Metallurgical Processes [and Discussion]

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Metallurgical processes

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[Plates 23 to 26]

The shape of metallurgical processes in the 1980s will be basically similar to those obtaining today modified to accommodate solutions to various constraints, industrial and economic. These include the availability and relative costs of different sources of energy, a need to reduce production costs and improve product quality to meet market requirements new and existing, and the general pressures to provide healthier working conditions and greater job satisfaction for employees.

It is expected that oil and natural gas will be more extensively used as sources of energy and as a supplement to coking coal for the reduction of iron ore, but the prospect of diminishing reserves will, in the longer run, focus increasing attention on nuclear energy for metallurgical uses.

Further reductions in manufacturing costs may be expected as the result of an increasing scale of operation, but there may also be opportunities for smaller scale enterprises using different technologies to coexist profitably with the larger works of the future with advantages to both.

The increasing scale of metallurgical operations raises the question of continuous versus batch processing. In both ferrous and non-ferrous metallurgy the processes of extraction, casting and working are for the most part continuous in that the material flows through the plant but are operated intermittently because refining is still done in batches in various types of melting and refining vessels. In spite of efforts to increase the continuity of metal manufacture, the advantages are by no means all on one side and these are discussed.

There have been many attempts to speed up the rate of reaction of metallurgical processes in the interests of increasing productivity. These may be based on the provision of a higher surface to volume ratio, as in the flash smelting or fluidized bed treatment of copper ores, or on more concentrated reagents such as the use of oxygen in steelmaking. Other examples of not only speeding up metallurgical reactions but substantially reducing the subsequent processing and working of metals by new means are referred to.

A comparison of a metallurgical works (in steel or elsewhere) of today with one of 50 years ago would show how much has been done to improve the conditions of work. The generation of heat, noise and dust is inseparable from metallurgical operation on a large scale and the metallurgical processes of the 1980s will almost certainly embody improved methods of keeping this under control.

Although metallurgical plants of today tend to be larger in capacity, better engineered and more elaborately controlled than their predecessors of 15 years ago, the metallurgical processes themselves are basically unchanged. I believe that a comparable statement, namely, that the metallurgical processes of today will not differ significantly in principle or basic practice from those 15 years hence, will not be found wanting 15 years from now, since most metallurgical processes develop slowly in response to technical and economic opportunities and constraints; and how these factors can influence the changes we may expect to see between now and the mid-1980s is the subject of this paper.

One can not overlook the possibility that some entirely new processes may emerge by the late 1980s since attempts by scientists and engineers (as representative of technologists) are continually and properly being made to outflank the limitations of conventional processes by some radically different approach; but the mortality rate of these attempts is high and only those that have already successfully reached the pilot plant stage are likely to have obtained a foothold in regular production by the 1980s. Some radical change in access to or availability of raw materials may demand more urgent adoption of an alternative process or some completely revolutionary invention of obvious economic advantage (prima facie even if not subsequently realized) may change the time scale of acceptance, but neither of these conditions at present obtains on the general world scene.

The economies of scale

One of the most persistent features in the development of metallurgical processes is the trend towards larger units of production. This is apparent in both the non-ferrous and ferrous industries; in the former, for example, the larger aluminium reduction plants have grown since the war from a capacity of less than 100000 tonnes per annum (t/a) to more than 300000 t/a, and in the steel industry new integrated steelworks of more than 10×10^6 t/a capacity are no longer unusual where prewar 2×10^6 t/a was considered large in this country. A consequence of this trend is the high contribution to metallurgical processes of capital cost compared with the operating expenditure; this is illustrated in figure 1 for a high growth product. The economies of scale that follow from the increasing capacity of a modern steelworks represented by the fall in capital cost per annual ton is shown in figure 2. The same trend is apparent in the cost of production of aluminium ingots from electrolytic reduction plants ranging from 20000 to 100000 t/a as illustrated in the figures quoted for capital charges in table 1.

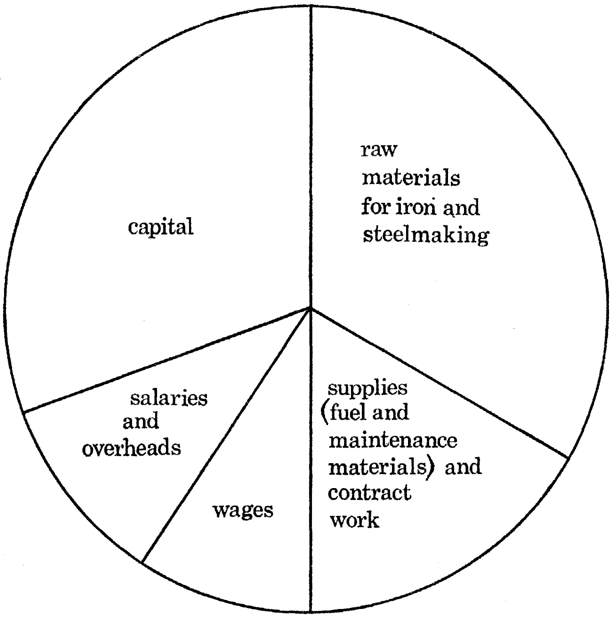

FIGURE 1. Pie diagram of steelmaking costs.

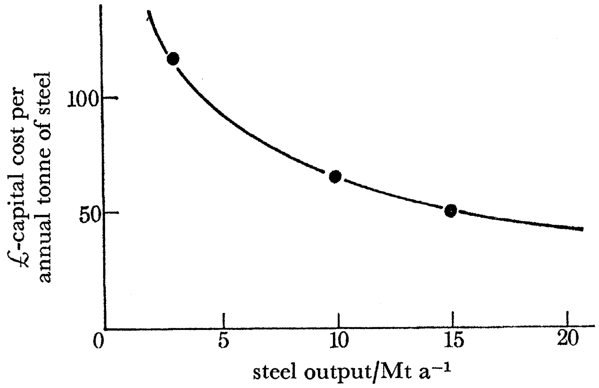

FIGURE 2. Capital cost/tonne versus output – steel graph.

A question that is much in people's minds at the moment is how far this trend to larger units should continue. The benefits of scale can only be realized if new plant is quickly brought into full production and kept there by the calls of full demand and technical reliability. The first of these conditions is possible where there is a rapid sustained growth in demand for the product; where growth is slow and/or subject to severe cyclical movements, it may be economically more justifiable to settle on an optimum size rather than the largest that is technically possible at the time. A rule recently propounded in connexion with the petrochemical industry, but of possibly more general application, is that the right size is that in which the projected demand for the product will absorb the whole of the new capacity within 2 to 3 years.

TABLE 1. AVERAGE PRODUCTION COSTS OF ALUMINIUM INGOTS HYPOTHETICAL U.S. PLANTS (DOLLARS/TONNE OF OUTPUT)

capacity, tonne/year	20000	30000	60000	100000
alumina	150	150	150	150
fluorides	25	25	25	25
carbon	25	25	25	25
operating and maintenance supplies	18	18	18	18
power	61	61	61	61
labour	54	51	45	42
miscellaneous and general expenses	50	48	40	38
capital charges:				
depreciation	72	66	58	53
interest on fixed capital	53	48	41	38
total	508	492	463	450

Two features of manufacturing technology in the metal industries of the 1980s which derive from their costly capital intensity are the need to ensure minimum construction and commissioning times on the one hand and technical reliability on the other. The first implies careful preconstruction design, the planning of the complex contributions of civil, mechanical and electrical engineers in construction and the training of the personnel for commissioning and operation. As example, one months' delay of Anchor, the U.K.'s largest steel plant complex about to come on stream costs an extra £1$\frac{3}{4}$M in construction costs and some £10M in lost production. On the second, i.e. delay times or outage, the trends towards acceptance of terotechnology which combines building in safeguards against breakdown, designing for ease of maintenance including continuous monitoring of plant condition while it is operating, and the supply of comprehensive manuals on fault finding and repair, are an important feature of new capital investments.

Quality

Production *per se*, i.e. output per unit size of plant, is not the total and sufficient criterion determining manufacturing technology in the 1980s. On the contrary, variations or even new processes and corresponding plant may have to be introduced to meet the user demand for improved product quality; cleanness (from inclusions) soundness, surface quality, closer dimensional tolerances, optimum combinations of physical properties, consistency of properties etc. This condition is perhaps more difficult to meet in the development of future technology, but it is implicit in what follows that such quality considerations are always in mind.

The problem of installing new plant is complicated by an increasingly difficult social issue – that of maintaining employment in a capital intensifying world. Old plant which, because its products are no longer able to meet more modern standards of quality and in many cases low costs, have to be taken out of production and replaced by less labour intensive plant; these social problems may be rendered more difficult when old plant is not only replaced by new, but the new plant located elsewhere. The economic consequences of deserting an area which has significant past investment in its infrastructure – housing, schools, services, etc. – have to be taken into account in determining an investment programme notwithstanding the difficulties in ascribing values to these assets; and artificially created incentives (many temporary or changeable) to move plants to a particular area are a further complication.

Increasingly (for anti-pollution and economic reasons) waste recovery is being given attention in industry. There has always been a scrap metals market and processes for treating these wastes. In the ferrous industry one process for manufacturing steel has been by melting and refining scrap in electric arc furnaces as an alternative to the use of melting scrap in basic oxygen steelmaking converters.

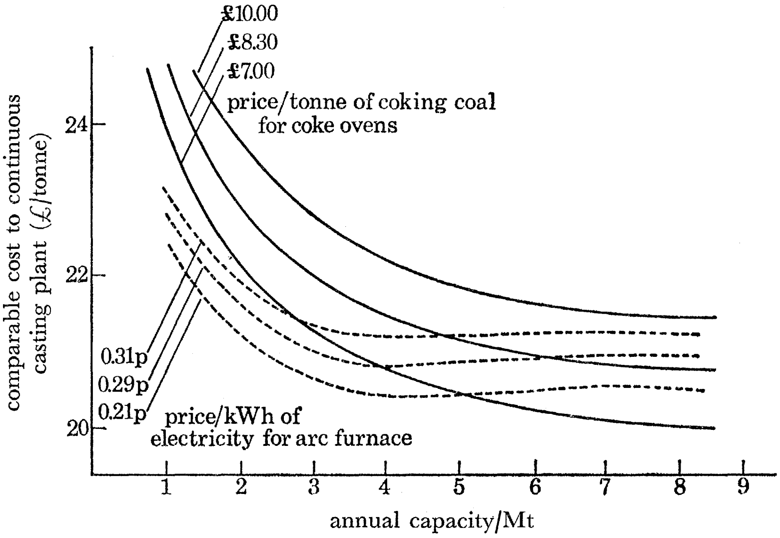

Figure 3. Maxi versus mini steelworks costs: —, blast furnace/basic oxygen; ---, direct reduction arc/furnace.

