THE APPLICATION OF INFRA-RED HEATING TO PHARMACEUTICAL PRODUCTS

PART I. PRELIMINARY INVESTIGATION

BY H. W. FOWLER

From the School of Pharmacy, Leicester College of Technology

Received June 30, 1952

INTRODUCTION

THE manufacture of many pharmaceutical preparations involves heating processes and in the past these have largely been carried out by conduction or convection methods. In both cases there are disadvantages. In the former the substance is in contact with a hot surface so that overheating may occur, while in the latter hot air is used and heat losses are considerable.

The use of radiation as the method of heat transmission has the advantage that the heat is transmitted directly from the emitter to the substance, without the losses due to an intermediate stage.

THEORY

Radiant heat is emitted by all bodies, the amount and the quality of the energy depending on the temperature of the body. By the Stefan-Boltzmann law, the total energy radiated by a black body (which is a perfect emitter) is proportional to the fourth power of the absolute temperature.[1] Radiant energy is distributed over a range of wavelengths above the red of the visible spectrum, hence the commonly used title of "infra-red" to describe this radiation. The infra-red band ranges from the "near infra-red" with a wavelength of less than 1 μ to the "far infra-red" with a wavelength of more than 100 μ.

The emission of energy at any temperature is not evenly distributed

TABLE I

WAVELENGTH, TEMPERATURE, ENERGY, AND TYPE OF GENERATOR

Wavelength of peak emission in Ångstrom units	Temperature of generator ° C.	Energy per sq. ft. of generator surface in B.Th.U./hour	Type of generator
10,000	2,700	1,300,000	Electric lamp
14,000	2,000	450,000	Electric lamp
20,000	1,200	80,000	Electric lamp
21,000	1,100	62,000	Electrically heated rods
25,000	875	28,800	Gas panels and electric rods
30,000	700	14,400	Gas panels and electric rods
35,000	550	7,500	Gas panels, electric rods and discs
47,000	340	2,400	Large surfaces gas heated vapour and liquid heated tubes
50,000	300	1,800	Ditto
55,000	250	1,350	Ditto

over the infra-red band, but there is a maximum or peak wavelength, the position of which depends again on the temperature. Wien's law states that the wavelength of the peak is inversely proportional to the absolute temperature.[2] Wien also found that the intensity of the radiation at the peak wavelength is related to the temperature, being proportional to the fifth power of the absolute temperature.[2]

Hence if intensity of radiation is plotted against wavelength, curves of the form shown in Figure 1 are obtained.

Thus, by varying the temperature of the generator, it is possible to choose approximately a particular peak wavelength, which, therefore, gives control of the intensity of the emission and hence, of the heating effect. Table I shows the relation between wavelengths, generator temperature, energy emitted and the type of generator producing these wavelengths.[3]

The heating effect in any substance on which radiation falls will depend partially on the intensity of radiation as shown and partially on the absorptivity of the substance. This varies according to the wavelength of the radiation, the colour of the surface and the nature of the surface.

The mechanism of drying can occur in two ways according to circumstances. Stout *et al.*[4] have investigated the mechanism of drying in beds of solids up to 1 inch thick and find that it does not differ substantially from atmospheric and vacuum drying when using sand, soap and magnesium stearate. The penetration of the radiation did not appear to exceed $\frac{1}{16}$ inch.

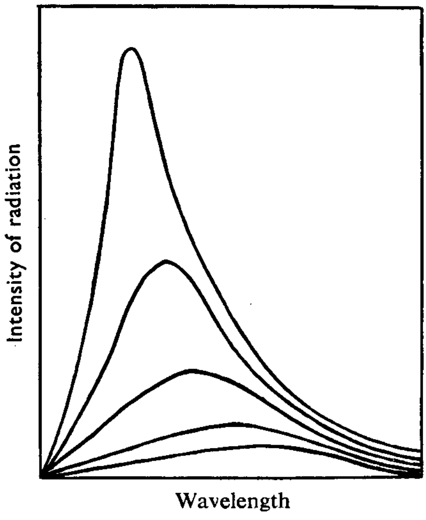
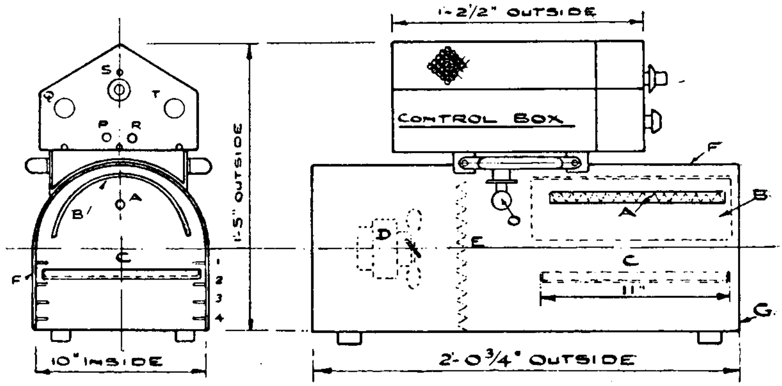


