H. Barber

Electroheat

ELECTROHEAT

H. Barber

Senior Lecturer
University of Technology, Loughborough

GRANADA
London Toronto Sydney New York

Granada Publishing Limited-Technical Books Division
Frogmore, St Albans, Herts AL2 2NF
and
36 Golden Square, London W1R 4AH
515 Madison Avenue, New York, NY 10022, USA
117 York Street, Sydney, NSW 2000, Australia
60 International Boulevard, Rexdale, Ontario R9W 6J2, Canada
61 Beach Road, Auckland, New Zealand

British Library Cataloguing in Publication Data
Barber, H.
Electroheat
1. Manufacturing process 2. Heat
I. Title
621.39'6 TK4661

ISBN 0 246 11739 7

First published in Great Britain 1983 by Granada Publishing
Distributed in the USA by
Sheridan House Inc., 175 Orawaupum Street,
White Plains, NY 10606

Printed in Great Britain by
Richard Clay (The Chaucer Press) Ltd,
Bungay, Suffolk

ELECTROHEAT

Preface

This book is intended as a teaching text for all those who have an interest in industrial process heating. Inevitably, since most aspects of the subject are covered the scope is extremely wide, and it will be necessary for those readers involved in one or another of the particular areas to reinforce the material contained herein by making reference to more highly specialised texts. Details of the more significant of these specialised books and articles are given in the bibliographies at the end of each chapter. One of the more difficult problems posed in writing a book of this type is concerned with the decisions involved as to which material to omit. The author has been guided by his own personal views with regard to the relevance of the material to a comprehensive teaching programme at undergraduate or higher technician level. The book has no pretensions to be a research text other than as an introduction to the subject for those whose primary interest lies in other areas of technology.

The material contained in this book is based on the cumulative efforts of many individuals who have been working in the field of Electroheat for many years. The author wishes to acknowledge the help received from the Electroheat equipment manufacturers in the UK and from the Electricity Supply Industry. A considerable debt is also owed to all those who have been, and still are, active in the work of the British National Committee for Electroheat. In particular the author wishes to thank Professor John Davies and Dr Alan Bowden of the University of Aston and also Jack Sharples, John Long and Mike Thelwell, the successive Executive Officers of BNCE. Finally, and most significant in terms of the source of much of the material contained in the book, the author wishes to place on record his grateful thanks to his colleagues at Loughborough University of Technology and in particular to Dr John Harry with whom during the past ten years he has shared a collaborative and fruitful relationship in the teaching of that subject which has come to be known as Electroheat.

H.B.

Contents

1

Introduction to Electroheat Processes

1.1 INTRODUCTION

The use of electric power as a source of heat in industrial processes has grown steadily since the first commercial utilisation of the electric arc furnace in the late nineteenth century. Now there are few, if any, manufactured goods in the production of which electric heating techniques, electroheat, have not played a part. The number of different techniques available, ranging from the radiant heat produced by the passage of an electric current through a wire to the use of heat generated by dielectric polarisation, is extremely diverse and explains the range of this book.
For a complete understanding of the subject, the student must be familiar not only with the different electrical techniques involved but he must also have an adequate knowledge of heat transfer, an understanding of the behaviour and properties of materials, and an awareness of the nature and purpose of the manufacturing processes concerned. The choice of a particular heating technique will be based on economic as well as technical factors. Electricity is a secondary source of energy, it is derived from primary sources such as coal, oil and nuclear, by conversion at a generating station where the fundemental nature of the process implies that the energy conversion ratio cannot be higher than 50% and, in practice, it is unlikely to be much greater than 35%. Thus, when comparing the use of electricity and a fossil fuel for a heating process, it can be said that there is an inherent 3:1 bias in favour of the latter. Hence, if the use of electroheat is to be viable then there must be other factors which potentially outweigh the apparent unit cost disadvantage. In practice these other factors often rely on the relationship between the heating unit and the remainder of the process.

These factors include :

(a) more efficient conversion into useful heat in the workpiece,
(b) a better quality output with fewer rejects,
(c) higher production rates and improved productivity,
(d) improved working conditions,
(e) better space utilisation

and others which are specific to particular situations. The practising engineer in this field must therefore be able to take all aspects of the production situation into account in their proper context.

1.2 ELECTROHEAT TECHNIQUES

Possibly the simplest technique is that which basically depends on the replacement of a fuel-fired burner by an electrically energised source, i.e. an heating element, from which the heat is transferred, either by conduction, convection or radiation, to the load, or 'workpiece'. Heat transfer will depend on the source temperature being higher than that of the load and therefore a major limiting factor will be the temperature which the source can be allowed to reach before it becomes unusable by virtue of changing mechanical or electrical properties. The nature of the environment in which the source operates will have a significant effect on the maximum allowable temperature and, in some cases, it will be necessary to provide electrical insulation between the element and the workpiece, i.e. the element will need to be sheathed.