A recent development (if development it can be called) is the emergence of so-called 'mini' steelworks. These melt and refine either scrap or iron units derived from a direct reduction process in an electric arc furnace to produce a limited range of specialized products close to their markets. The basic unit of such plants is an electric arc furnace of some 100 tonnes capacity; where scrap is melted the plant size is of the order of 200000 t/a; where pre-reduction units are the source of iron, the unit may rise to some 500000 t/a. An indication of how the costs of the two process routes compare over a range of capacities is shown in figure 3. To gain perspective on this development, however, it should be recognized that the ratio of blast furnace/basic oxygen steelmaking to electric arc (in total) will settle at about 85:15.

Rate of reaction

The high capital cost of metallurgical plant has stimulated attempts to increase its productive capacity without adding to its cost. As far as the primary processes of extraction and refining are concerned, this means speeding up the chemical reactions on which these processes depend.

A classic method of achieving this is to increase the surface to volume ratio of the reactants; for example, the normal method of smelting copper from its ores which contain copper and iron sulphides involves a long period of controlled oxidation after melting in batches of several hundred tons, but this reaction is greatly speeded up in the Noranda process by violent air agitation of the molten bath.

The Outokumpu flash smelting process goes further; the copper ore is injected as a powder into a tower furnace, together with flux and a little fuel, and the mixture rapidly burns to produce liquid copper and slag at the bottom. The Torco process, which is used for non-sulphide copper minerals, reacts these with coal and salt in a fluidized bed which requires a residence time of only three minutes, and produces copper particles which are separated by flotation. In all these cases a greater surface-to-volume ratio among the reactants is the principal factor in speeding up the extraction process.

An alternative method of accelerating chemical reactions is to increase the concentration of the reagents. This is at the back of the revolution in steelmaking that has taken place in the last 25 years. Formerly, dilute oxygen in the form of air was used to burn out the impurities in the crude iron that was charged into the steelmaking furnace. Today, pure oxygen is blown into the steel. By this means the time of the steelmaking process has been reduced by an order of magnitude, i.e. from about 8 h in the old open hearth furnace to 30–40 min in a modern oxygen converter. Surface-to-volume ratio also plays an important part in this process, however. From the researches of Meyer and Trentini it appears that during the blow, a fine emulsion of molten metal and slag is formed. Samples of slag taken at the time show the presence of many fine particles of metal embedded in the slag (figure 4, plate **23**).

When further attempts are made to speed up the process by consciously combining high surface-to-volume ratio with increasing concentration of reagents as in the case of spray steelmaking where a falling stream of molten iron is atomized by powerful jets of oxygen, difficulties obtain in controlling so fast a process in overcoming the constraints of diffusion of oxygen to the spray particles and dispersing the concentration of heat generated in a comparatively small space. It may well be that the oxygen steelmaking process is nearing the limit of its practical development and the 1980s will see no more than marginal improvements in its efficiency.

Batch versus continuous processing

Most of the operations of metal manufacture are continuous in the sense that the material flows through the plant as it is being treated. The notable exception is melting and refining in the molten state which is carried out in batches even in the case of easily handled, low melting point metals such as aluminium and lead. The idea that one might build a metallurgical works in which the raw material flows in at one end and is processed in an unbroken line until the finished product emerges at the other end, has a certain fascination because of its seeming elegance.

It is true that there are certain areas in which a move towards greater continuity seems sensible. For example, continuous melting for continuous casting (to which I will return later) has become well established for copper in the past ten years. Pure cathode copper is melted without oxidation or gas pickup in a bottom-fired tower furnace and is fed to the casting machine through a subsidiary furnace for temperature adjustment. The melt rate can be flexibly controlled between zero and maximum by altering the fuel/air input.

In the ferrous industry much effort has been spent in tackling this problem at the most difficult end namely steelmaking. Perhaps the fact that the blast furnace process is in principle continuous (although at present the practice is to tap it intermittently but at very frequent intervals) and that continuous casting of the molten steel into ingots is now well established, encourages people to bridge the gap between them with a continuous steelmaking process. I doubt if we shall see the disappearance of batch processing of molten metal by the 1980s; the advantages of the present processing route are too great. A vessel full of liquid metal is self-mixing and smoothes out any variations in the quality of the material fed into it (and in commercial production consistency is often more important than accuracy in meeting a particular specification). The task of achieving the same consistency by treating the metal 'on the wing' poses difficult problems of control. There is also the problem of changing over from one composition to another without producing a quantity of unwanted material of intermediate compositions.

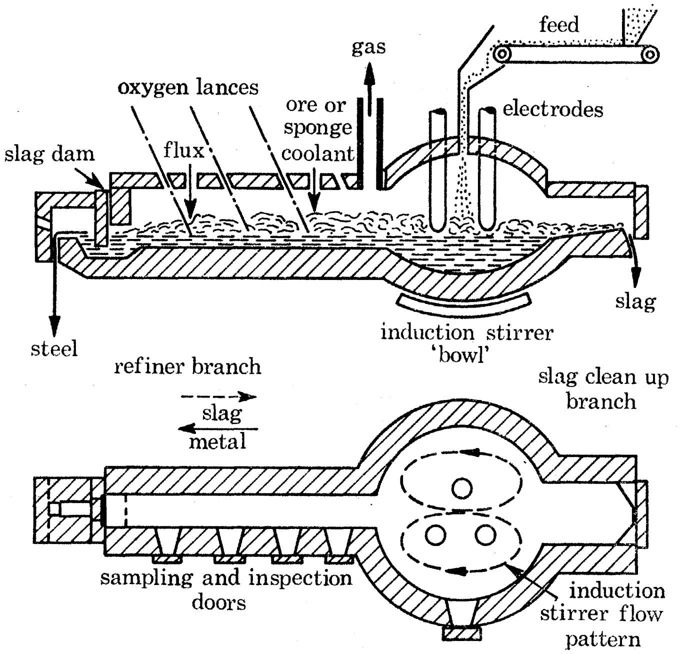

Figure 5. Continuous steelmaking (Worner).

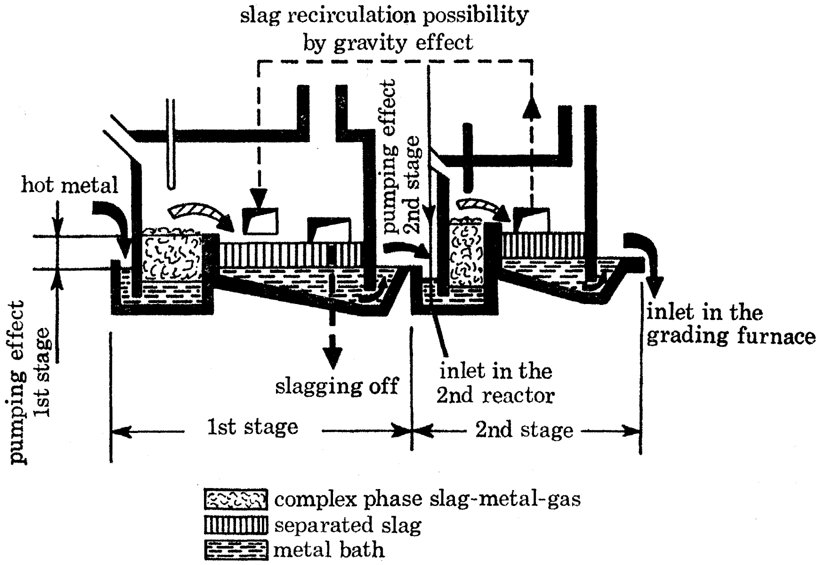

Figure 6. Continuous steelmaking (I.R.S.I.D.).

A batch process also serves as a useful buffer between the preceding and following processes, making the whole system easier to manage than if they were all coupled together.

It is, however, worth taking a look at some of the proposals that have been made for the continuous refining of molten metal. I have already referred to the spray steelmaking process which is essentially continuous in the sense that the material flows through the zone of treatment in this case the atomizing jets of oxygen. Continuous steelmaking processes suggested by Thring and by Worner (figure 5) are based on the counterflow of a layer of the refining slag over a stream of the molten metal. Two other processes one developed in France by I.R.S.I.D. (figure 6) and another by the Moscow Institute of Steel and Alloys are based on a cascade system where the metal flows from one chamber to another enjoying in each a brief period of slow movement and mixing, in which various reactions can take place, before flowing on.

In the non-ferrous metals industry moderate amounts of lead, tin and zinc impurities in copper scrap are removed by fire-refining in batches of up to 200 tonnes in a large reverberatory furnace. This process can be greatly speeded up by the use of slags which selectively absorb particular impurities according to the operating conditions chosen thereby permitting successful attempts to carry out refining continuously in the launder along which metal is transferred from the melting furnace to the casting machine.

Electrolytic processes

Electrolysis, particular at room temperature, has technical attractions over high temperature processes. Although electrolysis is widely used for the production of metal coatings, it has not established itself as a method of producing semi-finished metal products even in the case of copper where electrolysis is easiest and most efficient technically. Aluminium is not capable of being deposited from aqueous solutions. A pilot plant for the production of tinplate strip from ferrous salts was in existence in South Wales at the end of the 1940s, but further work was abandoned in the face of difficulties in producing good properties and a discouraging economic assessment. It is thought very unlikely that cold electrolytic processes for the production of bulk material will have appeared on the scene by the end of the 1980s.

Mechanical processing

I have concentrated so far on the primary metallurgical processes of extraction and refining. I now turn to what might be thought of as the 'second half' of the metallurgical industry, namely the method by which the refined metal is solidified and worked into its final shape and given the properties that make it useful.

The traditional method is to cast the metal into ingots and to work these down, usually by successive reductions in a rolling mill until the final shape, be it strip, rod, tube or other section, is achieved. The reasons for this are that not only is it difficult to cast long individual thin lengths of material, but that a thorough working of the ingot is needed to break down the cast structure which is inherently weak and develop a strong homogeneous texture in the wrought material.

These difficulties have largely been overcome by the process of continuous casting which was first developed in the non-ferrous metals industry. In its simplest form this consists of casting into a mould and chilling the outside rim in which the still liquid metal is held and withdrawing this as fresh molten metal is poured in at the top (figure 7). Solidification continues from the outside as the length is extended. For aluminium and copper base materials many processes utilize a graphite or metal mould built into the wall of the holding tundish or crucible, usually casting horizontally to improve product handling. One example is the process developed by B.N.F., using particularly stable non-metallic mould inserts for casting rod, shapes and flats. Unfortunately this convenient method is not open to the steel industry because of the solubility of graphite in molten iron and the lack of a practicable alternative so far in the form of refractory material. There are many variations on the continuous casting of these, but in practically all cases the structure of the cast metal is superior to that of a conventional ingot so that only a small amount of additional working is necessary to develop the full properties.