FIG. 1. Typical curves showing peak wavelength varying with temperature.

In the case of paint finishes, which would be of less than this thickness, McCloud[5] concludes that the drying is from the inside outwards, the radiation penetrating the paint, heating the metal and hence, the inner paint layers. The theory is supported by the difficulty of infra-red drying paint finishes on woods. The drying of films, such as scale preparations, would occur in this way.

Much has been published with regard to heating and drying by infra-red radiation, but this has been mainly confined to the drying of paint finishes and other industrial processes, such as drying textiles, heating plastics, etc. Publications referring specifically to pharmaceutical applications are surprisingly few in number. Youngken and Hassan,[6] while carrying out pharmacognostical and chemical studies of Indian belladonna, dried berries of *Atropa acuminata* and *A. belladonna* using infra-red lamps. A number of samples were dried for 1 hour using 2 lamps, one 10 inches above and the other 10 inches below the berries. In these cases a temperature of 145° C. was obtained and considerable loss of alkaloid occurred. Further samples were dried for 2 hours using one lamp 24 inches above the fruits giving temperatures of 55° C. The alkaloidal content of these samples was comparable with results obtained on berries which had been dried spontaneously at room temperature over a period of 6 to 8 weeks. Patel *et al.*[7] have carried out an investigation of the effect of infra-red radiation on a number of substances commonly used in tablets. Their work will be referred to in more detail in Part II of this paper. Déribéré has given descriptions of a number of infra-red lamp dryers but unfortunately no useful performance figures are given. The dryers described include drum dryers[8] of two types for syrups and liquids. The first combines steam and infra-red, the liquid in the feed tank being preheated by lamps and the drum itself heated internally by steam and externally by further lamps. The second is heated externally by infra-red lamps only. An account has been given of a number of smaller dryers.[9] A lamp may be simply used in a universally jointed stand and placed at a suitable height over the work, or cabinet dryers used, with adjustable grille shelves and heated by one or three lamps according to size. Also a vacuum dryer is described consisting of two bell-shaped portions fitting together and each containing a lamp, so that one is above and the other below the work. This is intended for moisture tests and it is claimed that a sample of 5 to 10 g. can be dried by 2 × 250 watt lamps in 5 to 8 minutes at 65° C. Dériběré also describes two commercial installations.[10] The first, a cabinet dryer intended for drying vegetable extracts, is about 6 feet in height and has 7 or 8 perforated shelves, the top shelf only being radiated by infra-red lamps. The remainder of the shelves do not receive radiation and are used for preheating, so that drying capacity would be low in relation to the surface area in the cabinet. The door has an inspection window but this is mounted too low to see the top shelf where the actual drying process takes place. The second is a tunnel dryer heated by 60 × 250 watt lamps, and trays are passed through from end to end. Radiant heat has been used by Zamzow and Marshall[11] to supply the heat of sublimation in the freeze-drying process and it was found that the rate of drying was increased compared with conduction heating. An infra-red lamp has been used as the heating unit of a moisture tester suitable for pharmaceutical products.[12] A 5-g. sample is placed on the pan and by means of a continuous weighing device a pointer indicates the percentage moisture content directly on a scale.

