment used for a particular heating problem is a matter of personal choice, but for the purpose of small-scale tests reflector-type lamps (Fig. 3–3) usually are to

be preferred because of their small size, low cost, and ease of installation. Small banks of these lamps arranged as illustrated in Fig. 5–6 or Fig. 5–7 generally serve to provide sufficient data

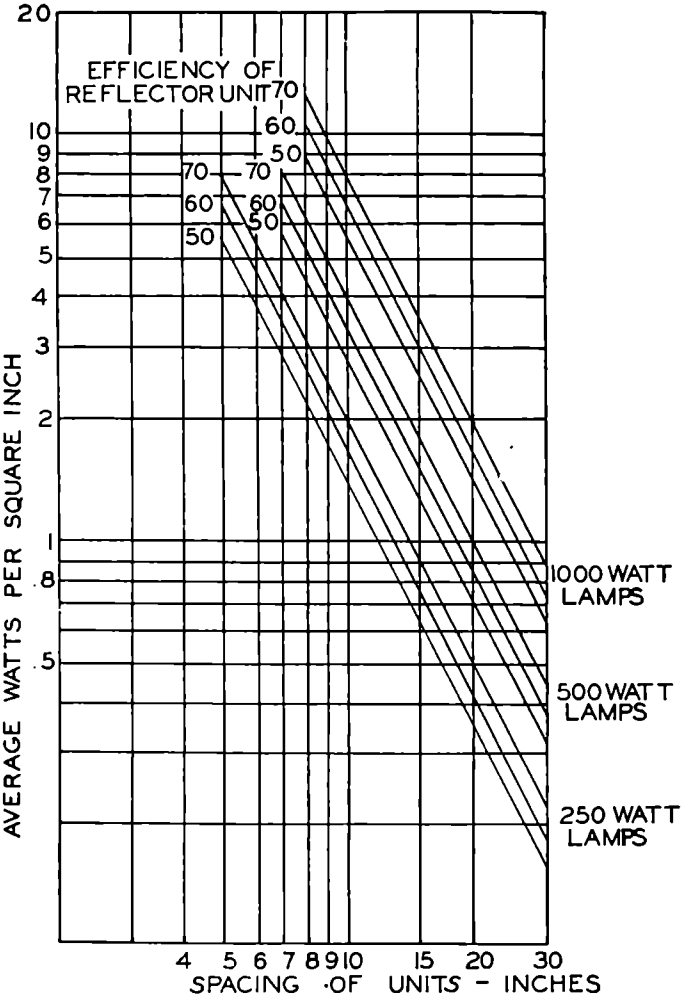


FIG. 5–8.—Spacing of infrared lamp units for obtaining desired concentrations of radiant energy. These data are for a staggered arrangement of units (Fig. 5–6). When lamps and reflectors are mounted in a square pattern (Fig. 5–7), the concentration of energy will be approximately 87 per cent of that obtained with a staggered arrangement. (*Courtesy of Howard Haynes, I.E.S. Transactions*, **36**, *p.* 61.)

to determine the feasibility of radiant heat for a given purpose. The actual size of the test banks will depend upon the size of the object or material to be dried or heated, but in many cases a minimum of seven lamps per bank arranged as shown in Fig. 5–9 or 5–10 will serve satisfactorily. As will be seen, this arrange-

ment is equivalent to a section of a larger bank of lamps arranged as shown in Fig. 5–6.

The sockets for a test bank may be mounted on suitable material on which has been inscribed a circle whose diameter is equivalent to twice that of the spacing of the lamps. For example, if a rather high concentration of heat is required, and it has been decided that lamps spaced on 5½-in. centers will be tested, the circle should be 11 in. in diameter. One socket should be located at the center of this circle while the other six sockets should be located and spaced on 5½-in. centers on the circumference of the circle. One such bank would suffice if the conditions of the processing of the material are such as to allow application of the heat to only one side. Two banks would be needed where, in the final installation, it is proposed to apply heat to both sides of the material.

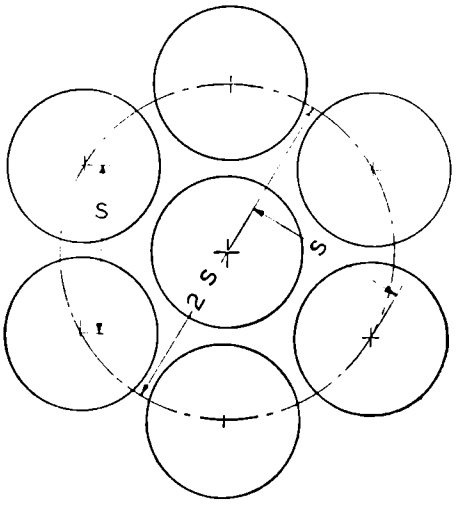


FIG. 5–9.—Suggested arrangement of lamps for test purposes. *S* is a trial lamp spacing. The lamp sockets are located at the center of, and on the circumference of, a circle whose diameter is equivalent to 2*S*.

Test Procedure

Assuming that the problem under consideration involves the drying of cloth, paper, or other similar material, or the baking of enamel on metal sheets, a square sample of the material whose dimensions preferably do not exceed that of the spacing of the lamps should be used. For example, if the lamps are spaced on 6-in. centers, the sample should be approximately 6 in. square. The sample may be suspended or held vertically, horizontally, or in any other desired plane before a single bank of lamps or between and equally distant from two parallel banks of lamps facing each other. In either event, the bank or banks of lamps should be located in a plane parallel to that of the material. The distance of the lamps from the sample would depend upon whether in the final installation the material being dried would be station-

ary or moving with respect to the lamps. An example of the former might be the intermittent production of painted steel sheets placed before or between banks of lamps for drying; of the latter, the drying of cloth passing before the lamps as it is processed.

Requirements for Uniformity of Radiation

The degree of uniformity of radiation required varies with the application. The maximum degree of uniformity necessary would be found, for example, in the radiant-heat drying of a finish applied to the surface of some nonconducting material such as wood, while a much lesser degree of uniformity would be acceptable in the application of energy to a metal sheet where conduction of the heat in the metal from the higher to the lower temperature areas would largely prevent excessive temperature differentials. Where the heat conductivity of the material is poor, any nonuniformity in the application of energy is reflected in a like nonuniformity in the temperature of the material.

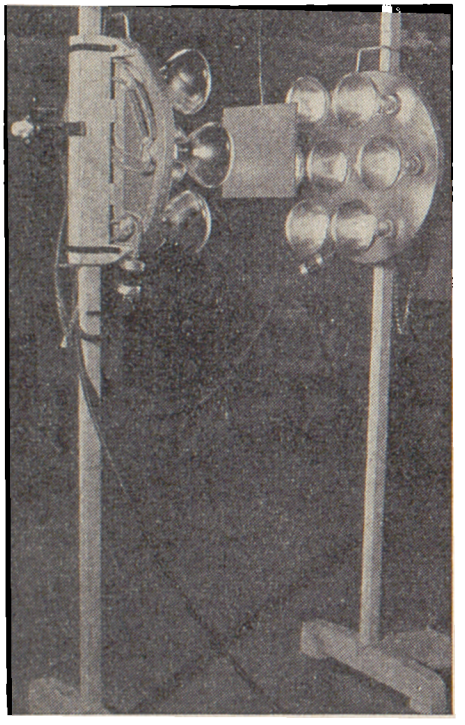


FIG. 5–10.—Portable infrared units used by public utility for demonstration purposes. Note that the lamps are arranged as suggested in Fig. 5–9.

Attainment of Uniform Radiation

Where it is more important to have uniform coverage in order to prevent spotty or uneven application of heat, the heating units should be located at a distance sufficient to provide an overlapping of the radiant-heat beam pattern. With reflector lamps located on about 5½-in. centers this distance should be at least some 6 in. If the material is to be moving with respect to the lamps, the two may be separated by a distance sufficient only to prevent actual contact, provided the staggered arrangement as shown in Fig. 5–6 is used.

If the temperature reached by the material is too high or is attained too rapidly, as might occur in the baking of surface finishes, the test may be repeated using increased spacing of the lamps, greater distance between the lamps and the material, or a combination of the two. It should be remembered that increased spacing of the lamps requires that they be located at a greater distance from the material if the heat application is to be uniform.

Attaining and Maintaining Given Temperatures

If the heating problem requires that the desired temperature be attained rapidly and be maintained at this point without further rise, the desired results can be achieved by several different arrangements of the heating units if the material is passing continuously through the heat zone. A rapid rise in temperature can be accomplished by the use of closely spaced lamps in the first stage of the heating process. Then, when the proper temperature is reached, the material may pass into a zone where the temperature is maintained by means of more widely spaced lamps or by increasing the distance between the lamps and the material. Another method would consist of applying the heat to both sides of the material to raise the temperature rapidly and then to only one side to maintain the temperature. Lamps of varying wattages also are used to accomplish the same purpose (Fig. 5–11).

Simulation of Actual Operating Conditions

Movement of material, as on a conveyor, past a bank of lamps or between two banks of lamps can be simulated in the test by moving the test piece slowly around in its own plane within the circumference of the circle on which the sockets for the outer lamps are located.

The primary object of a small-scale test is to assist in determining the most suitable arrangement of the units. When this is known, the approximate equipment and power requirements can be estimated. It should be recognized that the use of seven (one bank) or fourteen (two banks) lamps to heat a small sample of material does not mean that this proportion of lamps per unit area of material will hold in the finished installation. Since the radiant-heat beam pattern from the usual infrared unit is divergent, it is obvious that any given point on a surface being radiated by a bank of lamps absorbs energy not only from the lamp directly

opposite but also from adjacent lamps. Hence, larger banks of lamps are necessary to simulate conditions that will prevail in the final installation.

Determination of Length of Oven

If, for example, the test shows that a time of 5 min is sufficient for the required heating or drying, a single or a double bank of lamps of the same spacing and arrangement as the test bank or

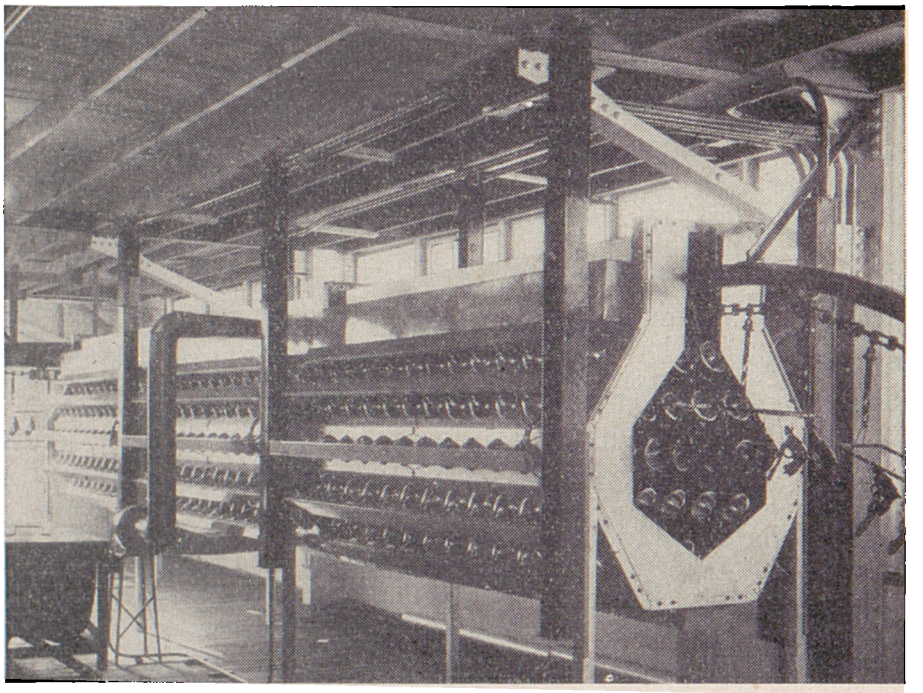


FIG. 5–11.—Ninety-kilowatt oven for baking finish on variety of 20-gauge steel toys in 4 to 13 min. The first third of the 27-ft oven is equipped with 375-watt and the rest with 250-watt lamps.

banks and covering the full width of the material will be necessary. If the material is to be heated or dried in batches, the length of the banks naturally will be that of the longest piece of material. If the material is being processed continuously, as in the case of cloth or other material passing through the heat zone on a conveyor, the length of the bank of lamps should be equivalent to the travel of the material in 5 min.

Design Refinements

Subsequent illustrations will serve to suggest the general design of an oven for a given purpose. These illustrations, however, do

not picture certain design refinements that should be considered in either the purchase or construction of an infrared oven. Among some of the more important of these refinements might be included the following:

1. In order to prevent the possibility of bulb breakage, infrared ovens should be so designed that drops of water, paints, or other liquids from the material being processed do not fall on the lamps. Even though the lamps should escape breakage, it may be found very difficult to remove paint, etc., from the bulbs once it has been baked by the heat of the glass.

Electrostatic detearing[1] may be used to remove drops of liquid from objects prior to processing. Where it is used, lamps may be located directly under the objects with a minimum danger of bulb breakage.

2. Where an infrared oven is being used to heat objects of diversified shapes and dimensions, possible damage to the lamps and the oven may be averted by using a mechanical guard at the oven entrance. This guard should be connected to the power circuit so that the conveyor is stopped automatically in the event attempt is made inadvertently to process pieces of excessive size. Also, an additional protection to the lamps can be provided by the use of wide-mesh wire screens located in front of the banks of lamps so that bulbs are not broken by swinging articles suspended from an overhead conveyor. This precautionary measure is of particular importance where there is small clearance between the lamps and the objects being processed.

3. One of the most important features of most infrared-oven design is that of interlocking the power circuits to the lamps and to the conveyor drive so that the lamps are turned off automatically when the conveyor stops for any reason. This not only conserves power but also prevents spoilage of material left in the oven when the conveyor stops—there being little latent heat in the usual type of infrared oven.

[1] Electrostatic "detearing" is a method whereby excess drops of paint, etc., are removed automatically from parts subsequent to dipping and prior to baking. Before detearing, the parts are allowed to drain until the flow of paint has ceased and tears have formed at the drain-off points. After this the parts are passed over an electrically charged grid, which, by virtue of the electrostatic field created, draws off the excess paint, thereby making it feasible to dip satisfactorily and economically many articles that formerly were sprayed in order to obtain best results.

In a batch-type oven the circuit-interlocking feature can be replaced by an automatic switch for turning off the lamps at a predetermined time.

4. Infrared ovens using separate lamps and reflectors usually are so constructed that cleaning and replacement of lamps must

FIG. 5–12.—Infrared oven designed to facilitate removal of lamps from the outside of the oven. Too close spacing of the lamps in each row or too close spacing of the rows themselves would necessitate removal of the lamps from the inside of the oven.

be done from inside the oven. Ovens employing reflector-type lamps may be so designed that lamps may be removed from the outside (Fig. 5–12) without interfering with the flow of materials through the oven. Where this feature is desirable, care should be taken to locate and space the lamps and design the supporting structure so that ample room is provided for the removal of the lamps.

5. Where reflector-type lamps are inserted through openings in the walls of an oven, the openings should be of generous size (preferably of a diameter at least ½-in. greater than that of the part of the lamp adjacent to the oven wall) so that no metal comes into contact with the glass, a contact that might cause the bulb to crack or break. Sockets improperly spaced or aligned and variations in individual lamps serve to prevent the satisfactory use of oven-wall openings of a size more closely approaching that of the lamp itself.

6. Maintenance of infrared-oven conveyor equipment is more economical and less troublesome if, as far as possible, all lubricated parts are located outside the heat zone.

7. Oven parts often reach high temperatures. This dictates the need for using high-temperature-melting-point solder where soldering operations are necessary in the construction of the oven.

8. Not only immediate needs but also possibility of future increases in the capacity of an infrared oven should govern the design and installation of the required wiring, switches, etc. In addition to wasting power, excessive voltage drop in the electrical system reduces the productive capacity of an oven in proportion to the reduction in wattage of the lamps (Fig. 3–5).

CHAPTER VI

SPECIAL APPLICATION PROBLEMS

Heating Three-dimensional Objects

Infrared radiation usually is most effectively and most easily applied when there is a 90-deg angle of incidence of the heat rays with the surface being radiated. An example would be the drying of essentially two-dimensional objects such as sheets of cloth, paper, metal, or other materials by means of one or two banks of lamps located in a plane or planes parallel to that of the sheets and with infrared units of nondivergent beam pattern.

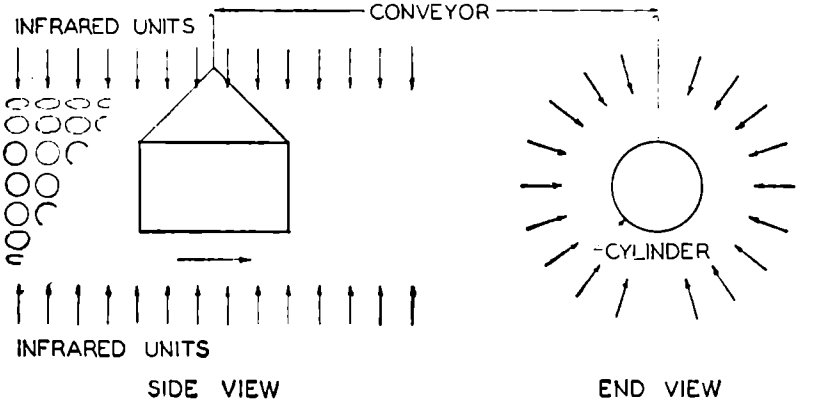


FIG. 6–1.—Method of processing wherein a cylinder passes through a cylindrical-shaped oven while remaining stationary with respect to its axis.

Many heating problems involve use of infrared radiation for heating objects having three dimensions or irregular contours. If the requirements are not such as to necessitate uniform application of energy to all surfaces of an object, an oven consisting of two parallel banks of lamps, each located in a single plane, may be entirely satisfactory. An example would be the drying of a metal object after cleaning with chemicals or water.

Where uniformity of infrared application, such as in the drying of surface finishes, is important, it is necessary for most satisfactory results to provide an oven having a cross-sectional contour similar to that of the object to be heated, or to convey the object

through the heat zone in such a manner that all its surfaces are exposed to the direct rays from the lamps. For example, a painted open-ended cylinder could be dried effectively by passing it horizontally through an infrared oven having a circular cross-sectional contour (Fig. 6–1).

If it should be desired to dry the cylinder in a vertical position, it should be rotated on its axis (Figs. 6–2 and 6–3) as it passes between two vertical parallel banks of lamps facing each other. The cylinder may be suspended from above or supported by a rotating platform.

Drying of a globular-shaped object would necessitate the use of an oven that has a circular cross section and also revolving the object on its vertical axis as it passes through the oven. A cubical-shaped object to be radiated might be suspended from one corner and rotated as it passes through an oven of approximately circular cross section.

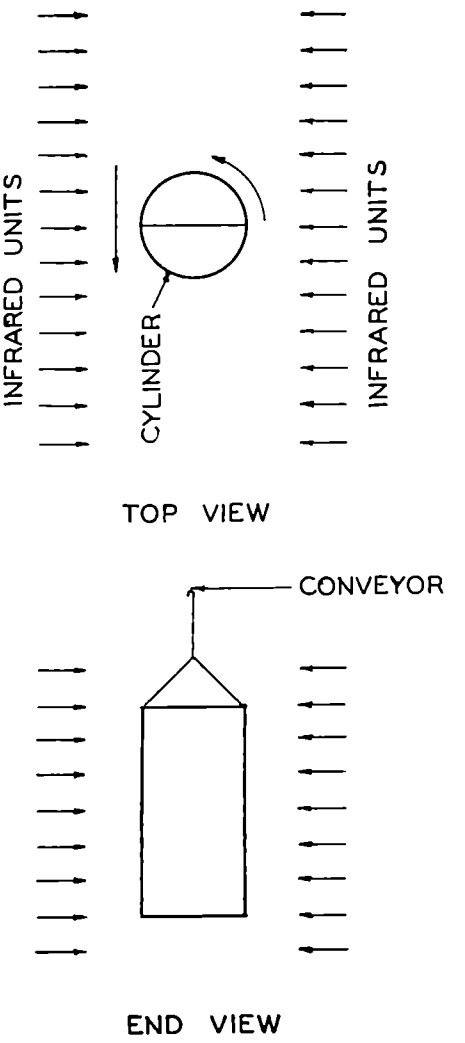


FIG. 6–2.—Two vertical parallel banks of lamps used for heating a cylinder that rotates on its axis as it passes through the heat zone.

Radiation of Materials Having High Infrared Reflectivity

Although there may be certain advantages that dictate its use, generally infrared cannot be used economically to heat materials such as gold, silver, copper, chromium, aluminum, etc., which reflect a relatively high percentage of the radiant energy falling on their surfaces. This reflected energy, of course, does not serve to raise the temperature of the material and is wasted. Usually, the conventional convec-

tion oven is most economical for this purpose. However, it should be noted that radiant heat may be used satisfactorily to dry various types of finish applied to the surface of an infrared-reflecting material (Fig. 6–4).

Infrared Heating of Glass

Just as infrared radiation generally is not economical for heating a material having a high infrared-reflection factor, it likewise is not

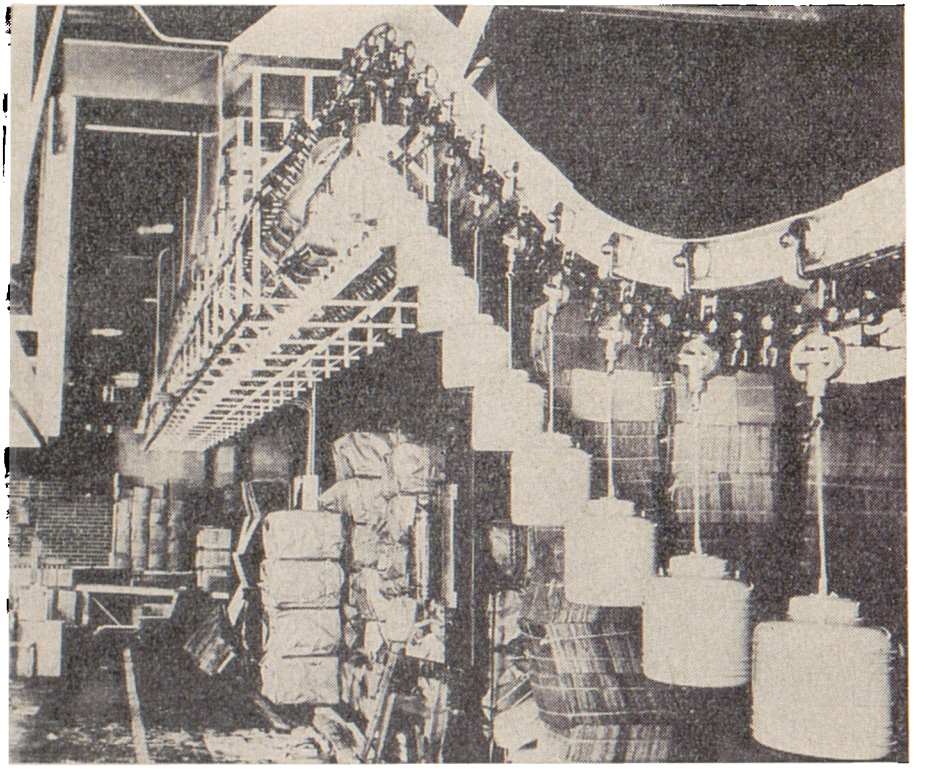


FIG. 6–3.—Infrared tunnel 50 ft long installed on ceiling for baking of finishes on thermal jugs at the rate of 450 to 500 per hr. The jugs are suspended on a revolving spindle conveyor and are baked at a temperature of 250°F for 5 min as compared with 1½ hr required when convection equipment was used. Four hundred twelve 260-watt lamps and gold-plated reflectors are used.

especially suited for heating a material such as most kinds of glass, having a high infrared-transmission factor. Obviously, any radiation that passes through a material does not serve to increase its temperature and hence is wasted.

Where factors other than economics dictate the use of infrared for a problem such as that of heating plate glass, the efficiency of

the process may be improved by special arrangements of the glass and the drying equipment. Inasmuch as each plate absorbs some of the radiant energy, all the energy from an infrared unit may be absorbed by glass if a sufficient number of plates are stacked together and heated simultaneously. If a unit or bank of lamps is used on each side of the stack of plates, tests will show the maxi-

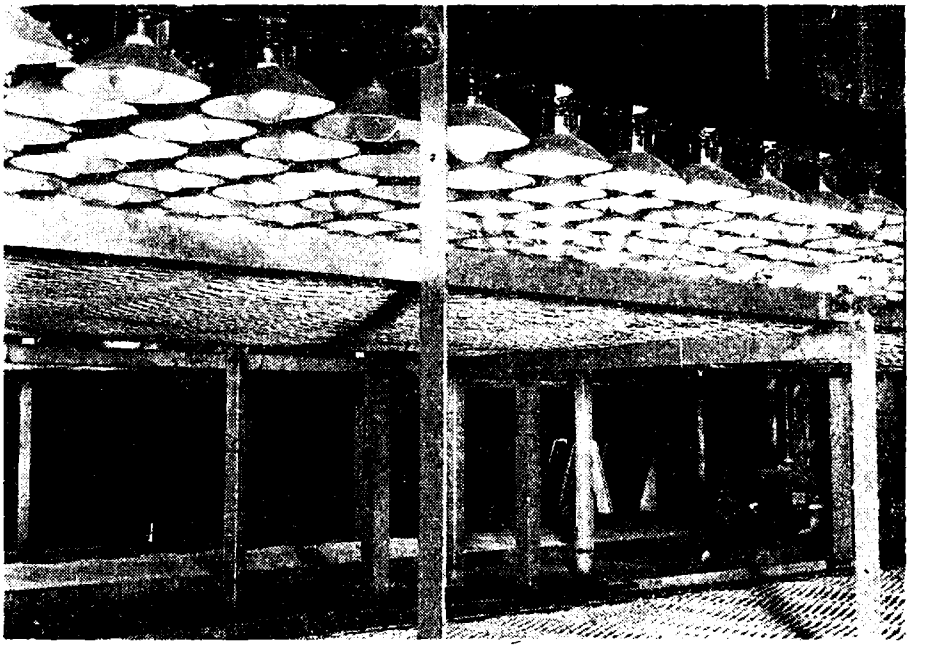


FIG. 6–4.—Bank of one hundred sixty 250-watt infrared lamps over a flat conveyor to bake du Pont zinc chromate primer on various thicknesses of Alclad aluminum sheet. Baking schedules range from 30 sec upward depending on Alclad gauge. After the primer has been applied, the sheets are formed and used in the construction of fuselage and airplane parts.

mum number of plates that can be heated most uniformly and effectively.

If processing requirements are such that single plates of glass must be heated, the efficiency may be improved by causing the transmitted energy to pass through the glass a second time. During the second passage, additional energy is absorbed. This can be accomplished by placing a reflector of Alzak aluminum or plated gold on the side of the glass opposite from that on which the infrared unit is located.

Infrared radiation may be applied to plate glass by an indirect method wherein each side of the glass is covered with a metal sheet

on which the energy is directed. The metal sheets absorb th radiant energy and, being in contact with the glass, transmit th energy in the form of heat by conduction to the glass.

Glass is a good insulator or, in other words, is a poor conducto of heat. This fact should be kept in mind in applying heat t glass. Unlike metals, when heat is applied to glass, very littl

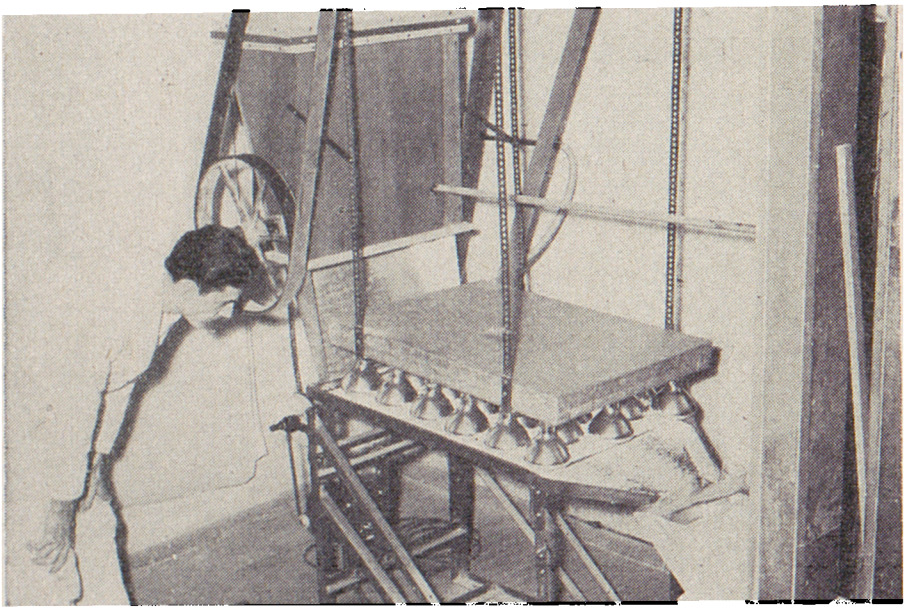


FIG. 6–5.—Twenty-eight 250-watt reflector infrared lamps used in conjunction with vibrating chute or conveyor to toast wheat germ at 215 to 220°F in approximately 15 sec. Lamps are mounted about 3½ in. above surface of chute. Note staggered arrangement of lamps to provide uniform coverage of heat.

of the energy is conducted away from the point of absorption with the result that a high temperature differential between different areas of the glass may be created if energy is not applied equally to all areas. This condition is liable to cause the glass to crack; hence, infrared units for this purpose should be designed with maximum uniformity of heat distribution as the prime objective.

Radiation of Granular Materials

In the drying or heating of materials of granular nature or of small particle size, for most satisfactory and uniform performance it is desirable to pass the material through the heat zone on an inclined vibrating surface (Fig. 6–5) so that the particles are kept

in constant motion and thereby each particle is subjected in turn to the direct radiation.

If the material is being transmitted by a conventional conveyor and is of appreciable depth on the belt, the lower layers or particles not exposed to the direct radiation may be improperly heated or dried. This may be remedied by use of a series of stationary plows or rakes arranged above the belt to keep the material well stirred. Somewhat the same results can be accomplished by use of a series of conveyors, each with its belt at a higher level than the succeeding belt so that the material is well mixed by being cascaded from one belt to another (Figs. 6–6 and 6–7).

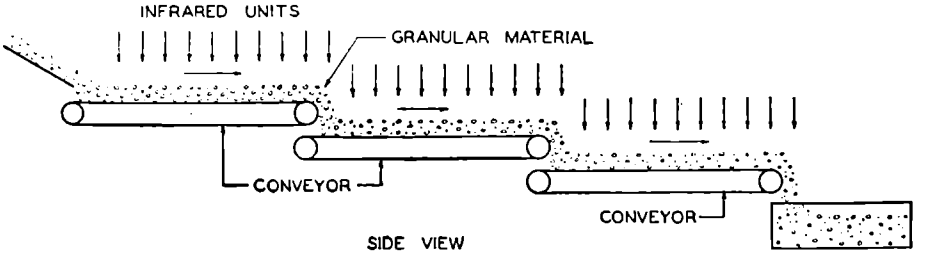


FIG. 6–6.—Arrangement of conveyor system for infrared heating of materials of small particle size. Cascading of the material from one level to another serves as a means of thorough mixing with resulting uniformity of drying of individual particles.

Heat Processing Involving Highly Explosive Volatiles

Because of the fact that there is a minimum danger of fire or explosion when infrared radiation is used in the conventional manner, there is little need for explosion-proof infrared equipment; hence, such equipment is not commercially available. If the conditions or the safety laws are such as to dictate the use of explosion-proof equipment, the need for such equipment may be circumvented by conducting the processing within a vapor-tight compartment with the infrared energy projected through plate-glass windows in the compartment by means of units located on the outside (Fig. 6–8).

Ordinary plate glass is unsuited for the compartment windows owing to its tendency to crack when subjected continuously to infrared radiation. The glass manufacturer should be consulted for information on the type of glass best suited for the purpose. The glass used should be heat-resisting and of a type that absorbs a minimum amount of infrared radiation.

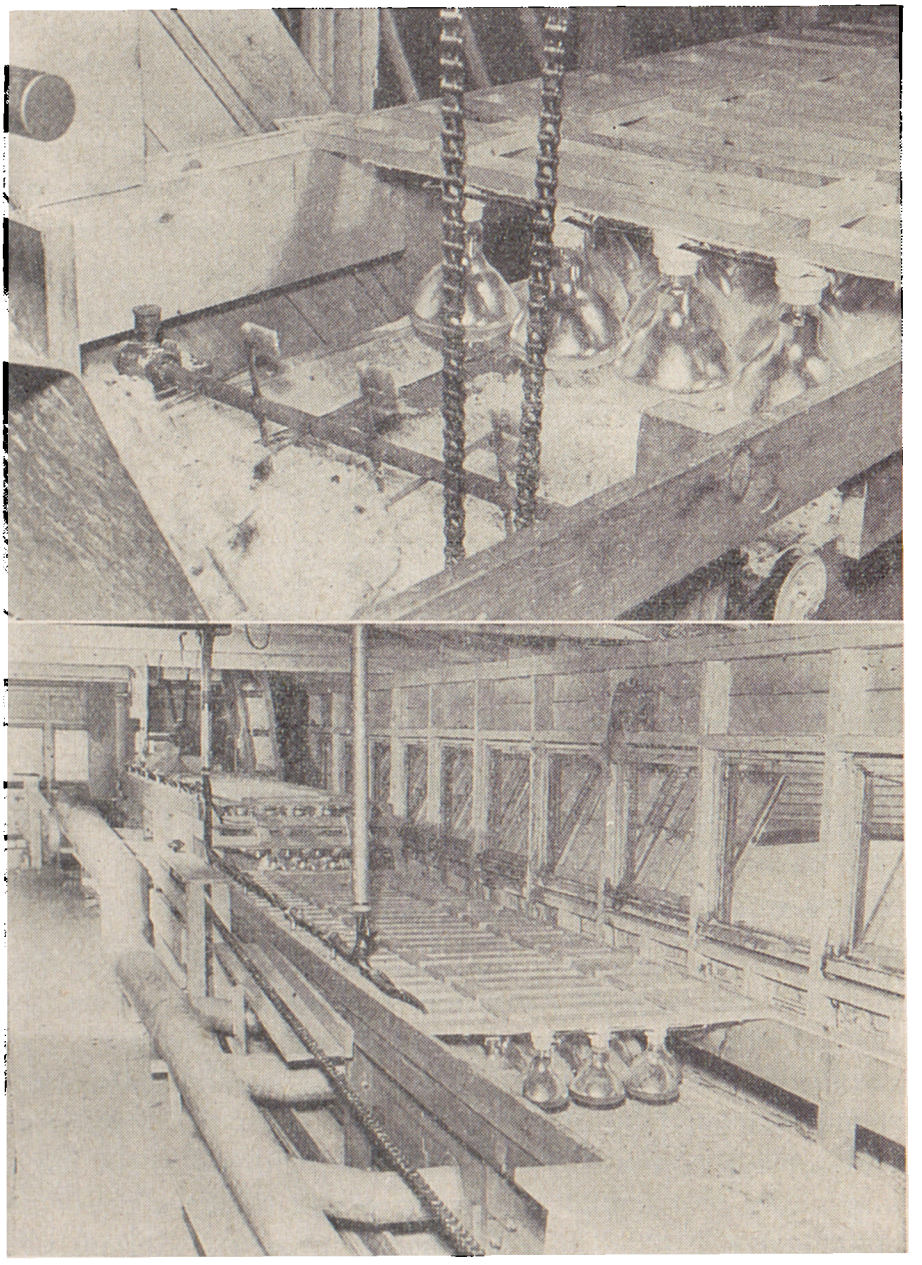


FIG. 6–7.—In this plant the problem was to remove moisture rapidly from grated fish and yet avoid the use of excessive temperatures which might tend to "cook" the fish. This problem was solved by the use of two lamp banks each consisting of one hundred ten 250-watt reflector infrared lamps arranged as shown. In the upper picture, the shredded fish is fed onto a steel mesh belt and spread out to a depth of ½ in. After passing under the first bank of lamps, the fish falls several inches onto the second conveyor as illustrated in the lower picture. This "cascading" serves to turn the grated fish over so that all surfaces are directly exposed to the heat from the lamps. An unusual feature of this installation consists of an air chamber located

Regardless of the type of glass, care should be used to arrange the infrared units so that the energy is projected through the window in as uniform a pattern as possible.