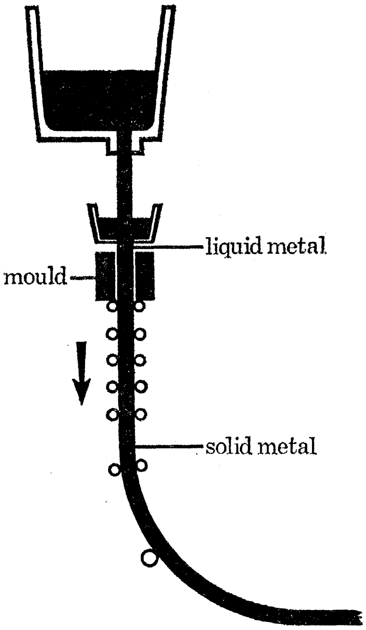

Figure 7. Principle of continuous casting.

A drawback of these methods is that they are rather slow so that for metals that have to be produced in large quantities a compromise is reached in which continuous casting is used to produce the blooms or slabs of fairly large cross-section which are then worked down by the rolling process which is able to shape the metal at very much higher speeds and yield better properties than can be achieved by any form of casting directly to size or near size. Such is the situation today in the steel, aluminium and copper industries.

This 'second half' of the metallurgical industry is still highly capital intensive as evidenced for example by the eight-strand continuous casting machine being installed at the Corporation's Lackenby Works (figure 8, plate 24). It is not surprising that serious thought is being given to a radically different approach. Instead of casting the metal into a large ingot and working it down, the melt is blown into a fine powder and worked up by compaction and sintering into the required product. Some idea of the simplification that can be achieved by this method is shown in figure 9 and, as might be expected, it favours the production of thin material. Although the process is still in its early stages, estimates of the comparative costs of material produced in this way and by present method suggest the economic advantage lies with the newer process (figure 10).

Another possible opportunity for powder metal technology is the replacement of certain

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liquid metal processes such as the conventionally screw-extruded lead cable sheathing that at present depends on a continuous molten metal feed. Particulate lead and lead alloy can be used instead as a powder feed, the plasticity of the metal at the working temperature making such a process feasible. The growth of powder processes in the future is very much linked with the extent to which advantageous structures and properties may be achieved with particulate metals; for example a dispersion-strengthened lead may be produced with superior properties to the conventially produced leads by dissolving other metals in it and quenching very rapidly by blowing into a powder so that the added metals precipitate in a very fine form which they would not do if the lead were cast conventionally. The powder is then consolidated into finished shapes; this technique is now undergoing trials for battery grids.

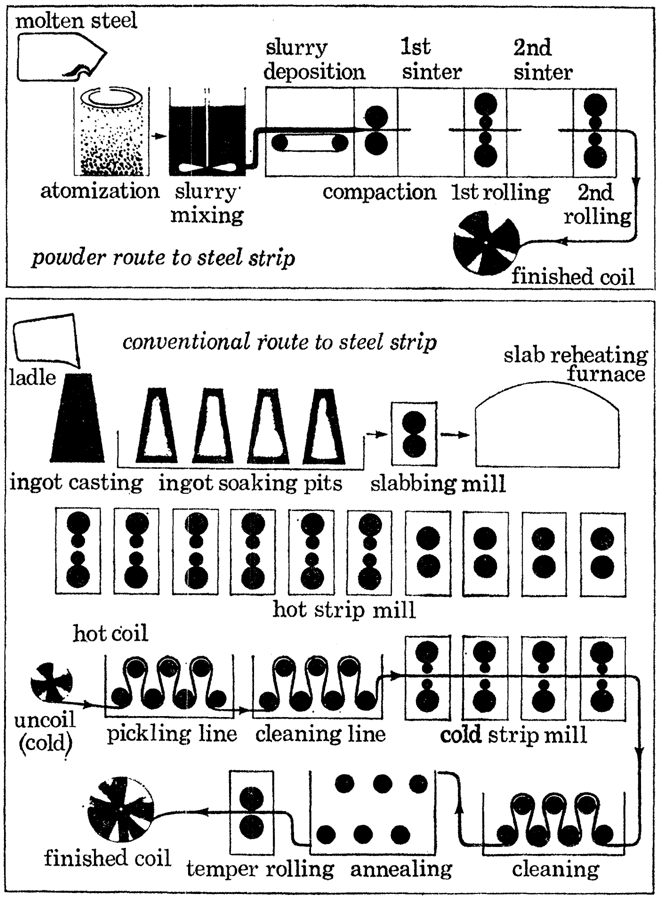

FIGURE 9. Powder versus conventional route for strip.

The extent to which powder methods will have replaced conventional working by the end of the 1980s is difficult to predict, but it may be expected to have made some headway in the production of certain special products such as thin stainless strip and non-ferrous alloys that are difficult to produce by existing methods.

It is worth mentioning an unusual method of going from very large to very small dimensions in a single pass which has recently made its appearance. Known as helical extrusion it involves bringing the metal into the plastic state in the throat of an extrusion chamber and machining off a thin continuous wire by means of a rotating die.

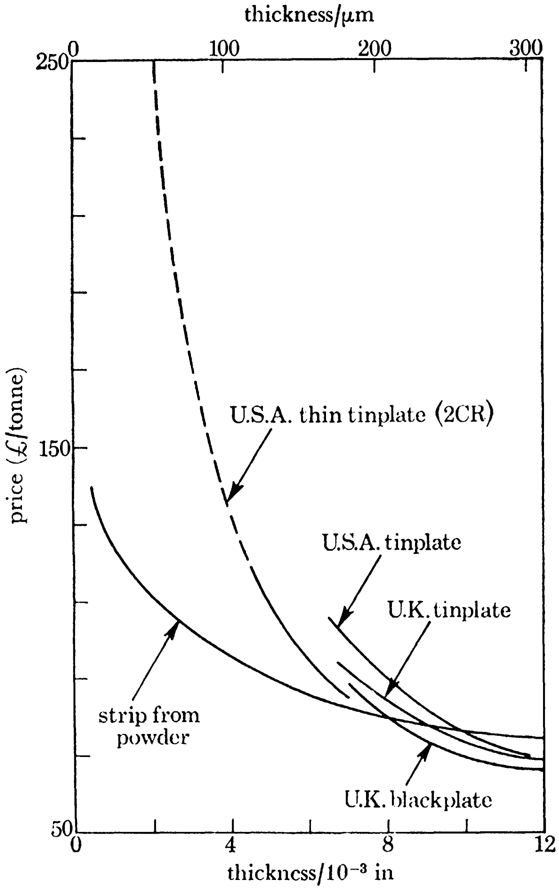

FIGURE 10. Comparative costs for strip from powder.

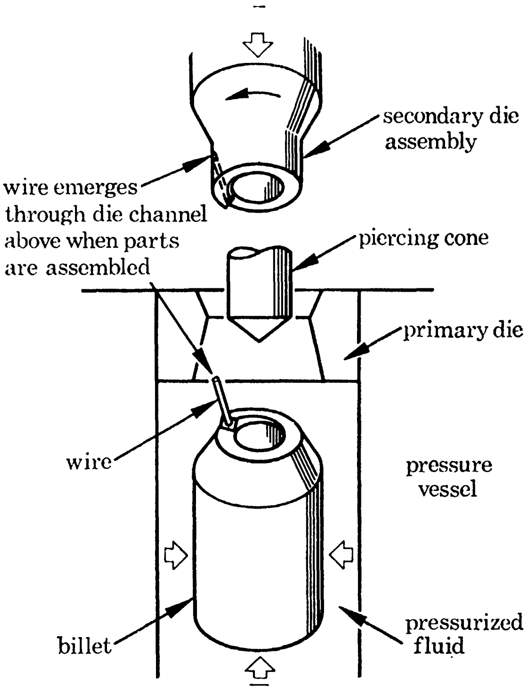

FIGURE 11. Helical extrusion.

Reduction in cross-section of 2500:1 have been achieved with copper by this method. An exploded diagram of the plant (figure 11) displays the elements of the process. Although early days to judge, this could make a significant contribution to wire production by the 1980s.

Fuel

No consideration of the future shape of metallurgical processes would be complete without some reference to future patterns of fuel consumption. Prediction in this area is particularly difficult even in the short term and the metallurgical industry may perhaps console itself with the fact that for the purpose of melting and heat treatment, its technologies are very flexible. Coal (coke), oil, gas and electricity are all widely used and the metallurgical processes themselves are not seriously affected by a change from one to another, although expensive changes in plant may sometimes be involved.

The shoe is likely to pinch hardest in the steel industry where coke is used as a reagent in the reduction of iron ore in the blast furnace. This is already becoming a major supply problem in the U.K. and in much of Europe. There seems little doubt that the industry will be forced to move away from coke produced from prime coking coals and will rely increasingly on cokes produced from lower rank coals. Some movement in this direction is exemplified by the process of preheating the coal before introducing it into the coke ovens (figure 12, plate 25) and a full-scale plant is at the moment undergoing trials on coke ovens at Brookhouse near Sheffield. Another approach lies in the manufacture of 'formed' coke in which lower rank coals are pulverized, mixed with a binder, pressed and heat treated to form briquettes suitable as a substitute for metallurgical coke (figure 13, plate 23).

However, the increasing cost of even the lower grades of coal is likely to stimulate methods of partially replacing the coke with oil or natural gas as a reducing agent in the blast furnace. In some of the British Steel Corporation's blast furnaces, oil injection is already replacing 10 % of the coke requirements and there is a good prospect of doubling this figure before very long.

Natural gas is unlikely to become a primary fuel source in the U.K. for by the end of the 1980s we may be two-thirds or more through our reserves. For this reason, long-term thinking is moving towards nuclear power. For a very large integrated works, a fully harnessed nuclear reactor capable of producing heated reducing gases to produce iron from ore, and giving low cost electricity for steelmaking, may prove attractive.

The human factor

At one time it was taken as a matter of course that heat, dust and noise were inseparable from metallurgical operations; where there was muck, there was money. This attitude has been changing very rapidly and a modern metallurgical works presents an altogether different scene in respect of amenity and safety from a typical works of 25 years ago. Expenditures for pollution control in large iron and steel works of the 1960s were about 5 % of the total capital investment; provision of other amenities accounted for another 1 to 2 %. In the new large works of the late 1970s and early 1980s such spending is likely to approach 10 to 12 % of total capital investment. The trend to more exacting pollution control will certainly continue and at times may find itself in conflict with the introduction of improved technology. Two examples may be given where such a conflict has been resolved by pressing the technology a little further.