With the exception of Zamzow and Marshall's work,[11] in which they use wavelengths of 2 to 4 μ, all the papers previously quoted have referred to infra-red lamps which operate at a peak wavelength of about 1·2 μ in the case of tungsten filament lamps and 1·4 μ if the filament is of carbon. McCloud[5] has stated that "of the various ways of applying heat to an object, radiation is recognised as the most efficient, provided the path that the radiant energy has to travel can be kept short." This is not possible for pharmaceutical purposes with lamps, since the greater heating effect of the short peak wavelength causes overheating, and in the cases already referred to it was necessary to place the lamps at distances of 1 to 2 feet to avoid this. Furthermore, the greater operating distance means that any unevenness of reflection will be of more importance so that "hot spots" may occur with corresponding irregularity of heating. Hence, this investigation has been confined to the use of lower powered generators emitting radiations with peak wavelengths of 3·2 and 3·6 μ which permitted the reduction of the operating



	A	INFRA RED GENERATOR
	B	REFLECTOR
	C	TRAY
	D	FAN
	E	CONVECTION HEATER
	F	MAIN CASING
	G	DOOR
CONTROL PANEL	O	LAMP
	P	I. R GENERATOR SWITCH
	Φ	I R GENERATOR WAVE LENGTH CONTROL
	R	AIR HEATER SWITCH
	S	AIR HEATER CONTROL
	T	MAIN SWITCH

FIG. 2. Diagram of laboratory infra-red dryer.

distance to approximately 10 cm. There is a further advantage to the use of these wavelengths since both water and ethanol show a great increase in absorption between 3 and 3·5 μ.[3] This means that at about these wavelengths there will be a considerable improvement in heat transfer to water or ethanol with correspondingly increased drying rates.

As a preliminary, various pharmaceutical substances and preparations have been dried with a view to finding whether the use of infra-red is physically a suitable method. In some cases comparisons have been made with other types of dryers. Generally, no attempt has been made to record temperature or to check for deterioration other than anything visually obvious.

EXPERIMENTAL

Apparatus.—A standard laboratory infra-red dryer, a diagram of which is shown in Figure 2 was used for this work.

The dryer, manufactured by the Kestner Evaporator and Engineering Co., Ltd., uses an electric rod generator made by winding resistance wire on a ceramic former. This is placed at the focus (A) of a parabolic reflector (B) so that a theoretically parallel beam of radiation falls on the drying tray (C). Resistances can be switched into the circuit so that the generator can operate at peak wavelengths of 2·4, 2·8, 3·2 and 3·6 μ. In addition, a current of air can be directed across the tray by an axial flow fan (D), the air being heated to any temperature up to about 60° C. by the spiral heating element (E). This allows the use of the apparatus for comparisons with convection drying and the combination of this method with infra-red.

TABLE II

DRYING RESULTS

Substance	Conditions of drying	Conclusion
Fresh drug (hyoscyamus).	Approximately 1 hour at 3·6 μ.	Shrivelled, but colour better than normal commercial specimens.
Extracts (cascara).	3·6 μ, the time depending upon the depth. 1 litre of percolate, in a layer initially 2 cm. deep, containing 3 per cent. of solids dried in 5 hours. Maximum recorded temperature, 70° C. Thin films dried in 15 to 20 minutes.	The product is hard and not so satisfactory as vacuum dried extracts. The surface tends to harden, while the bulk is still moist unless the layers are very thin.
Scale preparations (iron and ammonium citrate).	15 to 20 minutes at 3·6 μ.	Probably the best method for this type of preparation.
Precipitates (saccharated iron carbonate).	Time variable according to the thickness of the layer. Sample in layer 0·2 cm. deep dried in 20 minutes and in layer 1 cm. deep in 3 hours, both at 3·6 μ. Sample in 1 cm. layer in steam oven required 4½ hours. Ferrous carbonate content in both cases about 60 per cent.	Satisfactory. Quicker, especially in shallow layer.
Granules.	Time varies from 20 minutes for a layer 0·3 cm. thick to 2 hours for a layer 1 cm. deep. Depends also upon the initial moisture content, which was 30 to 40 per cent. in the above cases.	Very satisfactory. Much quicker than the usual methods. See Part II of this paper.
Pastilles (glycogelatin base, B.P.C.). (25 grain, 2 cm. dia. and 0·5 cm. thick.)	3·6 μ. Drying not completed.	Even low temperatures soften the base. Would probably be satisfactory for bases with higher melting points.
Lozenges. (Approximately 20 grains. Oval, 1·75 cm. × 1·25 cm. and 0·25 cm. thick.)	20 to 30 minutes at 3·6 μ.	Satisfactory provided temperatures are kept low. Otherwise lozenges swell and burst due to the outside hardening and shrinking before the inside is dry.
Lamellae.	Approximately 10 to 15 minutes at 3·6 μ.	Satisfactory.
Tablet triturates. (1 grain 0·5 cm. diameter and 0·25 cm. thick.)	Approximately 10 to 15 minutes at 3·6 μ.	Satisfactory.