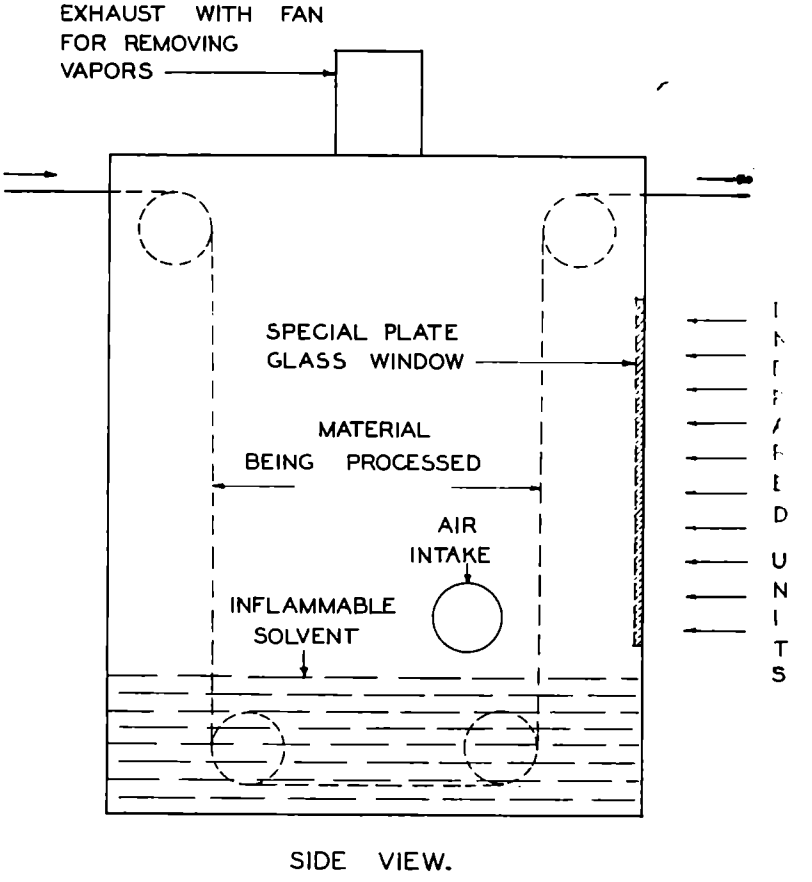


FIG. 6–8.—Suggested method of heat processing wherein it is desirable as a safety precaution to separate the infrared units from the vapors arising from the drying operation, due to the highly inflammable nature of the solvent used.

Heating of Loosely Woven Materials

In the application of radiant heat to single thicknesses of loosely woven materials or fabrics such as lace, mosquito netting, wire screening, etc., the operation may prove to be inefficient

below the mesh belt. Air at room temperature is supplied at low pressure to this chamber. The air is forced gently up through the layer of fish, thus removing the water vapor and keeping the temperature of the fish within safe limits. The capacity of the equipment is well in excess of the 500 lb of fish per hour for which it was designed. The results produced are of such uniformity that a minimum of supervision and checking is required.

because much of the radiant energy is not intercepted and hence passes through the material and is wasted. The efficiency of application can be improved greatly by providing a means for passing the material through the heat zone the number of times required to assure absorption of most of the projected radiant energy.

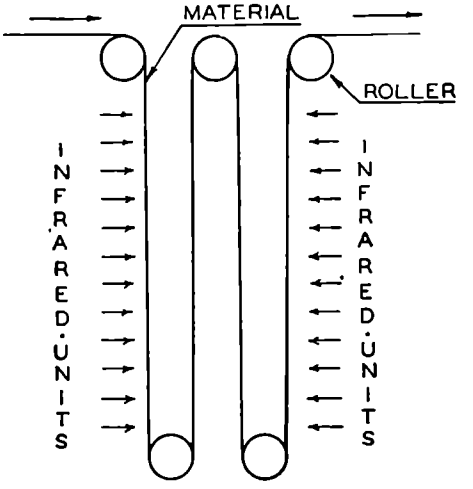


FIG. 6–9.—Suggested method for infrared drying of loosely woven fabrics. For most efficient use of the infrared radiation, the diameter of the rollers and their spacing in each row should be the minimum possible that is consistent with satisfactory equipment performance. Although the illustration shows four thicknesses of fabric passing through the heat zone, this number may be increased or decreased as desired—the more loosely woven the fabric the greater the number of passages required, and vice versa. Likewise, if preferable, the material may be passed through the oven horizontally.

Figure 6–9 shows a suggested method of heating loosely woven material by passing it over a series of rollers between two parallel banks of lamps so that any given section or surface of the material passes through the heat zone four times. As can be seen, the radiant energy that passes through the thickness of material adjacent to the infrared units will be intercepted by the succeeding thicknesses. The number of passages (four) shown in Fig. 6–9 was chosen arbitrarily to show the method only. Actually, in practice, the number of passages necessary to obstruct all of the projected energy depends upon the nature of the material being heated. Obviously, the more loosely woven the material, the greater the number of passages required, and vice versa.

CHAPTER VII

PAINTS AND OTHER SURFACE FINISHES

Although radiant heat has found use in numerous industrial heating and drying problems outside the surface-finish field, the latter offers by far the greatest possibility for this method of heat application.

If the general application of infrared has not yet developed into an exact science, how much more is this true of its use specifically for paint and surface-finish drying and baking. A broad general classification of surface finishes places them in one of four categories, namely, oil paints, lacquers, baking japans, and enamels. Each of these has its fundamental characteristics, while there are wide differences in the formulas for each depending upon the manufacturer and upon the specific requirements.

When these variables are added to those of the thickness, kind, and general characteristics of the material to which the finish is to be applied, it can be seen that it is impossible to develop specific rules covering radiant-heat requirements for this class of service.

Usually, the paint supplier is prepared to provide data on the details of application of infrared heat to his product or, if necessary, to develop new paint formulas to meet special requirements. Where the necessary information is not already in the possession of the user, it is wise to consult the paint manufacturer before embarking upon plans involving the use of radiant heat for any surface-finish drying or baking problem.

Although the paint manufacturer should be depended upon to supply specific details concerning a particular surface finish of his make, each of the aforementioned surface-finish classifications has certain general characteristics that become of interest and value when its use is considered. A recent issue of the *Power Sales Manual* contains a section devoted to this subject. This information is of such a clear, concise nature and is so readily under-

standable by the layman that, by permission of the Edison Electric Institute it is quoted in its entirety as follows:

PAINT CHARACTERISTICS

It is now quite generally recognized that any finish that can be baked at all can be baked with infrared radiation. It was formerly thought that there might be some special catalytic effect at work that would account for the frequently very remarkable accelerations in baking time that resulted from using lamps. However, a critical examination of the baking process will show that the reduction in baking time depends largely upon two factors: (1) a more rapid heating up of the work, (2) an increase in temperature of the work. In common with all chemical reactions, an increase in baking temperature results in a decrease in reaction or baking time, and, of course, the more rapidly that temperature is attained, the less total time is required for the process.

If one arranges a lamp oven and a conventional hot-air oven so that the heating curve of the work is the same, little, if any, difference will be noticed between the baking effectiveness of the two ovens. If one then increases the work temperature in the two ovens, the baking time will, of course, decrease. This process of increasing temperature and decreasing time can be continued until the finish being baked begins to discolor or lose gloss, at which point changes in the formulation of the finish must be made in order to effect further reductions in baking time. The finishes best suited to this speeding-up process are the "synthetics" *i.e.*, glycerol phthalate base materials, especially those that have been modified with urea formaldehyde resin. This modification yields a finish that will stand higher temperatures without discoloration or loss of gloss, that is more resistant to soap and alkali, that is harder and tougher, and that will cure or bake in about half the time of the unmodified material. At this point it is pertinent to inquire why, if all the above is true, there is any reason for using lamps. The answer is, primarily, that it is much easier and cheaper to arrange a lamp bank that will yield a high working temperature than it is to design and construct a convection oven to yield the same temperature on the work. In all discussions of baking, the temperature of the work, not of the oven, is the important factor.

Manner in Which Protective Coatings Dry

1. Evaporation.—Evaporation is a factor in paint drying as almost all paints, with the possible exceptions of house paints and artists'

colors, contain some solvent that must evaporate before the actual "drying" starts. In the case of lacquers, aniline inks, shellac, and similar solution coatings, the evaporation of the solvents is the only drying required.

2. Oxidation.—Oil paints, oleoresinous varnishes, enamels, and unmodified synthetics all dry primarily by oxidation; that is, oxygen from the air must be present to react with the unsaturated components of

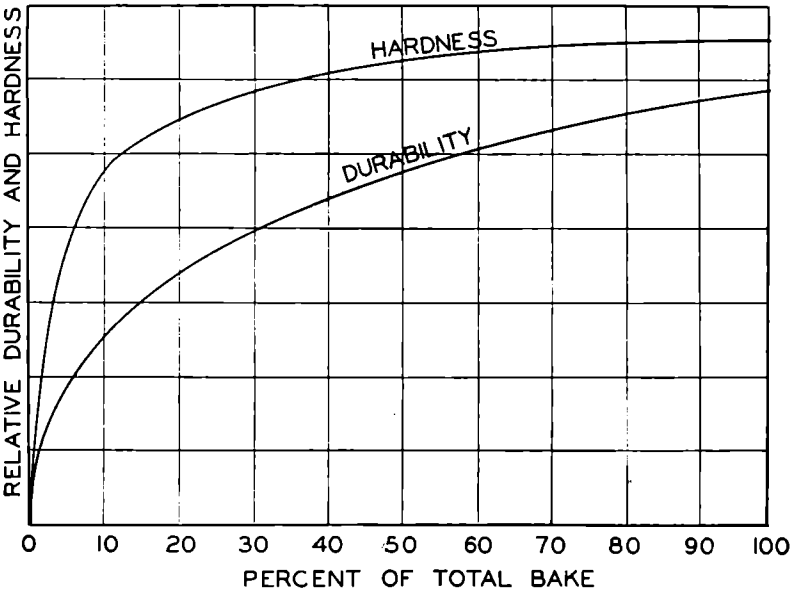


FIG. 7–1.—Relation of hardness and durability of color film to baking period.

the oils to convert them into the hard, tough material that forms the ultimate film. Most oxidation drying processes are accompanied by polymerized reactions, that is, the union of small units into larger ones.

3. Polymerization.—This process, which accompanies most oxidation drying processes, becomes more significant when we pass from air drying to baking, as polymerization is accelerated by heat to a greater extent than is oxidation. In the case of urea formaldehyde–modified synthetics it is the dominant and sometimes the sole means of converting the soft resin into a tough, hard film. It is this type of resin that is best suited for lamp baking or high-temperature baking in general.

The graph in Fig. 7–1 illustrates the manner in which the hardness (Sward rocker) of a urea formaldehyde–modified film builds up with baking time. As will be noted, the hardness builds up quite rapidly in the early part of the baking cycle and then flattens off. This affords the clue as to why this type of finish is ideally suited to speedy baking

processes—heavier parts or parts that for any reason do not get up to heat as rapidly as the main part of the piece will usually still get enough heat to yield a sufficiently hard surface to pass inspection. Unfortunately, as the curve shows, the durability does not build up quite as rapidly as the hardness in the early stages, and hence the baking time and temperatures are more critical when durability must be con-

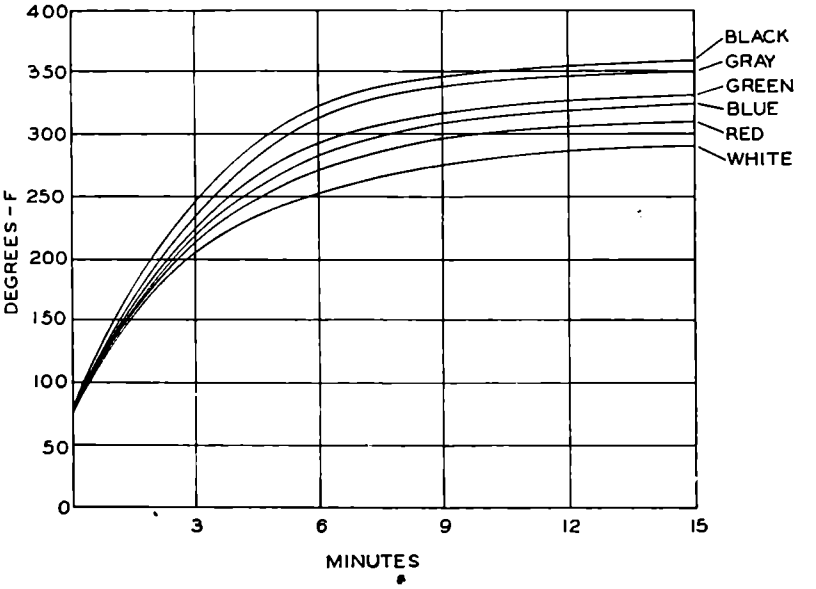


FIG. 7-2.—Temperature-time curves for typical paint colors.

sidered. The use to which the finished object is put determines which characteristic must be emphasized and, hence, the baking conditions required.

Effect of Color upon Infrared Baking

Since the temperature attained by the work is the most significant factor in determining the baking time in any baking operation, it is necessary at this point to inquire into those qualities of the paint that influence the temperature of the work. Of these qualities, by far the most significant is the color (more accurately, the infrared absorption). Figure 7-2 shows quite clearly the differences in the temperatures attained when the color is varied, other factors being held constant. These data were obtained using a flat lamp bank and flat panels, and these represent the extreme case. In a modern infrared oven the differences are less, and therefore not much change in formulation is required to produce different-colored enamels having the same baking time. However, the extreme cases, black and white, still represent too

great a spread to be handled by formulation alone, and usually a difference in baking time is required to give films of equal hardness.

Some of the less significant qualities affecting temperature of the work are:

1. The nature of the solvents. Very volatile solvents such as toluol, ethyl acetate, etc., leave the film quite rapidly with a few minutes' air drying so that little heat is wasted in evaporating them. On the other hand, very slow solvents like kerosene will require some heat for evaporation and will consequently lower the temperature of the work somewhat.

2. Amount of paint applied. This has an insignificant effect, as usually the mass of the paint is a quite small percentage of the total mass. It could, however, be of significance in such processes as paper or foil coating.

Color Coating Materials

Oil Paints.—Oil paints (house and barn paints, etc.) consist of the necessary pigments and an oil vehicle with minor amounts of thinners and driers. Because of the oil vehicle they dry largely by oxidation, and while they do dry more rapidly at elevated temperatures they cannot be baked by any method within the usual meaning of the term.

In this same class come porch and deck paints and interior enamels, which, although they contain varnish vehicles and are hence properly called "enamels," are still fundamentally air-drying or oxidation-curing materials and are not fundamentally suited to baking of any sort. In fact, practically all of the materials sold in retail paint stores are not suited for baking, which is essentially an industrial process.

Baking Japans.—These are produced by cooking together drying oils and various asphaltic materials, usually the harder fossilized varieties, with driers. Occasionally, some carbon black is added for greater opacity. Very high temperatures (around 450 to 500°F) are required to bake these materials, and while they can actually be baked with drying lamps, the time required (½ hr at 450°F, for example) makes the method impractical. Because they are low-cost materials, modifications designed to decrease the baking time or temperature are not economically feasible. Raising the temperature above the normal baking range of these materials results in blistering or actual burning of the film.

Lacquer. (1) *General.*—Lacquers in general are solutions of some film-forming ingredient, usually nitrocellulose (occasionally, ethyl cellulose, cellulose acetate, or chlorinated rubber), with a resin to furnish greater

fullness and gloss, a plasticizer to impart flexibility, and the necessary solvents and diluents. The application of heat in any form naturally accelerates the drying time, but the temperature permissible is usually limited to about 150°F or less because of the danger of blistering the film by too rapid evaporation of the very volatile solvents used. In addition, some plasticizers tend to "sweat out" and come to the surface of the film when heat is applied, resulting in the apparent paradox of a poor dry at higher temperature. Temperatures of 250°F or higher are, of course, not permissible because of the danger of decomposing the nitrocellulose.[1]

2. *Synthetic Lacquer.*—Synthetic lacquer may be considered in two ways: first, as similar to regular lacquer in which the usual resin has been replaced with a synthetic resin, usually an alkyd of the oxidizing or semioxidizing types; or, second, as synthetic enamels in which the film hardness and drying rate have been increased by the incorporation of nitrocellulose or a similar material. They are normally air-drying materials, the nitrocellulose portion drying by evaporation to yield a film free from dust-collecting tendencies and hard enough to handle in a short time, the ultimate film strength and hardness being attained by the oxidation of the synthetic resin. Usually, heat will accelerate both of these processes, although it frequently happens that improper application of the heat causes the still soft resin to come to the top of the film so that the surface is actually a resin and hence will not dry until oxidized, thus losing, as far as the surface dry is concerned, any advantage of the nitrocellulose. The film might just as well have been a synthetic enamel in the first place. This condition sometimes can be remedied by allowing the film to "set" before applying the heat.

Enamels.—Enamels can be divided into three classes:

1. Oleoresinous
2. Synthetic
3. Modified synthetic

In all three of these the pigmentation is similar and has no effect upon the baking process except as discussed above under color. The distinguishing part is the vehicle.

1. *Oleoresinous Enamels.*—In these the vehicles consist of varnishes prepared from drying oils and various natural resins and synthetic resins of the phenol-formaldehyde or Bakelite type with various thinners and driers. They dry both by oxidation and by polymerization. They are made in many varieties for both air drying and baking, and

[1] Author's note: Other sources state that certain types of lacquer have been baked successfully at temperatures as high as 300°F.

many of them can be baked quite rapidly with lamps. Too much heat is likely to cause discoloration of these vehicles, especially in white and the lighter colors; some of the darker colors can be baked at temperatures as high as 350°F without serious discoloration and therefore can be baked rather quickly (10 to 15 min) with lamps.

2. *Synthetic Enamels.*—The term "synthetic" as used in the protective-coating industry is usually restricted to material based upon the alkyd or glycerol phthalate type of resins. Alkyd resins are prepared from glycerin, phthalic anhydride, and fatty acids derived from a great variety of oils, both drying and nondrying. They dry both by oxidation and by polymerization and are used in both air-drying and baking enamels. The "longer oil" materials (that is, those containing 50 per cent or more of oil) are usually used in air-drying materials; the "shorter oil" varieties go into both air-drying and baking enamels.

The advantages of synthetic enamels and of oleoresinous enamels are better color and color retention, faster drying and baking, better adhesion and flexibility, greater resistance to discoloration from heat, (thus permitting higher baking temperatures and shorter schedules), and better outdoor durability.

Synthetics can be successfully baked with lamps, provided too short schedules are not required and the shorter oil materials are used. However, since unmodified synthetics require considerable oxidation to effect a cure, they do not respond to infrared as readily as the modified synthetics to be discussed next.

3. *Modified Synthetics.*—These materials are similar to the ones just discussed except that they are modified by the addition of varying amounts of heat-hardening resins such as urea formaldehyde. Such modifications result in faster baking, better heat and alkali resistance, better color and color retention. The use of urea formaldehyde also makes it possible to replace the drying oil alkyds with nondrying types, eliminating oxidation as a factor in curing the finish; in this case the alkali serves entirely as a plasticizer or softener for the urea-formaldehyde resin, which by itself is hard and brittle. Elimination of oxidation results in still greater improvements in color and color retention.

Urea formaldehyde–modified synthetics are unquestionably the best materials for use in infrared baking for several reasons:

First, they are essentially heat-hardening or polymerizing materials and hence do not require long periods of baking to effect oxidation. Some of them merely require heating to 350 or 450°F, holding momentarily, and cooling off again to effect a complete cure.

Second, once baked or cured, the films are relatively unaffected by further exposure to heat: that is, they have considerable latitude between the maximum and the minimum bake. This enables irregular-shaped articles or parts made of both light and heavy sections to be baked uniformly without overcuring the lighter parts or the parts close to the heat source.

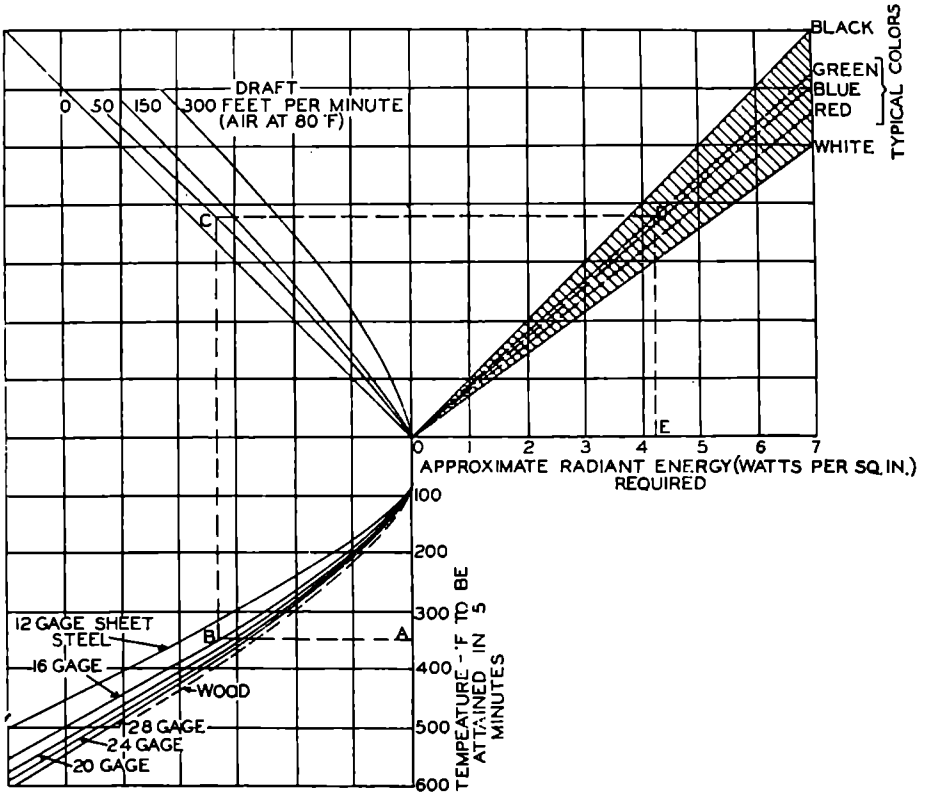


FIG. 7–3.—Determination of approximate radiant energy required for paint baking. Starting with a given temperature (for example, 350°F, at *A*) proceed clockwise to gauge of metal (or wood) (for example, 16-gauge sheet steel at *B*); then to draft at the work (for example, 50 ft per min at *C*); then to color (for example, green at *D*); then to final answer (in this case 4.2 watts per sq in. at *E*). (*Courtesy of Howard Haynes, I.E.S. Transactions, vol.* 36, *p.* 61.)

For data on spacing of units to produce watts per square inch determined by use of Fig. 7–3, refer to Fig. 5–8 wherein the information shown is based on use of a single bank of lamps. If double, facing banks of lamps are used, obviously the energy concentration (watts per square inch) is double that shown. For example, 250-watt lamp units having a 65 per cent efficiency

(such as the R-40 bulb infrared lamp) spaced on 9-in. centers would deliver approximately 2 watts per sq in. to the surface being heated. Two similar banks would deliver some 4 watts per sq in.

General experience indicates that some 10 to 12 in. distance between the painted surface and the infrared units is conducive to most satisfactory results. Owing to the greater absorption of dark as compared with light-colored surfaces (Fig. 7–2), it may be found that higher temperatures may be obtained by applying the radiant energy to the reverse, unpainted side of a panel of dark-colored metal painted with a finish of a light color.

Drying of Finishes Applied to Wood

The foregoing data and information relate primarily to the drying of finishes applied to metal objects and surfaces. Infrared heat may be used satisfactorily in drying finishes on wood, but such usage requires certain precautions that generally are not necessary where metal is involved.

When paint is applied to wood, the solvent is partially absorbed by the wood. In the drying operation care must be used to prevent the solvent from being driven out of the wood so rapidly as to cause blisters in the finish. This being true, the concentration of heat must be such that the temperature of the finish does not exceed approximately 150° F. The finish should be brought up to this temperature very slowly—on the order of 2½ to 3 min.

For producing the required temperature, radiant heat should be applied at an intensity equivalent to approximately that obtained from 250-watt R-40 bulb lamps located on or about 15-in. centers and at a distance of some 15 in. from the painted surface. With this arrangement of lamps, lacquer requires about 2 min to dry. Varnish or varnish enamel should be especially designed and carefully selected for the purpose. Preferably a reputable paint manufacturer should be consulted for information on the most suitable material. Varnish or varnish enamel requires some 20 min to dry. It is interesting to note that the same finish when applied to metal can be radiated at a much higher intensity and thus dried in approximately 5 min.

Tables of Metal Panel Temperatures

These tables, prepared by the Fostoria Company, are useful in preliminary consideration of the approximate arrangement and number of 250-watt lamps required for producing various temperatures in steel panels of different gauges. The lighter gauges heat more rapidly but do not maintain so stable a temperature as the heavier gauges. This latter may be partially attributed to the greater cooling effects of reradiation and stray drafts on the lighter material.

250-watt lamps on 7-in. centers. Located 10 in. from and on both sides of panel.

Time, minutes	12G	14G	16G	18G	20G	22G	24G	26G	28G
0.0	72	74	75	78	78	80	80	80	78
0.5	82	85	85	90	100	100	100	90	100
1.0	100	101	115	112	121	130	132	122	130
1.5	118	138	153	169	183	183	208	180	173
2.0	145	165	188	190	220	236	250	240	222
2.5	172	210	235	236	271	300	320	310	268
3.0	200	243	260	268	310	330	355	329	300
3.5	220	272	285	300	337	355	380	355	350
4.0	240	285	320	318	361	360	385	372	388
4.5	252	308	335	349	390	388	410	412	420
5.0	270	315	345	350	391	380	400	401	410
5.5	271	325	357	355	398	370	390	390	389
6.0	298	332	370	362	401	372	395	408	400
6.5	304	350	388	380	420	378	410	404	408
7.0	312	359	390	380	422	374	408	401	380
7.5	320	368	393	430	430	368	410	390	375
8.0	328	378	380	409	432	381	412	370	399
8.5	321	380	390	401	422	381	418	365	378
9.0	330	374	381	390	420	368	398	350	368
9.5	318	360	370	380	415	340	371	330	350
10.0	315	341	342	361	393	325	347	325	329

250-watt lamps on 7-in. centers. Located 10 in. from and on one side of panel.

Time, minutes	12G	14G	16G	18G	20G	22G	24G	26G	28G
0.0	80	82	85	82	85	85	87	87	88
0.5	82	90	90	90	90	98	98	98	99
1.0	90	98	102	100	104	113	111	112	116
1.5	100	112	120	117	130	140	135	140	147
2.0	121	132	150	131	165	173	180	177	190
2.5	140	160	190	160	206	235	245	250	250
3.0	150	171	201	170	220	248	255	256	258
3.5	157	178	212	187	230	251	254	260	258
4.0	175	198	234	195	252	270	270	273	279
4.5	190	216	260	218	272	300	303	302	305
5.0	190	230	260	215	271	291	292	295	280
5.5	192	219	255	215	268	280	280	278	270
6.0	198	227	261	231	272	282	281	282	271
6.5	220	240	284	240	299	310	306	300	310
7.0	218	242	284	230	296	297	297	290	291
7.5	219	240	280	230	292	289	285	285	280
8.0	221	245	288	235	300	300	300	300	297
8.5	237	262	305	240	320	318	320	320	322
9.0	240	258	293	230	305	295	298	297	300
9.5	229	250	280	225	290	275	275	275	272
10.0	228	238	267	217	272	255	250	252	243

TABLES OF METAL PANEL TEMPERATURES.—(*Continued*)

250-watt lamps on 10-in. centers. Located 6 in. from and on both sides of panel.

Time, minutes	12G	14G	16G	18G	20G	22G	24G	26G	28G
0.0	86	72	75	75	75	78	79	80	80
0.5	100	85	98	93	93	93	100	103	105
1.0	120	113	122	125	130	150	150	156	157
1.5	145	150	179	180	188	220	225	240	242
2.0	172	180	225	220	248	280	280	292	302
2.5	199	210	274	265	290	238	342	340	355
3.0	220	250	312	305	320	371	382	383	395
3.5	240	271	343	330	355	406	415	410	422
4.0	262	300	375	350	384	428	433	428	440
4.5	272	310	397	360	409	440	444	458	450
5.0	295	332	415	382	420	450	452	463	455
5.5	299	343	429	430	435	452	457	468	460
6.0	318	270	436	444	450	460	457	470	460
6.5	320	380	443	438	448	462	460	468	461
7.0	330	370	448	450	462	459	468	468	460
7.5	338	365	450	450	462	460	462	461	460
8.0	340	390	450	464	455	455	453	456	451
8.5	340	391	448	431	440	445	445	445	430
9.0	345	391	445	428	440	440	431	432	413
9.5	345	386	432	409	420	415	412	420	390
10.0	330	371	410	422	418	380	378	383	363

250-watt lamps on 10-in. centers. Located 6 in. from and on one side of panel.

Time, minutes	12G	14G	16G	18G	20G	22G	24G	26G	28G
0.0	80	80	80	80	80	80	80	80	80
0.5	85	83	90	88	88	91	100	94	93
1.0	98	100	105	102	110	120	120	125	121
1.5	110	116	130	130	138	155	155	164	165
2.0	124	140	155	155	170	192	197	205	205
2.5	142	162	183	188	200	231	233	245	241
3.0	158	180	209	216	230	256	258	270	264
3.5	172	200	225	235	250	272	275	284	279
4.0	187	220	247	250	270	291	290	300	290
4.5	200	237	267	272	278	305	304	312	304
5.0	210	248	274	281	295	310	308	315	310
5.5	221	260	281	290	300	310	308	311	310
6.0	226	265	292	292	311	318	313	318	312
6.5	237	275	300	302	320	322	320	324	318
7.0	248	280	302	315	323	322	320	324	314
7.5	252	284	309	318	328	322	318	324	310
8.0	260	290	312	321	328	322	316	322	309
8.5	263	292	312	323	328	322	316	320	308
9.0	270	291	310	320	320	315	309	311	294
9.5	267	286	302	315	315	298	295	295	280
10.0	271	280	291	300	298	278	273	270	260

COMPARISON OF CONVECTION AND RADIATION DRYING SCHEDULES OF COMMONLY USED FINISHES FOR MILITARY PURPOSES[1]

Specification no.	Coating	Main component	Uses	Drying schedule	
				Convection	Radiation
P X S 783	Zinc chromate primer	Glyceryl phthalate	Ammunition orrosion inhibitor Corrosion inhibiting priming coat on metal structural parts	1½ hr at 160°F	30-90 sec
AN-TT-P-656-A	Zinc chromate metal primer	Glyceryl phthalate		10 min at 160°F	30 sec
	Zinc chromate primer	Glyceryl phthalate	Corrosion inhibitor for use on aluminum alloys or steel	1½ hr at 160°F	20-90 sec
QMC-ES 680	Rust inhibiting primer	Glyceryl phthalate	Army vehicles, artillery components, tanks and miscellaneous items	30 min at 200°F	4½ min
HQD-ES 680	Rust inhibiting primer	Glyceryl phthalate	Army vehicles, ordnance, artillery components, miscellaneous items	1 hr at 180°F	4½ min
Army 3-162B	Lacquer for ammunition	Nitrocellulose	Protection and identification of ammunition	15 min at 180°F	30-40 sec
Army 3-106E	Acid-proof black	Bituminous base	Inside coating on shells, bombs and land mines	30 min at 180°F	4½ min
Army Air Corp. 14105-C	Camouflage lacquer	Nitrocellulose	Camouflage over primer	10 min at 180°F	30-40 sec
AN-E-31	Aircraft enamel	Glyceryl phthalate	Exterior coatings for metal and fabric; also aircraft parts	15 min at 300°F	8 min
AN-TT-E 501	Black enamel	Glyceryl phthalate	Aircraft engine castings and instruments	15 min at 300°F	8 min
QMC-ES 680	Lustreless olive drab	Glyceryl phthalate	Army vehicles, tanks, pontoons and artillery components	1 hr at 250°F	4½ min
HQD-ES 680	Lustreless olive drab	Glyceryl phthalate	Automotive products	1 hr at 250°F	4½ min
ES 680-A	Stenciling enamels	Glyceryl phthalate	Lettering on exposed surfaces	30 min at 200°F	3 min
T 1103-D	Olive drab primer	Glyceryl phthalate	Portable landing mats	1 hr at 300°F	5½ min

Note: Drying Accomplished on Standard 20-Gauge Steel Panel.

[1] Courtesy of the C. M. Hall Lamp Company.

CHAPTER VIII

INDUSTRIAL APPLICATIONS

Drying Surface Finishes

Although infrared radiation was used prior to the Second World War, it took the increased tempo of wartime to bring it the wide recognition it now enjoys. The baking and drying of surface finishes where radiant heat received its industrial baptism is still its most prolific field. Without this modern source of heat, wartime production of tanks, guns, airplanes, and a thousand other devices requiring surface finishes would have been difficult, if not impossible. Certainly, with the drying methods formerly used, today's production rates would require almost immeasurable increases in oven-equipment costs and in floor space to house it.

With the coming of peacetime, it requires no seer to foresee the future of radiant heat in the greatly expanded automotive industry, the manufacture of commercial airplanes, and the production of widely needed household appliances and numberless other products requiring surface finishes.

Accelerated experience gained during the Second World War will be of inestimable value in this field, which, as before the war, no doubt will continue to offer the widest opportunities for the use of infrared with its almost miraculous drying speeds.

Textile Drying and Finishing

Following the drying of paints and other surface finishes, the textile industry perhaps is next in offering opportunities for the use of infrared as a drying agent. Bleaching, dyeing, sizing, sanforizing, carbonizing, etc., consume tremendous amounts of steam and gas for heat. Scarcely a single textile manufacturer will admit complete satisfaction with the conventional methods of drying. This fact should presage a bright future for infrared in the textile field.

Already radiant heat is being applied to a variety of textile operations. Postwar needs for increased production on one hand

and inability to obtain conventional heating equipment on the other hand have led to widespread use of infrared as a supplemental means of increasing the speed of existing equipment. In some cases, this new equipment has been installed without interfering with the production of existing equipment and at the expense of little or no additional floor space.

The flexibility of radiant-heat application makes it particularly suitable for use in those textile operations involving the use of synthetic resins where several different temperature ranges are required. The high rate of energy transfer possible with infrared heat makes it especially adaptable to woolen-cloth carbonizing. Cost of radiant-heat equipment for this application is only a fraction of that of conventional carbonizers, while the savings in floor space occupied are very much worth while. Further, it is claimed that the newer method results in a product of superior quality.

The Textile Division of the American Society of Mechanical Engineers is now engaged in a comprehensive survey and investigation of the use of radiant heat in the textile industry. There is available evidence to the effect that results obtained from a number of trial textile infrared installations have been disappointing because of the fact that they were inadequately and improperly engineered. It is expected that the findings of the Division will serve as a guide for the correct application of radiant heat to textile processing and thereby will greatly increase the possibilities of its use for this purpose.

Processing of Ceramics

Radiant heat lends itself readily to many of the problems of the porcelain or ceramics industry. Porcelain insulators are now dried more rapidly by infrared lamps, which have replaced hot-air blowers. Portable banks of lamps are being used to speed the drying of freshly molded porcelain bathtubs prior to their being placed in high-temperature kilns for glazing. This eliminates the need for moving the tubs, while still wet, to drying ovens with resultant reduction in spoilage due to distortion. The greater speed of drying has reduced the required floor space to about one-half of that formerly necessary.

The effectiveness of infrared for the drying of china flatware has revolutionized pottery-manufacturing methods. In a typical installation the former drying time of 90 to 150 min has been reduced to 12 to 15 min, and the number of molds for a given item from 150–200 doz to 25–30 doz. It has been found that pieces with embedded and concealed foreign particles, such as wood, plaster, or dirt, or air blebs will crack in an infrared dryer, thus reducing the number of defective pieces from the bisque fire. Infrared is replacing air in the drying of lacquer finishes on pottery with a great reduction in handling and resultant breakage. Here, too, the floor-space savings are great.

It would appear that the possibilities for the use of infrared in this field are almost without limit.

Manufacture of Paper

The manufacture and processing of paper in its almost endless types and varieties consume power in the form of heat in quantities second not even to the textile industry. Owing to general similarity of the drying and heating problems of the two industries, it is expected that knowledge gained in the investigation of infrared application to the textile industry will be of value in determining the suitability of radiant heat for use in the many different types of processes in the making of paper and paper products wherein heat is used.

So far, infrared has been used in the paper industry principally as a supplementary means of water evaporation and for the drying of paper coatings, glue, etc.

Metalworking

Drying of metal forms, parts, and sheets following degreasing and plating operations is now being accomplished with greater speed and at less cost with infrared-lamp equipment. Radiant heat has been found economical and most useful in preheating of metals prior to high-temperature welding operations. Likewise, the cleanliness, speed, and exactness of control possible with infrared equipment make it best suited for metal-expansion problems such as shrink fitting of gears, insertion of pins in pistons, etc. Infrared also offers possibilities in the rapid heating of sheet metal

prior to punch-press operations for the purpose of reducing wear on dies and tools.

Skin Drying of Foundry Molds

The speed and portability of radiant-heat equipment have modernized foundry practice by replacing antiquated methods used in the skin drying of sand molds. Banks of lamps have replaced kerosene torches and charcoal burners to reduce labor costs greatly and to produce cleaner molds of superior quality. Damage to green molds due to handling is practically eliminated because, the equipment being portable, infrared heat is applied to the molds before they are moved. Likewise, infrared is being employed in the curing of binders used in core-making.

The success of this new drying method ensures the future widespread use of infrared equipment throughout the foundry industry.

Manufacture of Plastics

The rapid growth of the plastics industry during wartime portends the future use of plastics to replace metal and glass in a thousand and one different postwar uses. Infrared equipment is being used not only in the manufacture of plastics but also in their fabrication into finished products.

Plastics powders are being dried, while molding preforms are baked with radiant heat. In fabrication, plastic sheets are softened to facilitate cutting or stamping or to provide the flexibility needed for forming. Colored surface finishes for plastics require drying. The many advantages of radiant heat have made it the choice for these operations.

The foregoing discussion covers only a few of the more important fields where radiant heat is finding use. To them might be added almost any industry or manufacturing process where heat is required.

Specific Installation Information

As has been pointed out previously, the fact that the application of infrared heat is not an exact science often makes it necessary to conduct trial tests to determine the final requirements for a given problem. Knowledge of the results accomplished by others is

helpful not only in determining at the outset the feasibility of infrared heat for a proposed application but also in arriving at the final details on the type and arrangement of the equipment.