Heating elements can be constructed in a wide variety of ratings and configurations - they may be used as free-standing heat sources or they may be built into complex heating units in the form of ovens and furnaces. The range of applications is extensive and a particular advantage is that the heating elements gives the designer of the heating unit a greater range of design possibilities than is likely to be the case if fuel-fired burners are used. The conversion of electrical energy to usable heat is very high and is largely independent of total power rating whereas, at the present time, the improvements in efficiency which have been achieved with fuel-fired burners are usually restricted to the larger units. A further advantage is that the electrical heating element merely needs an electrical supply at the correct voltage whereas fuel-fired burners need to be supplied with the particular fuel and, in addition, they require combustion air, mixed with the fuel in the correct proportions, if efficient combustion is to be obtained. Any surplus air, together with the flue gases will need to be removed from the unit and hence a chimney, perhaps with forced draught and fume cleansing equipment, will also be needed. The oxygen-rich environment and the nature of the flue gases leads, in some cases, to difficulties in respect of unwanted chemical reactions between these gases and the heated workpiece. These difficulties can often be overcome in fuel-fired applications but the result is usually a decrease in efficiency whereas the atmosphere in which electric heating takes place can be chosen to suit the needs of the process. Both the heat source and the workpiece can be situated in a vacuum during the heating cycle if necessary. Finally, in general terms, the possibilities of a close and relatively complex control of heating rates and, up to a point, temperature profiles in the workpiece are possible. The use of indirect resistance heating must therefore be considered seriously when one or more of the above factors is of significance in the process under consideration.

Conceptually a more simple technique than that described above in which heat is produced by the current flowing through the resistance of the heating element is to pass the electric current through the workpiece itself, thus obviating the need for heat transfer. This process, which is known as direct resistance heating, is applied to metals, although there are important limitations as discussed in Chapter 4, and to liquids. It is also used as a means of melting glass. The most significant general advantage in those areas where the technique is applicable are related to the high heating rates which are possible although there are other arguments in favour of direct resistance heating in so far as the individual processes are concerned.

It is possible to transfer the energy from the electrical source to a metallic workpiece via an electromagnetic field. Electric currents are induced in the workpiece and heating again takes place through the I^2R effect although, in this case, the need for a direct electrical contact between the source and the workpiece is eliminated. This technique, induction heating, is characterised by a non-uniform current distribution which, in turn, produces a non-uniform heating pattern. The distribution is a function of the frequency of the electromagnetic field and this property may be used to advantage in some applications such as, for example, the surface heating of metallic components which require to be hardened. The technique is also used for metal melting, where it is in competition with fuel-fired methods such as the cupola, and with the electric arc furnace. It is also employed for through heating metallic components as well as for specialised applications such as, for example, soldering, the manufacture of semiconductor crystals and many others. Given the ability to vary heating patterns by the appropriate selection of frequency then the choice of this frequency becomes important and it follows that a range of power sources of the appropriate rating needs to be available. The normal frequency range in question lies between 50 Hz and 500 kHz although, occasionally, higher values are used for specialised applications. The types of power source involved include the mains supply, magnetic frequency multipliers, rotating machines, thyristor inverters and triode oscillators. The ratings can be up to several MW at the lower frequencies, even at the higher end of the frequency range they may reach 500 kW.

The sustained electric arc, which may be thought of as a gaseous conductor, can also be used as a source of heat and the electric arc furnace, used for melting and refining metals, was one of the earliest examples of industrial electroheat. The conventional units are three-phase with the arcs struck between the electrodes and the main body of the melt. The arc temperatures are extremely high and the heat is transferred by radiation either directly onto the melt or by re-radiation from the furnace walls. Present day units, ranging in size up to 160 MVA, are capable of producing 400 tonnes of molten metal. Special furnaces relying on the arc principle have been developed for particular applications where a high output is required. Arc heating is also used in other industrial processes in which the arc is encouraged to adopt a large volume and becomes a plasma. The materials to be heated are passed through this plasma in order to carry out the required processing.