The first which is best understood by a glance at figure 14, plate 26, shows what happened when pure oxygen was tried as a means of speeding up the decarburizing process in an electric arc furnace. Any attempt to contain and control the fine red fume that is produced would have proved very difficult and expensive. The simultaneous injection of some fuel oil produced the result shown in the second picture (figure 15, plate 26) without slowing up the rate of carbon removal. The muck had gone but the money was still there.

We shall continue to see such improvements in the metallurgical environment; after all, the skilled worker today drives himself to and from his work in a machine in which comfort, quietness and ease of control have been given the very closest attention. He will increasingly expect to find the same standards embodied in the design of the machines that he controls in the course of his daily work; thus in the design of plants consideration will apply in the design of chairs, suiting against heat, easily read indicators, better designed buildings with controlled environments. This trend will be strongly reflected in the design of the metallurgical plant of the 1980s.

My other example concerns the mental environment to which the metallurgical worker is exposed. One problem of perhaps lesser difficulty in metal plants than in the more ordered mass production in machine-controlled processes such as assembly lines, is boredom through repetition which is not a general feature of metal plants requiring constant relief. Muzak is not installed in metal manufacturing plants. This is because processing has its constant upsets and variations which require concentration and decision constantly and not human intervention at very infrequent intervals and because work is done generally in groups. There may be places where isolated individuals, e.g. in pulpits overseeing mechanical devices, are often called upon to make decisions for which he may lack sufficient time and information and yet for which he is held responsible. This is a consequence of the steady increase in the volume and speed of production. One solution is to bring in the computer but this can reduce the operative to a mere button pusher. In a scheme that we have under test at the moment, the computer is placed in the hands of the operative himself who uses it to explore very rapidly the consequences of a number of alternative decisions, but his skill in doing so and his interest in the job are both greatly enhanced.

Accident prevention

One area of management concern which will take more thought and effort in the 1980s lies in accident prevention and safety of operators. Our present techniques for rationalized action leave much to be desired.

Generally speaking 'safety' within industry is based upon the investigation of existing fatality and injury to workpeople. This is a long-established, laudable, humanitarian approach to the problem, backed up by law and the Factory Inspectorate. Recent research in the Corporation (and this may well obtain elsewhere) has revealed serious shortcoming in this approach however, confirming as it does that only one in every ten industrial accidents results in injury at any given time and only one in every ten injuries leads to absence from work. Thus, by concentrating effort upon the examination of lost-time injuries – as is required under the Factories Acts – only 1 % of the accidents at work are actually examined on hindsight.

In the short term, the usefulness of existing injury information is being improved by making a necessary distinction between the causes of accidents and the causes of injury in these situations because they call for two types of remedial action. Simply analysing the incidence of head injuries in a works may suggest the provision of safety helmets as a solution. The wearing of head protection may prevent or reduce head injuries; but it will not stop things being dropped on people's heads! Since introducing this double analysis three years ago to establish the separate

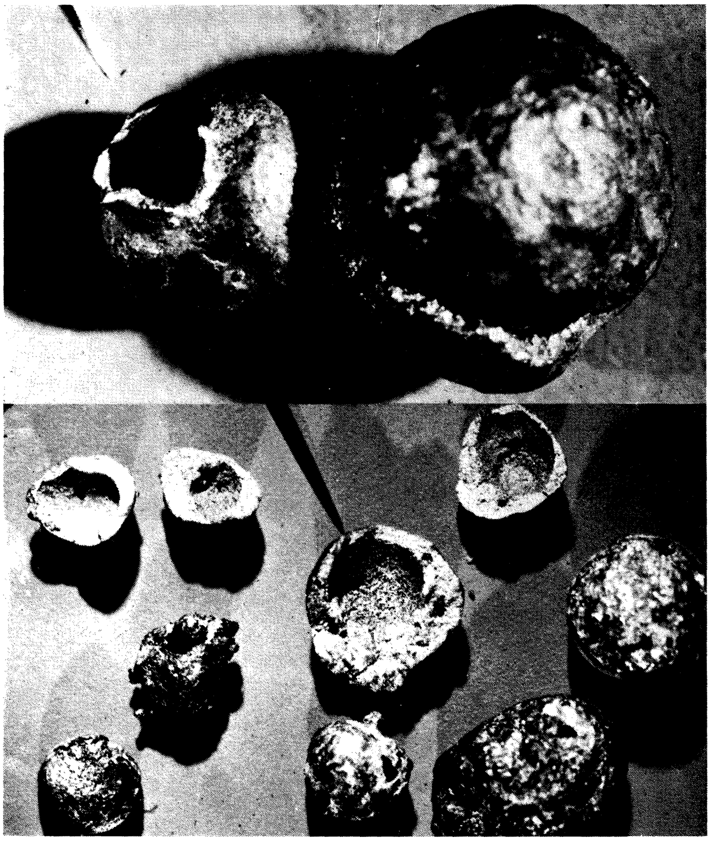

FIGURE 4. Particles of steel in slag (Meyer).

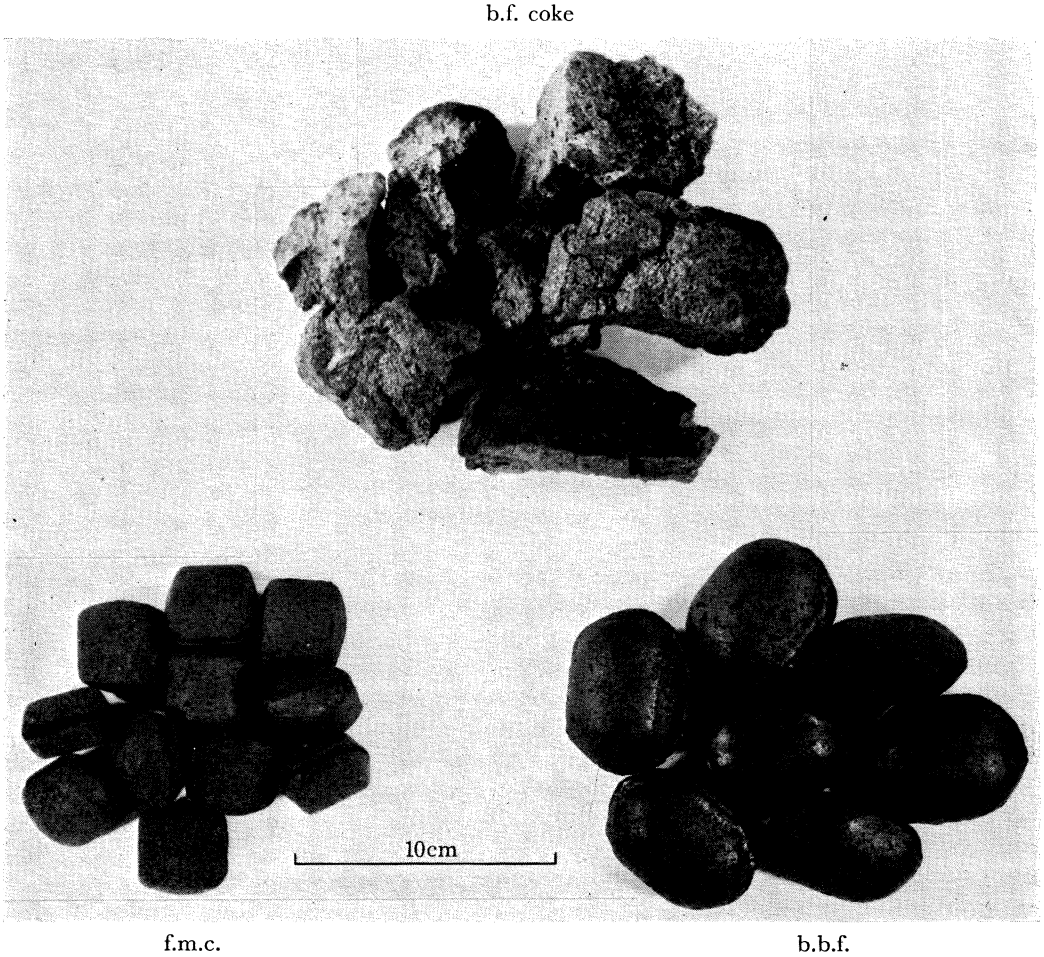

FIGURE 13. Formed coke.

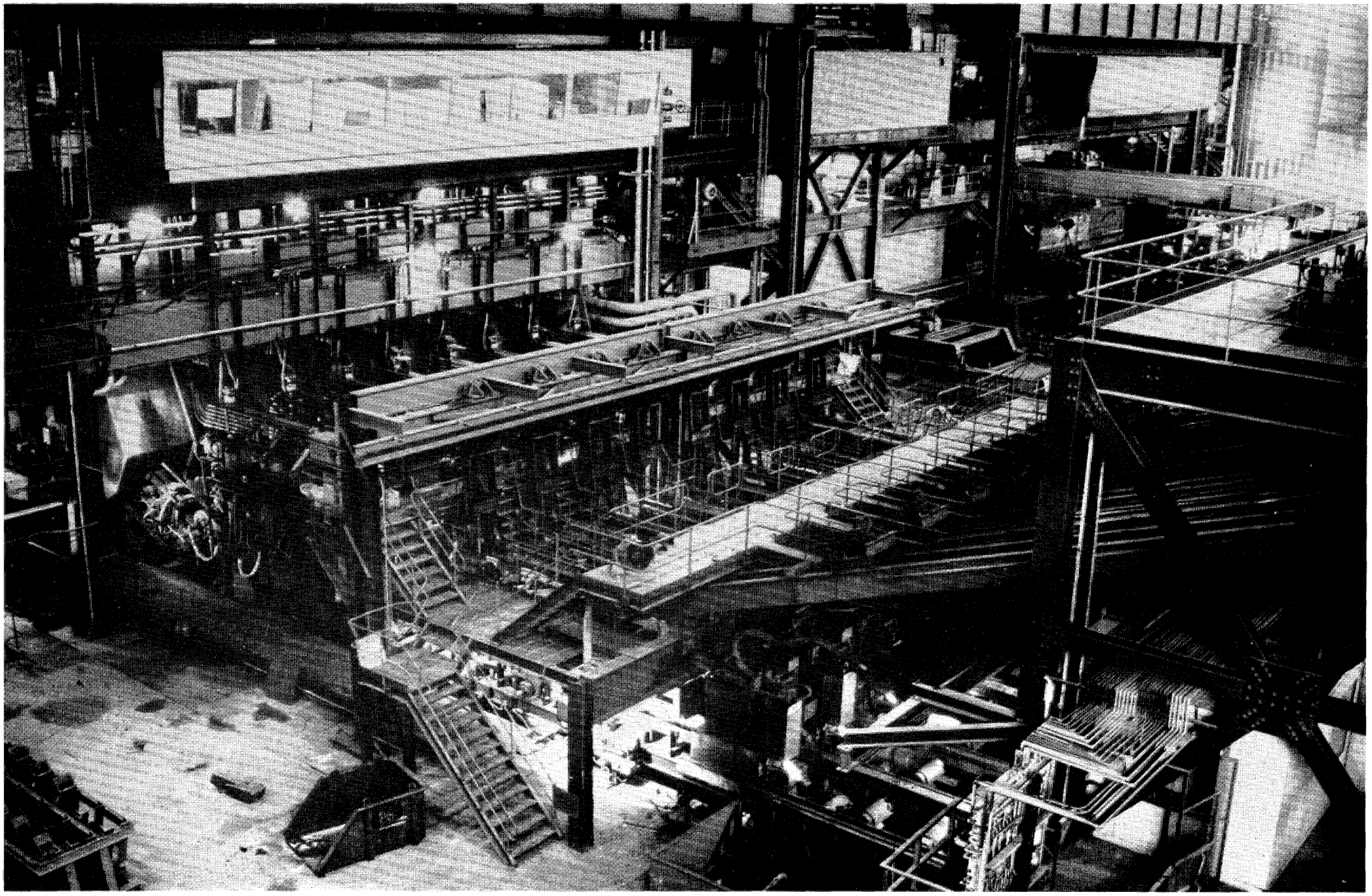

FIGURE 8. Continuous casting plant – Lackenby.