In collecting data on going radiant-heat installations effort was made to obtain information on as many varied applications as possible. If the accent appears to be on the smaller installations where only a relatively few heating units are used, it is because of the fact that such installations far outnumber the larger ones and hence generally are of interest to the greater number of prospective users. Obviously, the larger installations, in many cases, consist essentially of expansion of the smaller, less formidable applications.

It should not be concluded that the types and arrangement of equipment used for any particular described application are necessarily the best for the purpose in question. In many cases as good or better results may be had from the use of other equipment or of the same type of equipment differently arranged. Price and efficiency of the equipment, conditions of processing, and personal choice are factors that influence the final decision. In reaching this decision care should be taken not to give undue weight to first cost of equipment. In the larger installations the cost of power may be considerable; hence, most efficient use of the power is essential.

There is no intent to imply that inexpensive equipment is necessarily inefficient or, on the other hand, that the most expensive equipment is necessarily the most efficient. It is hoped that the thought conveyed is that care should be given to selection and purchase of equipment. Just as efficiency of conversion of power into light is a major factor for consideration in the purchase of lamps and lighting equipment, so should the efficiency of conversion of power into usable heat be of prime importance in the purchase of infrared equipment.

A variety of radiant-heat installations is illustrated and described for the purpose of suggesting possible uses and of assisting in the selection and arrangement of suitable equipment. The uses are almost endless while available equipment may be arranged and installed to suit the requirements of the service or the fancy of the user.

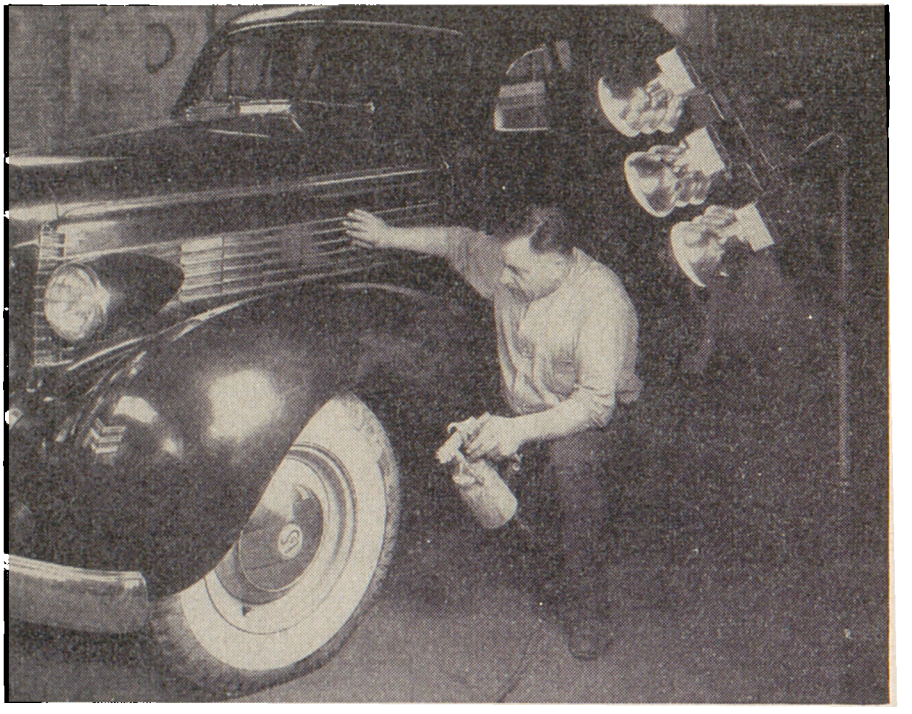


FIG. 8–1.—A portable radiant-heat drying rack of 250-watt infrared lamps is used in a shop where body repairs are given three prime coats and three finish coats of paint. Under the previous air-drying method, drying time per coat was as much as 1½ hr. With radiant heat, each operation is completed in 20 min.

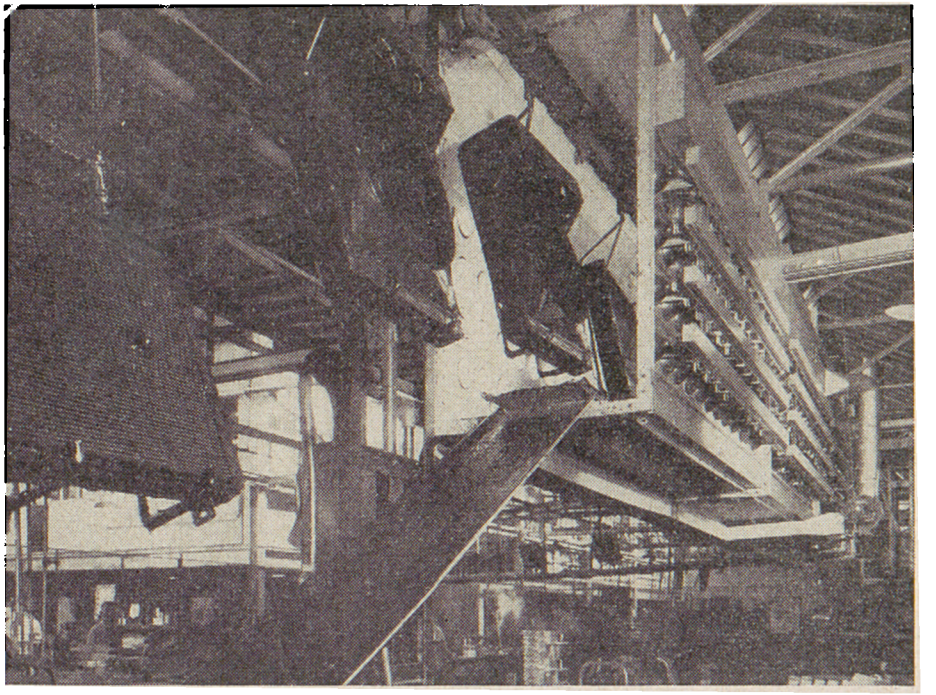


FIG. 8–2.—Black paint on automobile radiators being cured in infrared oven which replaced steam oven with result that curing time was cut in half (6 to 3 min).

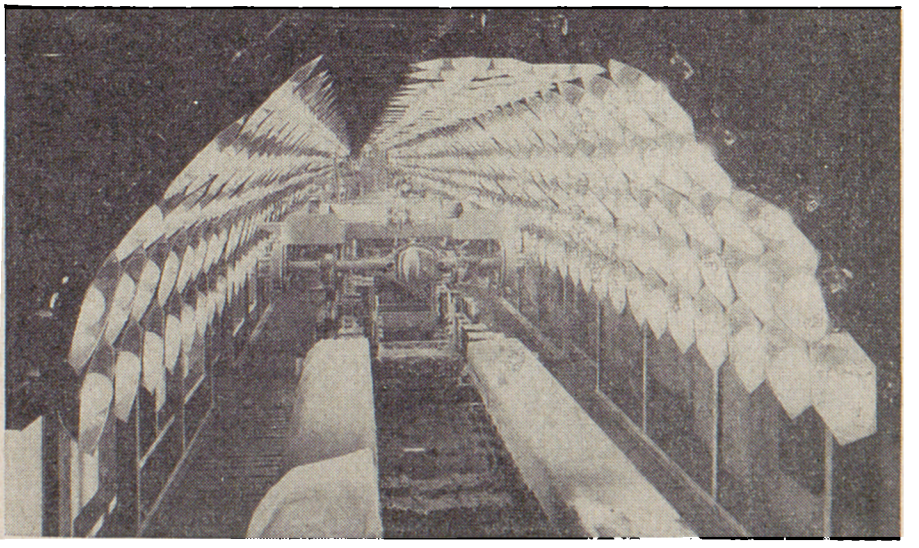


FIG. 8–3.—Moving at a speed of 8 ft per min, jeep trailer parts (fenders, springs, safety chains, axle, leg, and bracket) are dried in 4 min for each the red-oxide primer and the olive-drab finish. For each coat, a tunnel 32 ft long using five hundred four 250-watt lamps is required.

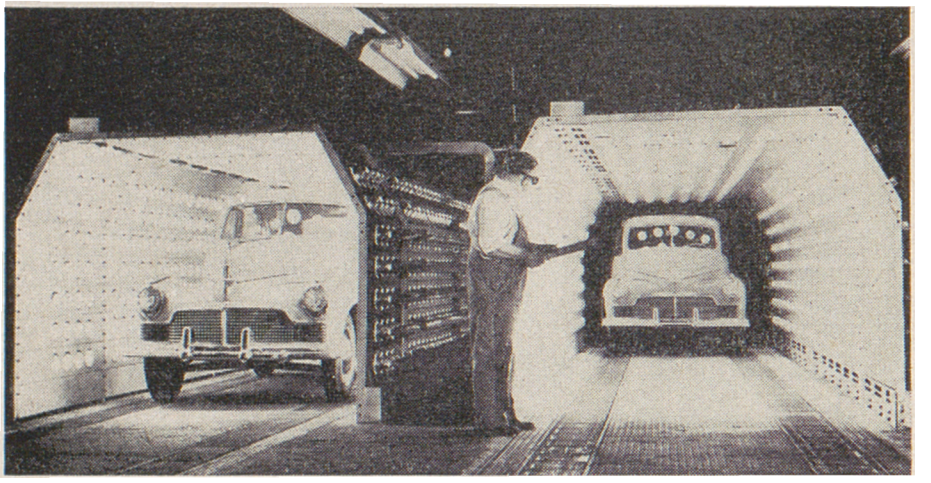


FIG. 8–4.—Thirty-two-foot infrared oven employing eight hundred 250-watt reflector lamps used for touch-up drying of prime coat on automobile bodies in approximately 3 min.

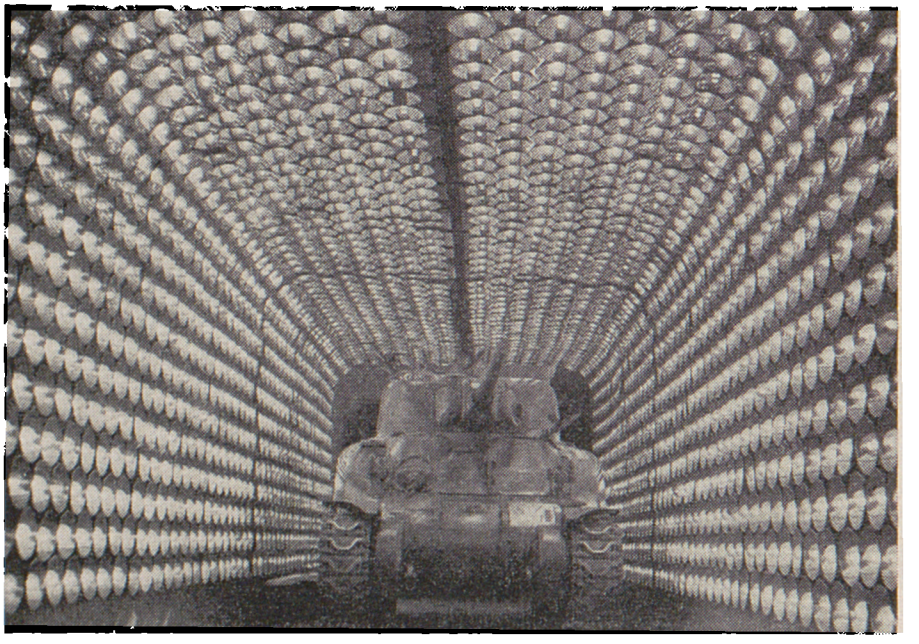


FIG. 8–5.—Freshly painted U. S. Army tank being dried in 4 min in a tunnel consisting of some two thousand 250-watt infrared lamps. This time compares with 24 hr required for air drying. It is interesting to note that the tank driver remains at his seat within the tank throughout the drying process. (*Official photograph U. S. Army Ordnance Department.*)

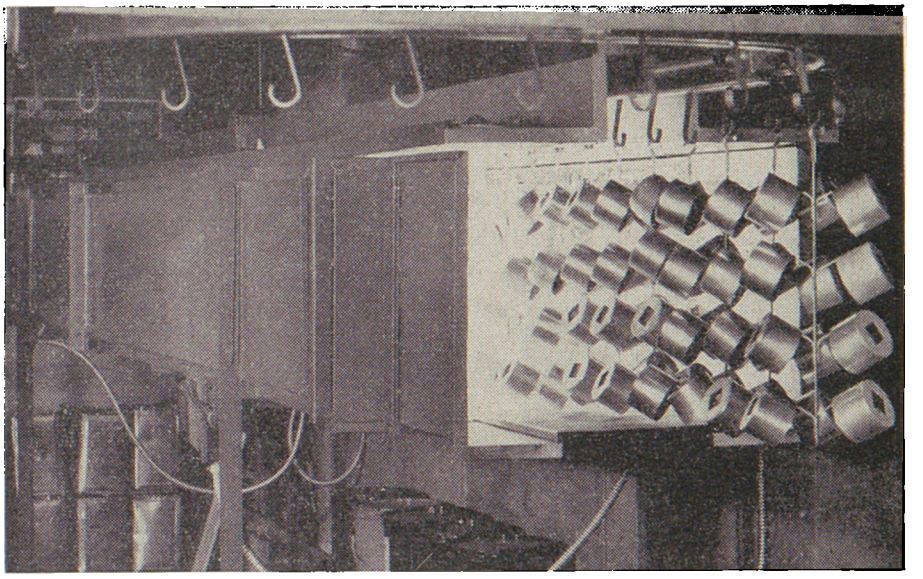


FIG. 8–6.—Formerly with a convection oven it required over 30 min to flash and bake the finish on these aircraft instrument parts. Now, with this infrared oven, the same results are accomplished in 12 min. Seventy-two 250-watt reflector-type lamps are used. Volatiles are removed by a blower system located in the top of the oven.

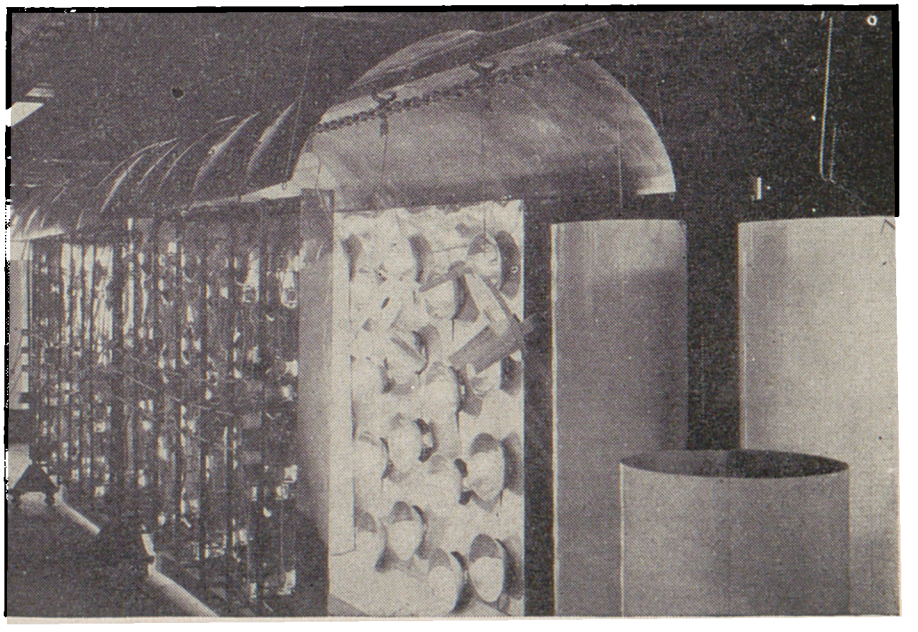


FIG. 8–7.—This installation of one hundred twelve 250-watt lamps and gold-plated reflectors is used for baking synthetic finishes on hot-water-heater bodies. Change to radiant heat increased production 33 per cent. Spoilage was reduced from 15 per cent to zero. Baking time is 15 min.

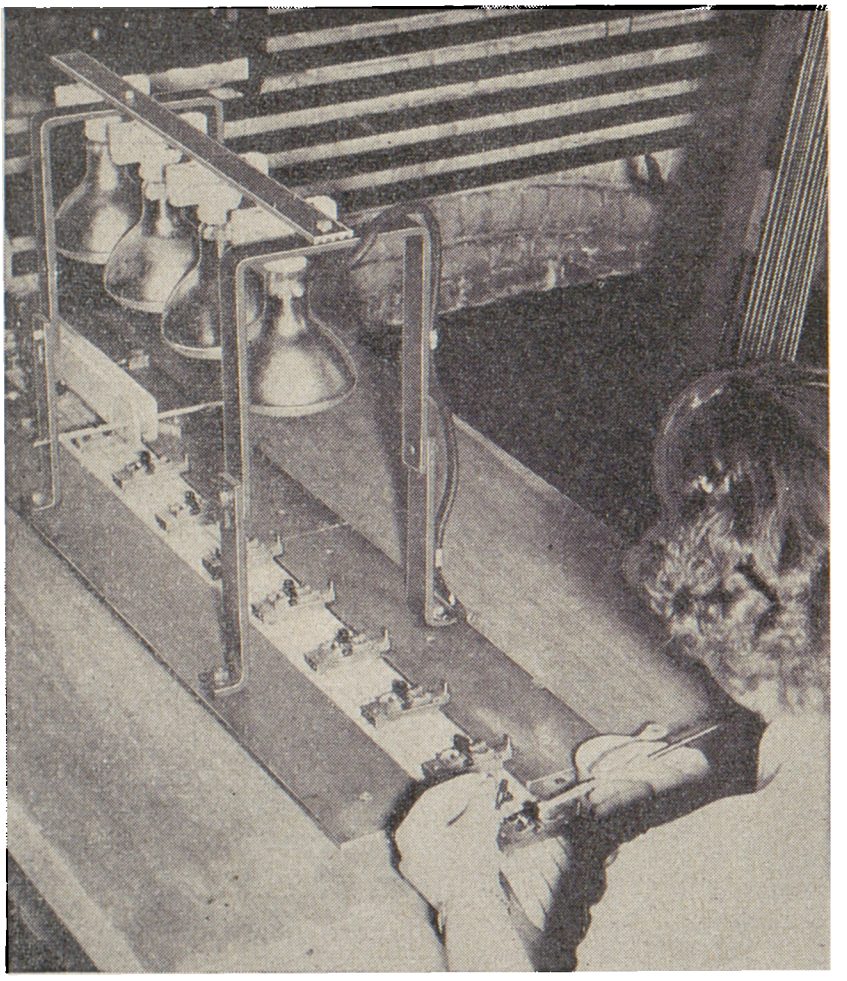


FIG. 8–8.—A conveyor-line dryer in the plant of an electrical-device manufacturer designed for drying the enamel filling applied to "On" and "Off" lettering on wall-switch handles. The enamel is applied by the operator and is dried as it passes four 250-watt reflector-type lamps.

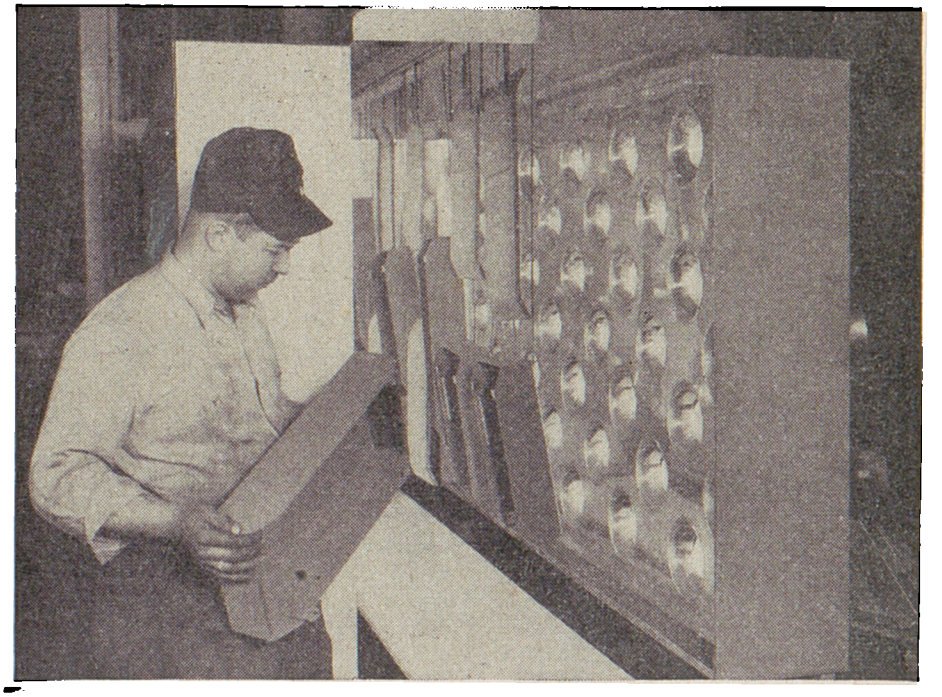


FIG. 8–9.—Seventy-six 250-watt lamps, 38 on each side, are used in this infrared oven for baking plain and wrinkle finishes on switch boxes. The oven is 8 ft 10 in. long, 6 ft 3 in. tall, and adjustable in width to provide spacing from 8 to 23 in. between the lamps and the work suspended on the reversible overhead conveyor. The outer shell of the oven is of 16-gauge sheet steel mounted on an angle-iron frame while the lining is 14-gauge polished aluminum sheet.

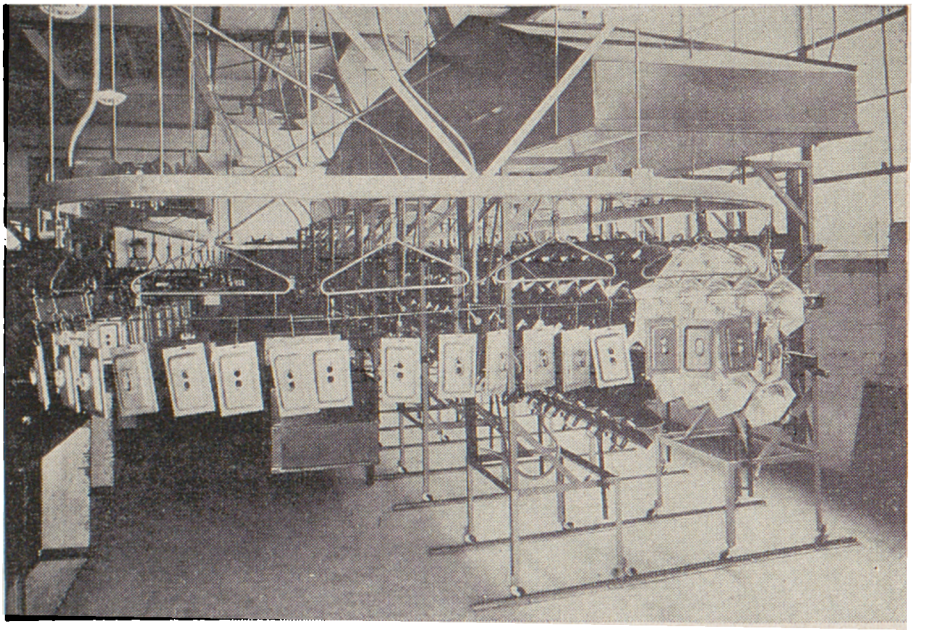


FIG. 8-10.—Drying of two coats of Pittsburgh Plate Glass Company synthetic gray paint applied to electric switch boxes. Each coat requires 7 min (prewar paint, 3½ min) as compared with 40 min for gas batch oven. Two hundred seventy-two 250-watt lamps are used.

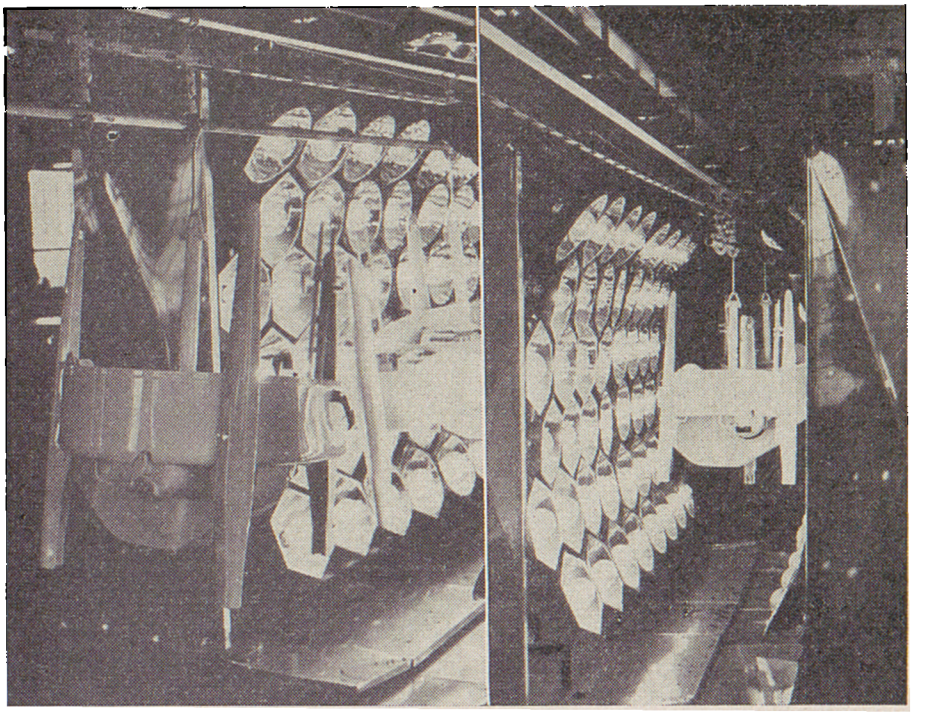


FIG. 8–11.—Drying of Ault and Wiborg white and aluminum paint No. 56 on washing-machine bodies which pass through the tunnel twice requiring a total of 25 min drying time. The installation consisting of sixty-four 250-watt lamps also is used for baking the finish on ironers, wringers, and various parts required for the complete units.

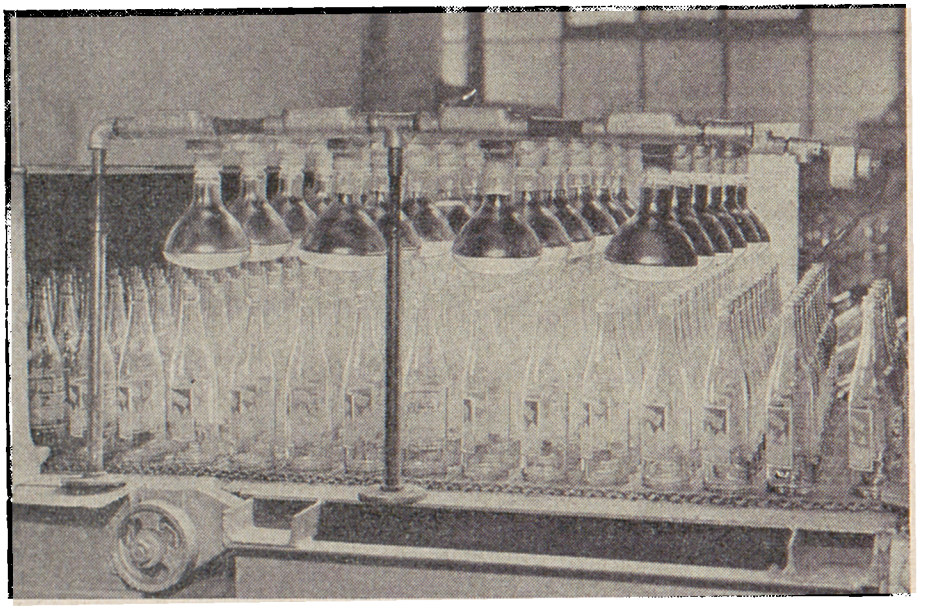


FIG. 8–12.—This installation of twenty-four R-40 bulb infrared lamps supplements a high-temperature gas-fired oven used for fusing the special label paint to glass bottles. Previously the oven was the "bottleneck" of the operation; now the oven processes the bottles as rapidly as the labels are applied. The plant engineer reports that the installation represents an investment of $65 which affords a daily saving of $18.

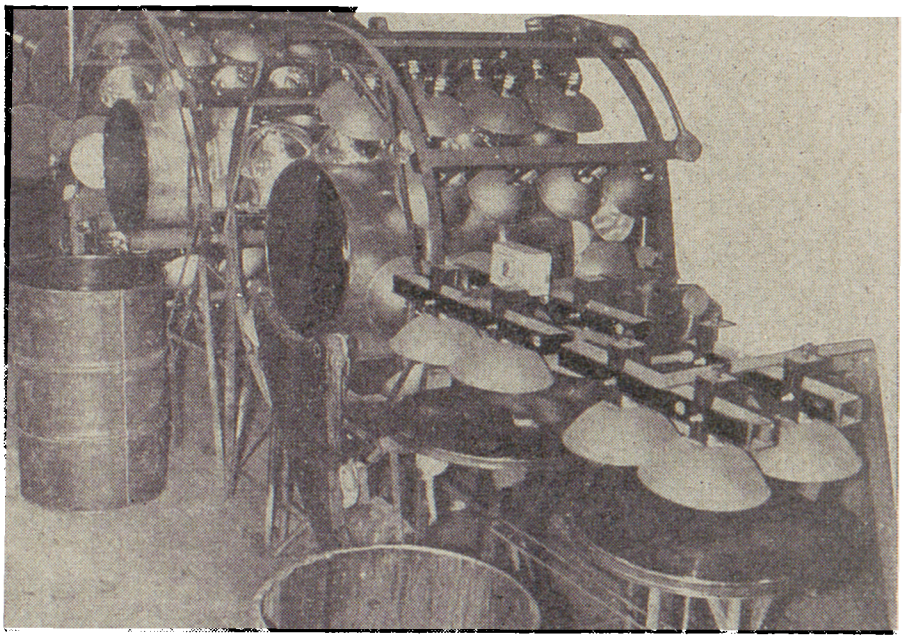


FIG. 8–13.—Drying of sanitary paint liner on inside of drumheads and 55-gal steel drums in which fat or lard is stored. In order to provide uniform radiation, the drums are rotated at a speed of 42 rpm. It formerly required 16 hr to air dry; with radiant heat, only 6 min are necessary. Seventy-two 260-watt lamps are used.

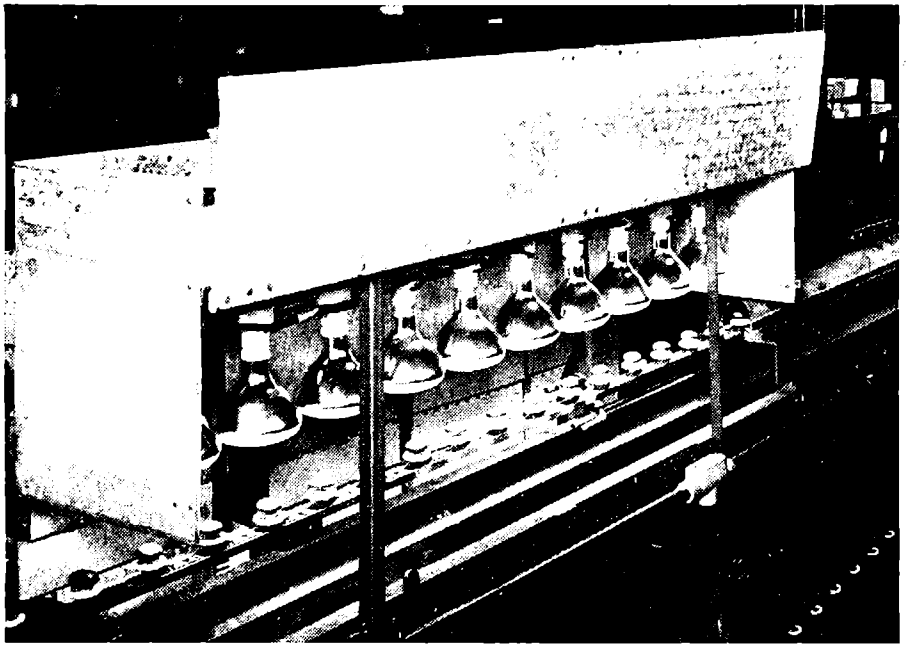


FIG. 8–14.—Application of 250-watt R-40 bulb lamps for predrying of black enamel applied to automobile lamp bulbs prior to fusing of the enamel to the glass in a high-temperature gas-fired oven. Formerly the bulbs were allowed to air dry approximately two hours after spraying before being processed in the oven. Installation of 10 lamps over the conveyor, reducing the drying time to 1 min, has made it possible to process the bulbs as rapidly as the enamel can be applied. This has resulted in reduced cost, increased production, and a product of better quality with fewer rejects.

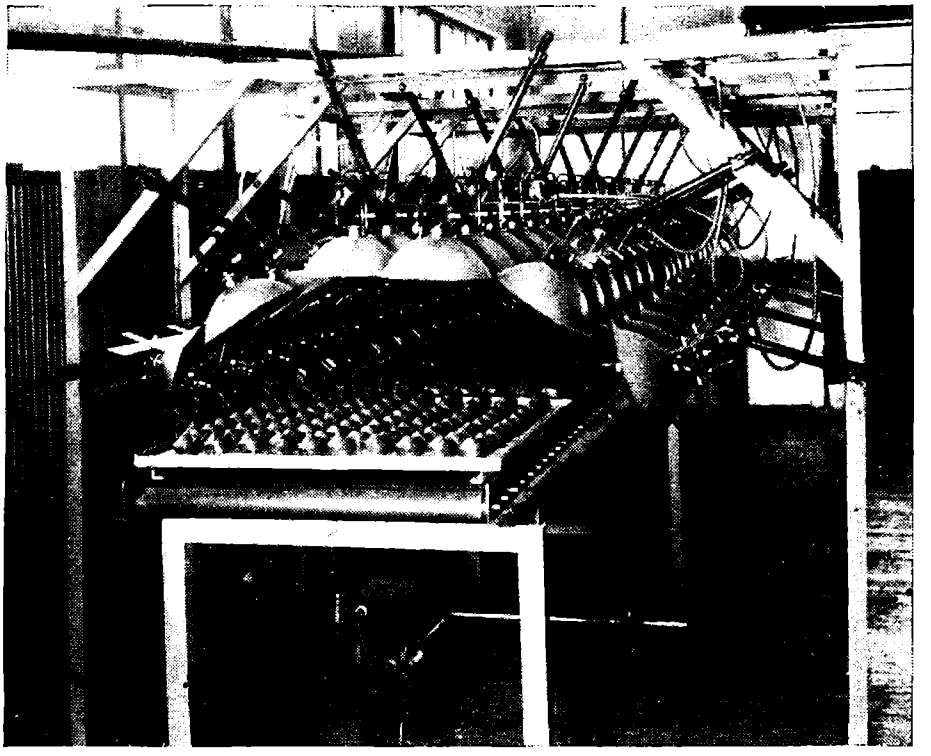


FIG. 8–15.—Infrared equipment using one hundred eight 250-watt lamps for drying Berry Brothers special smooth and wrinkle finishes on castings and light-gauge metal auto accessories. From 8 to 14 min are required, compared with 90 min necessary in the 300°F convection oven formerly used. A batch-type rather than a continuous conveyor is used. Uniformity of heat application is assured by a 6-in. alternate back-and-forth movement of the "conveyor."

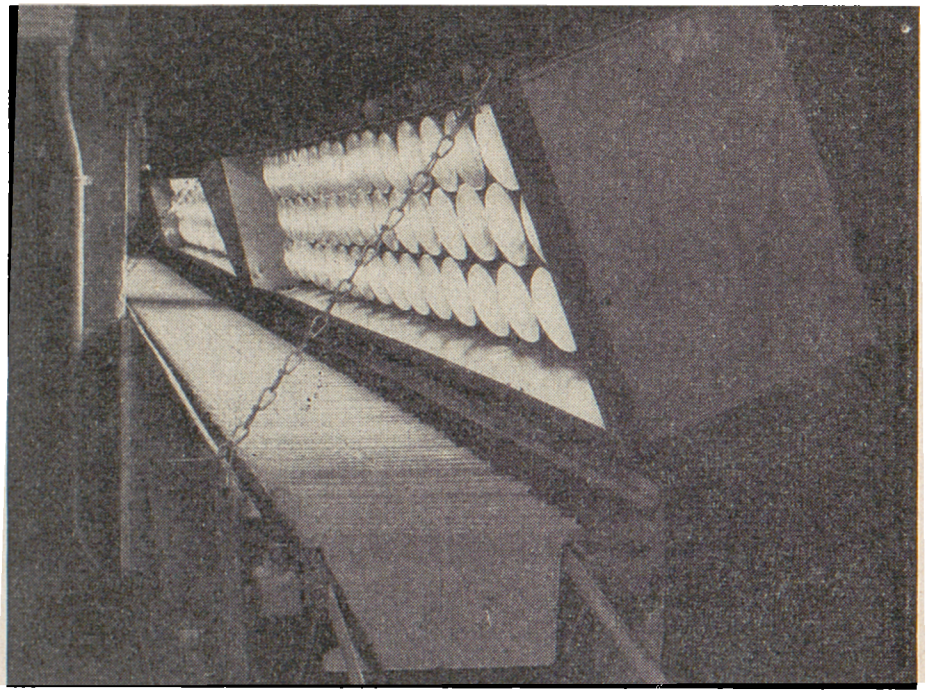


FIG. 8–16.—Use of ninety-six 250-watt reflector-type lamps for drying of impregnated battery grid plates. By means of this method complete drying is possible in 20 min. With the open-flame oven formerly used, only partial drying was accomplished; to complete the job an additional 24-hr rack drying was necessary. As will be noted, the hinged banks of lamps are raised to permit removal of the plates.