By and large the techniques described above rely on the passage of current through some form of electrical conductor and heating is produced by the Joule (i.e. I^2R) effect. An alternative principle, suitable for those materials which do not conduct electricity well, is to make use of the phenomenon of dielectric polarisation whereby heat is produced in dipolar materials when they are situated in an alternating electrical field. Provided that the material has the appropriate electrical characteristics the technique is effective in giving extremely high heating rates. This is a particular advantage since the materials in question are usually poor thermal conductors and those heating methods which rely on heat transfer through the surface are either slow or they involve temperatures liable to cause surface damage. This technique is also applied to the heating of mixtures, the components of which have different electrical properties, with the result that the great bulk of the energy passes into one constituent leaving the other comparitively unheated, hence it can be particularly useful in drying processes. A prime requirement however is that the electrical frequency must be high and commercial equipment uses either the band between 10 and 60 MHz or the ISM (industrial, scientific and medical) frequencies of 896 MHz or 2.45 GHz. The power sources are industrial radio frequency triodes in the one case and microwave devices in the other. Considerable design experience is required to obtain correct load matching conditions and to ensure that the interaction between the electric field and the material to be heated is effective.

New electroheat techniques involve the use of lasers and electron beams, each of these has a part to play in specific applications which tend to be those where the cost and complexity of the technology is justified in terms of the nature of the process and the quality required of the end product.

1.3. HEATING PROCESSES

Process heating is undertaken for a wide diversity of reasons, equally diverse are the relevant characteristics of the materials involved. This section contains a brief description of some of the more common processes so as to introduce the terminology involved and give some idea of the temperature ranges of interest, see Table 1.1.

Table 1.1 *Typical process temperatures (°C)*

Material	Melting	Annealing	Hardening	Forming
Nickel	1450			1200
Steel	1380 - 1520	700 - 1200	500 - 1400	1200
Cast iron	1150 - 1400			
Copper	1000	250 - 450		600 - 800
Brass	900 - 1020	550 - 650		600 - 800
Aluminium	650	390		400 - 450
Zinc	400			
Lead	320			
Glass	1500	500 - 600		1020

1.3.1 Metals industries

1.3.1.1 Melting. After the metal bearing ore is extracted from the earth it is first concentrated, a process which usually involves heat or a chemical (or electrochemical) reaction or a combination of these. the energy requirements are very large but close control is not usually of paramount importance and hence fuel-fired methods are normally used except for materials such as aluminium where electrochemical techniques are fundemental. The next stage is the refining or alloying of the raw metal and it is here that the choice of heating technique, based on both economic and technical factors, can become critical. Generally speaking the process consists of raising the material to its melting point, typical temperature values range from 300 - 400 °C for lead and zinc to 1500 °C for steel. The alloying additions are then made and time at temperature is needed for the necessary metallurgic reactions to take place. The molten material is then poured into moulds, which may themselves need to be preheated and cooled. In some cases the cooling cycle is a critical factor in determining the final quality of the material. Usually a batch process is involved, the melting furnace is first charged with raw material which is then melted and refined. the furnace is then emptied, i.e. 'tapped', and the cycle, which may take up to several hours, can begin again. The castings from the furnace usually take the form of rectangular ingots.

1.3.1.2 Forming. The next stage in the process is to change the shape of the ingot to a form which corresponds more closely to that of the finished article. In practice this means that the ingot is rolled into sheets of varying thickness, or into bars of varying shape and diameter, or extended into tubes. Most metals must be raised to a temperature very near to their melting point before this change of shape can be effected. Typical temperatures are given in Table 1.1. The rolling temperature is critical, as is also temperature uniformity across the cross-section, if the process is to be carried out satisfactorily and if a reasonable life is to be obtained from the rolls or dies in the forming machine. Following this bulk forming process the next stage of shape adjustment is to carry out a more critical rolling or to make use of other shape-changing techniques such as forging , pressing or further stages of extrusion. In those applications where preheating is necessary then, again, temperature values and uniformity are critical.

1.3.1.3 Heat treatment. The final properties of the metal component are obtained by subjecting the near-finished article to a heat treatment cycle. the method chosen can be such as to affect the whole body of the component or a selected part, such as the surface. The more common heat treatment processes are outlined below, in the majority of them the important parameters including heating rate, length of time at temperature and the cooling rate.

(i) Annealing. The purpose of annealing metals is to reduce hardness, to improve machinability and to facilitate cold working, the general effect of the process being to change the grain size of the material. The temperature of the material is raised until it becomes almost plastic but it must not be allowed to reach the value at which permanent deformation occurs. Typical values of temperature are : mild steel, 700^{o}C; cast iron, 500^{o}C ; brass, 650^{o}C; aluminium, 400^{o}C. Cooling is an important part of the annealing cycle and, generally, the cooling rate should be slow. If the heat losses are excessive it may be necessary to incorporate some heating during the cooling period. When the material, usually steel, is allowed to cool slowly in still air the process is known as 'normalising'. An annealing process applied to cast iron in order to improve its ductility, and in which both heating and cooling rates are slow, is called 'malleablising'.