Procedure.—Infra-red radiation was used to dry representative drugs and various preparations which were made in the usual manner. The results are summarised in Table II.

Conclusions

Drying by infra-red radiation appears to be satisfactory for certain types of pharmaceutical preparations, when using a peak wavelength of about 3·6 μ. In all these cases the drying times are shorter than those obtained by conventional methods. The method appears to be useful for materials which may be dried in films or thin layers, for granular preparations in shallow layers and for small solids such as lozenges. The degree of usefulness will vary with the individual substance being treated, since it will depend upon the properties of that substance, with regard to reflection, transmission or absorption of the appropriate wavelength. If reflection is high, then the heating effect is reduced, while if absorption is great the surface will be heated excessively and transmission take place to the remainder by conduction or convection. It is therefore, important when considering the application of infra-red drying, to assess at what point the energy will be transformed from radiant energy to heat energy. Some transmission of the radiation in the substance is desirable so that the transformation to heat takes place within the substance and not on the surface. The investigation of this property for pharmaceutical substances is necessary. The infra-red dryer was not found suitable for extracts in its present form since a vacuum-dried extract is much more convenient in handling and use. It is possible that a dryer for operation under reduced pressure could be designed.

Summary

1. An account of the theory of infra-red radiation is given and the literature on the pharmaceutical uses of such radiation is reviewed.

2. The advantages of using a radiation having a longer peak wavelength than that emitted by infra-red lamps are stated.

3. A laboratory infra-red dryer is described.

4. The method has been used successfully, with shorter drying times, for fresh drugs, scale preparations, granular preparations, wet precipitates, lozenges, lamellæ and tablet triturates.

5. The method was not found to be suitable at present for extracts and for soft pastille masses.

Part II. Drying of Granules

Introduction

As indicated in Part I of this communication, infra-red radiation is a satisfactory means of drying granular preparations at a rate greater than that obtained by the usual methods. The drying process in the preparation of tablet granules is of great importance, if good quality tablets are to be produced. This is especially true if the tablets are coloured, as improperly dried granules can produce unevenly tinted tablets.[13] Patel *et al*[7] have investigated the effect of radiation from infra-red lamps on a variety of substances used in tablets. 67 chemicals were heated by lamps of various wattages and at various distances and any decomposition noted. In the majority of cases there was little or no change. The work was extended to tablet granules of 55 different formulæ, of which 22 were of inorganic compounds, 19 of organic compounds and 14 were compound formulæ. No difficulties were experienced in 90 per cent. of the cases, the only unsuccessful formulæ being those containing yellow mercurous iodide, sodium acid phosphate, tannic acid, dextrose and buchu and atropine compound. It would, therefore, appear that the infra-red drying of tablet granules merits further investigation, and the object of this work was to prepare a standardised granule and to ascertain the effect on the drying rate, of the peak wavelength and of passing a current of air over the drying surface.

Experimental

Apparatus.—The infra-red dryer described in Part I was used for the experimental work with a modification to allow the sample to be weighed without removal from the dryer, so that drying conditions were not disturbed. The drying tray was supported in the correct position on two cantilevers which projected into the dryer from the front. These were attached to vertical members which were in turn fastened to two other cantilevers mounted on a balance underneath the dryer. The proportions were arranged so that the centre of gravity of the structure together with the loaded drying tray was exactly over the centre of the balance pan. A lock was provided so that the drying tray remained at the same distance from the infra-red generator except during the actual weighing process. Theoretically, slight variations of this distance should have no effect as the parabolic reflector should give a parallel beam. An attempt was made to indicate approximately the temperature during drying by drilling a hole in the front of the drying tray close to the bottom and inserting a mercury thermometer.

Procedure.—It was necessary that the substance used for the granules should be inert and heat stable so that at first kaolin was tried but this was found to be unsuitable as it returned to the clay state on moistening. Finally, light magnesium oxide B.P. with 2 per cent. of acacia B.P. as a binding agent, moistened with distilled water and passed through a No. 16 sieve was found to give a satisfactory granule.