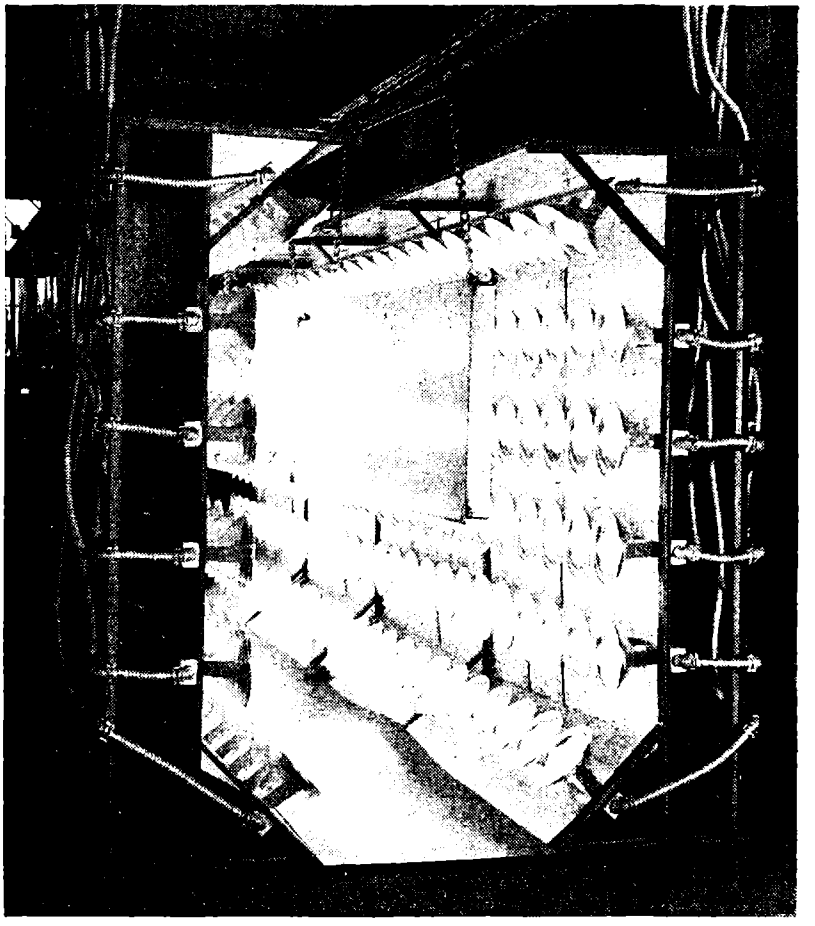


FIG. 8–17.—Infrared-baked enamel was found to be an effective war time substitute for zinc and aluminum in the manufacture of vacuum-type refrigerating plates. This 20-ft tunnel consisting of three hundred thirty-six 250-watt lamps in Alzak aluminum reflectors serves to bake such plates in about 12 min as they pass through the heat zone on a conveyor. Note the side and bottom enclosures that prevent excessive drafts and conserve heat.

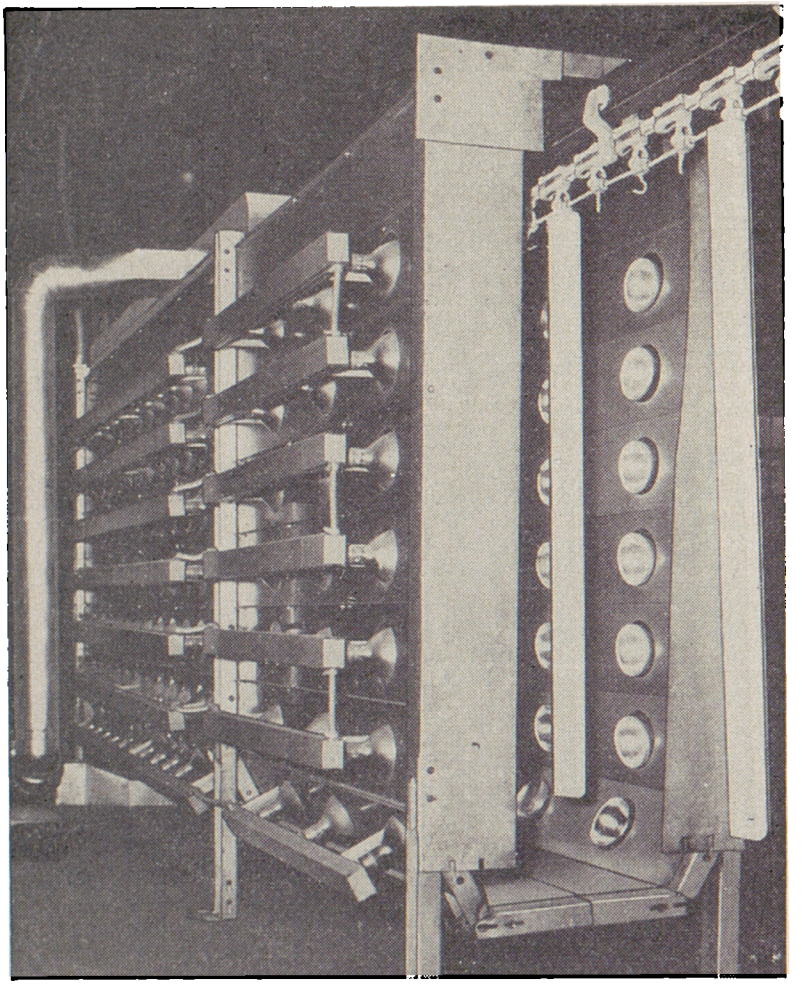


FIG. 8–18.—Fourteen-foot infrared oven using two hundred ten 250-watt reflector-type lamps employed in drying paint on fluorescent fixtures in approximately 10 min. At a conveyor speed of 1½ ft per min, the oven processes 75 pieces hourly.

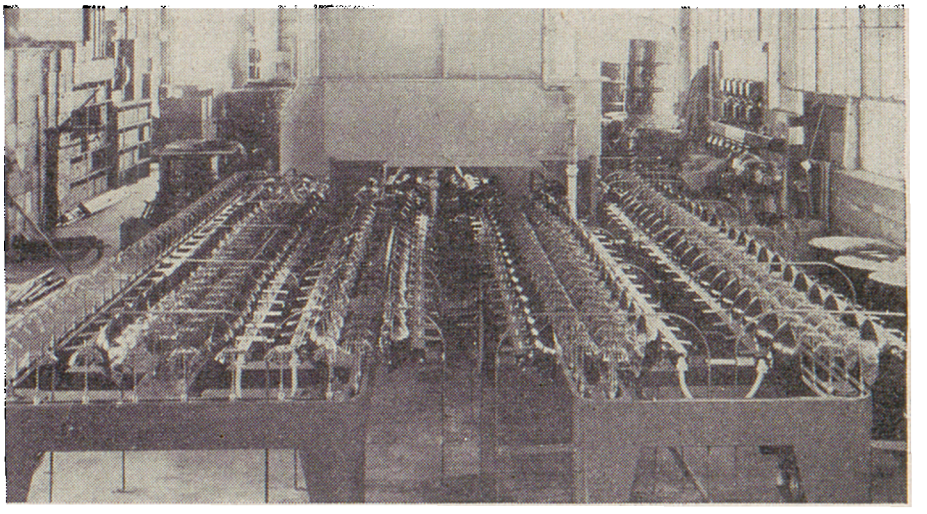


FIG. 8–19.—This infrared installation for drying paint on patented garter grips not only reduced the personnel on the finishing operation, but also made possible a reduction of work hours with an increase in production from 42,000 per working day to 64,000 per working day. Previous to the installation, a 37-kw electric oven was used and a crew of eight people worked for 12 hr. Since the new installation, five people are required for a period of 8 hr. A Paseké conveyor with two automatic spray booths carries the grips through the radiant-energy zone after they have had a du Pont prime coat and baking for 6 min followed by a du Pont enamel finish coat and 11 min baking. About a dozen of the small grips are mounted on each upright conveyor arm, which are spaced at intervals on the conveyor chain that moves past the lamps. A total of one hundred eighty-two 250-watt lamps are used.

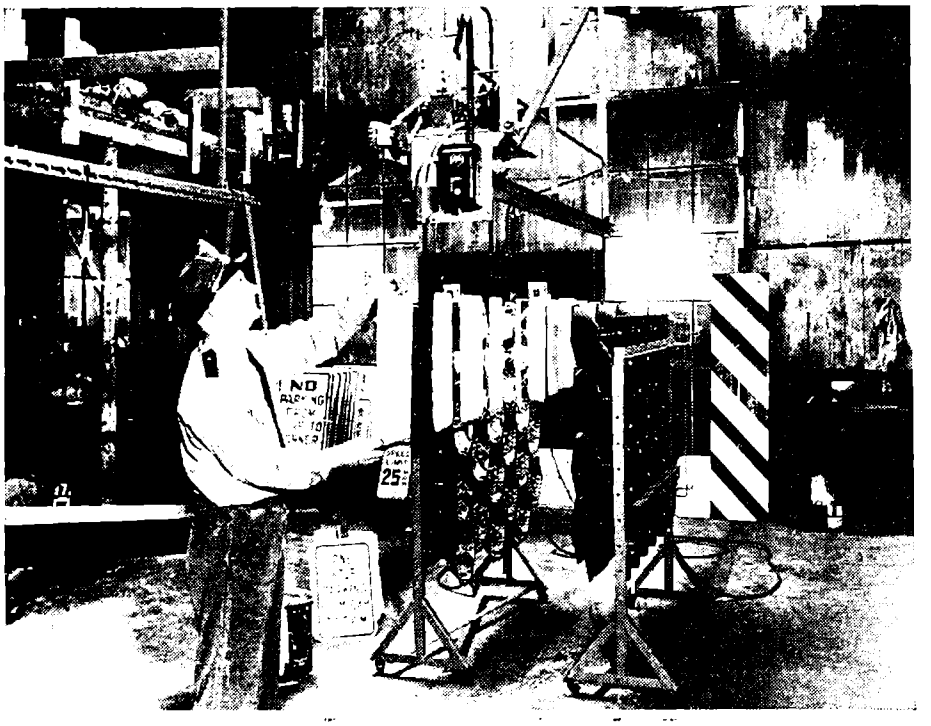


FIG. 8–20.—Two banks of sixteen 250-watt lamps are used to bake synthetic enamel on traffic signs. Two minutes baking time is required for each color. The life of the signs has been increased by this method of baking.

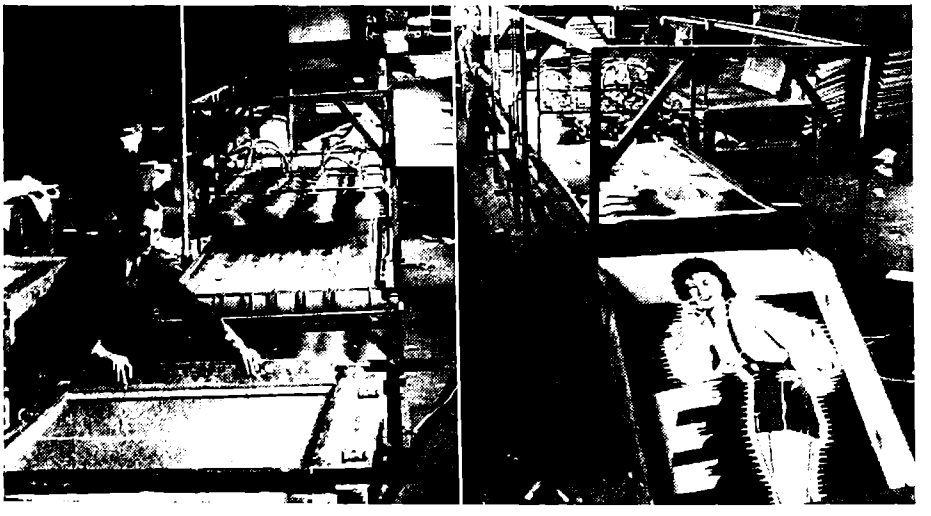


FIG. 8–21.—The paint on processed posters dries in 1 min under a bank of forty-eight 250-watt infrared lamps instead of in the 2 to 5 hr previously required when they were air dried in racks.

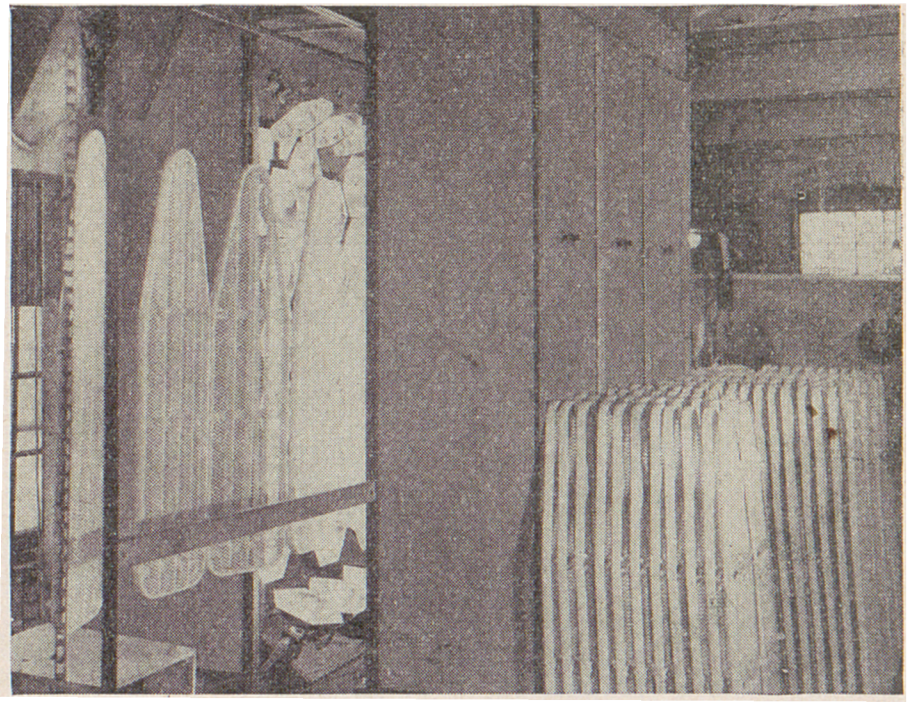


FIG. 8–22.—All-metal ironing boards of 16-gauge metal, 54 in. long, get white finish (Speed-A-Lag synthetic white paint No. 7123) baked in 8 min. Six hundred boards are processed in an 8 hr day. The conveyor speed is 9 in. per min; the board is 10 in. from the reflectors. This process relieved a bottleneck caused by stacking the boards to air dry before packing. One hundred twelve 250-watt lamps are used.

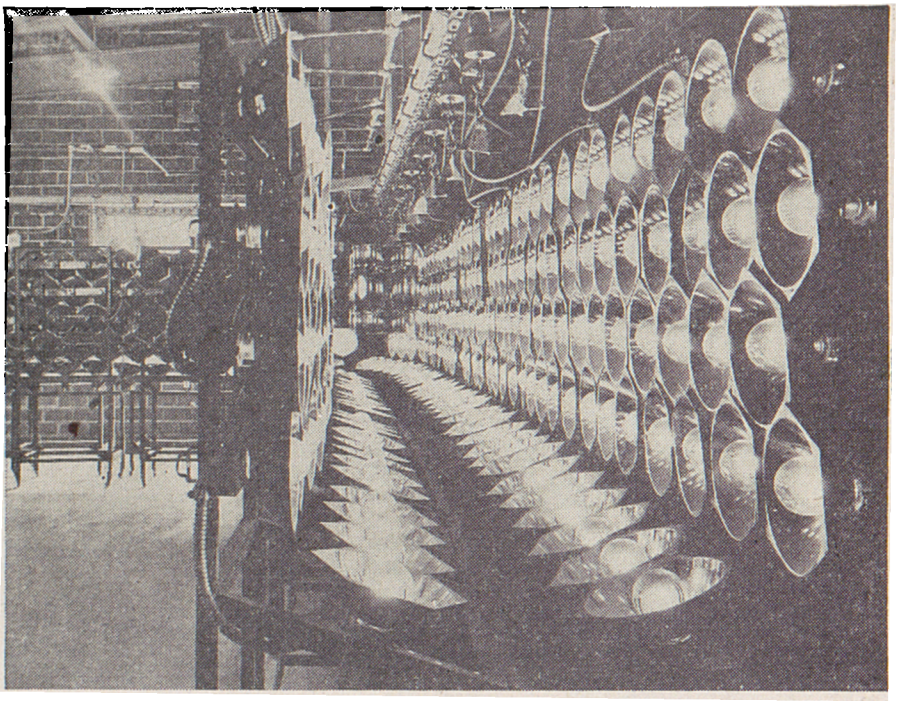


FIG. 8–23.—Baking paint on steel drums at the rate of three drums per minute. Normal conveyor speed is 6 ft per min, drying time 6 min. The steel drums are spaced 24 in. apart and vary in size from 14 by 15 in. diameter to 32 by 18 in. diameter. This installation, having a total length of approximately 36 ft, was erected in the form of an "L" in order to conserve space. Four hundred forty 250-watt lamps are used.

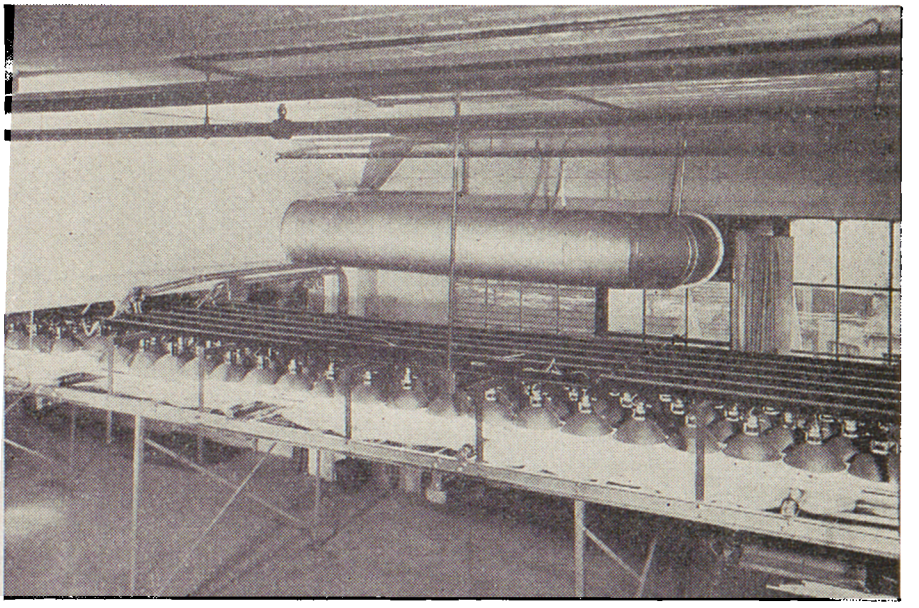


FIG. 8–24.—Equipment consisting of one hundred sixty-eight 260-watt lamps and reflectors used in conjunction with a Chambers Varnish Machine having a production speed of 1,900 52 in. wide sheets per hour. Reflectors are 3¼ in. from the conveyor surface. Radiant heat has replaced the gas oven, which is now used to cool sheets after they come from the infrared section by operating a blower which was part of the circulation system in the oven. The final product shows that infrared process yields a better and more uniform finish. Conveyor belts are not affected by infrared heat as was case with gas oven.

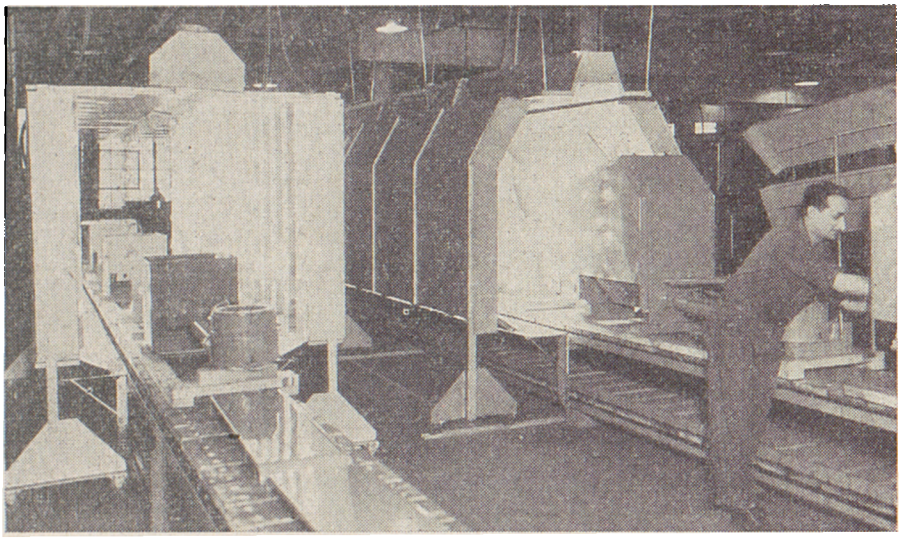


FIG. 8–25.—The finish on coal-stoker parts and finished stokers is dried at 225°F in 6 min in these two ovens using 250-watt lamps with aluminum reflectors located in apertures in the polished aluminum sheets which line the ovens. The walls of the oven are mounted on casters to provide an adjustment range of 8 in. to 3 ft between the lamps and the middle of the conveyor. The oven at the right, of a more recent design, uses one hundred seventy-two 250-watt lamps.

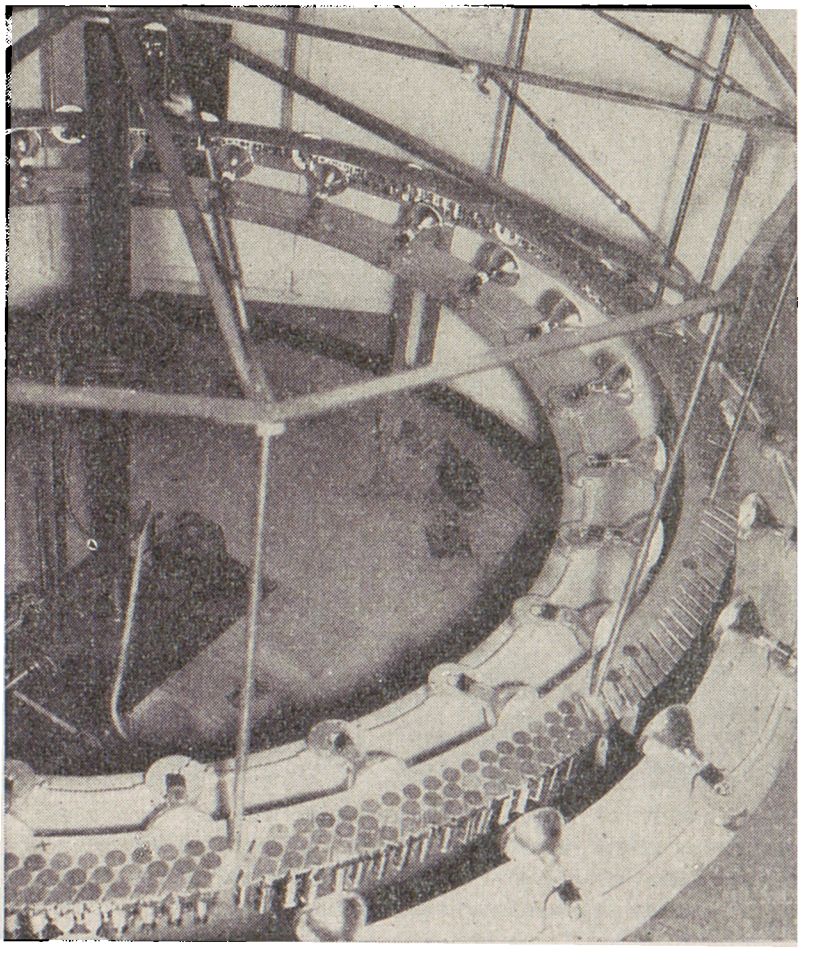


FIG. 8–26.—The unusual features of this oven serve to accent the versatility and adaptability of radiant-heat application. This "merry-go-round" infrared oven is used to thoroughly cure bakelite varnish on small coils of wire. The 250-watt R-40 bulb reflector infrared lamps are mounted in two concentric circles, with the lamps in one circle facing those in another. The inner circular rack holding the coils rotates between the two stationary circular banks of lamps. The first operation consists of dehydration of the coils, after which they are dipped into bakelite varnish contained in a circular tank located directly beneath the coil rack. Then the coil rack is again rotated slowly until the varnish is cured. The apparatus is located in a room especially built for it. The coils are loaded through the window shown in the rear, while control of the mechanism is by means of switches located outside the room. The bakelite fumes are expelled from the room by an exhaust fan located in the outer wall. Introduction of this oven was said to have made possible a 300 per cent increase in production with the use of one-third to one-half the amount of labor formerly required.

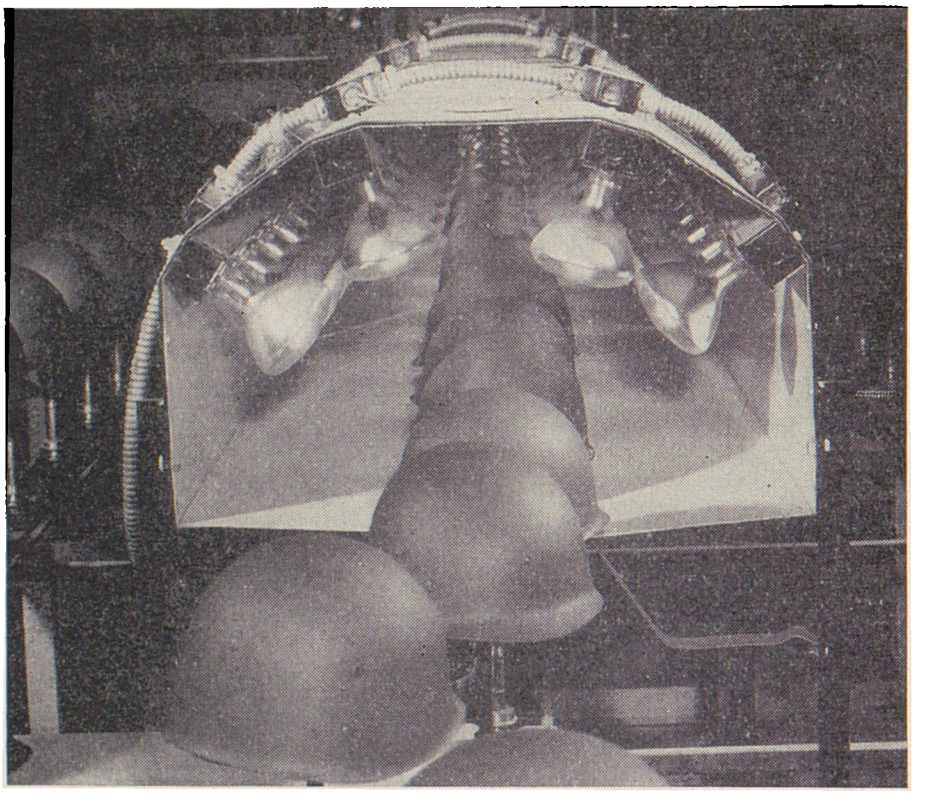
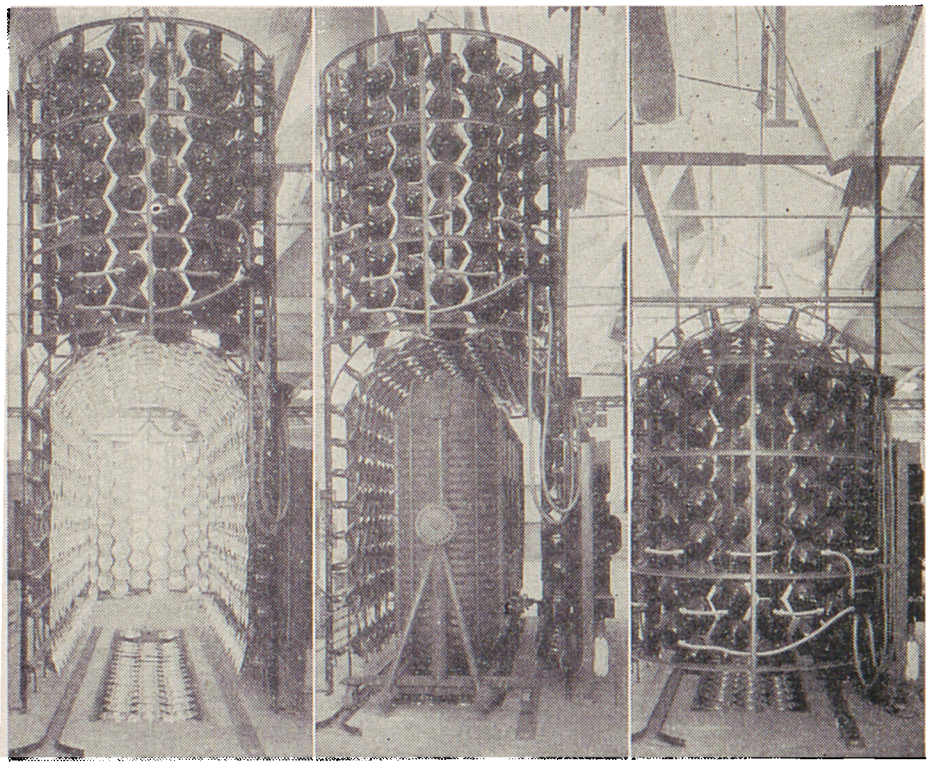


FIG. 8–27.—Drying of painted micarta helmets (used for heat insulation inside steel helmets) at 240°F by means of one hundred twelve 250-watt reflector infrared lamps. The installation, costing $600, is 19 ft long and dries the helmets in 95 sec. A convection oven for the same purpose would have cost some $2,500 while the drying time would have been approximately 15 min. Uniformity of drying is accomplished by rotating the helmets slowly as they pass under the lamps.



(*a*) (*b*) (*c*)

FIG. 8–28.—Ingenuity and originality combined to make this a most satisfactory infrared oven for drying the paint on metal life rafts in 20 min, or one-half the time required when an electric convection oven was used. The installation consists of 1,056 units using lamps ranging from 250 to 500 watts. Complete enclosure with infrared units makes it possible to bake all sides of the raft at a required uniform temperature of some 250°F. (*a*) End gate open to permit placing raft in the oven. (*b*) Raft on dolly in place. (*c*) End gate closed.

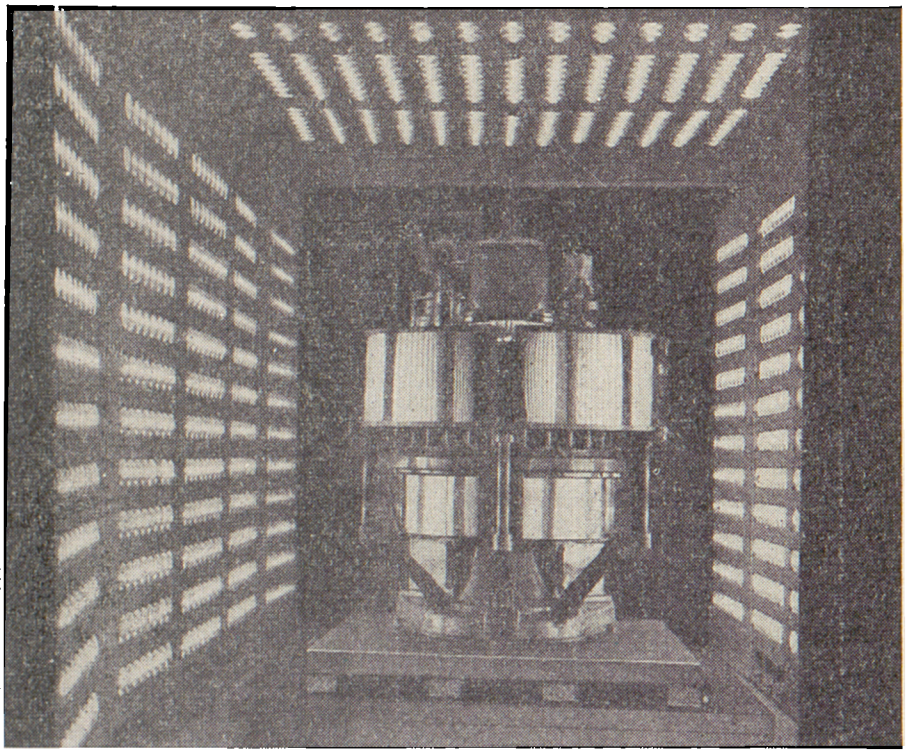


FIG. 8–29.—Batch-type oven employing one thousand two hundred seventy-two 250-watt reflector lamps for drying synthetic enamel on beverage-bottling equipment. This oven is used to process a variety of equipment, with a minimum of 15 min required.

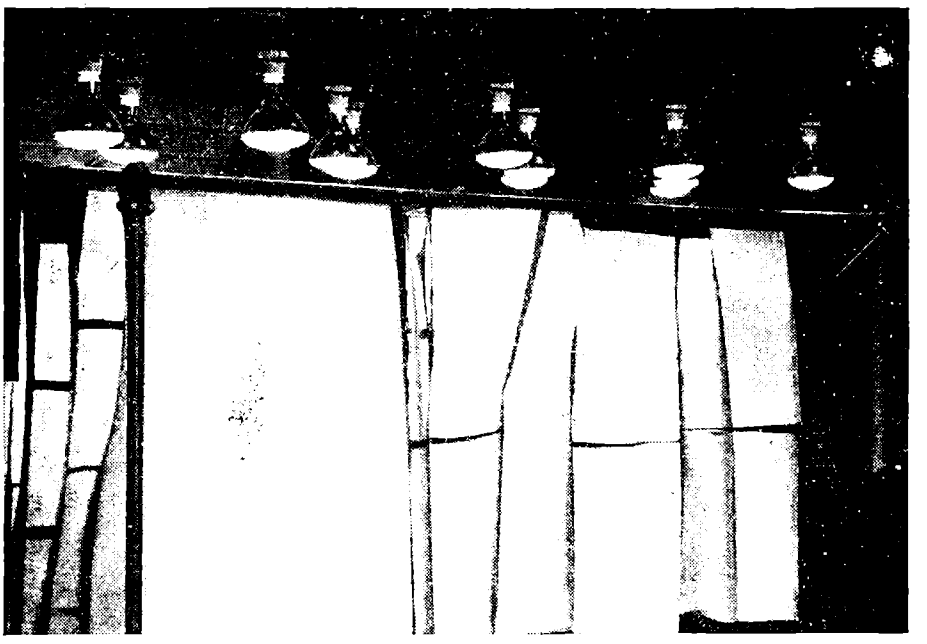


FIG. 8–30.—This installation of twelve 250-watt R-40 bulb infrared lamps used for drying tracing reproductions, transparent contact prints, Vandyke or brown prints, etc., has produced such gratifying results that "it has been decided definitely to use this means of drying exclusively, primarily because it is the only drying process we know of whereby distortion can be reduced to an absolute minimum. It is our intention to use these lamps in our photographic section for drying contact and bromide prints."

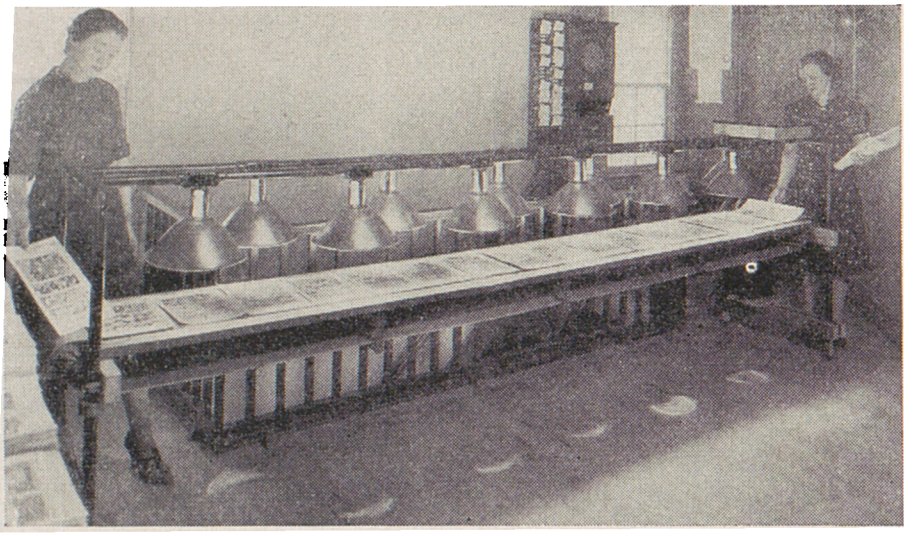


FIG. 8–31.—Twelve 250-watt infrared lamps and reflectors are used to dry sample cards wherein swatches of cloth pasted to the paper pass under the lamps on a conveyor belt. Approximately 1 min is required for drying. Prior to use of radiant heat, cards were stacked and allowed to air dry. This resulted in spoilage and loss of time, both of which have now been eliminated.