(ii) Stress relieving. The deformation of metallic components by, for example, rolling or joining the metals using welding or similar techniques introduces stress into the structure. These become points of weakness and need to be removed by the process known as stress relieving. Again this implies taking the material through a controlled heating and cooling cycle similar to the annealing process.

(iii) Hardening and tempering. This is a heating and cooling process the purpose of which is to produce a hard structure. The particular requirement is that the cooling rate should be high and immediately after heating, i.e. as soon as the required temperature is reached, the component is 'quenched' in a cooling liquid whose main purpose is to effect a rapid heat transfer. Different quenching media are used depending on the material, these include water, caustic soda, oil, polyvinyl alcohol and air, or other gases.

(iv) Surface heat treatment. Here the requirement is to produce a component whose core is ductile, and which therefore is shock resistant, but whose surface is hardened to give good wearing properties. There are two possibilities, in the first the hardening is achieved by modifying the surface structure using a chemical process at elevated temperatures. The alternative is to produce the required effect simply by heating the surface followed immediately by quenching. Case hardening involves heating in a carbon-rich environment, such as a bed of coke, so that some of this carbon is absorbed into the surface layer. This technique has been largely replaced by gas carburising where the component is heated in a reducing gas such as methane. Other thermochemical hardening processes are heating in baths containing cyanide salts and nitriding. The purely thermal surface hardening techniques include flame hardening and induction surface heating.

1.3.1.4 Other metal processing techniques

(i) Sintering. This is the production of a solid component by first compressing a powder and then heating it to a high temperature. The process is both time and temperature dependent.

(ii) Joining. Welding is used to join larger masses of material together, at its simplest the process consists of heating the two metallic surfaces to be joined and allowing them to fuse together. Soldering and brazing on the other hand make use of an intervening material, the solder, which interacts with both surfaces and, when cool, holds them together.

(iii) Surface coating. This involves applying a coating material to a metallic surface and then using heat to fuse the two together. As part of the process it may be necessary to dry the material or, in the case of paints, to polymerise it.

1.3.2 Other Industries

1.3.2.1 Ceramics. The clay is first formed into shape and heated, i.e. 'fired' in a kiln at a temperature up to 1400°C. Most products are required to be glazed, this is carried out by dipping the object into the glazing material after which it is again heated, this time to around 1200°C. Finally, the design is applied followed by a further stage of heating.

1.3.2.2 Glass. The glass constituents, mainly silica, are heated to around 1600°C at which point the chemical reactions take place which result in the formation of glass. After being held at temperature for refining the glass is transported along 'fore hearths', which may also require heating, to the machine which forms the plastic material into the required shape. Stresses induced in the glass during the forming operation may need to be removed by annealing.

1.3.2.3 Plastics and rubber. Both these materials may need to be heated during their manufacture and forming. They may also need to be cured to give them the stable properties required and additional heating may be required at this stage. The temperatures involved are relatively low.

The above notes are merely typical of a wide range of processes in which materials need to be heated, others are mentioned in the remainder of this book. For more detailed descriptions the reader should consult the sources given in the Bibliography.

BIBLIOGRAPHY

Barber, H. and Harry, J.E. (1979) "Electroheat; Electric power for industrial heating processes". Proc. IEE, Vol. 126, No. 11R pp. 1126-1148.

Central Electricity Generating Board (1970) Modern Power Station Practice, Vols 1-8, 2nd Edition. Pergamon Press, Oxford.

Bryan, L.J., Masters, J and Webb, R.J. (1974) 'Applications of recuperative burners in gas-fired furnaces'. Instn. Gas Engnrs Publn 952, London.

Dryden, I.G.C. (1975) The Efficient Use of Energy. IPC Science and Technology Press, (UK).

Blow, C.M. (1971) Rubber Technology and Manufacture. Butterworth, London.

Newall, W.C. (1955) The Casting of Steel. Pergamon Press, London.

Miller, E.P. and Taft, D.D. (1974) 'Fundementals of Powder Coating'. Society of Manufacturing Engineers, Michigan.

Brooker, H.R. and Beatson, E.V. (1975) Industrial Brazing. Newnes - Butterworth, UK.

Koenigsberger, F. and Adair, J.R. (1966) Welding Technology. Macmillan & Co. Ltd., London.

United Steel Companies Ltd., Sheffield. (1965) Elements of Rolling Practice.

Howard, E.D. (Ed) (1958) Modern Foundry Practice. Odhams Press, UK.

Lindberg, R.A. and Braton, N.R. (1976) Welding and other Joining Processes. Allyn & Bacon, London.

Smith, W.M. (1964) Manufacture of Plastics. Chapman & Hall, London.

Shand, E.B. (1958) Glass Engineering Handbook. McGraw-Hill, London.