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THE MAGRAM PROCESS FOR THE RECOVERY OF MAGNESIUM METAL FROM ASBESTOS-CONTAINING WASTE MATERIALS

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Abstract

There is a growing recognition that the safest methods for the disposal of asbestos-containing wastes are those that result in destruction of the hazardous fibres. Although such techniques are already available, however, they have not become widely adopted owing to the high costs of treatment relative to the current costs of disposal to landfill.

An innovative process, the “MAGRAM” process, is being developed for the recovery of magnesium metal from asbestos-containing wastes with the addition, if necessary, of a supplementary feedstock containing magnesia. Asbestos fibres are completely destroyed in the process and an economic incentive is derived from the value of the magnesium product.

The basis of the new process is that magnesia in a molten slag, comprising the oxides of calcium, magnesium, silicon and aluminium, is reduced by aluminium and/or silicon to form free magnesium. The slag composition is carefully formulated to provide the important advantage of generation of magnesium vapour at or near atmospheric pressure rather than at the reduced pressure under which existing pyrometallurgical magnesium extraction processes must operate. The new process operates at high-temperatures, typically of about 1700°C, and is heated by a transferred electric arc in a furnace operating in open bath mode.

Thermodynamic modelling work has been undertaken to define the range of slag compositions and furnace temperatures within which magnesium may be produced at atmospheric pressure. The effect of slag chemistry, reductant addition and temperature on product quality and yield have also been investigated and key aspects have been tested in experimental measurements at the laboratory bench scale. The production of magnesium from a feedstock incorporating calcined asbestos mining wastes has also been demonstrated in an experimental plant rated at 300 kW and details of this pilot operation are described.

1 Introduction

The safe disposal of asbestos-containing waste materials is an increasingly pressing problem of concern to industry, commerce and society in general. The dominant current approach to the problem is to dispose of the wastes in controlled landfill sites. This is inadequate from a number of perspectives, not least of which is the fact that landfilling does not fully eradicate the hazards associated with asbestos fibres.

In recent years several *new* technologies have been developed in an attempt to address this issue. Several of these processes are based upon fusion techniques but the associated costs have meant that they have not found widespread adoption.

However, a new process being developed under the auspices of the European Communities "Brite-Euram" Industrial and Materials Technologies Programme, offers the potential to make the destruction of asbestos fibres profitable. This is accomplished by regarding the wastes as a raw material which may be incorporated into the mass balance of an improved process for the pyrometallurgical extraction of magnesium. The process is being piloted with chrysotile asbestos and its derivative products. Chrysotile (“white” asbestos) is reputed to be amongst the least harmful of the asbestiforms and its use and distribution far exceed that of the more dangerous amphibole fibre types (“brown” and "blue" asbestos).

2 Description of the process

In the MAGRAM process magnesium metal is extracted from asbestos and/or other magnesia-containing materials by the metallothermic reduction of MgO. The process operates at high temperatures and is heated by a transferred electric arc in a graphite electrode d.c. arc furnace. The MAGRAM process flowsheet is shown in Figure 1,

A key feature of the process is that the slag chemistry is carefully formulated to allow the plasma furnace to be operated close to atmospheric pressure. A major advantage of using a transferred arc system is that the power input is independent of the slag chemistry. The strongly basic slags required in the MAGRAM process are highly electrically conductive and, correspondingly, are not suitable for resistive heating as used in the Magnetherm process. Furthermore, the high power densities associated with the arc, together with the high fluidity of the slag, ensure efficient heat transfer to the surface of the slag enabling rapid melting and reaction rates in the furnace.

In operation the raw materials (i.e. asbestos-containing wastes, dolomite, magnesia and alumina) must be calcined to ensure the removal of all water and to decompose carbonates. The oxidic products are pre-blended with the reductant (i.e. ferro-silicon and/or aluminium) and fed at a controlled rate to the furnace through feed ports in the roof., The solid feed materials are quickly assimilated in the slag bath. The magnesium generated is volatile and the vapour leaves the furnace at the off-gas port and is recovered as liquid metal in the condenser which is close-coupled to the furnace. The off-gas from the condenser is flared to ensure the combustion of any entrained metal particulate prior to gas cleaning and final venting to atmosphere. Slag and metal are intermittently tapped from the furnace.