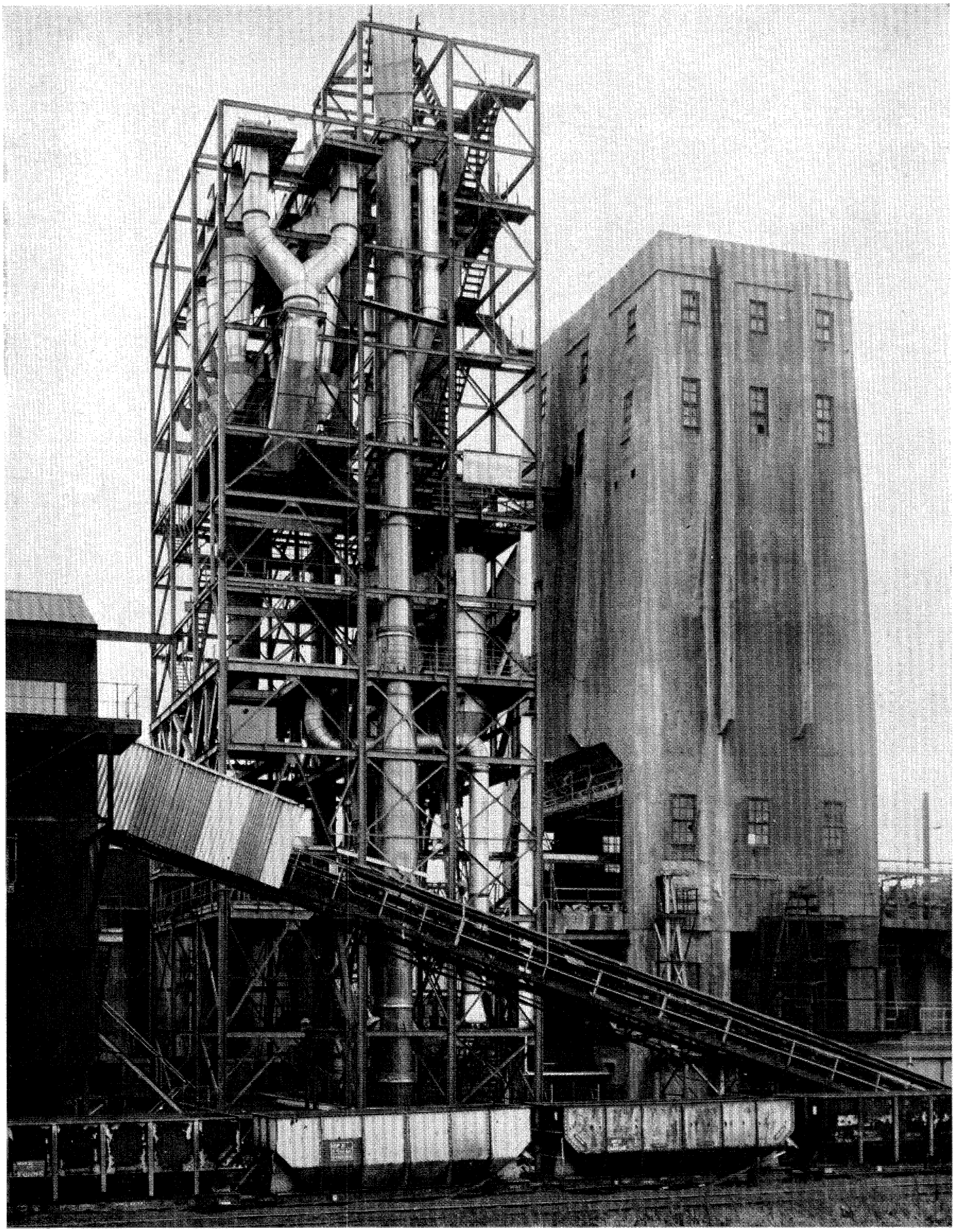

FIGURE 12. Brookhouse coal preheating.

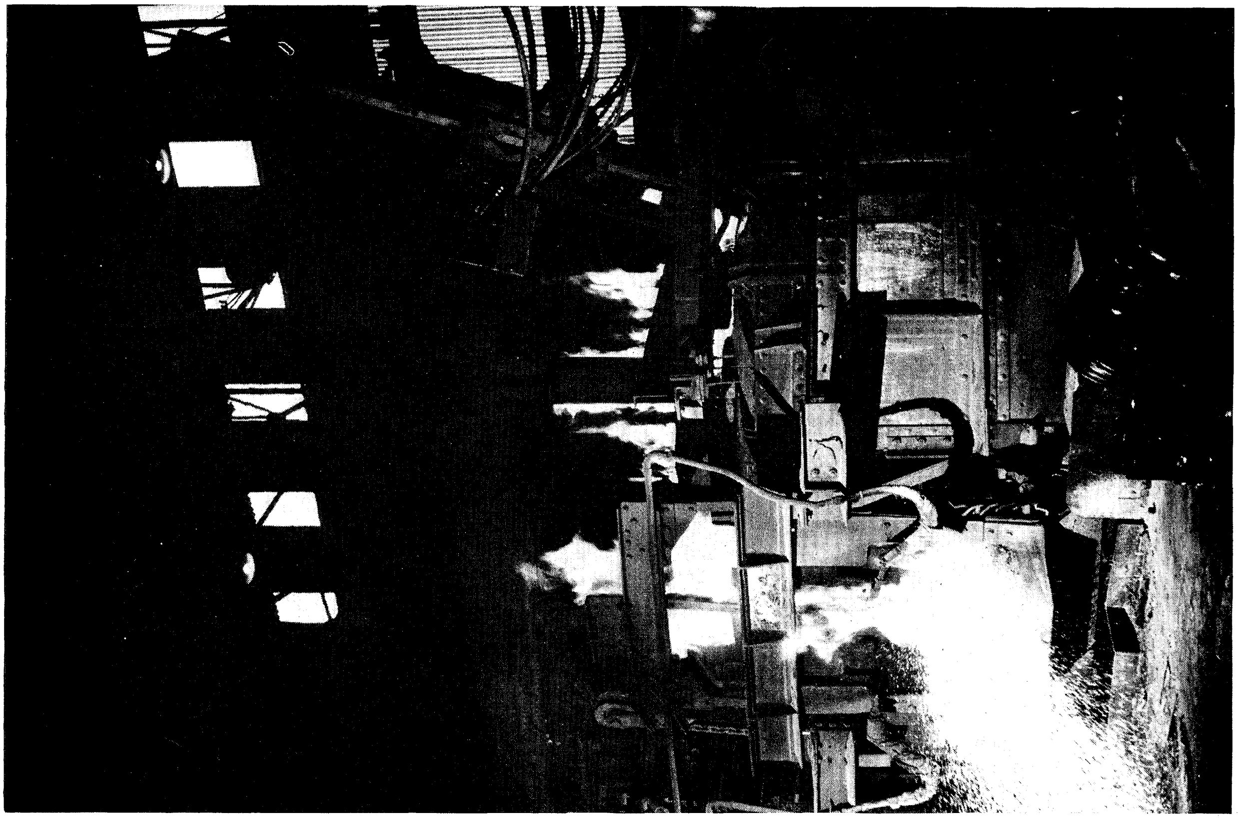

FIGURE 15. Arc furnace fume suppression.

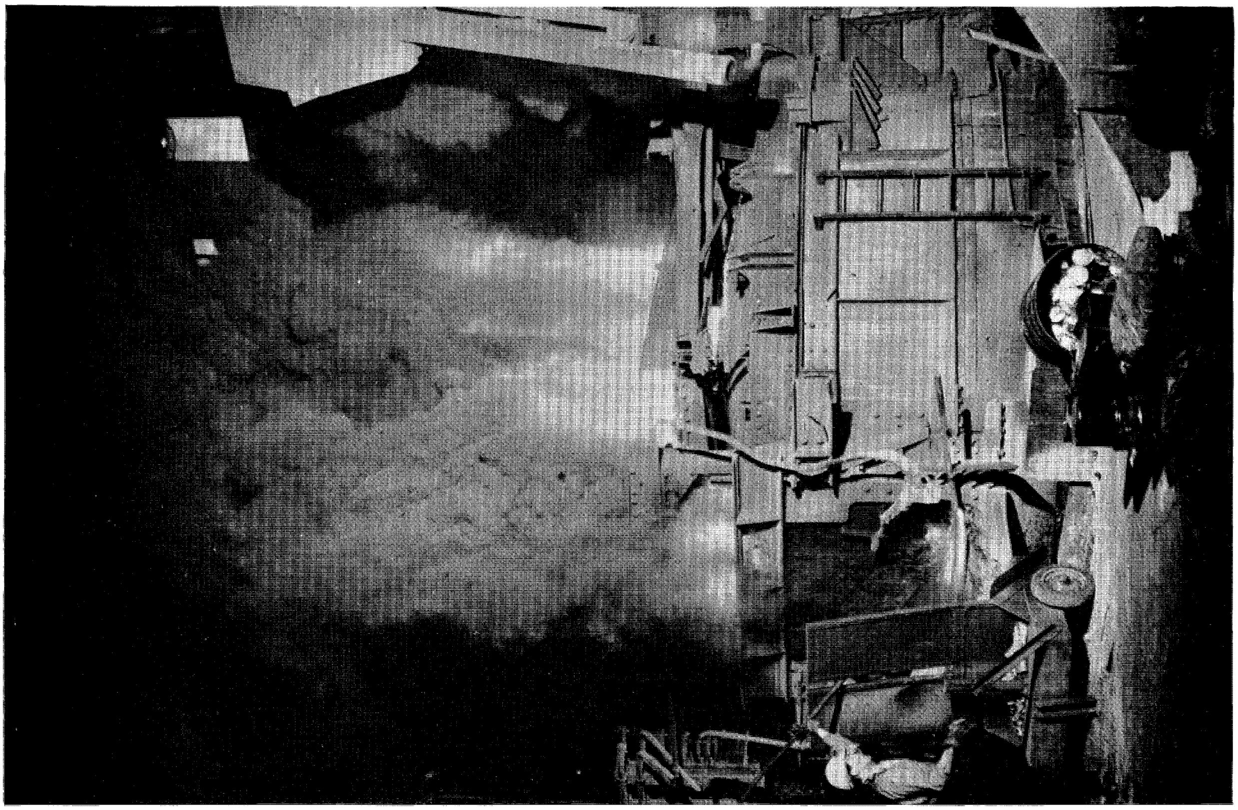

FIGURE 14. Arc furnace fume.

causal factors, there has been a 30% reduction of lost-time injuries in the Corporation through more effective remedial action.