The granules were evenly spread in the drying tray and placed in the dryer. The weight of the sample and the thermometer reading were recorded at intervals of five minutes during drying.

When equilibrium conditions were achieved, (i.e., when the weight remained constant over 15 minutes), the heating was increased until the completely dry state was reached. Using this dry weight, the weight of moisture at each time increment was obtained, from which the percentage moisture content was calculated. This is expressed in the accepted manner as "percentage moisture (dry basis)" by which is meant the number of parts by weight of moisture per 100 parts by weight of dry material.

Results

The results of selected drying runs are shown in Figure 1, in which the percentage moisture (dry basis) is plotted against the time in minutes. In each case the time was calculated from 25 per cent. moisture content. The drying runs are numbered and refer to the runs enumerated in Table I.

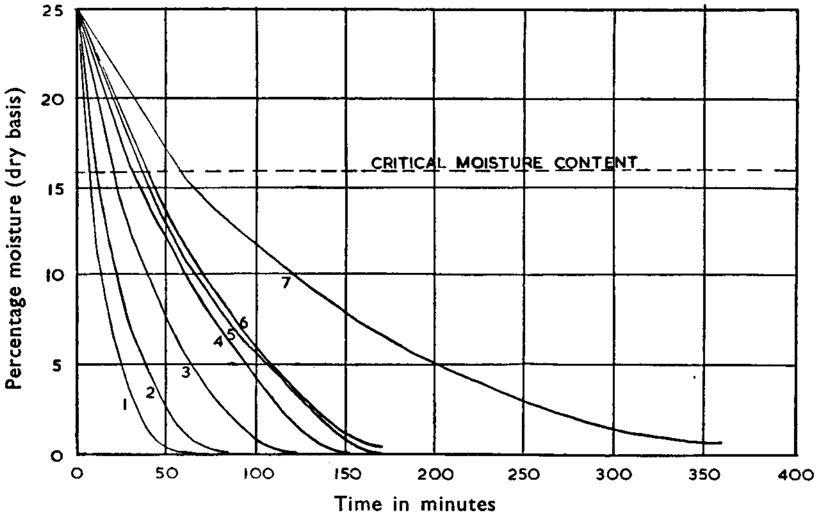


Fig. 1. Drying curves.

In Table I further data are given showing the conditions of drying during each run, the constant drying rate, the critical moisture content (i.e., when the constant drying rate ended), the temperatures during the constant rate and at completion, and the times taken.

TABLE I

Result of drying of granules

Run No.	Wave-length μ	Fan	Air temper-ature ° C.	Constant drying rate g./hr./sq. cm.	Temper-ature during constant rate period ° C.	Critical moisture content per cent. (dry basis)	Time to reach critical moisture content from 25 per cent. minutes	Time to reach equili-brium from 25 per cent. minutes	Temper-ature at equili-brium ° C.
1	3·2	Off	—	0·34	80	13·6	10	75	170
2	3·6	On	55	0·26	68	16·25	10	85	105
3	3·6	Off	—	0·18	65	15·8	20	125	105
4	3·6	On	40	0·107	55	17·7	25	140	75
5	3·2	On	15	0·099	55	16·6	40	160	89
6	3·6	On	15	0·091	50	12·4	55	160	72
7	Off	On	55	0·048	35	15·7	60	360	52

Depth of bed, 1 cm.; drying area, 375 sq. cm.; volume of air stream, approximately 50 cu. ft./minute; distance of drying surface from generator, 12 cm.; depth of centre of thermometer below surface, 0·5 cm.

Discussion of Results

Effect of wavelength.—The use of the shorter wavelength (3·2 μ) gave increased drying rates but, as would be expected, correspondingly higher temperatures, of the order of 80° C. during the constant rate period and rising to 170° C. at the end. It was felt that such temperatures were high in view of the thermolabile nature of many pharmaceutical substances and hence the investigation was confined mainly to the use of a peak wavelength of 3·6 μ. This gave satisfactory drying rates, but considerably lower temperatures.

Effect of air stream.—A current of air at 15° C. was found to give decreased drying rates and lower temperatures due to the heat losses caused by the greater air movement. This is in agreement with the work of Stout *et al.*[4] who observed a similar effect when drying sand with infra-red lamps. The heat losses are considerable, so that radiations of 3·2 and 3·6 μ with unheated air give similar drying curves. It is possible that the stream of cold air will slightly alter the peak wavelength of the radiation, since the air stream passes round the generator, the temperature of emission would be lowered slightly and this would in turn increase the peak wavelength and so decrease the heating effect.

