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ELECTROTECHNOLOGY VOLUME 7

ADVANCES IN ELECTRIC HEAT TREATMENT OF METALS

ANN ARBOR SCIENCE

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ELECTROTECHNOLOGY
VOLUME 7

ADVANCES IN ELECTRIC HEAT TREATMENT OF METALS

PREFACE

This book continues the series of studies initiated and sponsored by Electricité de France, surveying the status of electric technologies. The objectives have been to promote technology using electricity, and to diffuse information favorable to its development.

This volume reviews developments in electric heat treatment of metals to determine the outlook for market gain in some of the promising new technologies. The crisis in the fossil fuel supply creates higher costs for those fuels, and thus adds basic broad economic advantages to the use of electricity. As fossil fuel prices continue to rise, electric heat treatment technologies will become increasingly economical, despite their high capital costs.

Electrotechnology Vol. 2, Applications in Manufacturing (R. P. Ouellette, F. Ellerbusch and P. N. Cheremisinoff, Eds., 1978) presented the economic status and developmental state of electric technologies. Induction and other electric metal heating methods were discussed by G. Miller and M. Barbier. Several technologies, which at that time were regarded as only exotic laboratory tools, now have gained dramatically increased acceptance in commercial use, and are explored in greater detail in this volume.

The authors gratefully acknowledge Electricité de France for continuing its support in this work and sponsoring this study.

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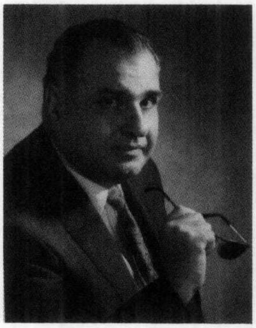

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Norman W. Lord is a broad-spectrum physicist with the MITRE Corporation. Dr. Lord's research areas include the structure of solids, ocean acoustics and atmosphere-land interactions. He has consulted extensively for government and industries on a wide variety of problems in operations and estimating technological trends.

He received a BEE from Brooklyn Polytechnic Institute, and earned his MA and PhD in physics from Columbia University. Dr. Lord has been a research physicist at the Johns Hopkins University Applied Physics Laboratory, Hudson Laboratories of Columbia University and Travelers Research Center in Hartford, CT. He has written more than 40 technical papers covering these areas and his research, and is co-author of *Heat Pump Technology, Electrotechnology Vol. 4*, a 1980 Ann Arbor Science publication.

Robert P. Ouellette is Technical Director of the Environment Division of the MITRE Corporation. Dr. Ouellette has been associated with MITRE in varying capacities since 1969, and has been Associate Technical Director since 1974. Earlier, he was with TRW Systems, Hazelton Labs, Inc. and Massachusetts General Hospital. He was graduated from the University of Montreal and received his PhD from the University of Ottawa. A member of the American Statistical Association, Biometrics Society, Atomic Industrial Forum and the NSF Technical Advisory Panel on Hazardous Substances, Dr. Ouellette has published numerous technical papers and books on energy and the environment. He is a co-author of the *Electrotechnology* survey series published by Ann Arbor Science.

Paul N. Cheremisinoff is Associate Professor of Environmental Engineering at the New Jersey Institute of Technology. He is a consulting engineer and has been a consultant on environmental/energy/resources projects for the MITRE Corporation. A recognized authority on pollution control and alternative energy technologies, he is author/editor of many publications, including several Ann Arbor Science handbooks on pollution and energy, such as *Pollution Engineering Practice Handbook, Carbon Adsorption Handbook, Environmental Impact Data Book, Industrial and Hazardous Wastes Impoundment,* and *Environmental Assessment and Impact Statement Handbook.* He is a member of the Ann Arbor Science Publishers Editorial Advisory Board.

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CHAPTER 1

INTRODUCTION

In earlier work,* the economic status and developmental state of electric technologies as practiced in U.S. industry were surveyed. Induction and other electric metal heating methods were discussed by Miller [1] and Barbier [2]. This Volume reviews the changes in technical development and economic status of all electric metal heat treatment methods that have taken place since the earlier work was completed.

For the electric heat treatment methods discussed in 1978, advances in available commercial technology essentially have been incremental. Electric heat treatment equipment has increased its market share primarily because of government-mandated reduction in the use of oil and improved economic circumstances for the use of electricity compared to natural gas. Induction heating and vacuum resistance heating, for example, have gained because their recognized technical advantages became much more cost-competitive as natural gas prices rose. With greater routine use a wider variety of special applications were tried and proven to further expand the market.

In part spurred by the increased familiarity with electric methods of metal heat treatment, several technologies, which were regarded in 1978 as only exotic laboratory tools, now have gained dramatically increased acceptance in commercial use. These technologies are laser and electron beam methods for localized heat treatment and plasmas for melting the more refractory metals. In addition, the economic status of electric arc melting for steel and ferroalloys has become so much more favorable that conventional steel production, which relies on coal combustion, soon may be substantially displaced. Hence, these technologies have been added to the report coverage. The book therefore will cover the following major technical categories of electric metal heat treatment.

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*Electrotechnology, Volume 2, Applications In Manufacturing.

- Electromagnetic Induction
- Lasers and Electron Beams
- Arc Melting and Plasmas
- Electric Resistance Heating
  - Vacuum and controlled atmosphere furnace
  - Resistance heating elements
  - Direct conduction heating

Notably absent from these is the use of infrared process heat. Most recently reviewed by Callaghan [3], it is apparent that its use is largely limited to nonmetallic materials, which are usually processed at much lower temperatures than are used in metal heat treatment. Infrared heaters may be fired by natural gas or may use electric resistance elements. In either case there is a low effectiveness of coupling to the metallic workpiece, which is not sufficiently compensated for by greater controllability.