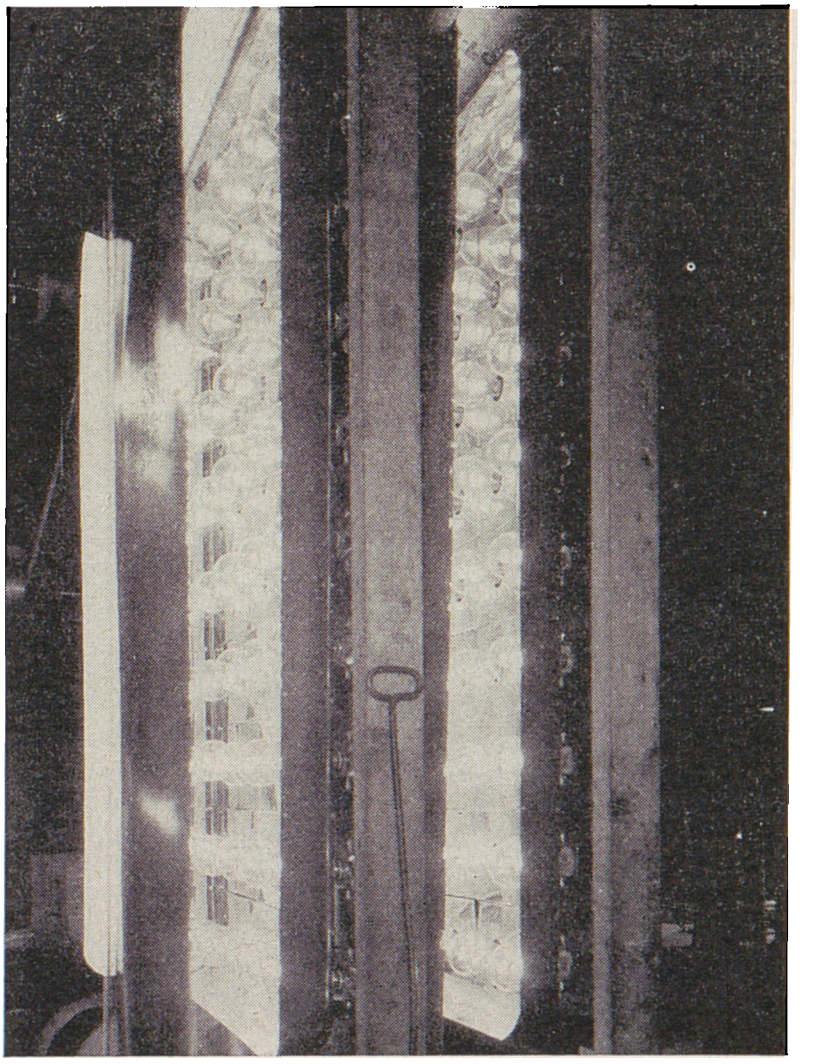


FIG. 8-32.—Pressboard (20 to 30 point) passes before two canopies each located 6 in. from the board. One side of board is radiated as it passes one bank and the other side is radiated by the other bank. This procedure was necessary to eliminate blistering which occurred on original installation when both sides of board were radiated at the same time by two opposed banks. Originally, after the first glazing operation the board had to be taken off the machine and dried on a separate steam dryer which tended to dull the glaze, thereby necessitating a second glazing operation. Now the board goes through one glazing, is dried on the same machine, and is ready for shipment. Savings amounting to thousands of dollars have been effected. Some two hundred twenty-five 250-watt lamps are used.

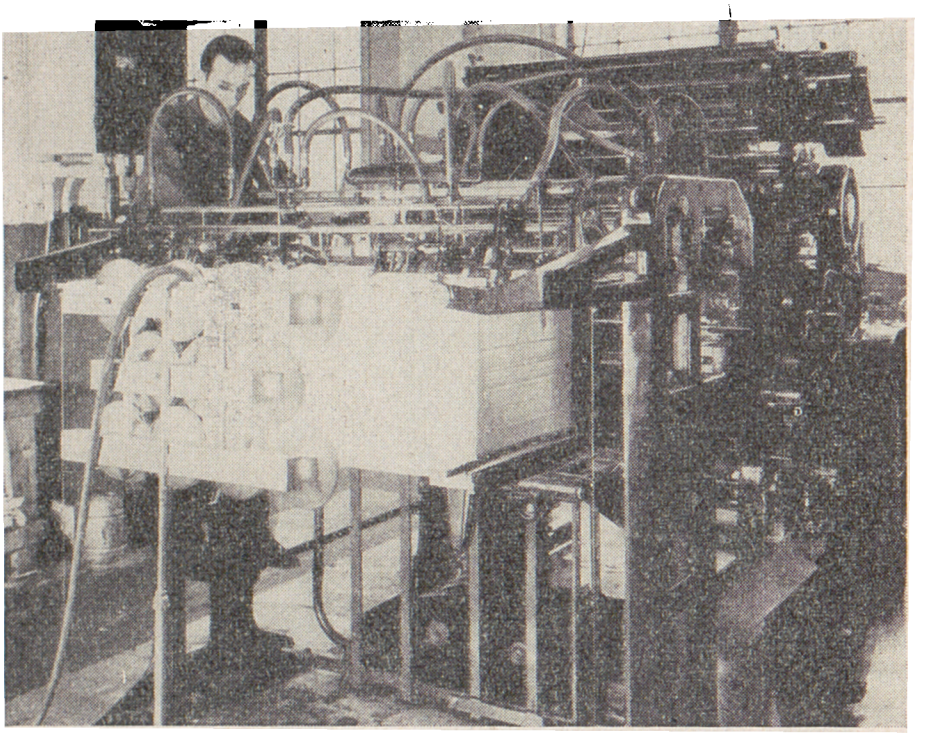


FIG. 8–33.—Change in humidity sometimes causes the edges of paper stock to curl with a resultant wrinkling of the sheet after being lithographed. A large lithographing company has reduced the spoilage due to this wrinkling by the use of 250-watt lamps and reflectors arranged as shown. The savings due to increased speed of production and reduced spoilage have made this drying-lamp installation a very worthwhile investment.

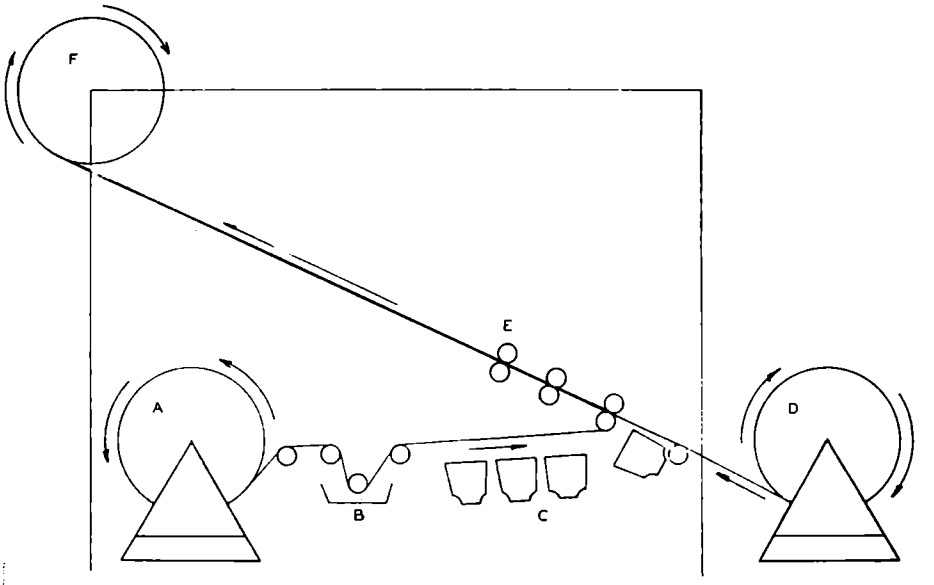


FIG. 8–34.—Application of infrared to the manufacture of coated paper. In the manner indicated, finished papers are glued to cheaper base papers. Sixteen 500-watt lamps with reflectors are used to dehydrate the glue after application to the paper but prior to its contact with the other paper. Paper is processed at a speed of 110 to 150 ft per min. Use of drying lamps eliminates wrinkling and buckling of paper previously experienced due to moisture from glue trapped between the two sheets.

A—Roll of coarse base paper.

B—Wet, hot glue applied at this point.

C—500-watt lamp reflectors.

D—Roll of finished paper.

E—Rolls through which the two sheets pass in being glued together.

F—Processed paper.

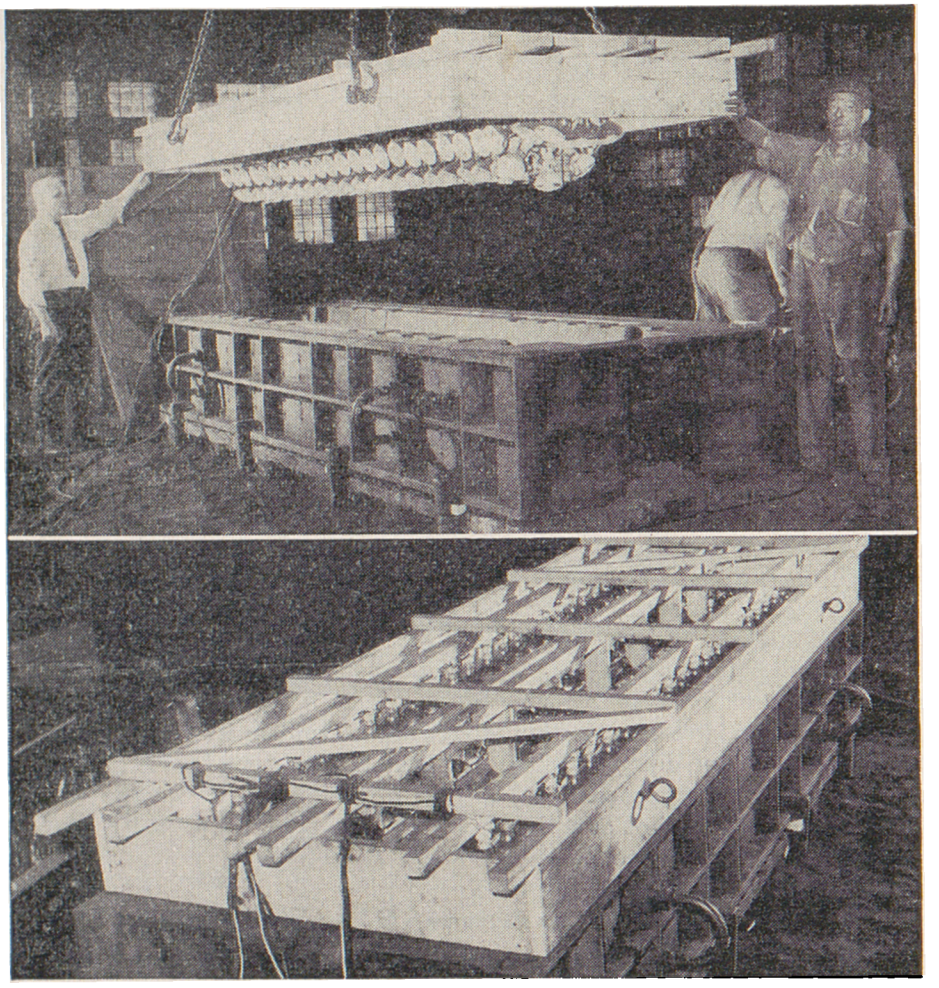


FIG. 8-35.—Above, an infrared mold drying unit being lowered over a mold for a 7,400-lb casting to be used for the shaft bearing of a Liberty ship. The picture, below, shows the unit in place. The unit is 4 ft wide by 12½ ft long and uses one hundred fifty 250-watt reflector-type lamps. The mold is dried in 3 hr at a cost approximately half that of torch drying. In this foundry, infrared lamps, sockets, etc., are used over and over again to build units of varying sizes and shapes that are required from time to time.

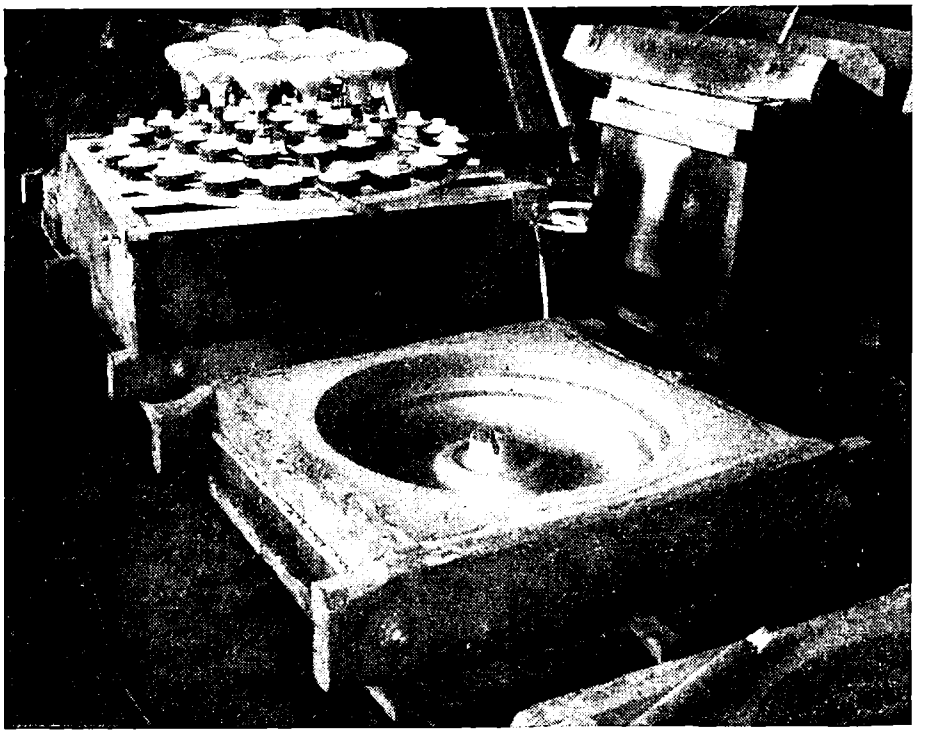


FIG. 8–36.—Radiant heat has found a ready welcome in many foundries for the skin drying of molds. As compared with the kerosene-torch method of drying, it is cleaner, less expensive, requires less labor, and produces more uniform results. In the background is an inverted bank of 250-watt reflector-type lamps for use in drying the mold in the foreground. Note how the contour of the lamp bank conforms with that of the mold—an example of the type of service for which the reflector-type lamp is especially suited.

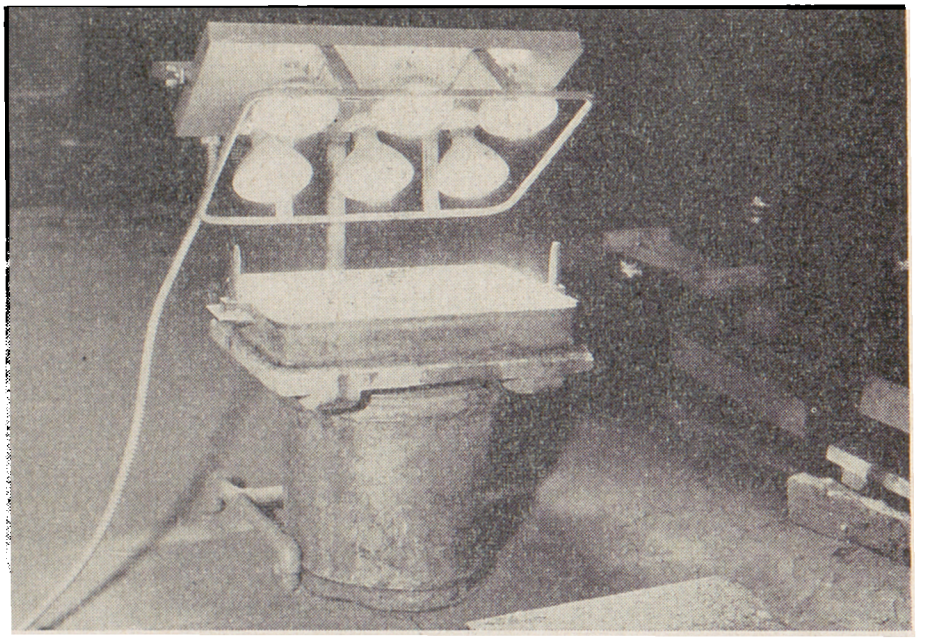


FIG. 8–37.—Infrared radiation by means of six 250-watt lamps used for skin drying of small foundry molds. In comparison with flame drying previously used, the newer method has reduced drying time two-thirds while rejects are 15 per cent less.

FIG. 8–38—Reflector-type infrared lamps used for drying continuously extruded ceramic resistors prior to baking in high-temperature electric oven.

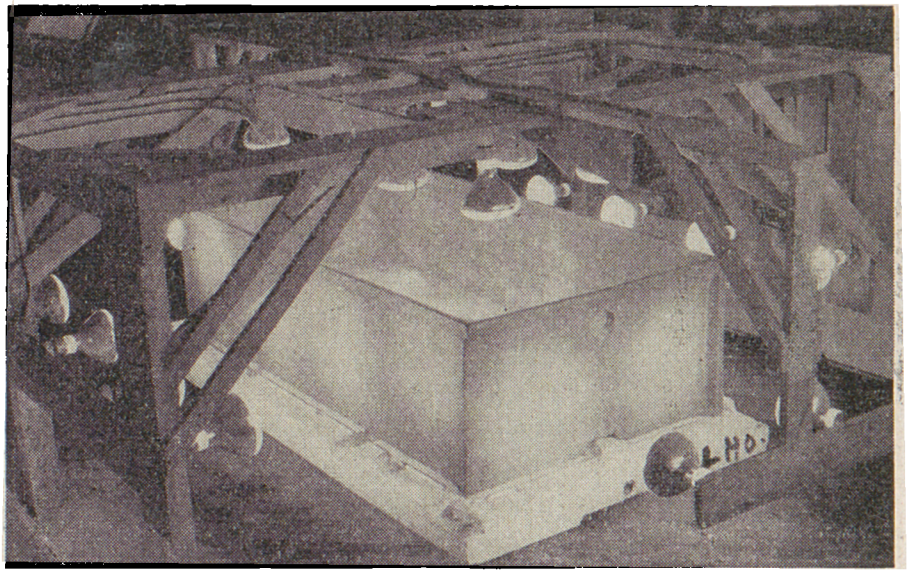


FIG. 8–39.—Reflector-type 250-watt lamps used in manufacturing porcelain bath tubs wherein 15 to 20 min infrared heating in humid weather saves an overnight air dry prior to "finishing." Following this operation is another drying period of 12 hr which previously required 18 days. In addition to increased speed, the new drying method requires half the space formerly needed. Also, use of lamps made it possible to discontinue operation of the boilers used with the old process.

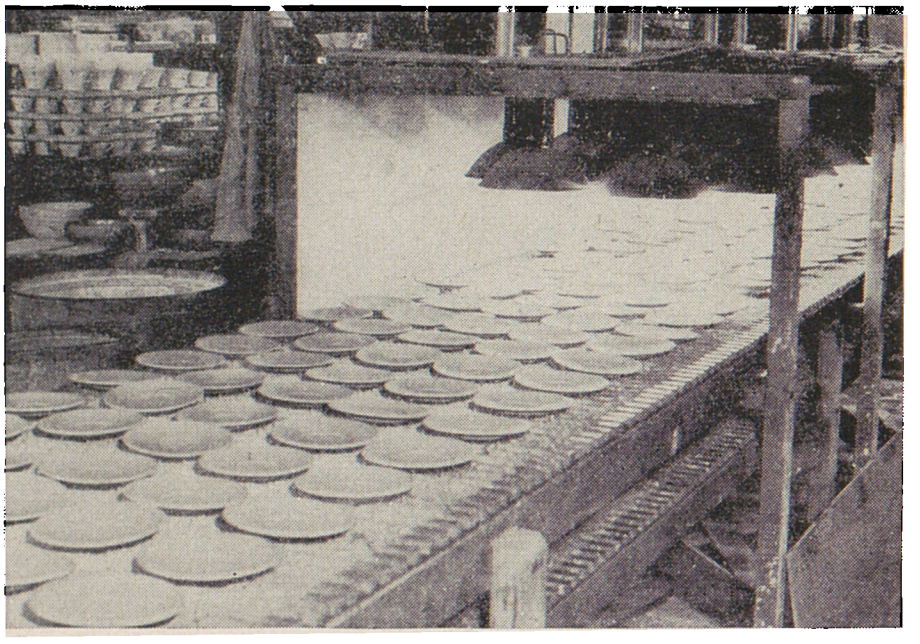


FIG. 8–40.—Pottery dinnerware and pottery cookingware after being dipped must be dehydrated before being placed in glazing kiln. In this installation, pottery is dipped and then placed on conveyor which carries it through a tunnel equipped with sixty 250-watt infrared lamps and reflectors in approximately 7 min from time of dipping. From the tunnel it goes into the glazing kiln. Material is spaced close together but not touching. Time factor at present is 7 min, formerly it was 240 min.

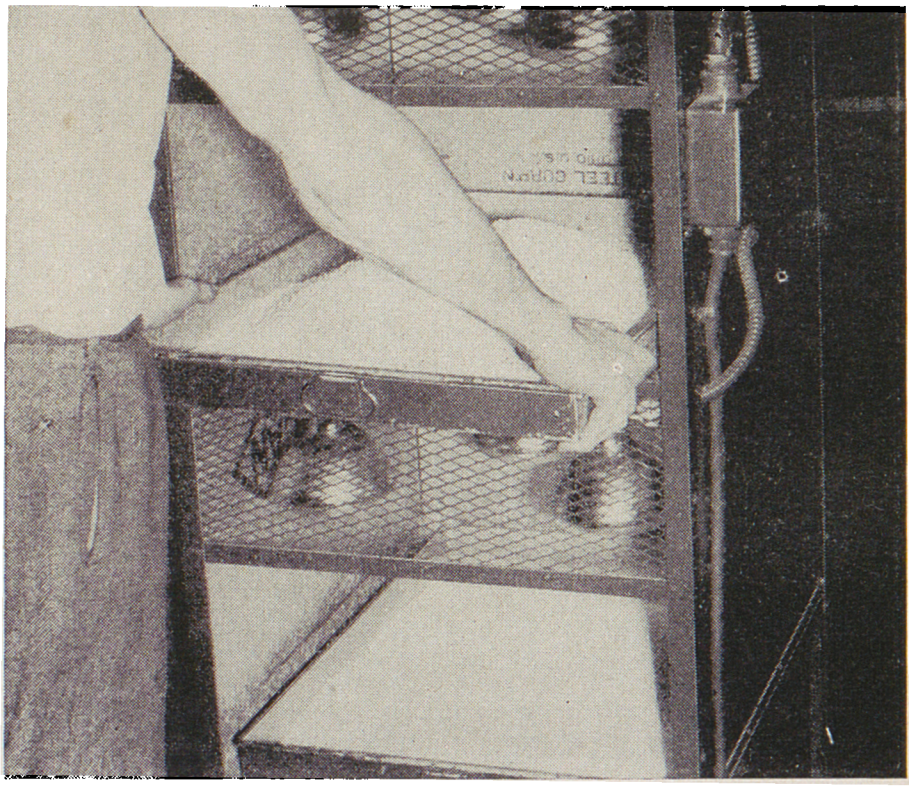


FIG. 8–41.—Injection-molding dryer using ten 250-watt reflector infrared lamps to remove moisture from granulated cellulose acetate prior to loading in press. This material readily absorbs moisture which, if not removed, causes film on the surface of the molded part, as there is no escape in the automatic injection-type molding press. The cabinet-type dryer in the picture has two 24 by 24 in. shelves each using five lamps located approximately 10 in. from the surface of the acetate which is 2 in. deep. The drying time is 15 min as compared with about 1 hr for the steam dryer formerly used.

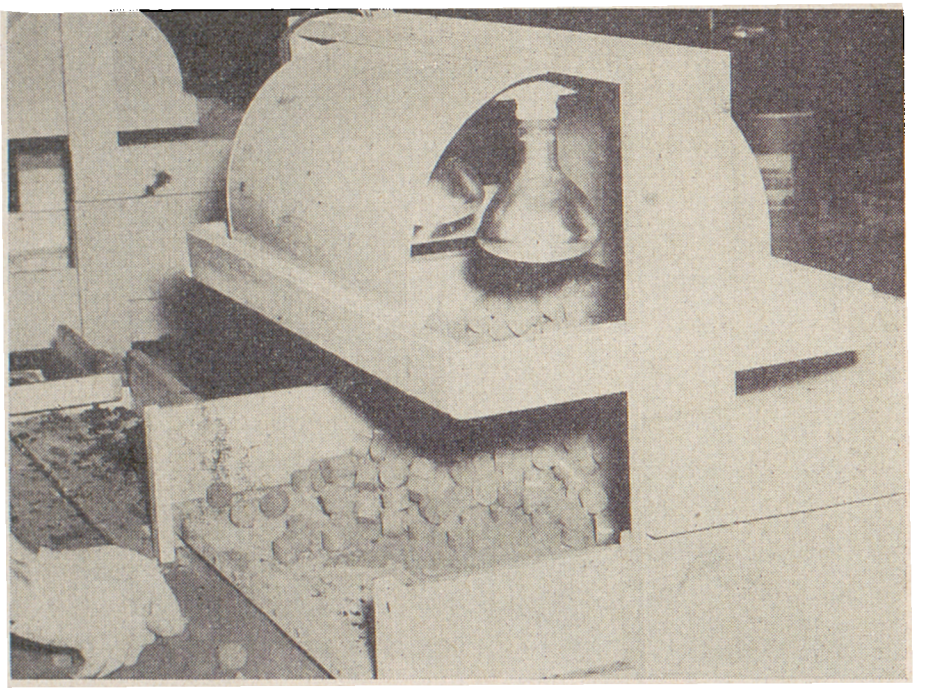


FIG. 8–42.—A plastic manufacturer uses two 250-watt reflector infrared lamps in each molding-preform dryer to remove moisture and to preheat the preforms prior to loading in press. This treatment serves to reduce the gases to be dissipated during the curing time.

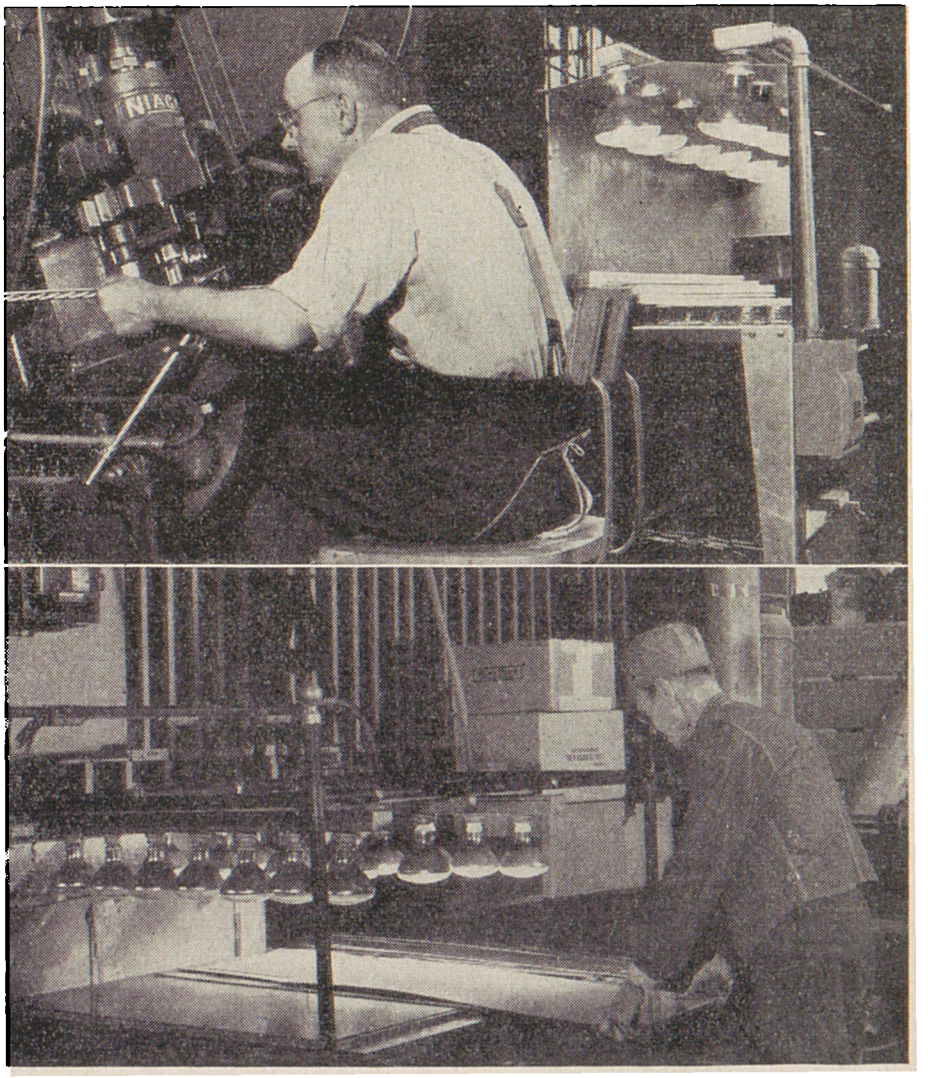


FIG. 8–43.—Infrared lamps used in the plastic industry—above, preheating strips prior to punch-press operation; below, preheating of sheets for stripping on square shear.

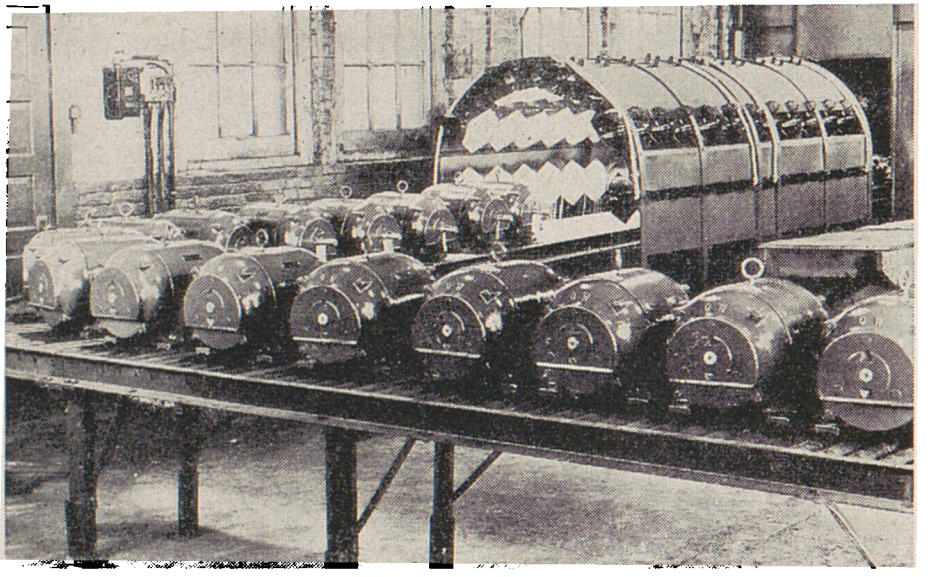


FIG. 8–44.—Infrared equipment used for baking finish on complete frames and shields of various size motors. After spraying, 10 min stand-out time is allowed, then 5 min to bake. Seventy-two 375-watt lamps with gold-plated reflectors are used.

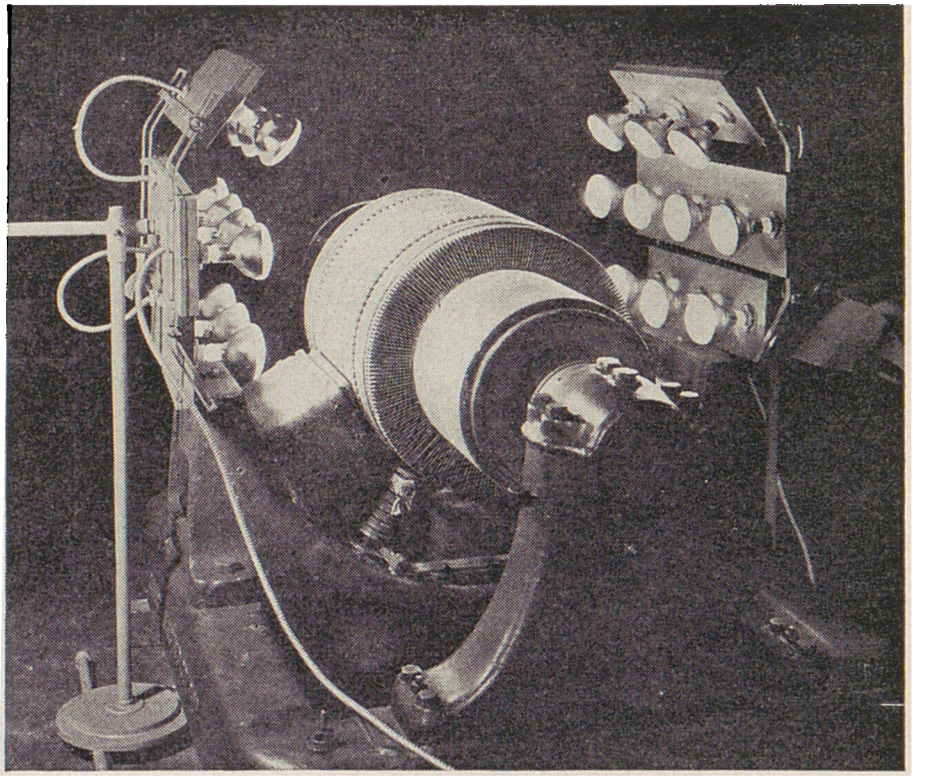


FIG. 8–45.—Portable racks each consisting of ten 250-watt reflector-type infrared lamps used for armature reconditioning (preheating and varnish baking). Air drying formerly used involved complete dismantling of the motor and required as much as 3 days to recondition the larger motors. With radiant heat a comparable job is completed in 12 hr.

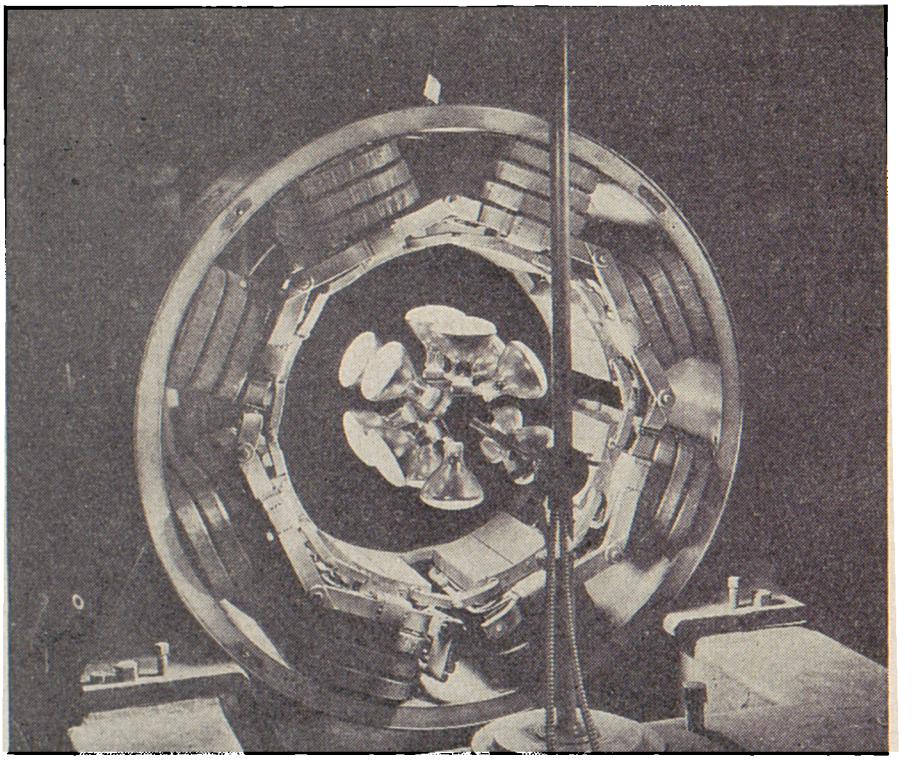


FIG. 8–46.—Refinishing of this motor stator is greatly facilitated by means of a simple arrangement of twelve 250-watt reflector-type lamps.

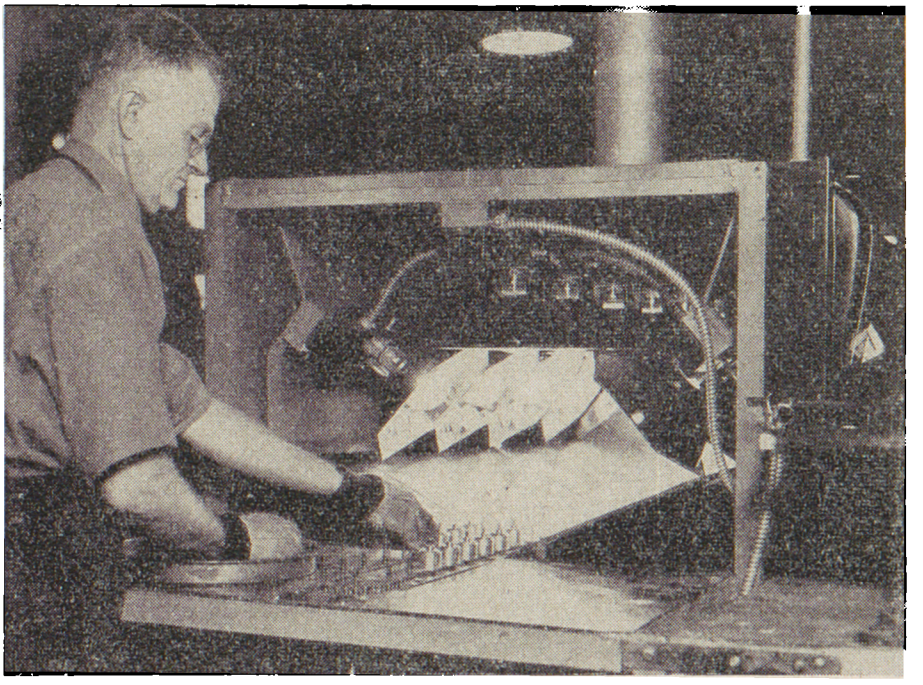


FIG. 8-47.—Fifteen 375-watt lamps for preheating small commutators prior to staking. A loop conveyor serves to pass the commutators through the heat zone twice. Radiant-energy baking has reduced the preheating time from 4½ hr to 11 min.