A stream of air warmed to 40° C. was found to have a similar effect in decreasing the drying rate. No increase of drying rate was obtained until the air temperature was raised to 55° C., but this was combined with higher temperatures so that the improved drying rate was probably due only to the greater heating effect. As well as giving further heat to the surface receiving radiation, the hot air would raise the temperature of the underside of the drying tray, whereas cold air would have a cooling effect on the latter. In addition, raising the temperature of the air increases the vapour pressure gradient and so enhances the chances of evaporation.

Temperature during the constant rate period.—The temperature quoted in Table I is only an approximate value as it tended to rise during this period. The temperature reached by such drying solids is of great importance for pharmaceutical products and it is proposed to investigate this in detail using temperature measurement methods of greater accuracy.

Critical moisture content.—The critical moisture content appears to be fairly constant for this granule at 16 per cent. The value given for run 1 is low, probably due to the fact that the 5-minute intervals were too long for the greater drying rate and hence the figure is not accurate. The results for runs 4 and 6 also seem to be inconsistent, but both of these runs used a radiation of 3·6 μ and air streams which showed a cooling effect. The drying curves for these runs fluctuated as shown in Figure 1, probably due to this same effect.

Time.—As would be expected the time increases as drying rate decreases. The only result not in agreement with this, is the time to reach the critical moisture content in run 6. The latter value is low and hence a longer time was required to reach that point.

Temperature at equilibrium.—In all runs there was a rise in temperature at the end of the constant rate period, in some cases quite marked. The rate of drying had decreased and hence the amount of heat used as latent heat of vaporisation was less. More, therefore, becomes apparent as sensible heat and showed a temperature rise. In some cases the rise was great, for example, in run 1, the temperature at equilibrium conditions reached 170° C. and was continuing to rise.

Conclusions

The use of infra-red radiation appears to offer a means of drying tablet granules rapidly. Granulations may be taken from 25 per cent. moisture content to equilibrium conditions (which is some cases represent actual dryness) in times varying from 75 to 160 minutes according to drying conditions. The use of conditions which give rapid drying in the early stages, tends to cause excessive temperature increase in the later stages. It is possible that a satisfactory procedure would be the use of a shorter wavelength (or a longer wavelength with hot air), until the end of the constant rate period when the heating effect could be decreased by increasing the wavelength (or lowering the air temperature). The time required to reach the end of the constant rate period could be estimated from drying curves such as those shown in Figure 1, provided the initial moisture content is known. It appears that an air stream does not assist in speeding the rate of drying, unless the air is heated, when it increases the rate by transferring heat to the underside. Normally, using radiation, only the upper layers are heated and the lower layers rely on conduction from the upper. This could be overcome by using thinner layers and by agitation. The effect of the latter is, at present, being investigated by other workers. A consideration of temperature is of great importance and it is hoped to investigate this aspect, especially with regard to temperature gradients through the bed of solid, since there is risk of overheating the upper layers before the lower layers are dry.

Summary

1. An account is given of work which suggests that the use of infra-red radiation does not harm the majority of substances commonly used in tablets.

2. A modification of a laboratory infra-red dryer, to enable the sample to be weighed *in situ*, is described.

3. The method is described, and the results given, for experiments to investigate the effect on the drying rate of granules of variations of the peak wavelength of radiation. The effect of an air stream, in addition to radiation is considered.

4. It is concluded that it might be possible to use the high heating effect of a short wavelength during the constant rate period, followed by a reduction in the intensity of the radiation to minimise the subsequent temperature rise.

The author wishes to thank the Principal of the Leicester College of Technology for facilities to carry out this work and for permission to publish this paper, also other members of the staff of the School of Pharmacy, especially Mr. J. P. Richards, Ph.C., who assisted with the experimental work, and the Kestner Evaporator and Engineering Co., Ltd., for the loan of the infra-red dryer.