In the longer term it is aimed to tackle the problem at the pre-injury stage by examining the causes of damage to plant, property, equipment and the product, as well as work interruption, and establish the injury potential in those situations. A recently completed pilot scheme using this approach suggests that accident control of this kind can not only take 'safety' out of the existing subjective aspects of interpretative factory law, but more importantly place it within the sphere of management accountability and the cost-effectiveness of running the business. If this idea matures, the technologies of the 1980s will involve safety or accident prevention as part of technology and not divorced or separated from it.

Discussion

PROFESSOR H. FORD (*Imperial College, London*) said that he would like to comment on several aspects of Dr Finniston's talk.

First, he believed that by 1980 conventional processes in the metallurgical industries would be under serious challenge. He said there were a number of reasons why the rates of change would be faster than Dr Finniston had indicated. The rising cost of one of the raw materials, which Dr Finniston had examined, was surely a factor, but so also were the cost of high-temperature energy; the need to deal with leaner ores and leaner metal values; the need to eliminate pollution; the needs of the end product; and finally, the possibility of competition from other materials. He thought that by 1980, in terms of sheer volume, plastics may have overtaken iron and steel.

Secondly, he believed that the possibilities of total energy schemes ought to be considered, especially in relation to the building of mini steelworks. Energy is becoming increasingly expensive, but four years ago he had pointed out that an industrial gas turbine, developed to use a number of different fuels, directly linked to a generator and to an arc furnace, might be a considerably cheaper way of running electric furnaces than the present method of taking energy from the grid. Thus the total cost of melting and refining by the electric arc could be reduced.

Thirdly, Dr Finniston had mentioned the benefits of scale that result particularly from an integrated steelworks, producing mainly sheet and strip and tending increasingly towards continuous processes. The mechanical engineering industry, on the other hand, is concerned with cutting up the products of the metal industries, with the possible exception of wire, into pieces which it can then forge or machine into smaller components. The whole pattern of steel production could be changed if the steelworks could be persuaded to tailor their products to the needs of the engineering industry.

Finally, as an aid to the elimination of pollution, he suggested the use of hydrometallurgy, and in particular of solvent extraction, for the reduction of ores. In the extraction of copper, for example, there are now processes highly competitive with pyrometallurgical routes for the extraction of copper of high purity from lean ores or even from the slag heaps of previous pyrometallurgical operations. These solvent extraction methods are either liquid solvent extraction or solid iron exchange processes. One is just about to be started in Zambia, pioneered from this country, to treat 55000 l/min of a low-content copper solution. There are cases where conservation is demanding that even mine water containing small quantities of copper must be treated by some means or other, because it can no longer be thrown into the seas. Here again one can show, by solvent extraction, competitive and indeed profitable operations which remove the copper and zinc from such mine waters and make copper which can be sold in the normal way. This was one inexpensive solution to the twin problems of pollution and low content ores. He estimated that by 1980 most copper would be produced by these routes rather than by the normal smelting routes.

Dr Finniston replied to these points. He thought that the continual argument about whether steel would be displaced by aluminium or by plastics was quite pointless. At present 600 million tonnes of steel are produced per annum and in 1980 it will be 900 million tonnes. Metals are still the basis of the industrial world, and the fact that the ratio changes as between one material and another is not an important factor in the discussion.

On the question of facts and fuel availability, so long as metals are produced from their ores, there must be a reductant, which is either naturally gained like coal or gas or oil, or is manufactured, in which case it requires some form of energy – coal or gas or oil. Whatever fuel is used, the processes do not change and will look much the same in 1980. Even new forms of heat like plasma jets which might go to higher temperatures than before will not change basic processes.

He conceded that the steel industry would no longer produce small lengths of steel for engineering use. Steel rod is now produced in coil form, the coils weighing between 2000 and 3000 kg, which can be straightened out and cut to the required lengths.

The problem with hydrometallurgy is that it does not produce a metal; it produces an intermediate salt which has to be processed into metal, either by electrolytic or pyrometallurgical means.

Professor J. M. Alexander (*Imperial College, London*) asked Dr Finniston's opinion on the value of research on a continuous extrusion process. He said that he had been working for many years on hydrostatic extrusion in the hope that it would be possible to develop a continuous extrusion process. The hydrostat invented by Derek Green at U.K.A.E.A. was not in fact a continuous process, although he is now working on this idea. They are experimenting with continuous processes at Western Electric in the U.S.A., in which the feed stock is fed into the extrusion container by circulating viscous fluid which drags in the material.

Dr Finniston replied that there was considerable value to be obtained from extruded products and he welcomed research on the subject, although he thought that continuity was only of secondary importance. In his talk he had referred not to the continuity aspect of hydrospin, but to the high reductions that could be achieved in one pass, rather than through a multiplicity of rolls or dies.

In this connexion Professor Alexander added that 14000:1 could be achieved with straight hydrostatics.

Professor M. W. Thring (*Queen Mary College, London, E*1) suggested that the best method of predicting the future is not to base predictions on the present, but to consider the situation in the 21st century and then work backwards from there.

His argument was founded on the premise that in the twenty-first century our perpetually expanding economy would have been replaced by an equilibrium economy. There will be a grave shortage of raw materials and the main source of material for the steel industry will be scrap recycling. The industry will probably not be allowed to use oil or natural gas, and the future of cheap electricity from uranium-235 is uncertain.

While he expected the world consumption of steel to remain static, at approximately 100 kg per head per annum, he forecast a contraction in the steel-making capacity of the richer countries. The poorer countries of the world will demand their own steel works and often these will be very small and will need to be able to process both raw ore and scrap. The steel-making world must prepare itself for these changes. He thought that the steel industry would continue to rely upon pyrometallurgical processes for the reduction of iron ore, but would probably adopt a low shaft furnace which has the counterflow between the gases and the fuel and the iron ore with the advantages of even distribution of the gases throughout the charge, which does not occur in a blast furnace, and the absence of the huge weight of material of the high-shaft furnace.

The fuel will be soft coal, of which there will still be large quantities and hard petrocoke. This will produce a 90 % reduced ore and will have the full thermodynamic efficiency of a blast furnace. Carbon, moreover, is ideal because it releases heat and still oxidizes to carbon monoxide which is a reducing gas. The coke oven will be a thing of the past, but in the transition period there may be briquettes of iron ore and coal or even of iron ore and fuel oil.

With regard to scrap melting, he favoured the development of a fully continuous process, either fuel-powered or arc-heated, or a combination of the two, as was tried experimentally at Paderborn in Germany about 15 years ago and which, because of the advantages of a fully continuous process with counterflow heat exchange, gave a high overall thermal efficiency in melting of over 50 %.

He dismissed Dr Finniston's objections to a fully continuous process for the refining of steel and the design of a furnace to take any proportion of hot metal or pre-reduced cold metal or scrap from 0 to 100 %. Whereas the L.D. process oxidizes the materials in the iron, the continuous process uses iron oxide and involves a fully counterflow slag which gives a bigger yield of metallic iron and produces no fumes. The problems of mixing and varying the composition can be overcome by using a computer programmed to produce the required result. Moreover, he suspected that the capital cost of a continuous process was likely to be cheaper in the long term than that of the L.D. process and this would reduce the price of steel.

Dr Finniston said that Professor Thring had looked considerably further ahead than he had in his own paper, and that this could account for the discrepancies in their ideas. He agreed that the shaft furnace reducing solid pre-reduced pellets, vertically instead of horizontally, and subsequently tied to an electric arc working horizontally might replace the blast furnace if continuous steel-making were to come about, but neither the economics nor the technology of the shaft furnace was sufficiently developed at the moment to persuade him of the necessity of its adoption in the next decade.

He noted that underdeveloped countries building their own steel works, because they have little scrap to be melted by electric arc, have often preferred to avoid the blast furnace stage of producing molten iron and to replace it by direct reduction which produced pre-reduced iron to be melted in electric arcs.