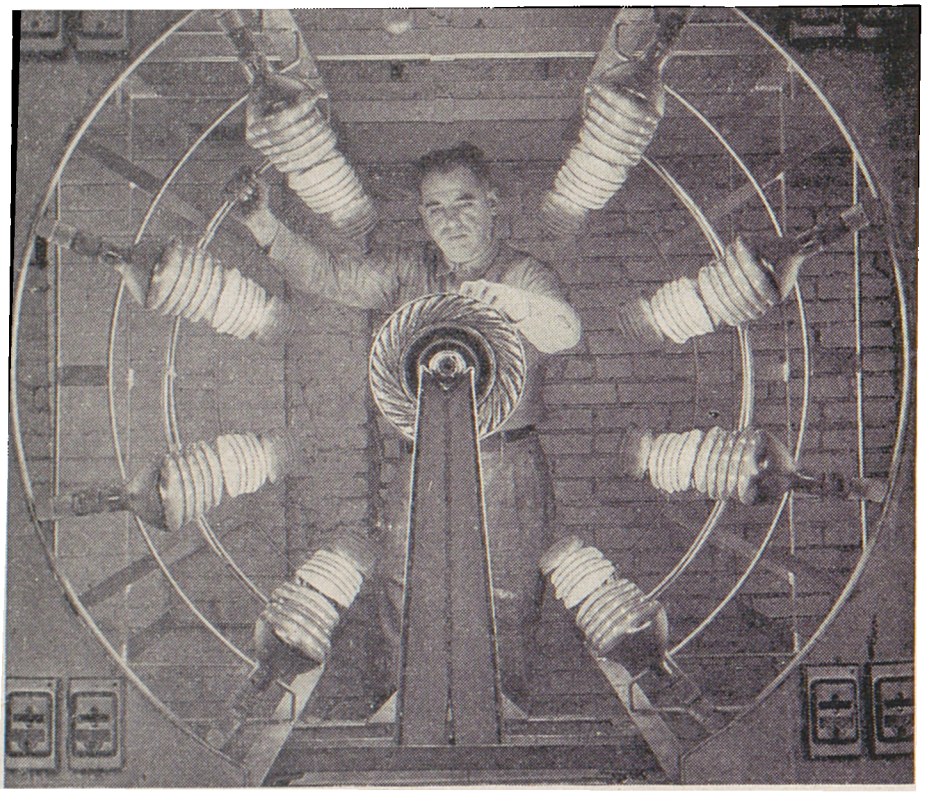


FIG. 8–48.—An unused gas-fired convection oven serves as the space for this modern installation of infrared lamps for the drying of repaired armatures. Each of the two semicircular sections is mounted on barn-door hangers and tracks to provide easy adjustment of the distance between the lamps and the armatures. The one hundred twenty 250-watt lamps are wired so that only the desired number may be used for a specific heating or drying job. In the illustration, only 40 lamps comprising 5 lamps of the middle section of each row are being used.

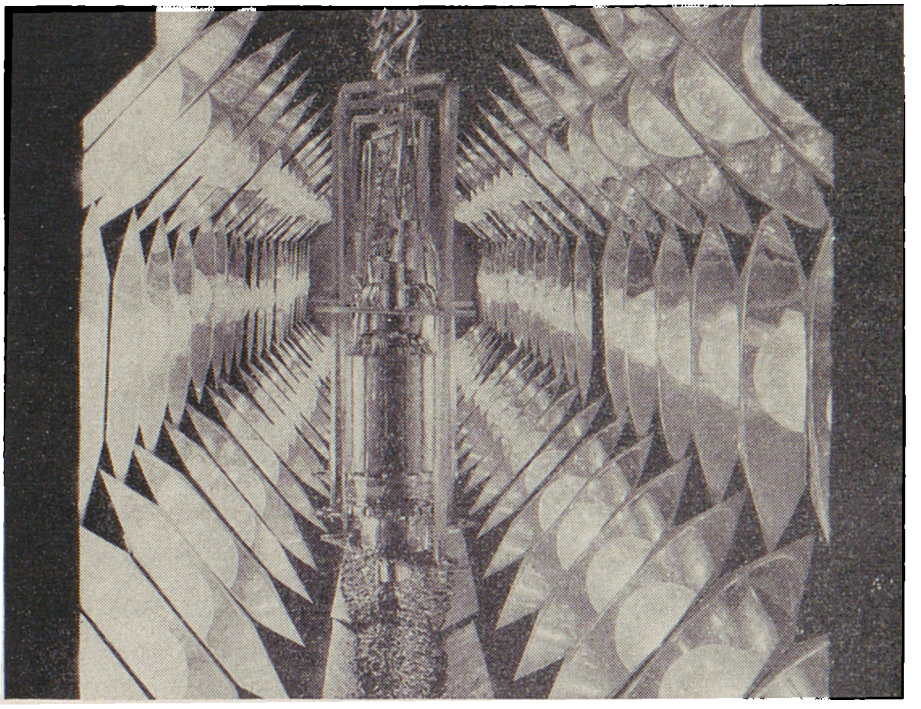


FIG. 8–49.—Baking insulating varnish on various size armatures for airplane generators. This installation also is used to bake two coats of sprayed black finish on the outside of generator housings. Armatures, which are impregnated under vacuum, are baked in approximately 50 min; housings are baked in 27 min. Overhead-type conveyor is used with 7 in. spacings for armatures and 10 in. spacings for housings. One hundred twenty-six 250-watt infrared lamps are used.

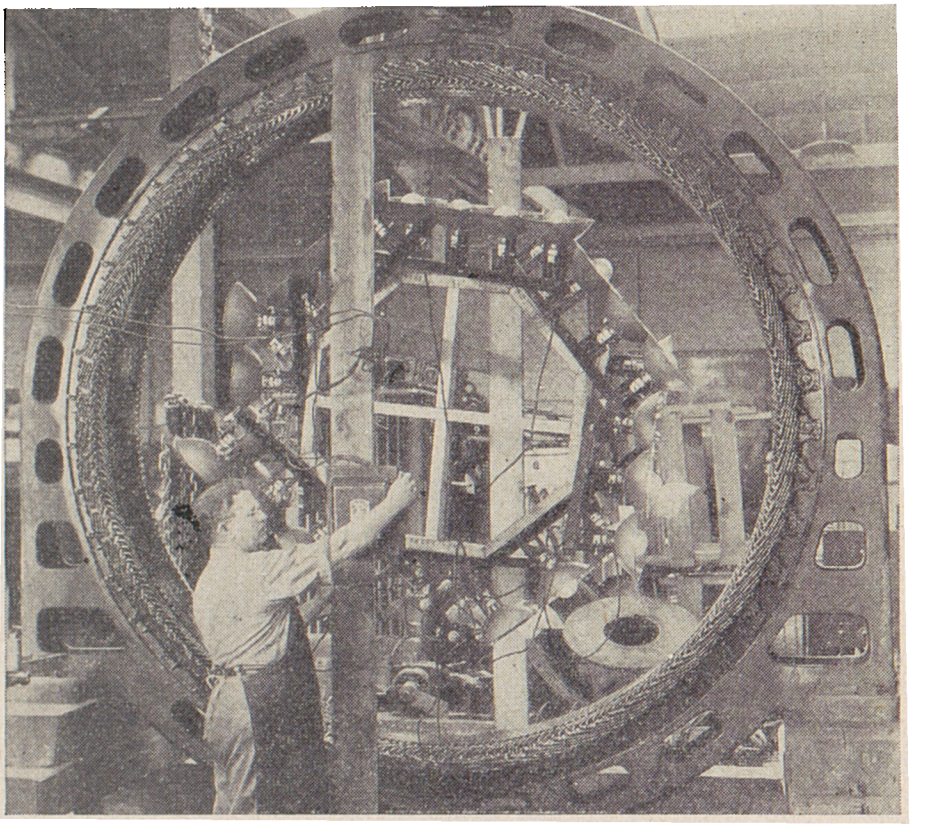


FIG. 8–50.—A 550 hp motor which had stood idle for years is placed back into service again by aid of thirty-two 250-watt infrared lamps. Before radiation it meggered 1 megohm; after 36 hr drying, it meggered infinity. A glyptol finish subsequently applied was dried in 8 hr. This latter represents a 16-hr saving over time required for glyptol air drying.

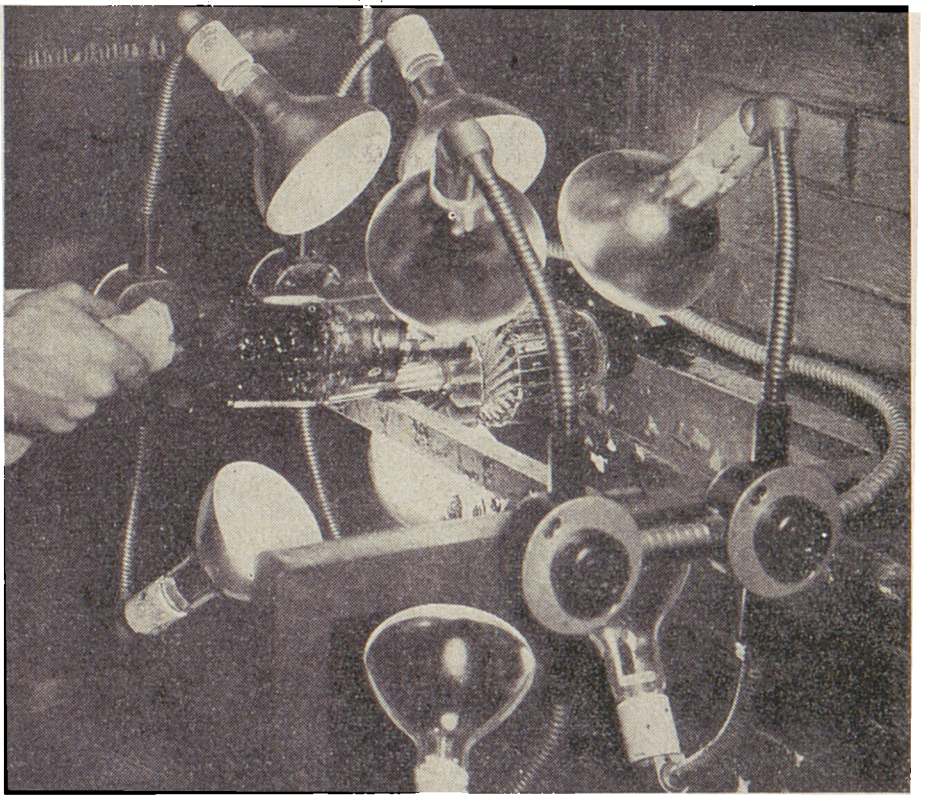


FIG. 8–51.—A simple arrangement of eight 250-watt reflector infrared lamps used in a refrigerator repair shop for the drying of armatures.

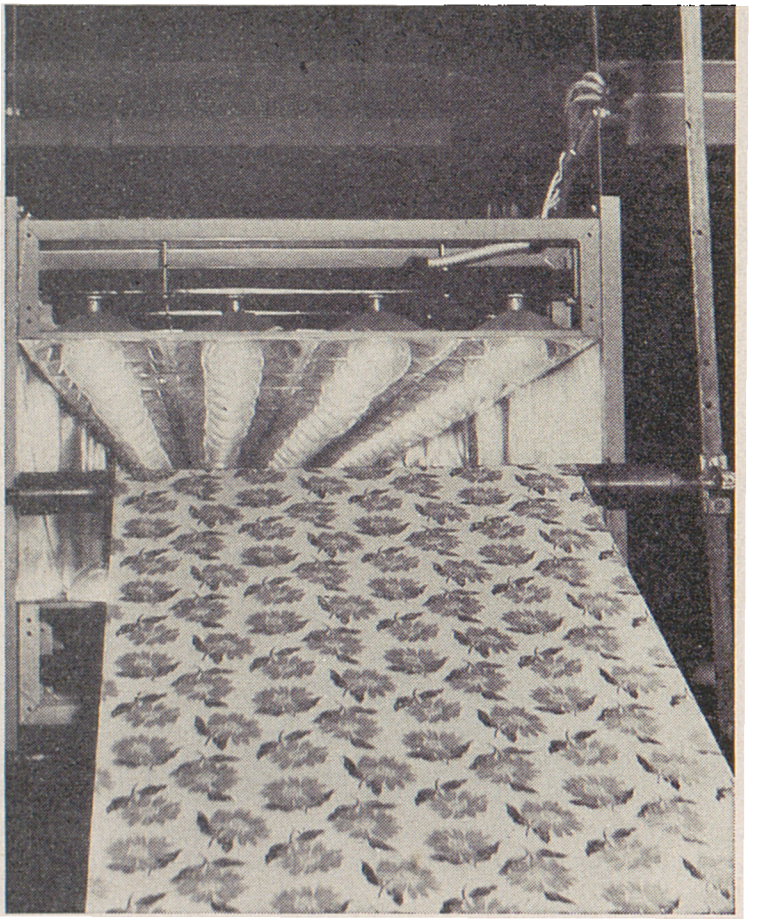


FIG. 8–52.—Two banks (one above and one below), consisting of a total of one hundred forty-four 500-watt lamps and gold-plated reflectors, are used to supplement steam in the drying of dye-printed pattern cloth. Use of infrared radiation has increased production from 75 yd per min to 110 yd per min on some patterns, and from 42 yd per min to 64 yd per min on others.

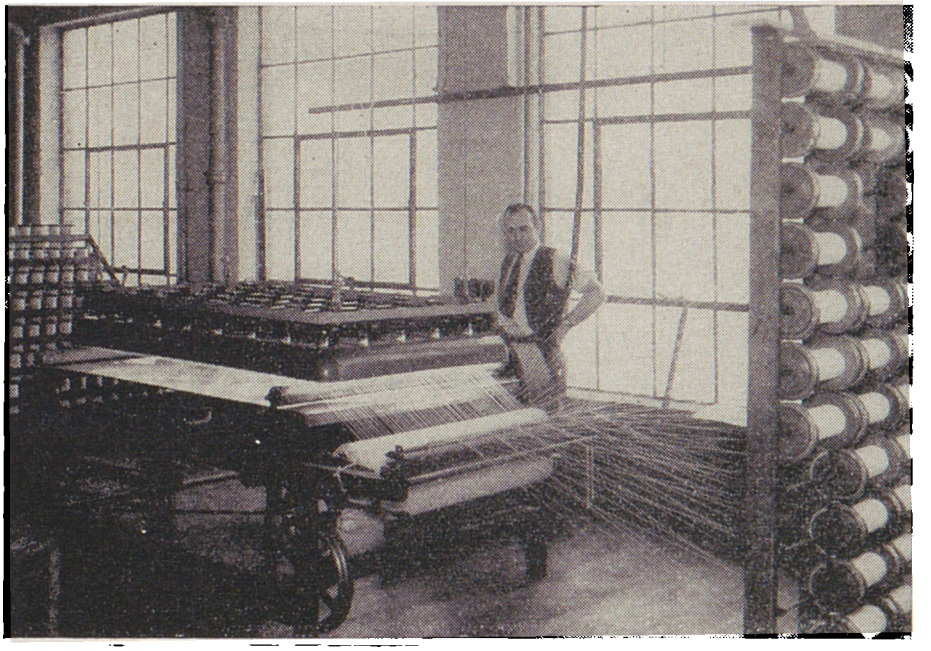


FIG. 8–53.—Composite unit of forty 375-watt lamps for removing approximately 7 per cent moisture from thread moving at a speed of 90 ft per min. Spools were formerly placed in convection oven from 4 to 16 hr. Use of radiant heat increased production from 25 to 100 lb per hr.

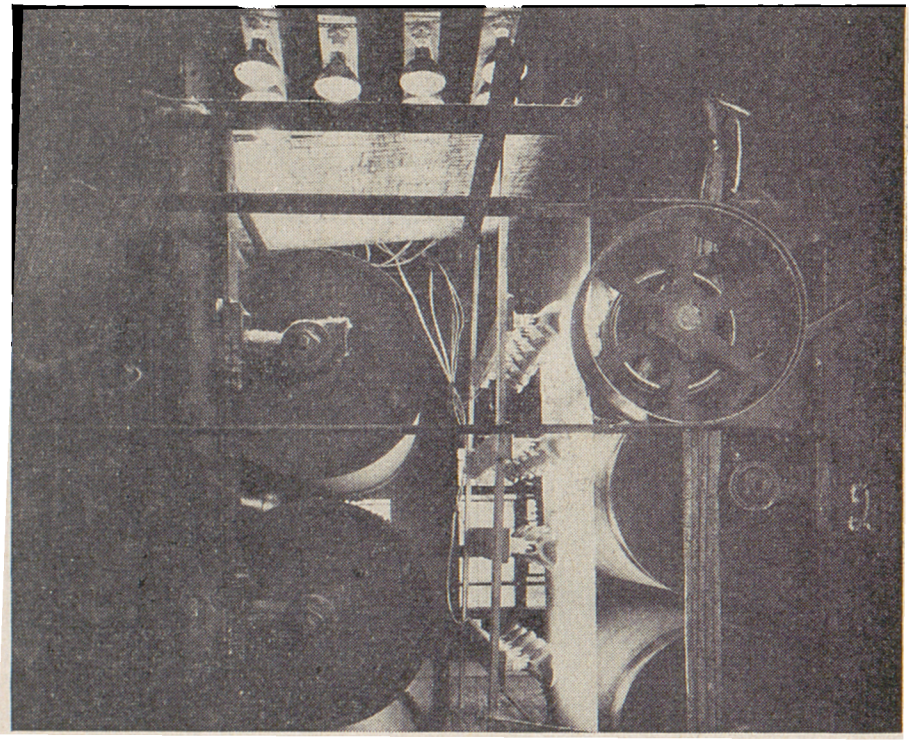


FIG. 8–54.—Supplemental heat supplied by forty-eight 250-watt reflector-type lamps resulted in 35 per cent increase in speed of conventional steam-can equipment used for drying burlap impregnated with a mold-resisting compound. The dryer now operates at a speed of 1,875 yd per hr.

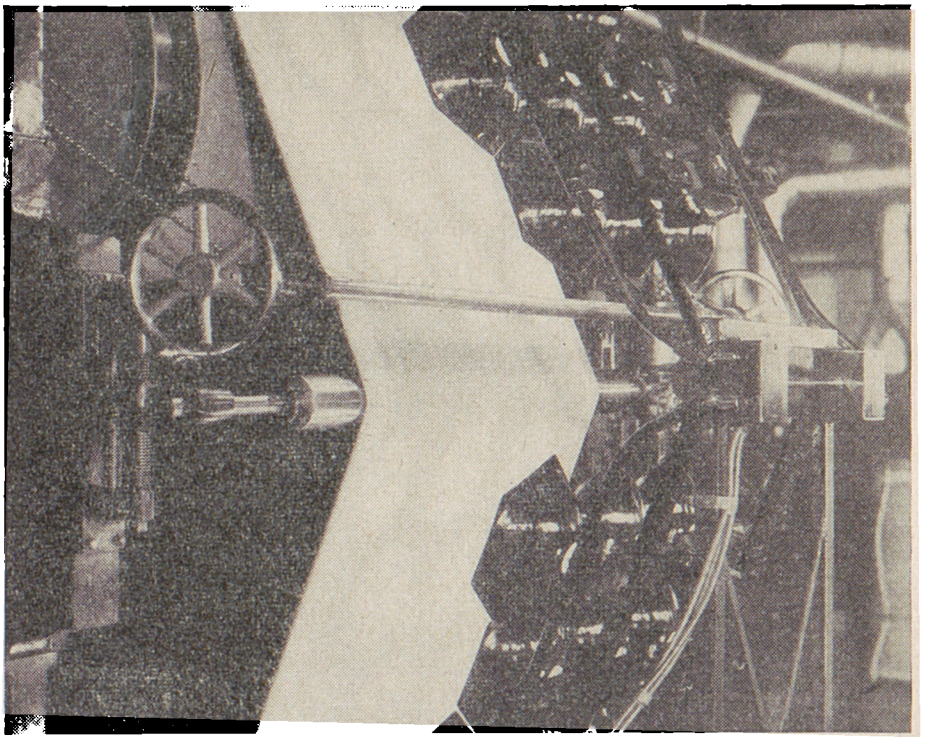


FIG. 8–55.—Use of infrared heat to supplement steam in drying the blanket on a sanforizing machine. By means of twenty-one 500-watt lamps and gold-plated reflectors, production of the dryer was increased from 18 to 21 yd per min. This method of drying also has served to increase the life of the blankets.

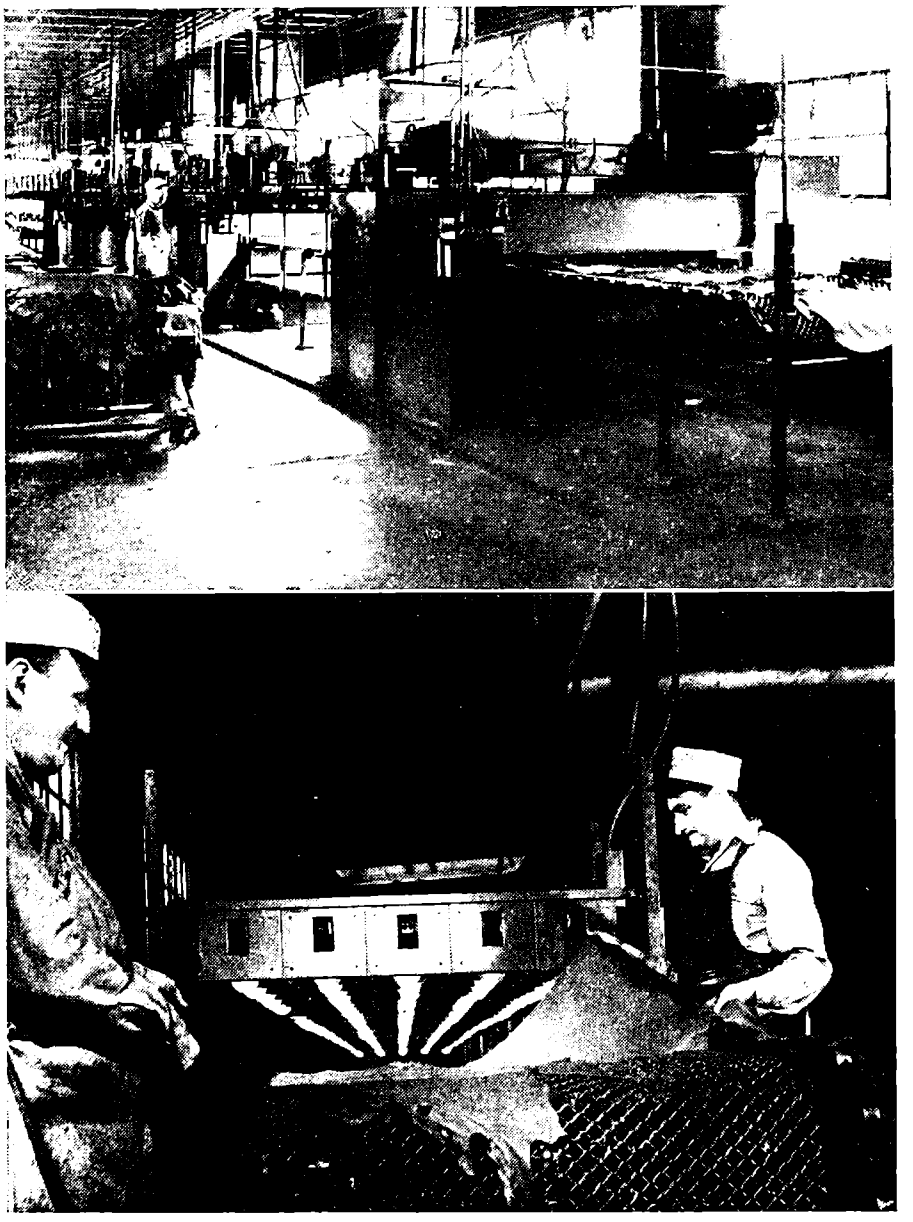


FIG. 8-56.—The equipment shown serves to spray-coat and dry the finish on animal hides at the rate of 27 per min. It consists of a series of automatic spraying stations each followed by a bank of infrared lamps adjusted to produce the desired dryness with no crusting or shrinking of skins and with no reprocessing required. Above, general view; below, delivery end of equipment.

FIG. 8–57.—Forty 500-watt lamps used to apply radiant energy for drying sprayed shoe-leather hides. Conveyor speed is 20 to 36 ft per min. The total length of the conveyor is 100 ft.

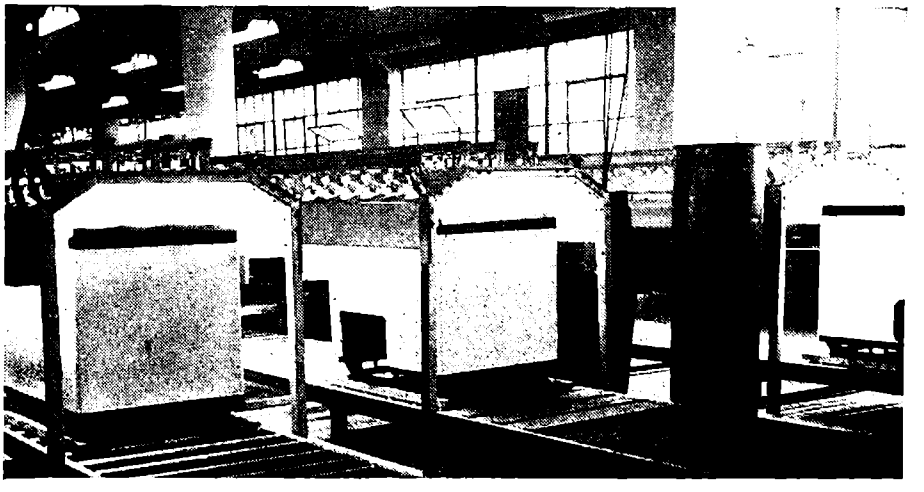


FIG. 8–58.—Fifteen kilowatt batch-type ovens used to plasticize the rubber cement serving as a bond between steel top and cabinet proper. Processing time about 5 min at 250°F.

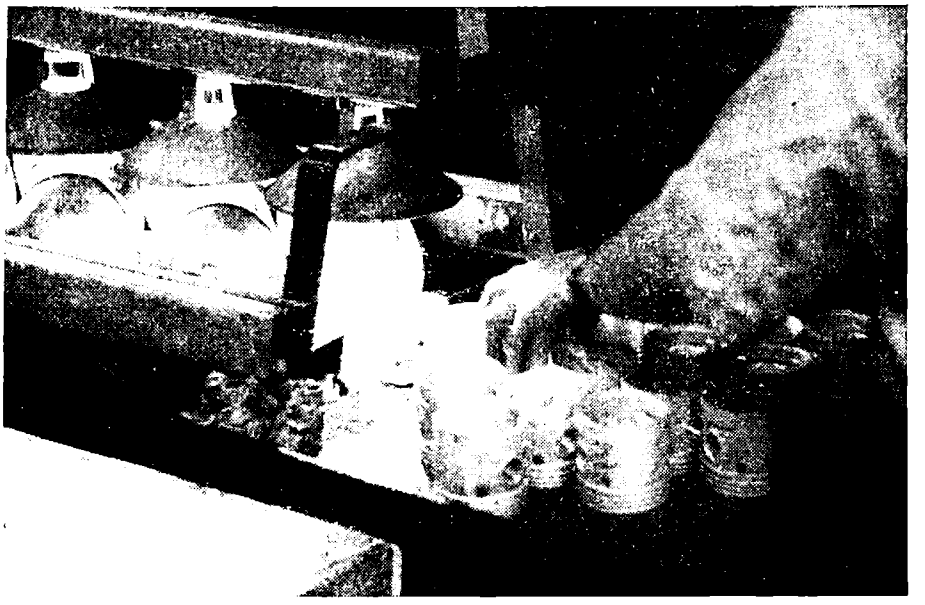


FIG. 8–59.—A small tunnel of 250-watt infrared lamps serves to provide the heat necessary for expanding automotive pistons sufficiently to allow insertion of the pins.

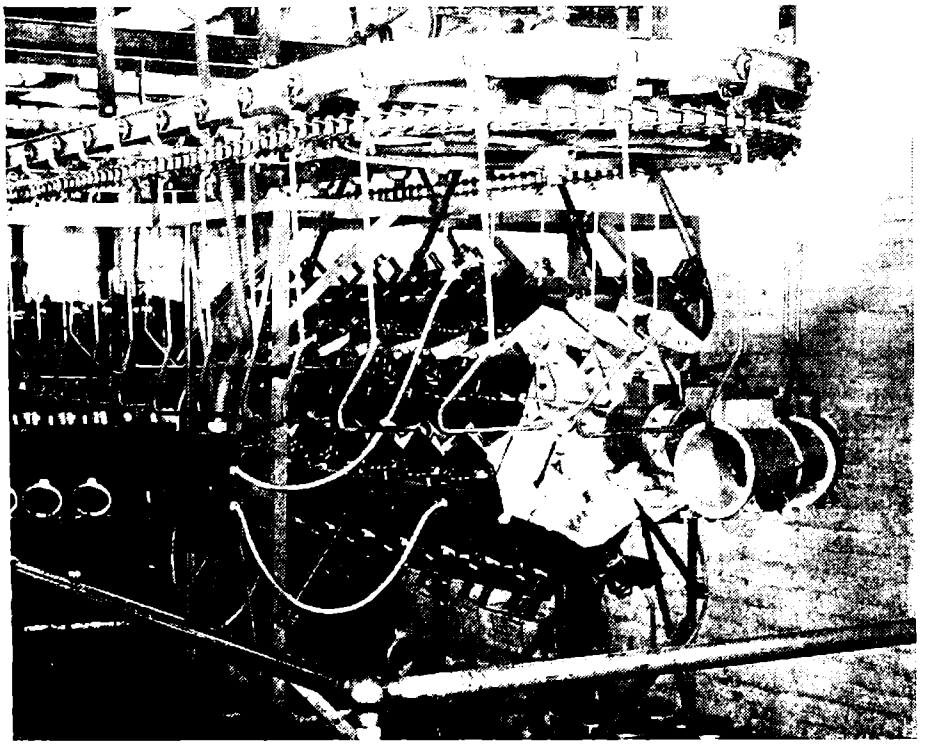


FIG 8–60.—Small aluminum motor frames being heated to 150°C by fifty-six 375-watt lamps. At this temperature, the 6¾ in.-diameter bore is increased by 0.02 in, which is sufficient to allow the wound primary coil to be dropped readily into place.

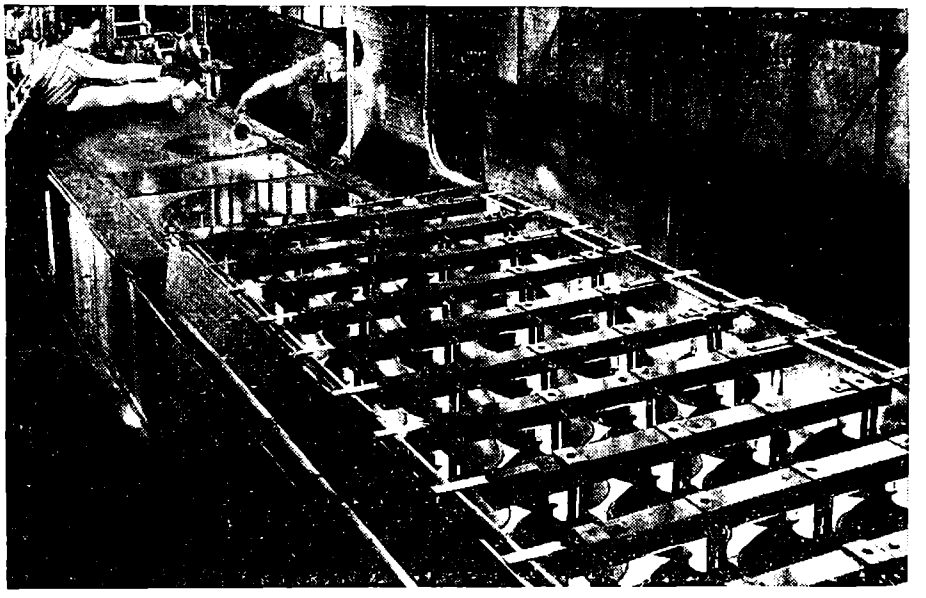


FIG. 8–61.—Infrared used for drying silver nitrate solution on back of mirrors. Drying time 15 min. Previously, steam coils were used beneath conveyor to keep temperature at 120°F. In summer it was necessary to fire steam boiler to supply heat for this one operation. The heat in the room was excessive. Use of infrared not only improved working conditions but also reduced the amount of equipment needed for the operation. Two hundred thirty-two 250-watt lamps are used.

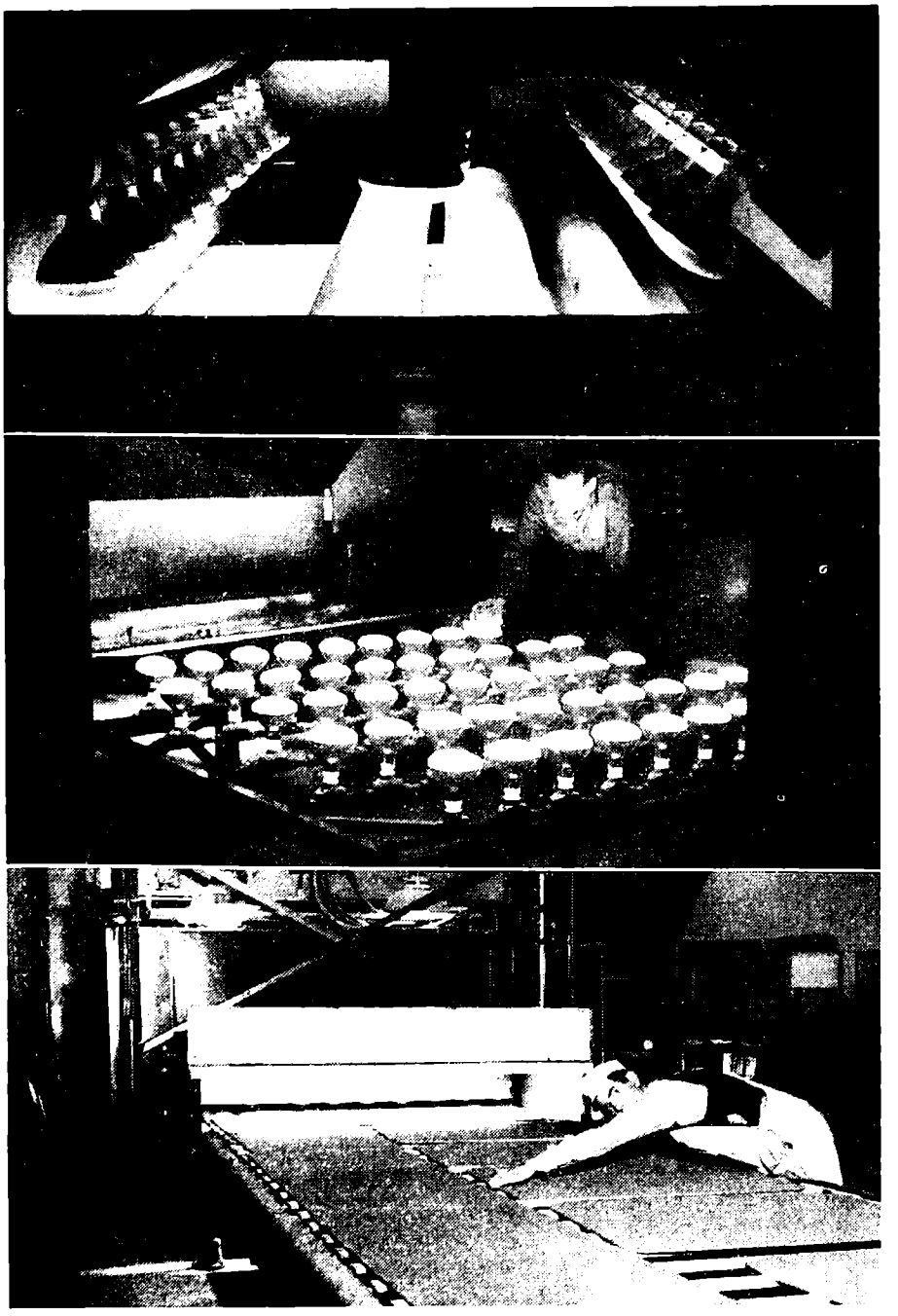


FIG. 8–62.—Infrared heat in the manufacture of glass mirrors. Top, the blotter installation supplemented with infrared lamps removes the water from the glass plates prior to preheating. Center, infrared supplies the preheat to the glass plates in preparation for spraying. The loss of energy which passes through the glass is more than compensated by the convenience and simplicity of the installation. Bottom, following application of a coat of shellac and of a standard backing paint, the mirrors are dried with more lamps and are then ready for final inspection. With this method there are few rejects.