REFERENCES

1. McAdams, "Heat Transmission," McGraw Hill, New York, 1942.
2. Fishenden and Saunders, "Introduction to Heat Transfer," Clarendon Press, Oxford, 1950.
3. Reavell, *Trans. Inst. Chem. Eng.*, 1944, **22**, 13.
4. Stout, Caplan and Baird, *Trans. Am. Inst. Chem. Eng.*, 1945, **41**, 283.
5. McCloud, *Industr. Engng. Chem.*, 1941, **33**, 225.
6. Youngken and Hassan, *J. Amer. pharm. Ass., Sci. Ed.*, 1948, **37**, 45.
7. Patel, Jenkins and DeKay, *ibid.*, 1949, **38**, 247.
8. Déribéré, *Produits Pharm.*, 1947, **2**, 408.
9. Déribéré, *ibid.*, 1948, **3**, 61.
10. Déribéré, *ibid.*, 1949, **4**, 63.
11. Zamzow and Marshall, *Chem. Eng. Progr.*, 1952, **48**, 21.
12. Barrington Brock, *Chem. Ind.*, 1947, 299.
13. Little and Silver, *Tablet Making*, Northern Publishing Co., Ltd., Liverpool, 1949.

DISCUSSION

The paper was presented by MR. H. W. FOWLER.

The CHAIRMAN observed that many pharmaceutical products were not brought completely to dryness but merely concentrated.

MR. R. L. STEPHENS (Brighton) said that the paper brought out the fact that all drying, even in the conventional convection oven, depended upon infra-red radiation, and tests which he had carried out had shown that probably 50 per cent. of the heating at 100° C. in ovens was due to infra-red radiation from the walls and top of the ovens. The heat transfer in a vacuum oven was very largely due to infra-red radiation and to conduction from the plates. The disadvantage of heating with infra-red lamps had been illustrated in the paper by the fact that the granules dried rose in temperature to 170° C. Had the author carried out any work on the use of radio frequency heating in the drying of pharmaceutical preparations? He had tried high frequency heating in which the material to be heated or dried became the dielectric in a condenser, and a radio frequency impulse was imposed upon that condenser. The heating effect depended on the dielectric loss of the material in question. The dielectric constant of a wet material was high and fell off rapidly as the moisture evaporated.

DR. W. MITCHELL (London) gave a brief account of the results obtained in routine control work with an infra-red moisture tester incorporating a continuous wave device. Most air-dried vegetable materials could be dried in 2 to 3 minutes, and fresh plant material of heavy moisture content in up to 20 minutes. Woody materials took a little longer. Extracts could be dried successfully in 20 minutes provided they were spread in thin layers, the resultant texture being similar to that of vacuum-dried material. It was difficult to measure temperature accurately on a continuous band machine, but even at maximum energy the temperature at completion of drying did not usually exceed 130° C., and it was obvious that for control work a machine such as that had great advantages. It had speed, accuracy comparable with ordinary methods, and no risk of rehydration of the material while allowing it to cool. Any industrial drying method to be satisfactory should be continuous. Therefore he considered that the only way in which to utilise the infra-red drying technique efficiently was to work it on a conveyor belt system.

MR. B. A. BULL (Nottingham) asked the author for some information with regard to the economics of drying by infra-red radiation. In his view the orthodox methods were less costly, although in special circumstances there might be a use in pharmacy for that type of drying.

MR. J. H. OAKLEY (London) stated that for the method to be effective it was necessary to have a thin layer, and that frequently led to difficulties because of the greater area involved. He asked for information on the drying of iron ammonium citrate scales by infra-red heating.

MR. C. L. J. COLES (London) asked for information concerning the difficulties in determining the temperature in the middle of the powder.

MR. H. W. FOWLER, in reply, said that the method was more advantageous in drying that in the concentration of liquids. With the infra-red drier the vapour produced went into the atmosphere. He had used with success a climbing film type of evaporator with infra-red heating instead of the usual steam jacket. Radiation was, of course, a very important point in ordinary ovens; but the trouble with the ordinary oven was that there was conduction, and where there was contact with the hot surface there was risk of local overheating. He had not done any work on radio frequency drying; the apparatus was far too elaborate and expensive. It was very much better to use infra-red driers continuously. He had not gone into the economics of infra-red drying, although there was the point that drying time was so much less that very often smaller plant occupying less floor space could handle the output of the larger plant required for other methods. He had obtained very quick drying of iron ammonium citrate. The question of temperature in the middle of the powders was one of the great difficulties of infra-red work. He hoped to continue the work using a number of thermocouples at various levels and obtaining temperature gradients through the material during drying.