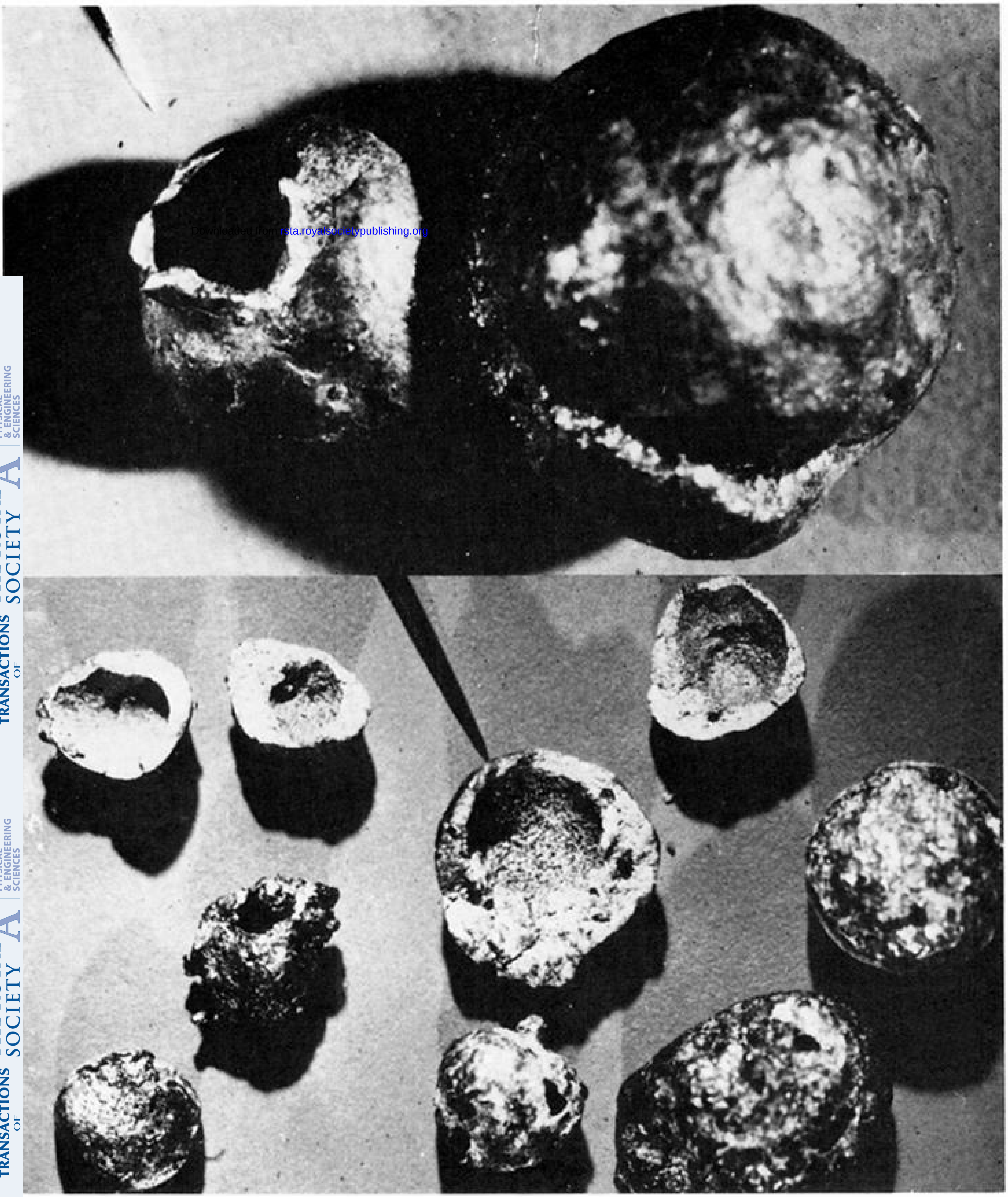

FIGURE 4. Particles of steel in slag (Meyer).

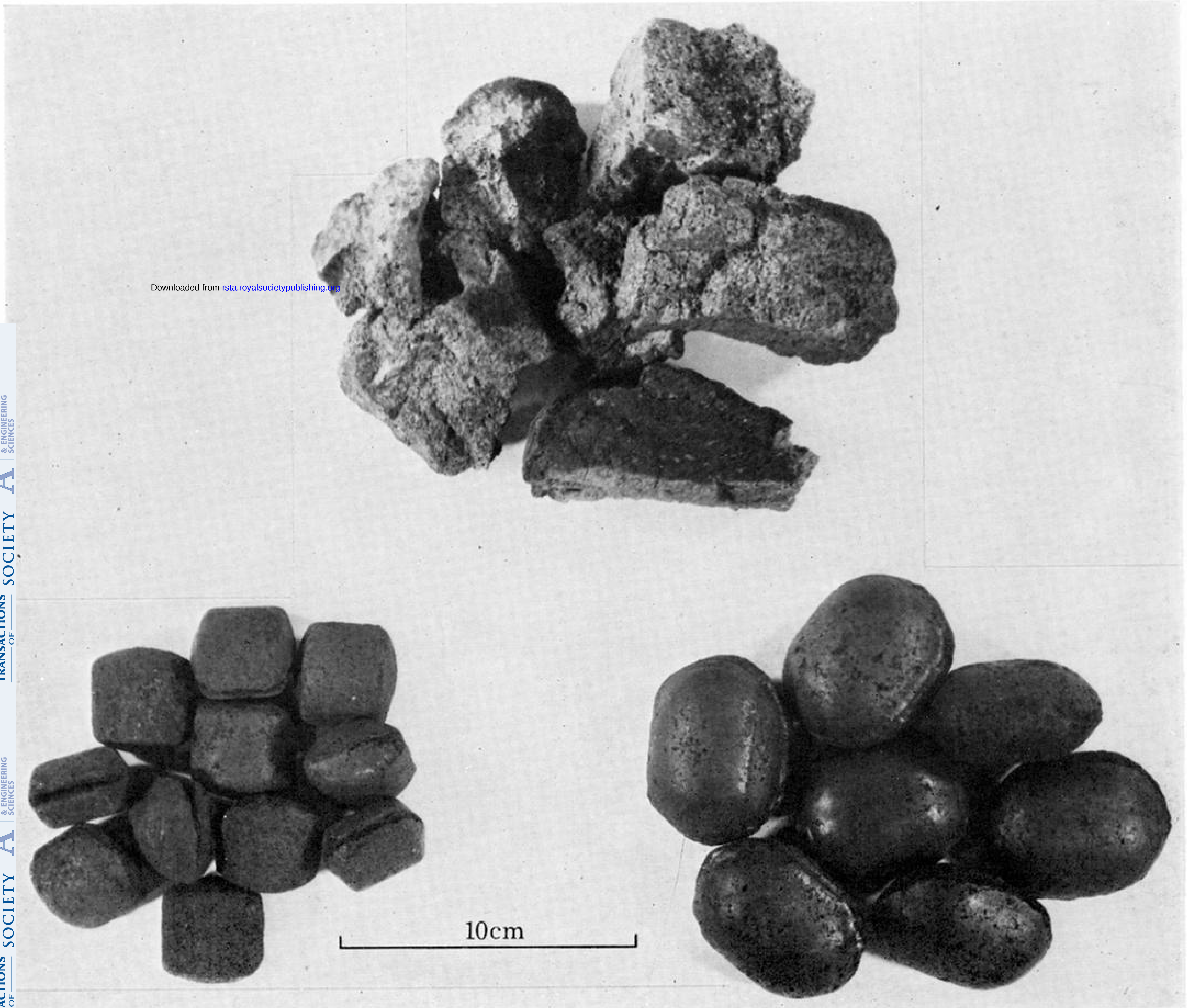

FIGURE 13. Formed coke.

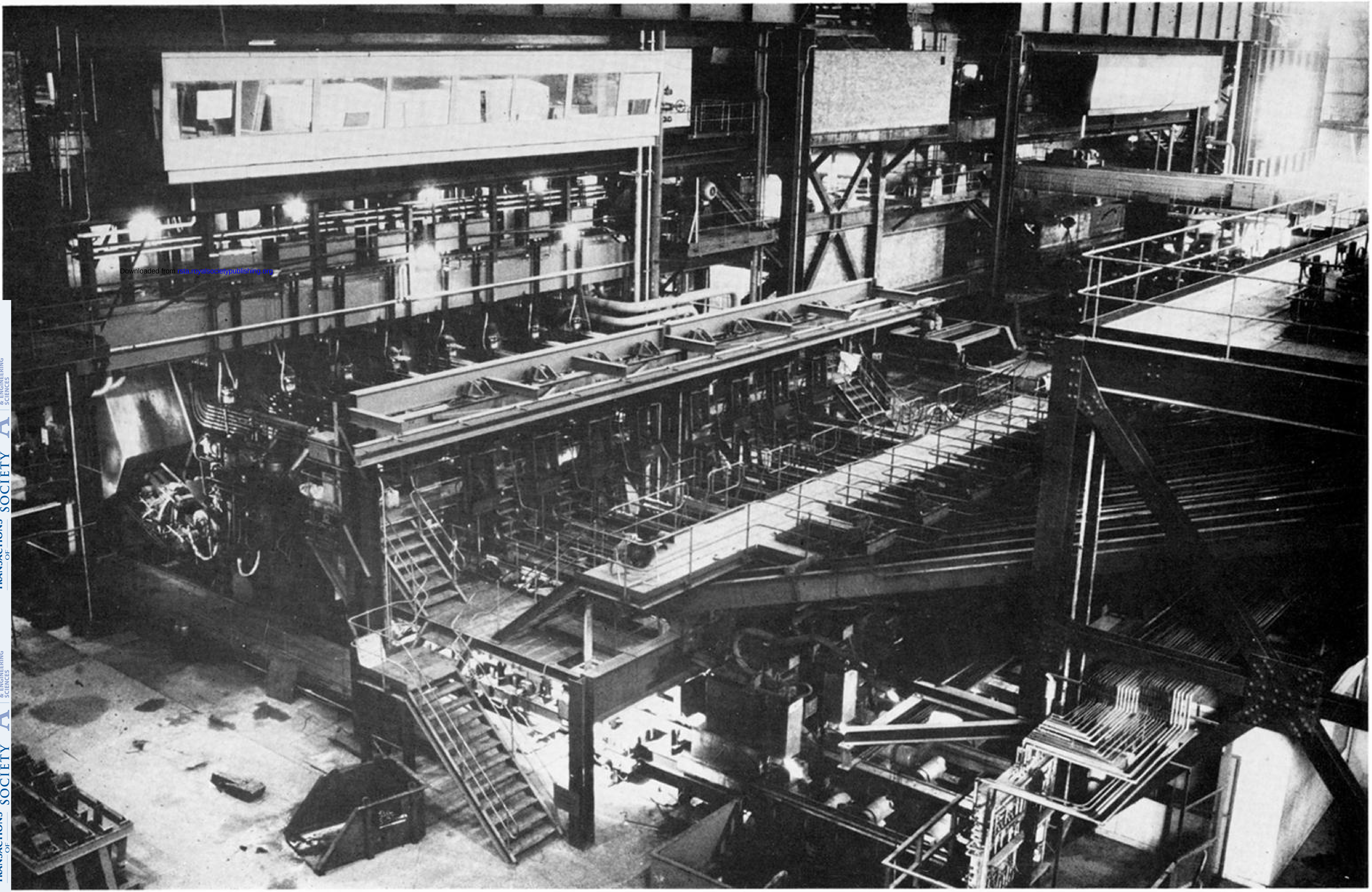

FIGURE 8. Continuous casting plant – Lackenby.