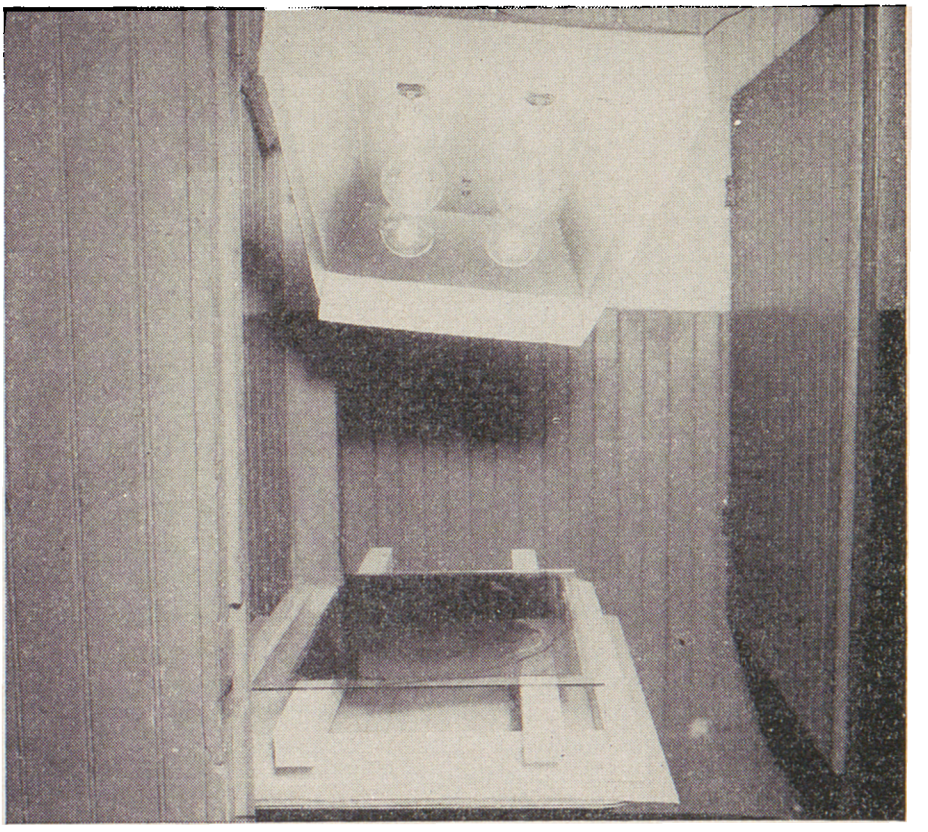


FIG. 8–63.—A photographic solution painted on glass is dried in 12 to 15 min by means of six 250-watt infrared lamps using a homemade reflector. Air drying formerly used required from 1 to 1½ hr and in hot, humid weather, could be done only in an air-conditioned room.

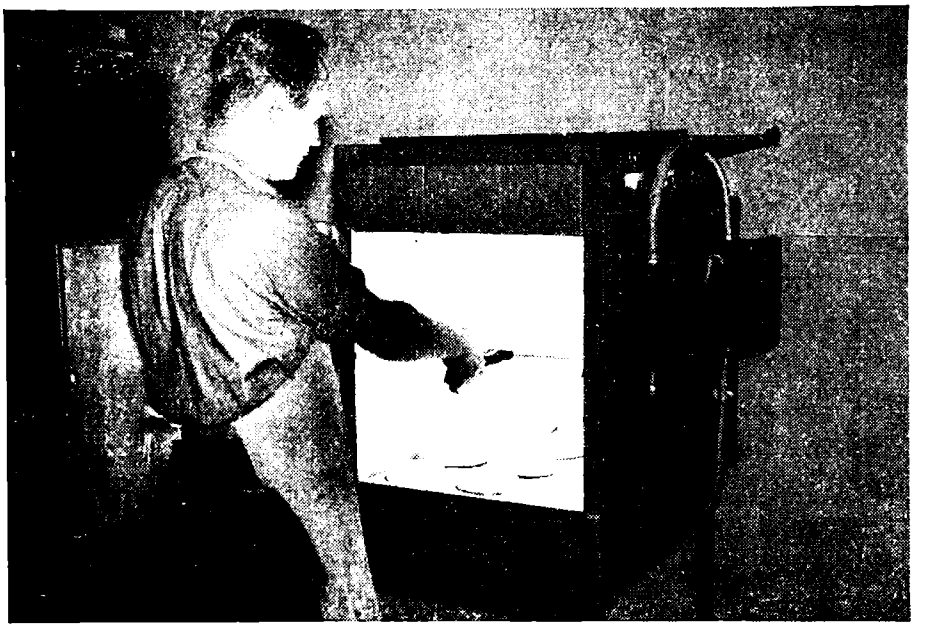


FIG. 8–64.—This infrared oven used in the photoengraving industry for baking or "burning-in" enamel on metal plates replaces the open-burner hand process formerly employed. The oven uses 24 (12 above and 12 below) 375-watt R-40 bulb reflector-type infrared lamps on a circuit connected to a timer which automatically turns off the lamps when the plates have been properly baked. The plates are cleaner, labor is saved, and "make-overs" eliminated.

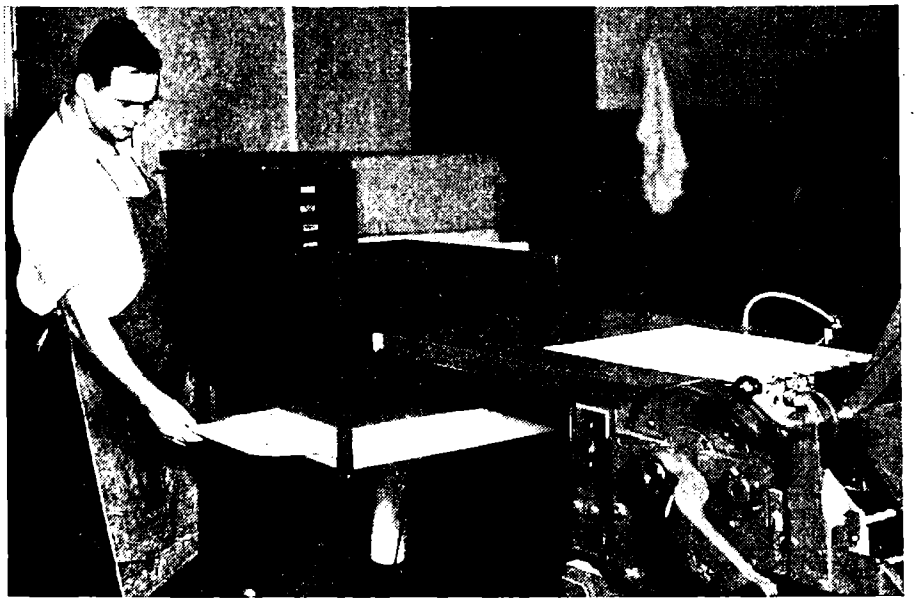


FIG. 8–65.—Smudging of proofs in this printing plant has been eliminated by this cabinet containing two 250-watt reflector-type lamps mounted eight inches above the shelf. The cabinet is portable so that it may be moved from one proof press to another as needed. The "inkiest" proof is dried in 54 sec

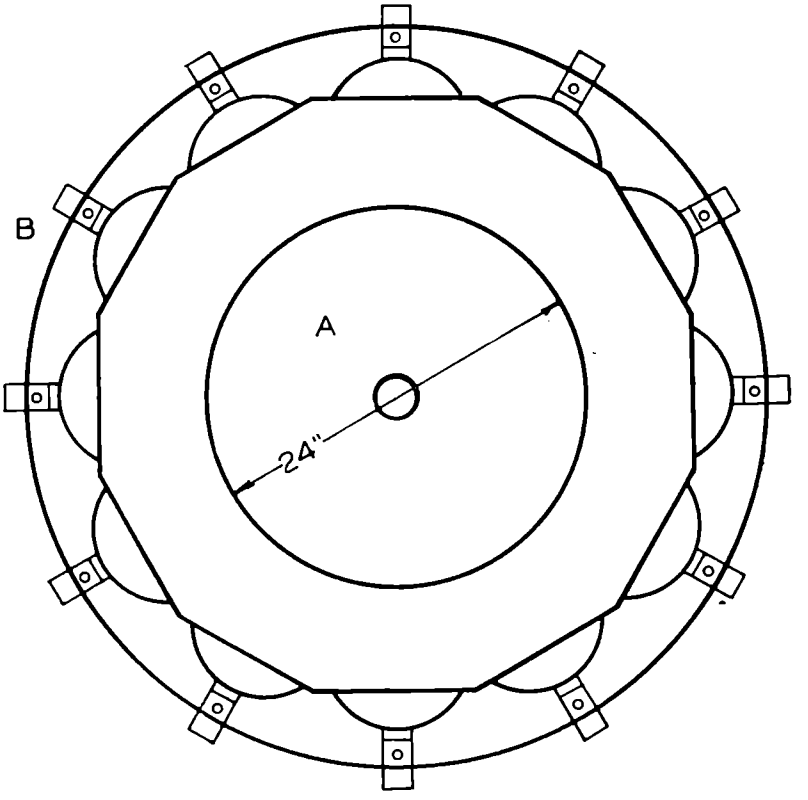


FIG. 8–66.—Arrangement of twelve 250-watt lamps and reflectors for drying ½-in.-thick layer of abrasives on grinding wheels 24 in. in diameter and 2 in. thick. Two wheels are dried simultaneously in 30 min. *A*, grinding wheel; *B*, steel ring for supporting reflectors.

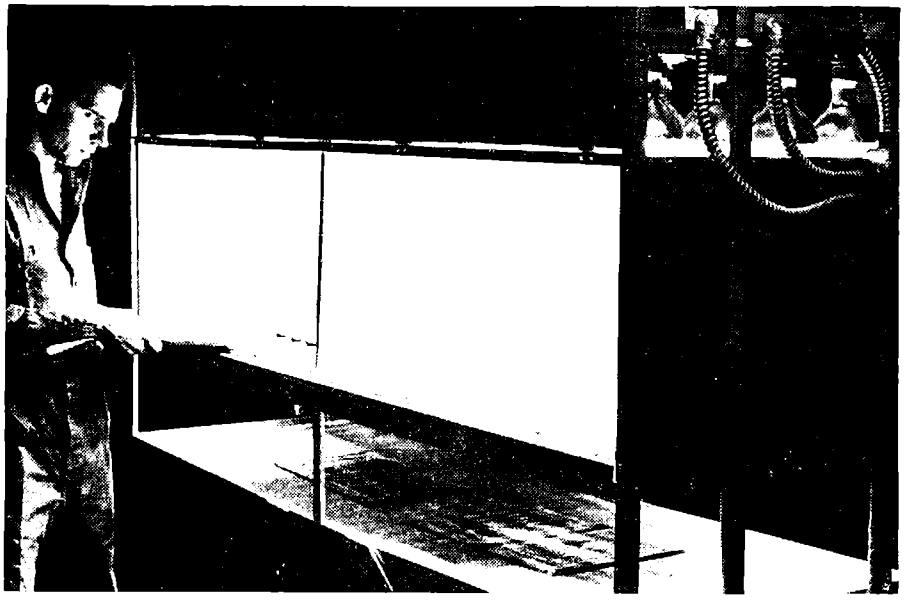


FIG. 8-67.—Enclosed cabinet using reflector-type infrared lamps for removal of moisture from the molding compound in industrial rubber-stamp patterns. The curing is accomplished in a few hours as compared with the several days required when conventional methods were used. In addition to increasing the speed of drying, the new method removed the threat of explosion formerly caused by generation of steam within the material when placed in the vulcanizing press.

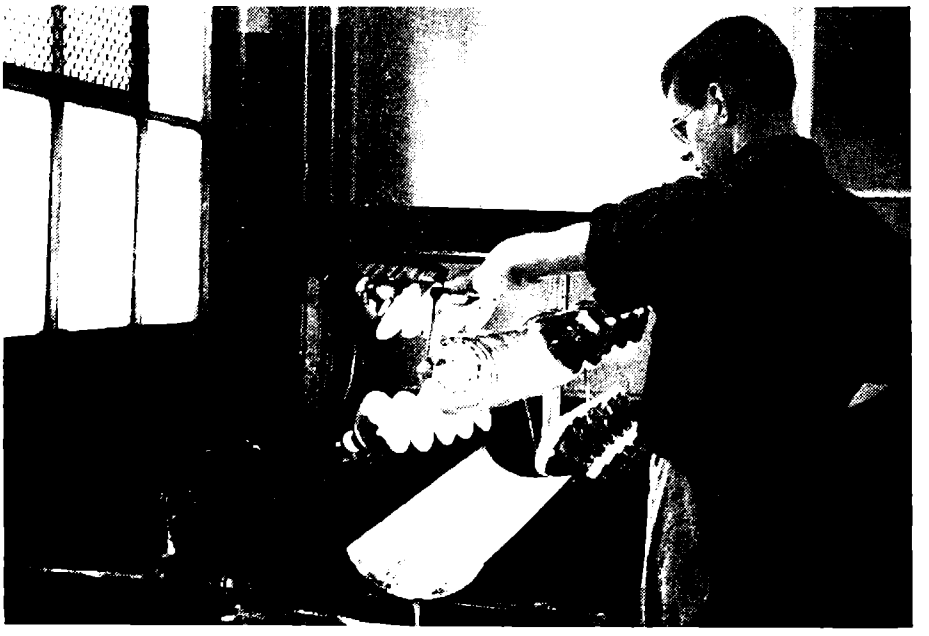


FIG. 8-68.—Reflector infrared lamps used for speedy drying of piston rings following cleaning operation.

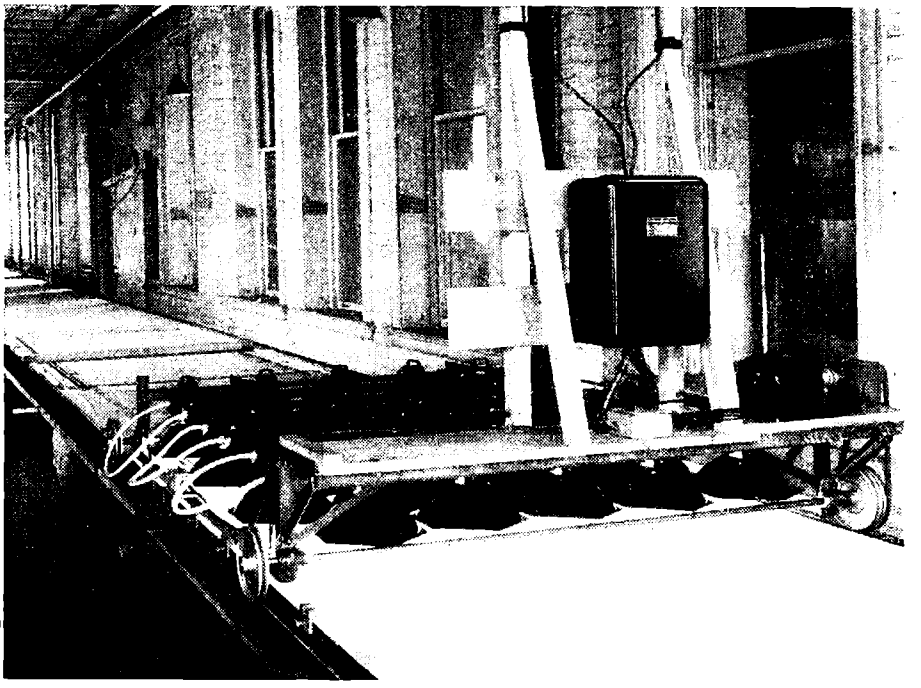


FIG. 8–69.—In this radiant-heat installation, the material remains stationary while the motor-driven unit consisting of thirty 250-watt lamps moves over it. Ink is dried on each 54 by 54 in. tablecloth (Koroseal) in 1 min 20 sec. Former method required 15 min for drying each cloth.

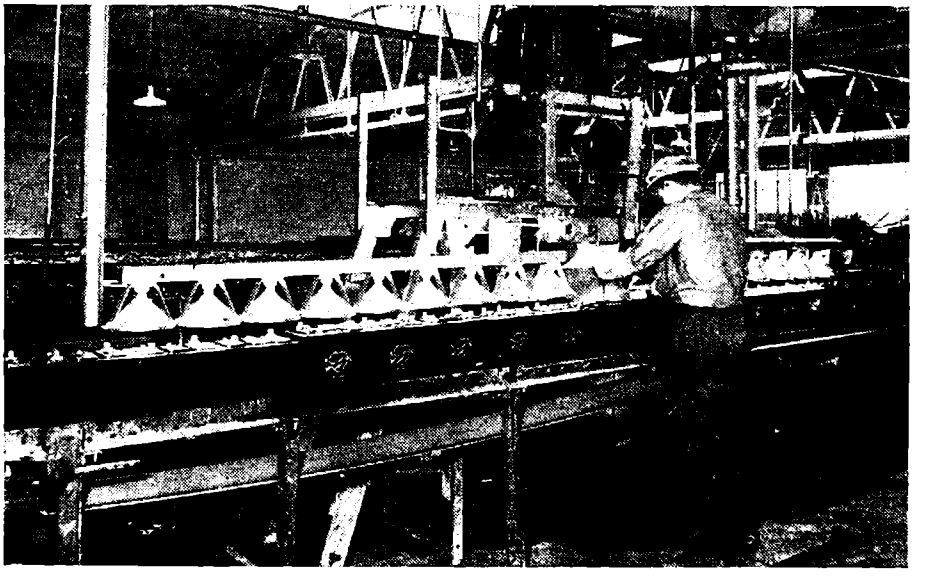


FIG. 8–70.—Fusion of the material in storage-battery cases with the tar used to seal them is accomplished more satisfactorily and economically by means of radiant heat than by heating methods previously used.

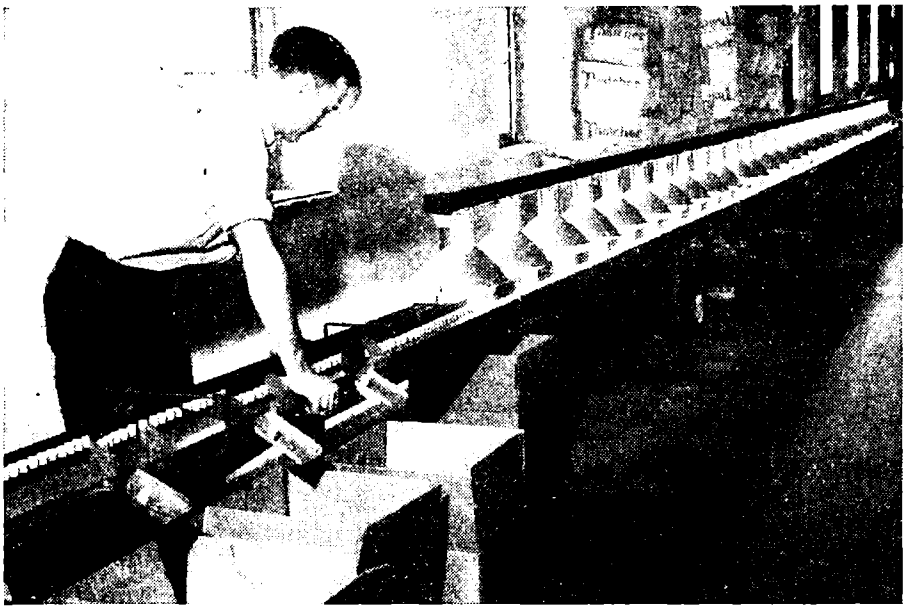


FIG. 8–71.—Here a bank of thirty-two 240-watt infrared lamps and gold-plated reflectors are used to dry the glue supplying the adhesive bond between wooden tops and cork shanks.

FIG. 8–72.—Strikers on safety-match cases are dried as they pass on a conveyor under six 250-watt lamps.

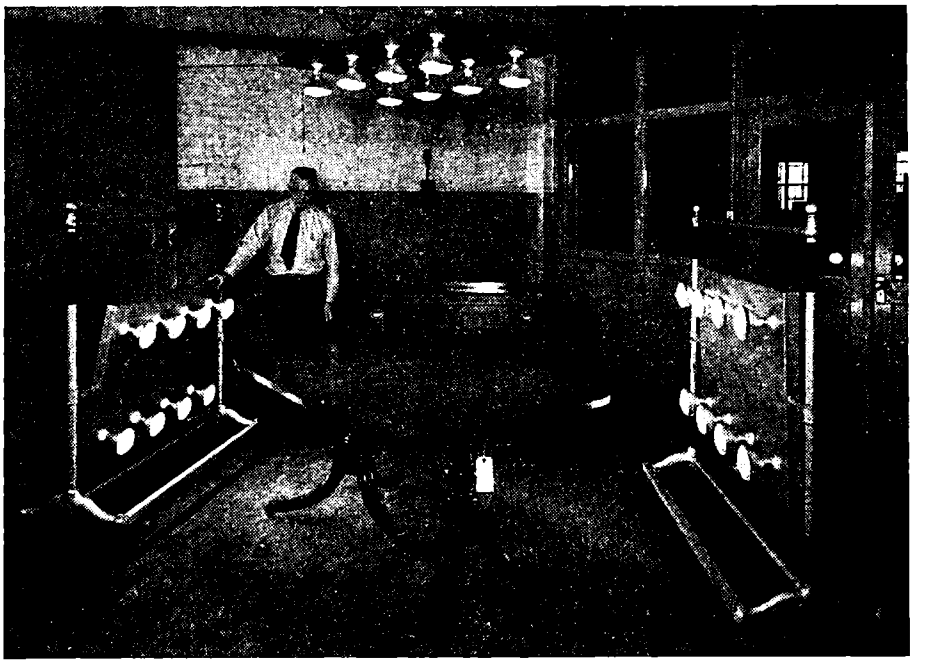


FIG. 8–73.—Refinishing of fine furniture often requires the application of several finish coats. With air drying, each coat usually is allowed to dry overnight. In this shop, the use of a few 250-watt infrared lamps reduced the drying time to 20 min per coat. Note that the floor stands are mounted on castors while the unit above is suspended on pulleys and weighted to provide for easy adjustment of distance between the lamps and the surface being dried.

CHAPTER IX

MISCELLANEOUS USES OF INFRARED RADIATION

Although infrared radiation has found by far its largest field in industrial-heating and -drying applications, its use is by no means restricted to the industrial field. Among many other uses might be included therapy, photography, industrial-plant protection, comfort heating, other applications in the home and office, and insect extermination.

Therapeutic Usage

Lower wattage incandescent lamps long have been used by the layman for the treatment of human ills where the application of heat seems to afford relief. Physicians and hospitals apply heat to the human body by means of 1,000- or 1,500-watt general-lighting-service lamps where larger areas are to be covered. Infrared heat has found favor for this purpose because the characteristics of the radiation produced by an incandescent source are such that the penetration of the human flesh is greater than can be accomplished by other devices, such as, for instance, hot-water bottles and heating pads. As the result of the penetration, infrared radiation produces the desired therapeutic results more rapidly and with less discomfort than possible with the other commonly used heating devices.

Much has been said of the curative or healing powers of infrared heat for numerous ills, it even having been reported that infrared shows promise in the treatment of burns. However, in this connection it should be noted that reputable lamp manufacturers make no specific claims concerning the therapeutic value of infrared lamps, this being in the province of the medical profession.

Infrared Photography

In contrast with usual photographic methods that normally require a bountiful supply of either natural or artificial light, photographs may be taken in total darkness by means of special

infrared-sensitive films and lamps (photoflash or photoflood) whose visible light is absorbed by infrared-transmitting filters. The filter may be a separate glass screen, or the lamp bulb itself may be of the light-absorbing infrared-transmitting variety. By this means photographs may be taken in the darkness without the knowledge of the subject being photographed (Fig. 9–1).

FIG. 9–1.—Photograph of skater taken in total darkness without the aid of visible light by means of an infrared photoflash lamp. The subject was not aware that the picture was being taken.

The haze- and smoke-penetrating powers of infrared radiated by the sun make it possible to photograph distant invisible objects.

Plant Protection

Protection of plants and critical areas against night theft and sabotage may be accomplished by means of incandescent lamps with light-absorbing filters in conjunction with infrared-sensitive photocell equipment. The lamp, with the proper reflecting equip-

ment, projects an invisible infrared beam onto and energizes a distant photocell so that, if the beam is intercepted by the passage of a person or object, the photocell will be deenergized. The cell is electrically connected to some remote point so that, when the beam is intercepted, an alarm will be given. Thus, it is possible to detect the presence of an intruder without his knowledge. Lamps for this purpose differ from those used for industrial heating in that they usually are of low voltage in order to provide a relatively small source (the lamp filament) of radiation suitable for projecting a concentrated beam.

Insect Extermination

Infrared in proper dosages has been used successfully in the rapid extermination of various types of insects having circulatory systems. Fleas on dogs may be killed with infrared without apparent discomfort to the animal. Likewise, radiant heat has been found useful in the delousing of clothes. Infected grain has been freed of weevils and other insects and larvae by subjecting it to infrared radiation. This is accomplished without harm to the grain.

In the Home and Office

In addition to therapeutic purposes (Figs. 9–2 and 9–3) infrared lamps are becoming more and more popular as a source of energy for many purposes requiring heat in or around the home. One or more lamps, used preferably in conjunction with a small electric fan, will dry small articles of clothing with great rapidity. A single lamp, also used with a small fan, provides the means for speedy drying of the hair (Fig. 9–4). Drying of fingernail polish (Fig. 9–5) in one-fourth the usual time can be accomplished by use of a single lamp. In the kitchen, the reflector infrared lamp finds use in quickly thawing out frozen foods (Fig. 9–6).

Infrared lamps in groups of two or more in the form of a portable unit may be employed for spot comfort heating (Figs. 9–7 and 9–8) in the same manner as open-coil radiant heaters. Lamps may be located on the walls (Fig. 9–9) or ceilings (Fig. 9–10) of bathrooms to provide comfort during shaving or bathing. Special heat-resisting glass bulb lamps (Fig. 9–11) can be had for use in those

areas where drops of water falling on the bulb might cause the usual type of lamp to break.

FIG. 9–2.—For either "chill chasing" or therapeutic purposes, a single reflector-type lamp provides a convenient and efficient source of infrared radiation.

Areas around workbenches in unheated attics, garages, and farm buildings can be made comfortable for winter use by suspending lamps from the ceiling above the working area (Fig. 9–12).

Infrared heating of the carburetor for a few minutes prior to use of the car facilitates cold-weather starting. Lamps may be used to expedite the thawing of frozen pumps and pipes.

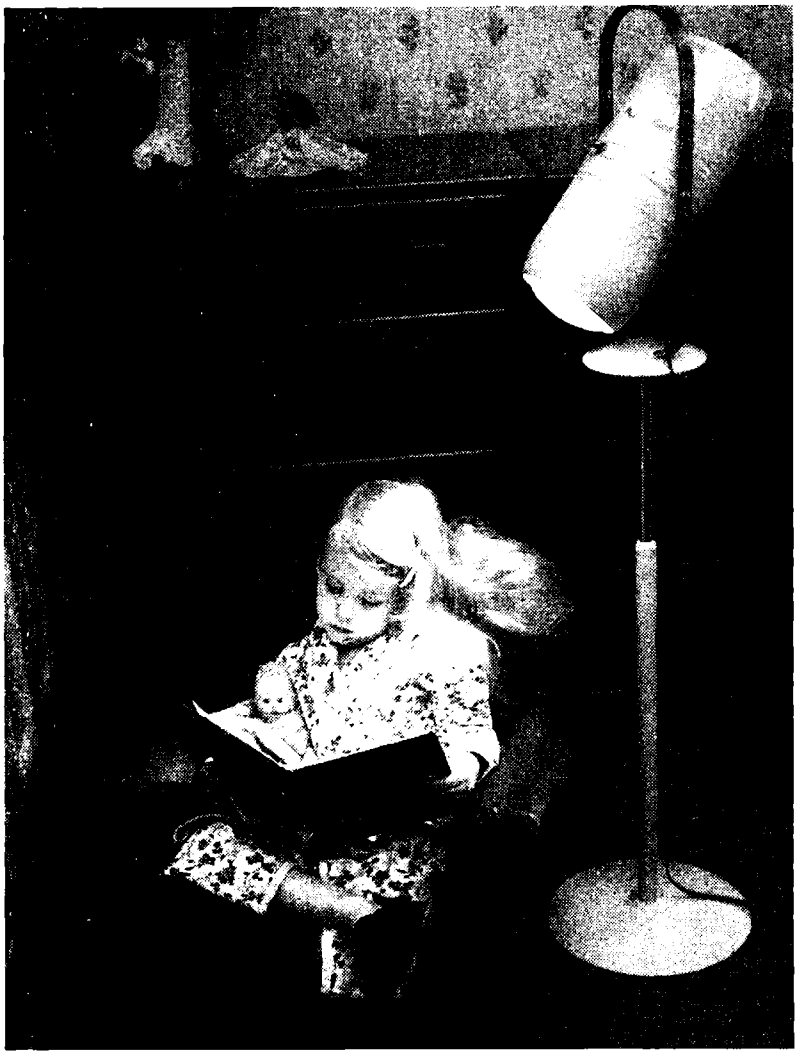


FIG. 9–3.—Dual-purpose unit equipped with both sun and infrared lamps for use in the home. The upper part of the unit may be disconnected from the upright stem and used as a table model.

FIG. 9–4.—Hair drying is made easier by means of a single 250-watt infrared lamp.

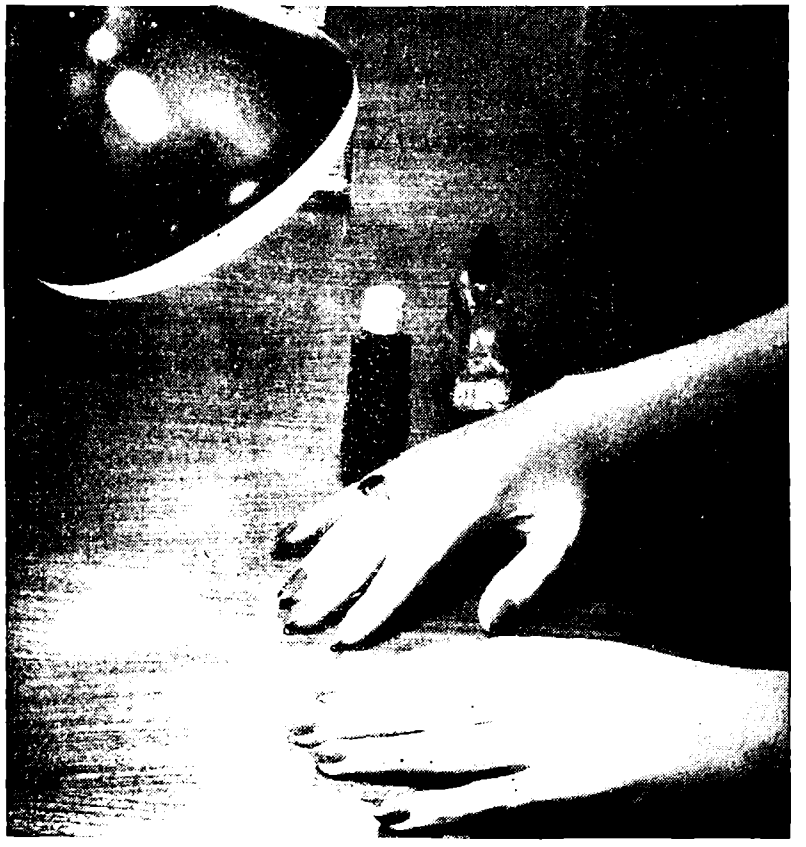


FIG. 9–5.—Ultra-high-speed drying of nail polish by means of a single 250-watt reflector-type infrared lamp.

FIG. 9–6.—No more meals delayed by waiting for frozen steaks, chicken, etc. to thaw—a single infrared lamp will expedite the process.

FIG. 9–7.—Two 250-watt infrared lamps on adjustable bracket attached to desk provide the supplementary heat often needed on cold days.

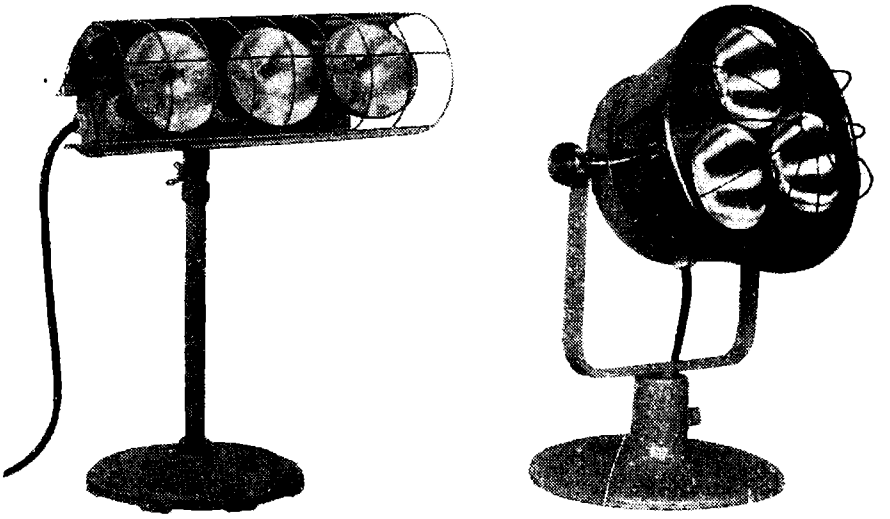


FIG. 9–8.—Experimental models of radiant heaters employing three 250-watt infrared lamps. These may be used as a source of comfort heating in the same manner as open-coil radiant heaters have been used in the past.

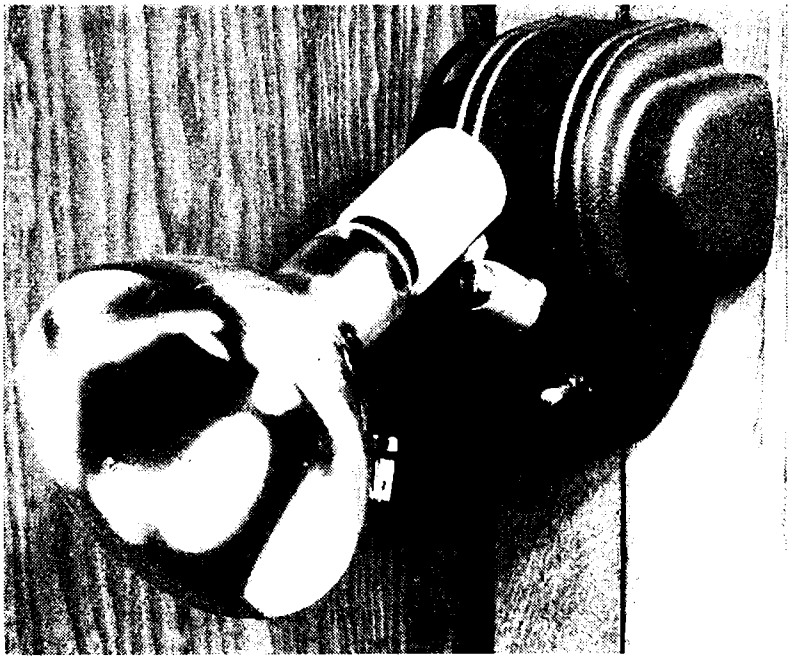


FIG. 9–9.—Typical infrared unit with reflector-type lamp for home use. It may be mounted on wall (as shown) or on table.

FIG. 9–10.—Ultramodern bathroom showing built-in ceiling units that accommodate not only an infrared lamp for comfort but also a sun lamp for tanning and health and a reflector-type lamp for general illumination.

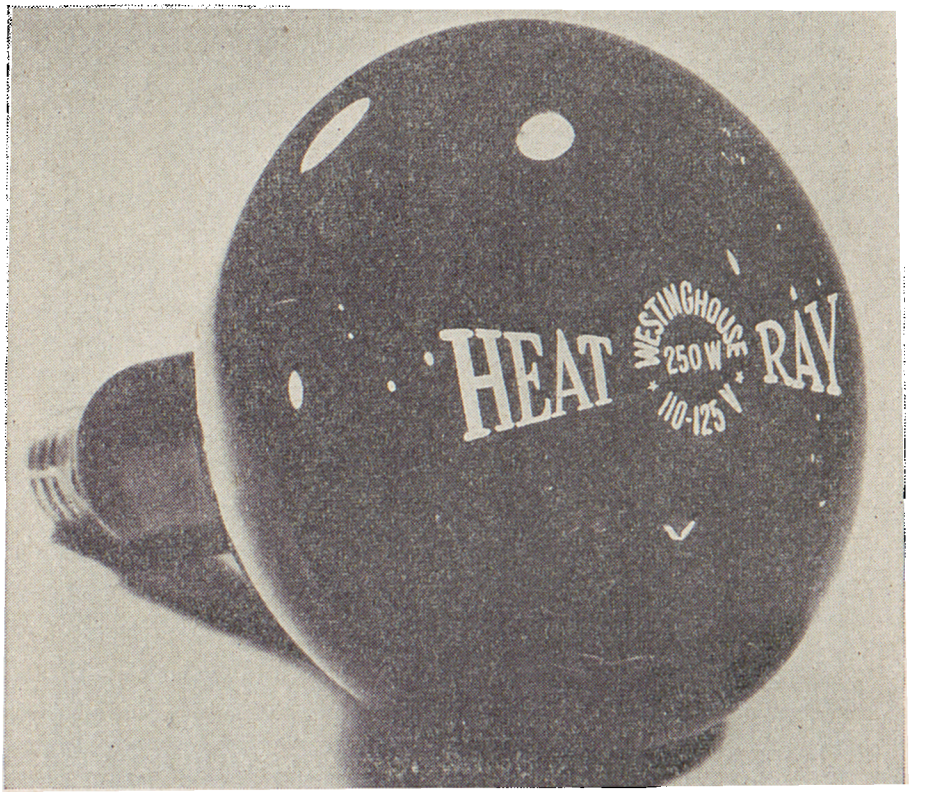


FIG. 9–11.—Reflector-type R-40 bulb infrared lamp especially recommended for home use. Its heat-resisting glass bulb minimizes possibility of breakage on contact with water, while distinctive red glass reduces glare and makes identification easy.