The acceptance of electric methods by U.S. industry may be growing but there are still many influences that are unfavorable from a strictly individual company viewpoint. In addition, the motives of private industry leading to a positive interpretation of the financial balance among all the factors involved do not match those of the U.S. Department of Energy (DOE), which attempts to influence U.S. industrial energy use from a national energy use viewpoint.

For example, any new investments in the U.S. steel industry must compete with an existing plant capacity for steel-making which is demonstrably adequate for the market. Szekely [4] has discussed this barrier facing any new steel-making technology. The average U.S. cost of steel production is about \$350/ton. Of this dollar figure, energy and raw materials comprise 45%, labor 35–45% and capital service charge 6–10%. Production of steel in the U.S. requires 36×10^9 J, 5 KWh/lb and 8.2 man-hours of labor. The book value of the plant is about \$120/ton of annual output (less than one third the operating cost), but replacement cost is estimated between \$1200 and \$1500/ton. An automated arc furnace facility may reduce the energy and materials requirements, improve the product quality, particularly in ferroalloys, and drastically diminish required man-hours per ton produced. However, the capital service charge for this new plant would be \$250–300/ton of annual output, completely overwhelming the savings in labor, increased product value and other benefits. Nevertheless, there are new plants being built because the oldest steel-making plants are much more expensive than the average, so that there is a realizable net return; also, individual company circumstances differ.

The situation in aluminum production as described by Brondyke [5] of ALCOA is somewhat different. Here, about 70% of the total energy consumed in aluminum production is used in the smelting process. It has always been feasible in aluminum production to introduce incremental energy saving improvements that have steadily reduced required energy. Brondyke cites the latest development of the ALCOA smelting process, which can produce aluminum at an expenditure of 4.5 KWh/lb (less than steel) compared to an ALCOA average of 7.5 KWh/lb. In the steel example, higher production, better quality and lower materials loss overcome a possibly greater energy expenditure for a net saving. In the case of aluminum, the saving is direct in energy and technically feasible without the high capital requirement of whole plant replacement.

The U.S. Department of Energy takes another viewpoint, which may be illustrated by comparing the ways in which it would view these two industrial initiatives. If no other factors are involved, a net energy saving is always regarded favorably. In ALCOA's case, DOE may be inclined to help support further technical development. If, on the other hand, there is a net increase in energy usage, then the Department considers how the change bears on its concern over domestic use of oil and natural gas. As Gross [6] pointed out, the use of oil is already under a strong absolute constraint for manufacturing processes. A conversion from natural gas to an alternate fuel (such as coal) may merit a tax reduction. On the other hand, in the case of the electrification of steel production there is, at best, no conversion since the utility may already use coal to generate supplied electricity and there is, at worst, unfavored fuel conversion if the utility increases its use of oil or gas to meet the new demand.

The foundry industry has been pointed out by O. Cleveland Laird [7] of the Department of Energy as one of the best examples illustrating the balance frequently struck between increased productivity and increased energy costs. Foundries generally are owned and operated by small companies. For the last 10 years they have been shifting fuel usage from oil and gas to electricity. However, James Williams [8], of Grede Foundries in Milwaukee, said that this trend has slowed recently due to a shortage of capital. The furnaces costs have been running \$100,000–200,000/ton of melt capacity. This is a large investment for the small family-run company, which is still largely the rule in the foundry industry. At the same time, the cost rise for natural gas and propane, which had been outpacing that of electricity, has been slowed. At current price levels of 30¢/therm (100,000 Btu) for natural gas and 50¢/therm for propane, there is insufficient energy cost advantage offered by electric induction or resistance heating. The advantage would be in capability to automate the foundry operation. An example of this has been described recently by Layton [9]. Most of the product value of a foundry is represented by cost of energy used to melt and the capital cost for the furnace and pouring/molding equipment. Williams pointed out that since 1972 foundries have cut their specific energy usage 17–20%. For the small plants of less than 10 ton/hr, induction heating has emerged as a strong competitor of gas.

A very large company, facing many energy-requiring steps in its manufacturing processes, has a much more complicated decision to make, as pointed out by Gerhard Stein [10] of General Motors. This company utilizes a wide variety of energy-using equipment, and selection of any particular heating method must be made in the context of the company's best overall interest in its energy use profile.

For example, Table 1-1 shows the gross comparison for GM as a whole between 1972 and 1978 for electricity, gas and steam fuel. Production of vehicles at GM increased from 6.2 million in 1972 to 7.7 million in 1978. There was a reduction in energy requirements of 20% per vehicle because total energy usage was about the same–206 $\times 10^{12}$ Btu vs 203 $\times 10^{12}$ Btu. The proportion of electric energy usage increased from 24% to 29%. However, this change reflects primarily the large reduction, per vehicle, of gas and steam fuel usage compared to a small reduction in electricity usage, rather

Table 1-1. Energy Use in GM Components of Energy Consumption in GM [10]

	1972		1978	
	TBtu	Percent of Total	TBtu	Percent of Total
Electricity	49	24	59	29
Process Gas	70	34	62	31
Steam Fuel	87	42	82	40
TOTAL	206	100	203	100

Consumption per Unit of Production (Millions Btu/Vehicle)

	1972	1978	Percent Change
Electricity	7.9	7.6	–4
Gas	11.3	8.1	–28
Steam	14.0	10.7	–24
TOTAL	33.2	26.4	–20

Average GM Energy Cost

	1972		1978		Percent Change in Cost
	$/MMBtu	Ratio[a]	$/MMBtu	Ratio	
Electricity	3.50	5.5	8.50	4.1	143
Process Gas	0.64	1.0	2.09	1.0	227
Steam Fuel	0.62	0.97	1.86	0.89	200

[a]Relative to process gas.