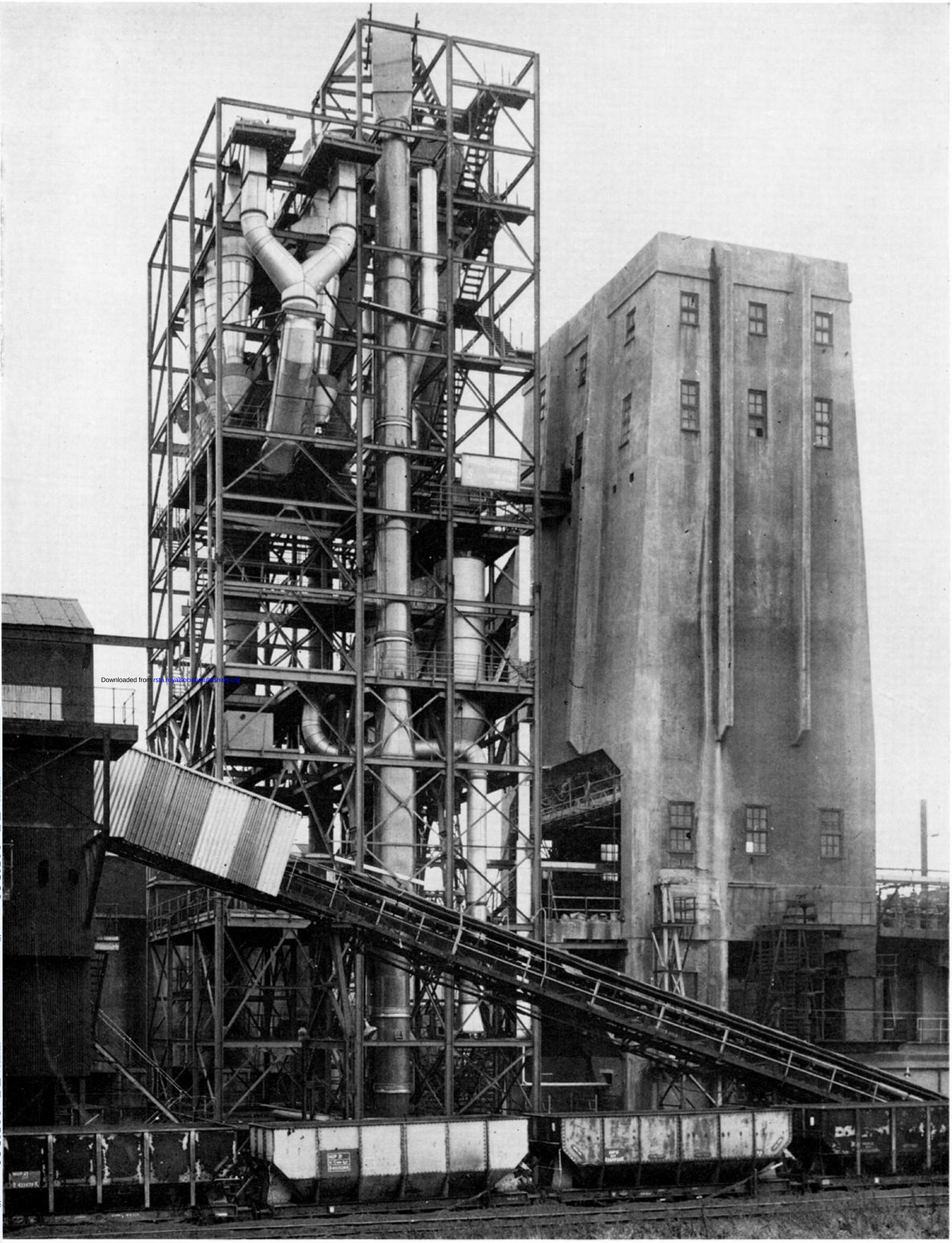

FIGURE 12. Brookhouse coal preheating.

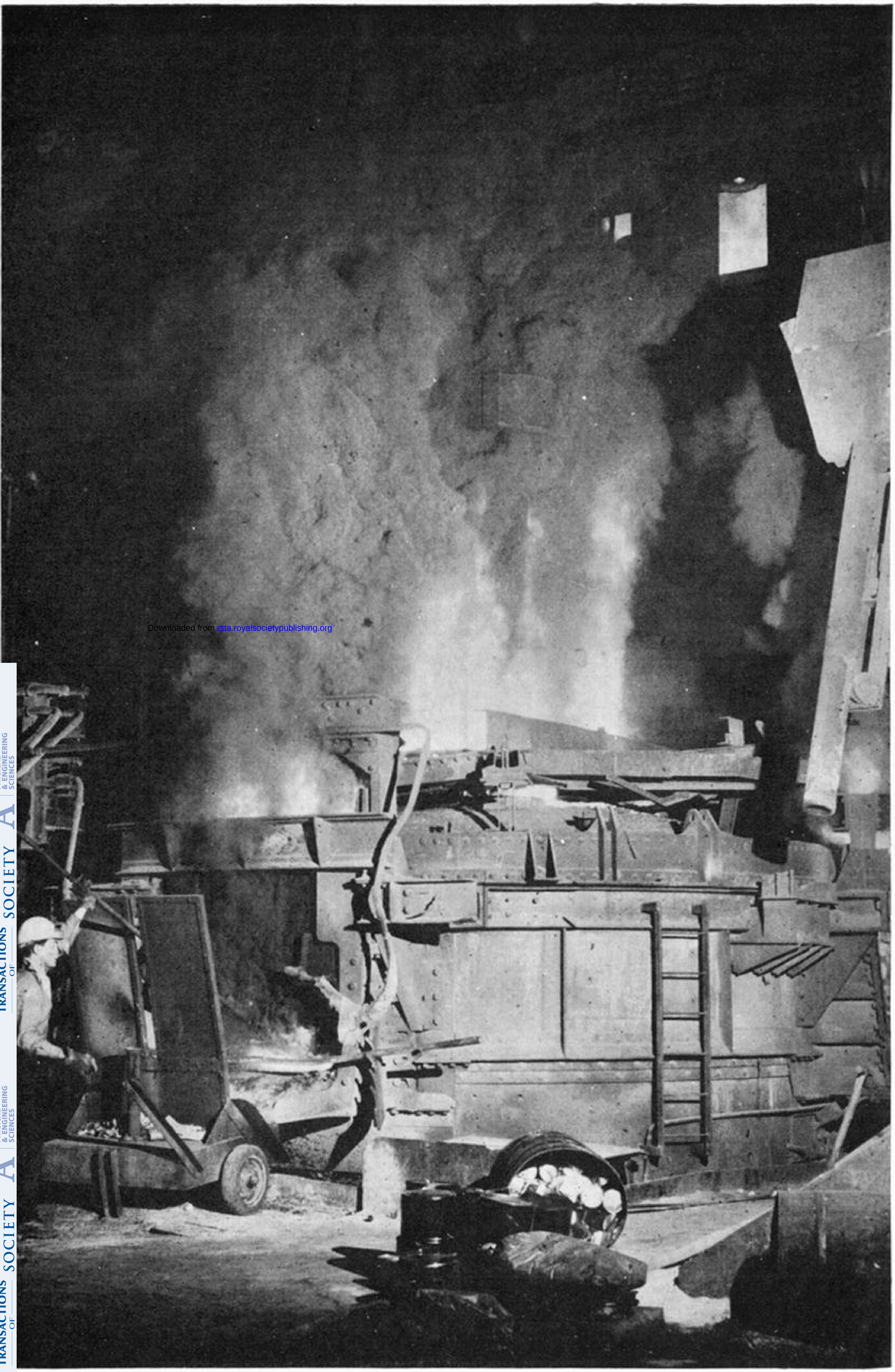

FIGURE 14. Arc furnace fume.

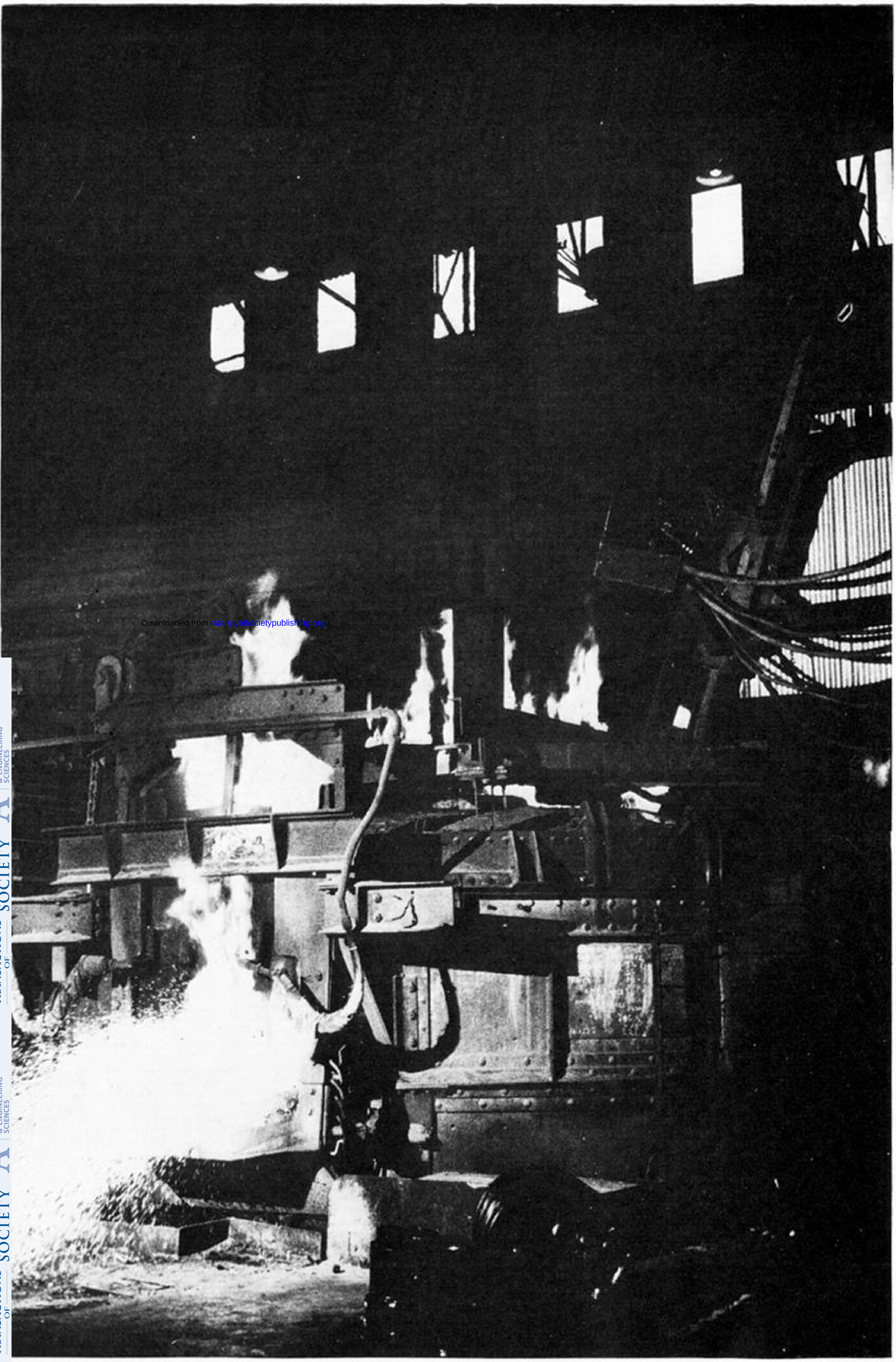

FIGURE 15. Arc furnace fume suppression.