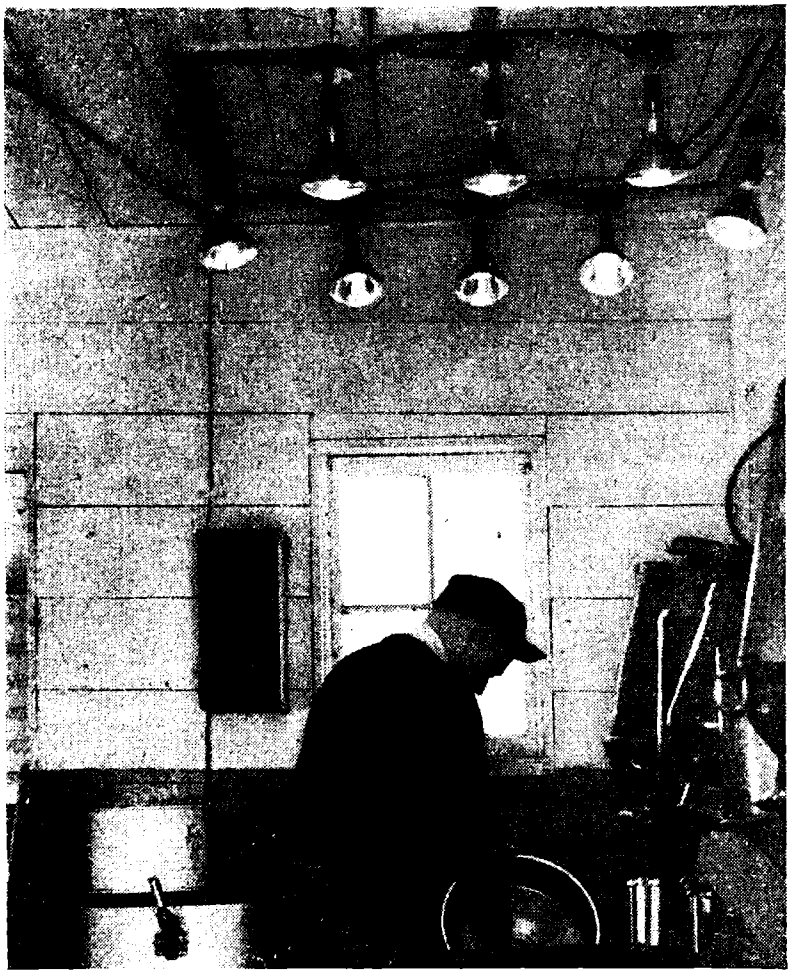


FIG. 9–12.—In this unheated milkhouse where the winter outdoor temperature is below freezing, the operator works in the comfort provided by the heat from a rack of 250-watt infrared lamps suspended overhead. The incidental light from the lamps supplies sufficient illumination for nighttime work.

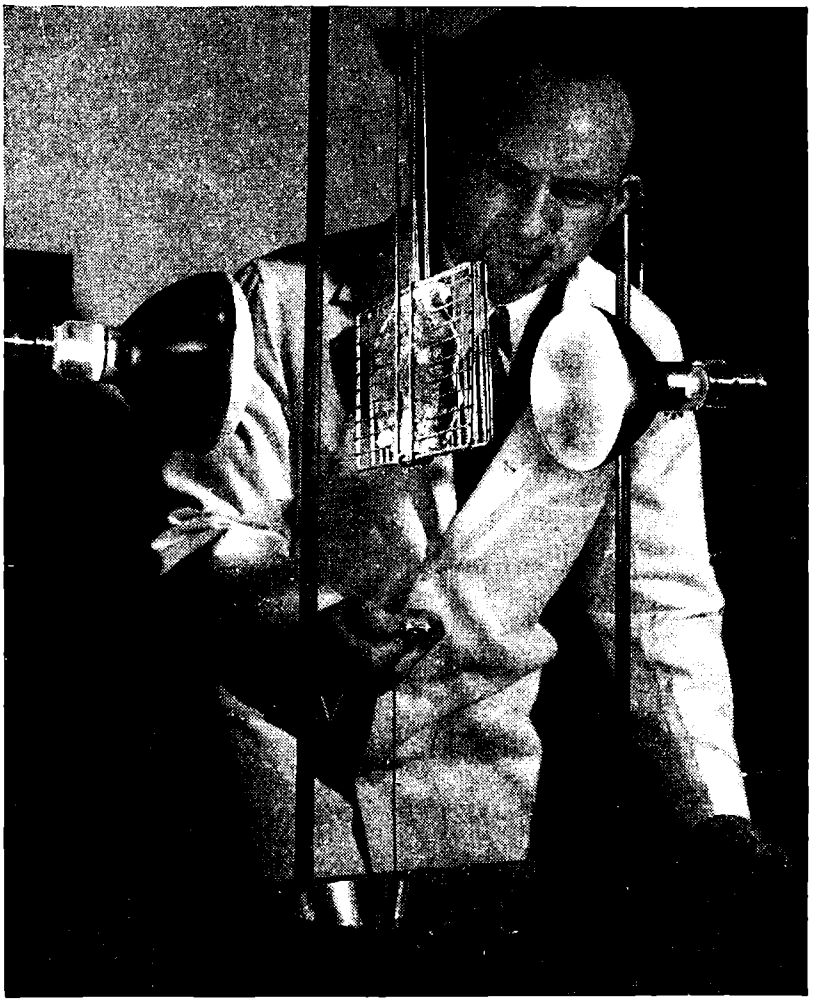


FIG. 9–13.—Experimental infrared cookery wherein two 250-watt reflector lamps are used in broiling steak in 8 min.

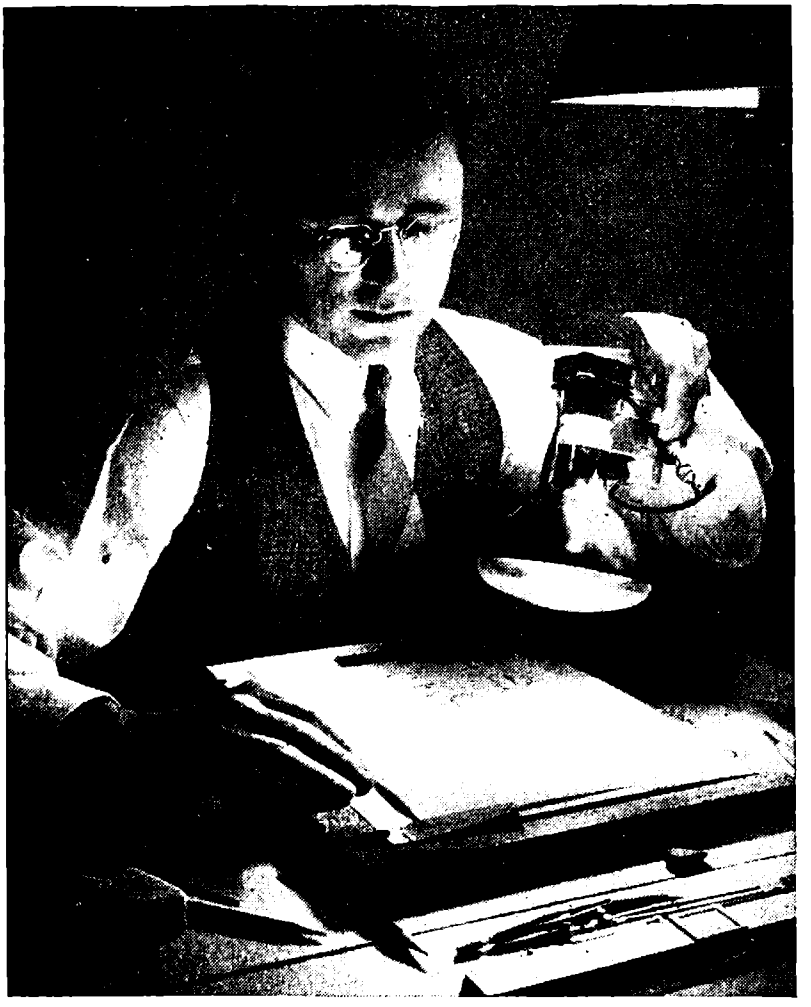


FIG. 9–14.—Although the wiring doubtless would not survive N.E.C. scrutiny, the 250-watt infrared lamp shown is found very useful by this draftsman in the quick drying of ink on patent drawings. It is especially effective in humid weather. Use of infrared largely eliminates the need for "touch-ups" following eraser cleaning of a drawing.

APPENDIX

EFFECT OF INFRARED RADIATION ON THE HUMAN BODY

Mindful of the painful effects of sunburn and conjunctivitis that sometimes occur as the result of exposure to ultraviolet radiation, queries have arisen from industrial users as to whether infrared might have a harmful effect on those working in the vicinity of an oven.

Effect on the Skin

Infrared will not produce a "sun" burn. Prolonged or excessive exposure to infrared radiation may produce a burn of about the same characteristics as, for example, a hot-water bottle. In industrial applications, there is no occasion for a workman to come in close contact with the lamps for a period of time sufficient to cause a burn of this nature.

Effect on the Eye

Infrared likewise will not cause conjunctivitis. Many statements have been made concerning the effects of infrared radiation on the different structures of the eye, but so many of these processes could and do occur without exposure to infrared radiation that it is difficult to evaluate the true role of infrared.

So far as is known, there are no recorded cases of eye injury resulting from the use of infrared lamps for industrial purposes. Probably there is some safe limit to which the eye can be exposed without producing ill effects, but there is no knowledge of a definite value having been established by a recognized authority. However, it appears that the eye would have to be within a foot or so of an infrared lamp over a considerable period of time before injury could be expected. Such a condition is most unlikely to exist in an industrial installation.

Where it is felt that protection of the eye from infrared radiation is desirable, special infrared-absorbing glass for use as eyeglass or goggle lenses is available. Among these are Calobar (American Optical Company) and glass filters No. 3961 and No.

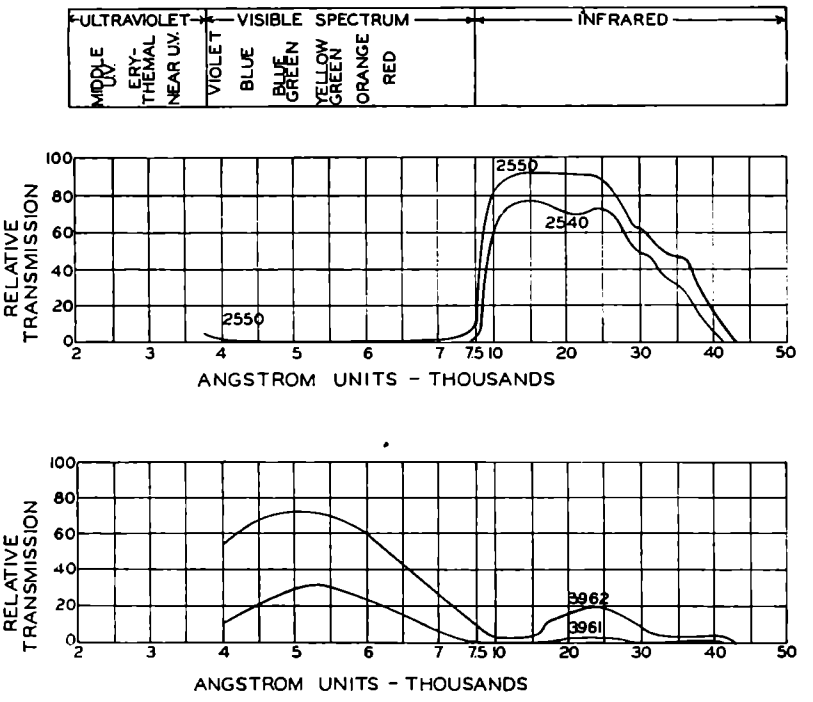


FIG. 9–15.—Curves showing transmission characteristics of four types of glass made by the Corning Glass Works. As indicated, numbers 2540 and 2550 are suited to applications where it is desired to screen out the visible light and transmit as much of the infrared radiation as possible. Numbers 3961 and 3962 are in contrast with numbers 2540 and 2550 in that the former are designed for absorbing most of the infrared radiation and transmitting a relatively high percentage of the visible light.

3962 made by the Corning Glass Company (Fig. 9–15). The usual type of glass lens transmits infrared radiation and does not serve as a protection to the eye.

Effect on Other Human Organs

Use of infrared lamps for bodily comfort in an industrial establishment developed the question as to whether radiated heat might be injurious to women, particularly to the reproductive organs.

There appears to be no evidence sustaining the belief that the use of infrared lamps is injurious to the reproductive organs of women. In this connection it should be pointed out that heat has been one of the basic forms of therapy for some years and is so recognized by the medical profession. In fact, special devices have been constructed for the purpose of applying infrared heat directly to the lower genital tract and to approach, as closely as possible, the intrapelvic organs themselves.

GLASS FILTERS

As previously indicated, certain infrared applications may require the use of filters that absorb most of the visible light while allowing a maximum transmission of the infrared radiation, as contrasted with filters designed for absorbing the infrared and transmitting most of the visible radiation. Figure 9–15 shows the transmission characteristics of typical glass filters suitable for the above purposes. There also are numerous other types of glass filters designed for use primarily in colorimetry and scientific work where it is necessary to isolate specific portions of the spectrum. The glass manufacturer should be consulted for data and recommendation on the type of glass that would be best suited for a given purpose.

GAS-FIRED INFRARED GENERATORS

Gas-fired infrared generators usually consist of a silica-brick device or a carbon-compounded ceramic unit (Figs. 9–16 and 9–17) that generates infrared radiation when heated to a high temperature by a gas flame.

The outstanding advantage of the gas as compared with the electric infrared generator lies in the former's ability to produce a higher concentration of heat than is feasible with electric equipment now available. For example, a burner of 2⅜ in. diameter (4.43 sq in. area), with a gas pressure of 1 lb per sq in., discharges heat at the rate of 32,000 Btu per hr; likewise, a 6⅝ in. diameter (34.5 sq in. area[1]) is rated at 103,000 Btu per hr. As compared with this, a 375-watt R-40 bulb infrared lamp with a

[1] Burners up to 40 sq in. area operating at temperatures as high as 3000°F are available.

5-in. diameter (19.7 sq in. area) generates a total of some 1,200 Btu per hr.

As would be expected, gas infrared equipment has been found to be most useful in those heat processes wherein the time element or some other factor makes very high concentrations of heat es-

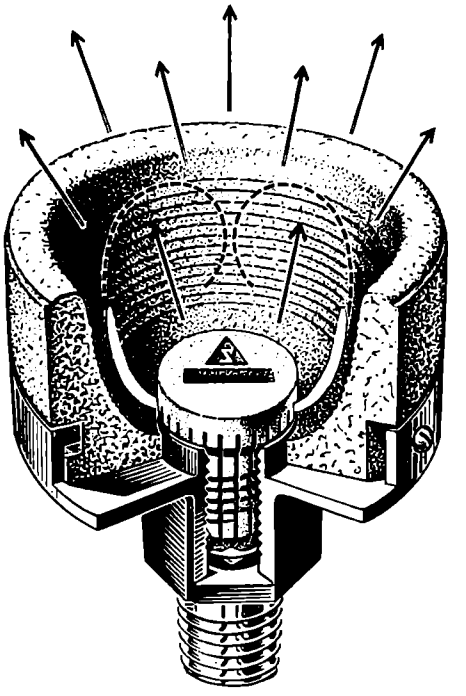


FIG. 9–16.—One type of infrared or "radiant-cup" gas burner wherein a mixture of gas and air under pressure feeds the flames emanating from slots located radially around center ceramic plug. These flames scud the cup wall heating it to incandescent temperatures as high as 3100°F.

sential. Among these processes might be mentioned annealing (Fig. 9–18), hardening, forging, and brazing (Fig. 9–19) of metals, the firing of ceramics, and the application to high-speed printing presses. In the latter, the time of exposure to the heat is extremely short; hence, if appreciable heat is to be absorbed by the paper, the concentration of the applied energy must be high.

In the metal heat-treating field, it is reported, for example, that "solid 3-in. round billets have been brought to a uniform 2100°F temperature in 8 min in a gas infrared apparatus no larger than an inverted wastepaper basket." Use of infrared gas burners is

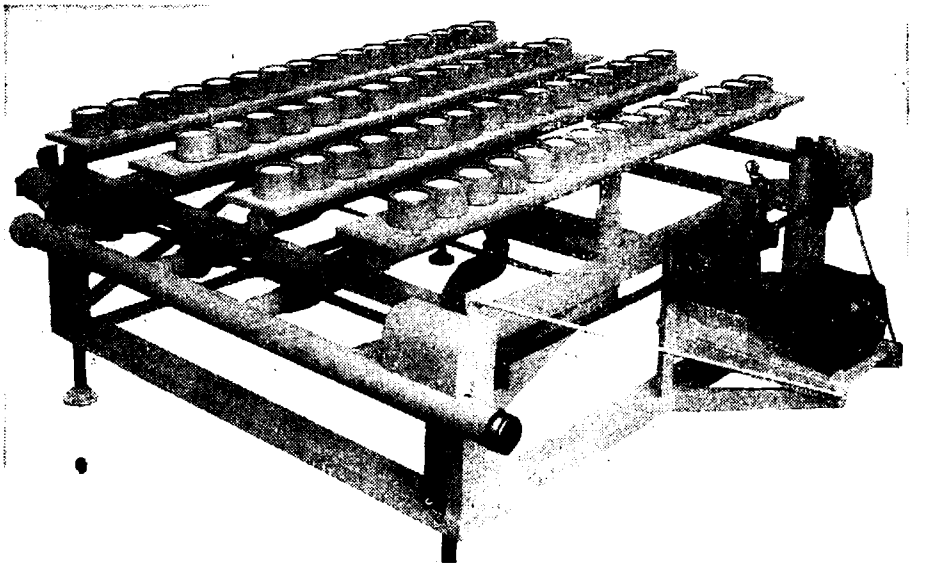


FIG. 9–17.—Typical arrangement of radiant-cup gas burners. Note motor-driven mechanism for raising or lowering the units by means of which the distance between the burners and the material being processed may be varied at will. The unit can be used in either a vertical or a horizontal (as illustrated) position.

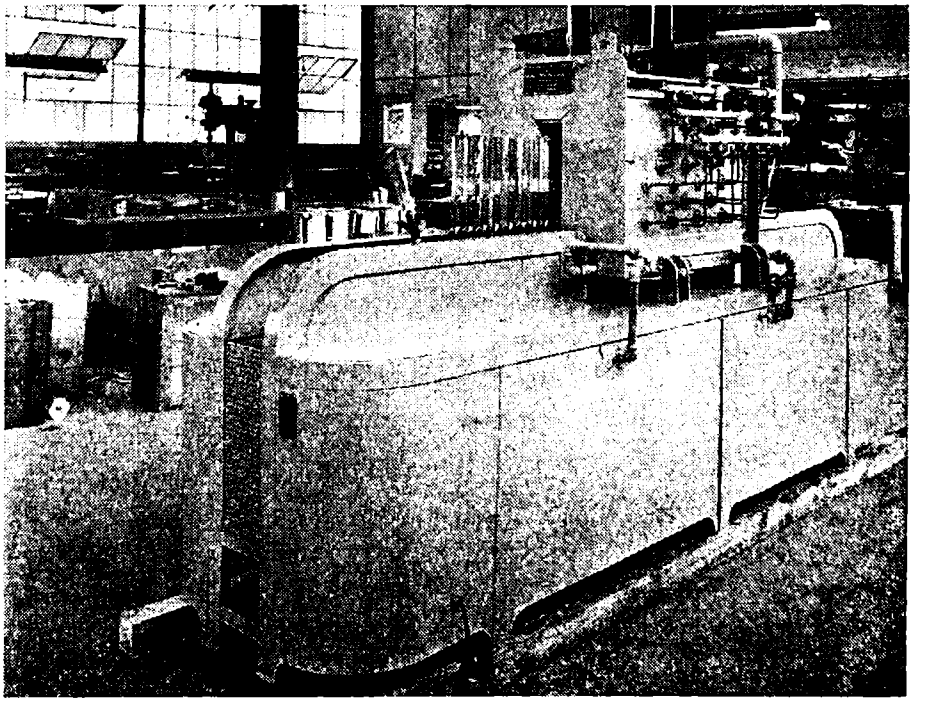


FIG. 9–18.—An enclosed radiant-gas-burner installation used for annealing collapsible aluminum tubes at a temperature of approximately 800°F.

said to have made it possible to increase printing-press speeds "from 350 ft to over 1,000 ft per min."

Although there may be some overlapping of service, it would appear that gas (as related to purely infrared and not to combined infrared and convection gas ovens) and electric infrared equipment each has a rather well-defined field of application in

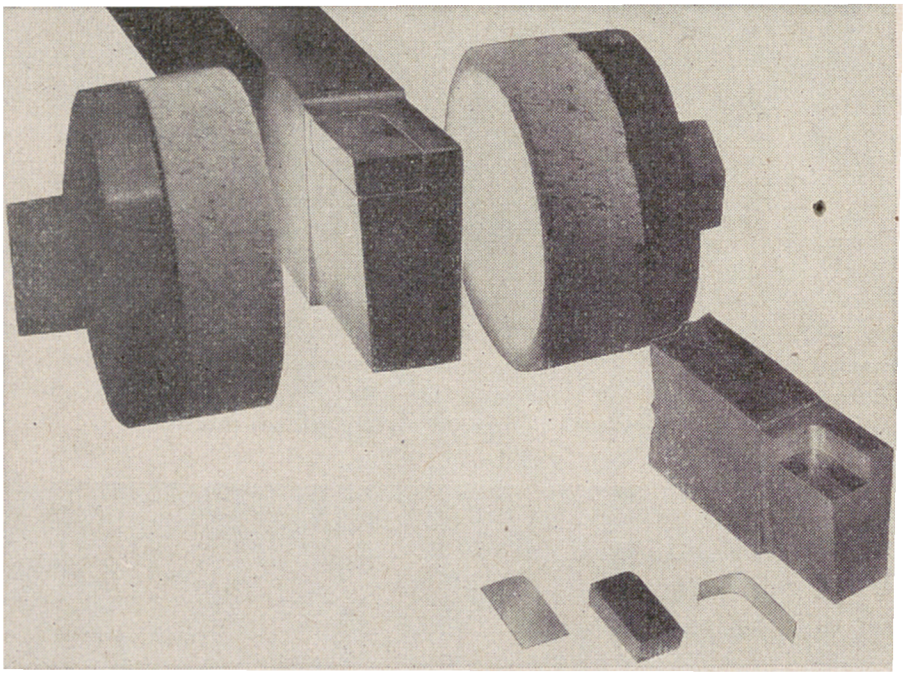


FIG. 9-19.—Two infrared gas burners used for silver brazing of carbaloy tip on tool shank in 3 min.

which it will suffer little from the competition of the other. The high heat concentration possible with gas burners cannot be approached with available lamp equipment. On the other hand, in the lower temperature fields, it is doubtful if gas ever will achieve the popularity and general suitability of electricity for the generation of infrared radiation as used for a great variety of industrial-heating and drying processes.

HERE AND THERE WITH INFRARED

Thick maple flooring in an armament plant swelled and buckled in damp weather. An ingenious chief electrician saved an expensive job of tearing up and relaying the flooring by drying

it out with a bank of 12 infrared lamps supplemented by lead weights to encourage the flooring to resume its original flatness.

Infrared was ineffective in drying paint applied to glass until the latter was placed on a metal plate.

A patent-department draftsman uses a single 250-watt reflector infrared lamp on an extension cord for a few seconds' drying of a finished drawing prior to cleaning it with art gum. The result is that there are no gray lines and no "retouching" is necessary. The system is especially effective in humid weather. This draftsman also applies infrared heat from the same lamp to keep the eraser thoroughly dry for neater erasures.

A bus-transportation company has practically eliminated winter starting troubles by keeping crankcase oil warm with infrared heat applied to the oil pan with a bank of four 250-watt lamps.

Smudging of mimeographed sheets, especially in humid weather, is minimized by application of radiant heat to paper, as it is mimeographed, with a single 250-watt reflector lamp.

Two mechanics at a workbench in an unheated factory room kept warm and comfortable by four 250-watt infrared lamps suspended overhead. Packers in an unheated warehouse have used the same method for keeping warm.

Model builder speeds glue and paint drying with an infrared lamp.

Lamps are finding favor as a means of supplying heat in chicken brooders.

Available information seems to disprove the claim that infrared lamps are a practical means of protecting citrus groves against frost damage excepting where very light frosts are involved.

A wallpaper manufacturer uses four lamps to dry production samples for color check in 1 min. as compared with 14 min. formerly required. If colors prove to be of the wrong shade, 13 min production of paper is saved.

An insulator manufacturer increased production of electrical insulators 20 per cent by substituting infrared for hot air in a glazing operation.

Tests indicate that infected cutting oil can be sterilized by infrared radiation, thereby reducing possibility of development of dermatitis on the part of those coming in contact with the oil.

Salvage of safety glass requires softening of the binder so that the sheets may be pried apart. Absorption of radiant energy by this glass is only about 30 per cent so that under normal conditions of application infrared is not economical for this purpose. Sandwiching the glass between two sheets of 20-gauge steel and then applying heat to the steel with flat banks of lamps greatly improved the efficiency and speed.

When infrared lamps are used for drying of photographic films, "fogging" is reduced by using lamps with natural ruby bulbs.

Concerning experiments with infrared heat, a bakery research engineer says, "I have been able to produce successfully all forms of cakes (cup cakes, loaf cakes, ring forms, cookies, and pies, using spice doughs, chocolate, yellow, and white dough of both lean and rich mixtures) with almost unlimited control of the finished crust color as well as the control of the oven spring (flat top or cracked top, etc.)."

Infrared radiation plays an important part in a new process for manufacturing smokeless ball powder developed during the Second World War.

High-speed raisins are the latest triumph of "electronics" in food processing. In California tests, infrared heat dried raisins

in 7 min compared with 17 hr by the usual heated-air method. Infrared equipment costs less and the fruit retains more flavor and aroma.

A Colombian inventor announces the development of an infrared coffee roaster for the retail trade. With a capacity of 1 lb per 2 min, the roaster has the reputed advantage of fresher coffee at a lower price.

Reflector infrared lamp replaces blowtorch in process of removing old paint from wood buildings.

USEFUL DATA

Calorie. The amount of heat required to raise 1 gram of water 1°C in temperature.

British thermal unit (Btu). The amount of heat required to raise 1 lb of water 1°F in temperature.

Specific heat. Number of thermal units required to raise a unit of weight of substance 1 degree of temperature at either constant pressure or constant volume.

Heat of vaporization. Quantity of heat absorbed by a substance per unit mass upon passing from the liquid to the vapor state, or released on condensation. It is a function of the temperature at which the transformation takes place. For example, 970 Btu are required to evaporate 1 lb of water at 212°F.

Kilowatt-hour (kwhr). One thousand watt-hours. Product of watts times hours divided by 1,000. One kilowatt-hour is equivalent to 3,413 Btu.

Cost of Operation. Formulas for determining cost of power for operation of infrared lamp installation:

(1) $\dfrac{\text{Wattage of individual lamp} \times \text{No. lamps} \times \text{hr burned}}{1{,}000 \text{ (watt-hr per kwhr)}} = \text{total kwhr}$

(2) Total kwhr $\times$ current cost per kwhr = cost of power

Example: Determine the cost of current for operating an installation of one hundred 250-watt infrared lamps one week of five 8-hr days (total 40 hr) with a current cost of $0.01 per kwhr.

Substituting in above formulas;

(1) $\dfrac{250 \times 100 \times 40}{1{,}000} = \dfrac{1{,}000{,}000}{1{,}000} = 1{,}000$ kwhr

(2) 1,000 kwhr $\times$ $0.01 = $10.00 cost of power

APPROXIMATE SPECIFIC HEAT OF SOME COMMON MATERIALS

Asbestos	0.20	Gold	0.03	Rubber	0.48
Brass	0.09	Iron	0.12	Silver	0.06
Bronze	0.09	Lead	0.03	Steel	0.12
Cellulose	0.37	Nickel	0.11	Water	1.00
Chromium	0.11	Paraffin	0.69	Wood	0.42
Copper	0.09	Porcelain	0.26	Zinc	0.09

TEMPERATURE CONVERSION TABLES

In the accompanying tables the columns headed *X* list the temperature either in degrees Fahrenheit or degrees centigrade that it is desired to convert into the other scale.

If converting from degrees Fahrenheit, the equivalent temperature in centigrade will be found in the column to the left headed "°C." Likewise, to convert from degrees centigrade the equivalent temperature in Fahrenheit will be found in the column to the right headed "°F."

For example, given a temperature of 50°F, determine the equivalent temperature in degrees centigrade. Find "50" in the *X* column and to the left in the °C column is the answer, 10°C. Likewise, given a temperature of 50°C, determine the equivalent temperature in degrees Fahrenheit. To the right of "50" in the *X* column, the answer 122°F will be found in the column headed "°F."

TEMPERATURE CONVERSION TABLES
0 to 100

°C	X	°F	°C	X	°F	°C	X	°F
−17.8	0	32.0	1.67	35	95.0	21.1	70	158.0
−17.2	1	33.8	2.22	36	96.8	21.7	71	159.8
−16.7	2	35.6	2.78	37	98.6	22.2	72	161.6
−16.1	3	37.4	3.33	38	100.4	22.8	73	163.4
−15.6	4	39.2	3.89	39	102.2	23.3	74	165.2
−15.0	5	41.0	4.44	40	104.0	23.9	75	167.0
−14.4	6	42.8	5.00	41	105.8	24.4	76	168.8
−13.9	7	44.9	5.56	42	107.6	25.0	77	170.6
−13.3	8	46.4	6.11	43	109.4	25.6	78	172.4
−12.8	9	48.2	6.67	44	111.2	26.1	79	174.2
−12.1	10	50.0	7.22	45	113.0	26.7	80	176.0
−11.7	11	51.8	7.78	46	114.8	27.2	81	177.8
−11.1	12	53.6	8.33	47	116.6	27.8	82	179.6
−10.6	13	55.4	8.89	48	118.4	28.3	83	181.4
−10.0	14	57.2	9.44	49	120.2	28.9	84	183.2
−9.44	15	59.0	10.0	50	122.0	29.4	85	185.0
−8.89	16	60.8	10.6	51	123.8	30.0	86	186.8
−8.33	17	62.6	11.1	52	125.6	30.6	87	188.6
−7.78	18	64.4	11.7	53	127.4	31.1	88	190.4
−7.22	19	66.2	12.2	54	129.2	31.7	89	192.2
−6.67	20	68.0	12.8	55	131.0	32.2	90	194.0
−6.11	21	69.8	13.3	56	132.8	32.8	91	195.8
−5.56	22	71.6	13.9	57	134.6	33.3	92	197.6
−5.00	23	73.4	14.4	58	136.4	33.9	93	199.4
−4.44	24	75.2	15.0	59	138.2	34.4	94	201.2
−3.89	25	77.0	15.6	60	140.0	35.0	95	203.0
−3.33	26	78.8	16.1	61	141.8	35.6	96	204.8
−2.78	27	80.6	16.7	62	143.6	36.1	97	206.6
−2.22	28	82.4	17.2	63	145.4	36.7	98	208.4
−1.67	29	84.2	17.8	64	147.2	37.2	99	210.2
−1.11	30	86.0	18.3	65	149.0	37.8	100	212.0
−0.56	31	87.8	18.9	66	150.8			
0	32	89.6	19.4	67	152.6			
0.56	33	91.4	20.0	68	154.4			
1.11	34	93.2	20.6	69	156.2			

TEMPERATURE CONVERSION TABLES
110 to 1000

°C	X	°F	°C.	X	°F.	°C	X	°F.
43	110	230	204	400	752	371	700	1292
49	120	248	210	410	770	377	710	1310
54	130	266	216	420	788	382	720	1328
60	140	284	221	430	806	388	730	1346
66	150	302	227	440	824	393	740	1364
71	160	320	232	450	842	399	750	1382
77	170	338	238	460	860	404	760	1400
82	180	356	243	470	878	410	770	1418
88	190	374	249	480	896	416	780	1436
93	200	392	254	490	914	421	790	1454
99	210	410	260	500	932	427	800	1472
100	212	413	266	510	950	432	810	1490
104	220	428	271	520	968	438	820	1508
110	230	446	277	530	986	443	830	1526
116	240	464	282	540	1004	449	840	1544
121	250	482	288	550	1022	454	850	1562
127	260	500	293	560	1040	460	860	1580
132	270	518	299	570	1058	466	870	1598
138	280	536	304	580	1076	471	880	1616
143	290	554	310	590	1094	477	890	1634
149	300	572	316	600	1112	482	900	1652
154	310	590	321	610	1130	488	910	1670
160	320	608	327	620	1148	493	920	1688
166	330	626	332	630	1166	499	930	1706
171	340	644	338	640	1184	504	940	1724
177	350	662	343	650	1202	510	950	1742
182	360	680	349	660	1220	516	960	1760
188	370	698	354	670	1238	521	970	1778
193	380	716	360	680	1256	527	980	1796
199	390	734	366	690	1274	532	990	1814
						538	1000	1832

TEMPERATURE CONVERSION TABLES
1010 to 2000

°C	X	°F	°C	X	°F	°C	X	°F
543	1010	1850	738	1360	2480	932	1710	3110
549	1020	1868	743	1370	2498	938	1720	3128
554	1030	1886	749	1380	2516	943	1730	3146
560	1040	1904	754	1390	2534	949	1740	3164
566	1050	1922	760	1400	2552	954	1750	3182
571	1060	1940	766	1410	2570	960	1760	3200
577	1070	1958	771	1420	2588	966	1770	3218
582	1080	1976	777	1430	2606	971	1780	3236
588	1090	1994	782	1440	2624	977	1790	3254
593	1100	2012	788	1450	2642	982	1800	3272
599	1110	2030	793	1460	2660	988	1810	3290
604	1120	2048	799	1470	2678	993	1820	3308
610	1130	2066	804	1480	2696	999	1830	3326
616	1140	2084	810	1490	2714	1004	1840	3344
621	1150	2102	816	1500	2732	1010	1850	3362
627	1160	2120	821	1510	2750	1016	1860	3380
632	1170	2138	827	1520	2768	1021	1870	3398
638	1180	2156	832	1530	2786	1027	1880	3416
643	1190	2174	838	1540	2804	1032	1890	3434
649	1200	2192	843	1550	2822	1038	1900	3452
654	1210	2210	849	1560	2840	1043	1910	3470
660	1220	2228	854	1570	2858	1049	1920	3488
666	1230	2246	860	1580	2876	1054	1930	3506
671	1240	2264	866	1590	2894	1060	1940	3524
677	1250	2282	871	1600	2912	1066	1950	3542
682	1260	2300	877	1610	2930	1071	1960	3560
688	1270	2318	882	1620	2948	1077	1970	3578
693	1280	2336	888	1630	2966	1082	1980	3596
699	1290	2354	893	1640	2984	1088	1990	3614
704	1300	2372	899	1650	3002	1093	2000	3632
710	1310	2390	904	1660	3020			
716	1320	2408	910	1670	3038			
721	1330	2426	916	1680	3056			
727	1340	2444	921	1690	3074			
732	1350	2462	927	1700	3092			

TEMPERATURE CONVERSION TABLES
2010 to 3000

°C	X	°F	°C.	X	°F.	°C	X	°F.
1099	2010	3650	1293	2360	4280	1488	2710	4910
1104	2020	3668	1299	2370	4298	1493	2720	4928
1110	2030	3686	1304	2380	4316	1499	2730	4946
1116	2040	3704	1310	2390	4334	1504	2740	4964
1121	2050	3722	1316	2400	4352	1510	2750	4982
1127	2060	3740	1321	2410	4370	1516	2760	5000
1132	2070	3758	1327	2420	4388	1521	2770	5018
1138	2080	3776	1332	2430	4406	1527	2780	5036
1143	2090	3794	1338	2440	4424	1532	2790	5054
1149	2100	3812	1343	2450	4442	1538	2800	5072
1154	2110	3830	1349	2460	4460	1543	2810	5090
1160	2120	3848	1354	2470	4478	1549	2820	5108
1166	2130	3866	1360	2480	4496	1554	2830	5126
1171	2140	3884	1366	2490	4514	1560	2840	5144
1177	2150	3902	1371	2500	4532	1566	2850	5162
1182	2160	3920	1377	2510	4550	1571	2860	5180
1188	2170	3938	1382	2520	4568	1577	2870	5198
1193	2180	3956	1388	2530	4586	1582	2880	5216
1199	2190	3974	1393	2540	4604	1588	2890	5234
1204	2200	3992	1399	2550	4622	1593	2900	5252
1210	2210	4010	1404	2560	4640	1599	2910	5270
1216	2220	4028	1410	2570	4658	1604	2920	5288
1221	2230	4046	1416	2580	4676	1610	2930	5306
1227	2240	4064	1421	2590	4694	1616	2940	5324
1232	2250	4082	1427	2600	4712	1621	2950	5342
1238	2260	4100	1432	2610	4730	1627	2960	5360
1243	2270	4118	1438	2620	4748	1632	2970	5378
1249	2280	4136	1443	2630	4766	1638	2980	5396
1254	2290	4154	1449	2640	4784	1643	2990	5414
1260	2300	4172	1454	2650	4802	1649	3000	5431
1266	2310	4190	1460	2660	4820			
1271	2320	4208	1466	2670	4838			
1277	2330	4226	1471	2680	4856			
1282	2340	4244	1477	2690	4874			
1288	2350	4262	1482	2700	4892			

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