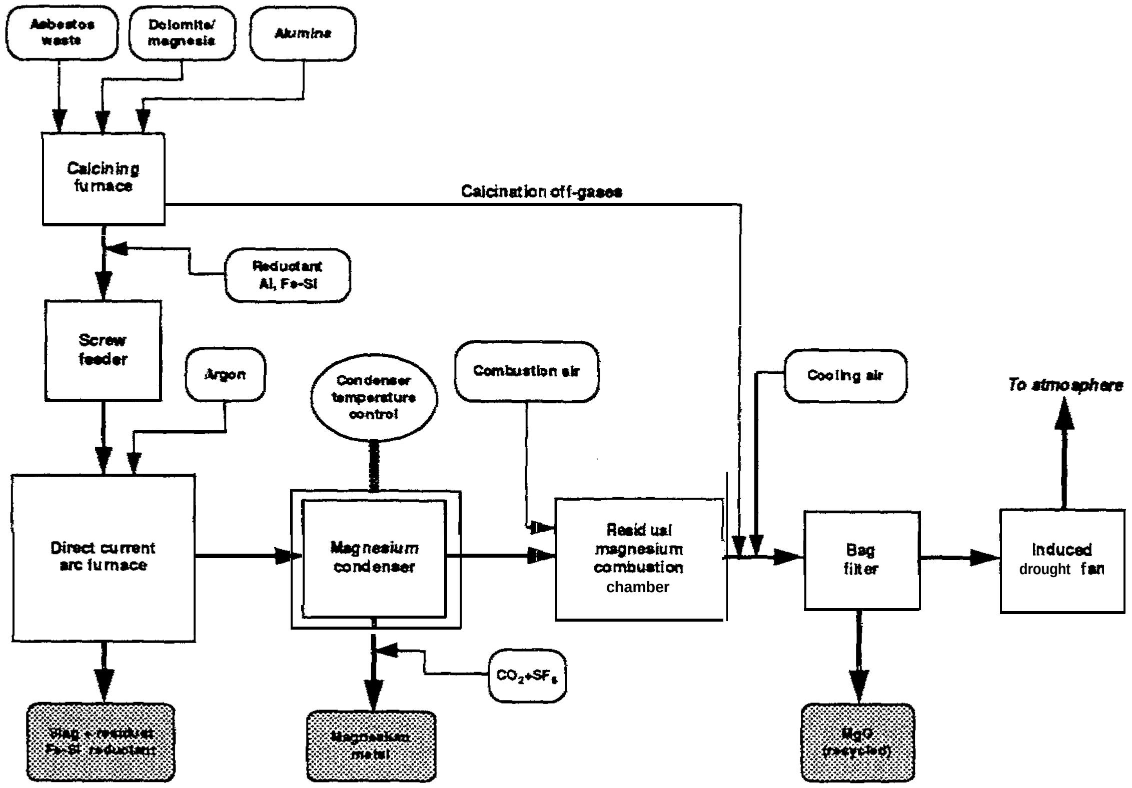


Figure 1 MAGRAM process overall flow sheet.

3 Thermodynamics

The process is founded on the application of novel slag chemistry developed to overcome the operating constraints of the Magnetherm process as currently employed for the production of magnesium metal.

3.1 Magnetherm process

In the Magnetherm process, magnesium is evolved as a gas phase via reaction of ferrosilicon with the MgO content of the molten slag phase. The process is operated at a temperature of 1550°C and at a pressure of 5 kPa. The slag composition is 6 mass% MgO, 14% Al_2O_3, 55% CaO and 25% SiO_2. The overall reaction maybe represented as

$$2Mg0 + Si \rightarrow 2Mg_{(g)} + SiO_2 \qquad (1)$$

for which the equilibrium constant is

$$K = \frac{P_{Mg}^{2} \cdot a_{SiO_2}}{a_{MgO}^{2} \cdot a_{Si}} \qquad (2)$$

Examination of the appropriate section of the quaternary phase diagram reveals that the Magnetherm slag has a liquidus temperature of 1850°C. It therefore forms a two phase mixture at the operating temperature of the process. By considering the solidification path of the slag, Christini[1] has shown that, at 1550°C, the liquid component is doubly saturated with respect to dicalcium silicate and magnesium oxide. In other words it has a composition of approximately 10% MgO, 23% Al_2O_3, 48% CaO and 19% $Si0_2$, and lies on the phase boundary of the di-calcium silicate and periclase phase fields. It is this liquid portion of the Magnetherm slag which participates in the magnesium production reaction and a knowledge of the activities of the constituent oxides enables the use of Equation (2) to determine the equilibrium pressure of magnesium as a function of the silicon content of the residual metal.

Such calculations reveal that the equilibrium silicon content of the reductant, under typical Magnetherm conditions (5 kPa, 1550°C), is of the order 20– 25%. In fact, the use of a graphite furnace lining means that the silicon content of the residual metal is an operating constraint of the process, since the volubility of carbon in Fe-Si-C alloys increases dramatically for silicon contents below 20%. Further constraints include the following:–

(1) Pressure; because magnesia and silica activities are fixed by the slag composition, attempts to increase the magnesium pressure at a constant temperature of 1550°C will result in higher silicon contents in the residual metal.

(2) Temperature: increasing the temperature in order to drive the reaction to the right will result in re-solution of the dicalcium silicate precipitate, thereby lowering the activity of magnesium oxide. Given that the activity of MgO is raised to the power of two in the expression for the equilibrium constant, the reduction in MgO activity tends to offset the less negative free energy of formation of MgO. High reaction temperatures also promote undesirable reactions such as the carbothermic reduction of MgO.

(3) Composition: sufficient alumina must be added to the slag to impart adequate fluidity. It should be noted that Christini reports a 40% solids content at the operating temperature of the process. If too much alumina is added the silica activity increases. As may be deduced from Equation (2), this will result in lower magnesium pressures and/or higher silicon contents in the residual metal.

Operational problems arise from the need to maintain reduced pressure conditions. For example, slag cannot be tapped, nor can metal be recovered from the condenser, without returning the system to atmospheric pressure. The Magnetherm process is therefore a batch operation characterised by substantial daily downtimes. This situation is exacerbated by the fact that up to 25% of the product magnesium is lost due to oxidation arising from air ingress to the low pressure furnace and condenser.

The technico-economic benefits which would arise from operation of the Magnetherm process at atmospheric pressure have long been recognised[2, 3] and it has been suggested that operating costs would be reduced by a minimum of 30% if this could be accomplished. Unfortunately, the constraints outlined above have frustrated all previous attempts to attain this desirable objective. For example, MINTEK[4] have operated a version of Magnetherm in which the conventional ohmic heating of the slag was replaced by a d.c. transferred arc plasma furnace. Conventional Magnetherm slag chemistry was retained, however. The equilibrium relationship between magnesium pressure and silicon content of the reductant may be calculated for the proposed operating conditions and is shown in Figure 2. It is clear that magnesium pressures of one atmosphere cannot be realised at the suggested operating temperature of 1950 K. In effect this process must utilise large argon flows to raise the total furnace pressure. Silicon contents in the residual metal will tend to be higher than in the conventional process. It is obvious that a novel approach is required if genuine atmospheric pressure magnesium evolution is to be realised.

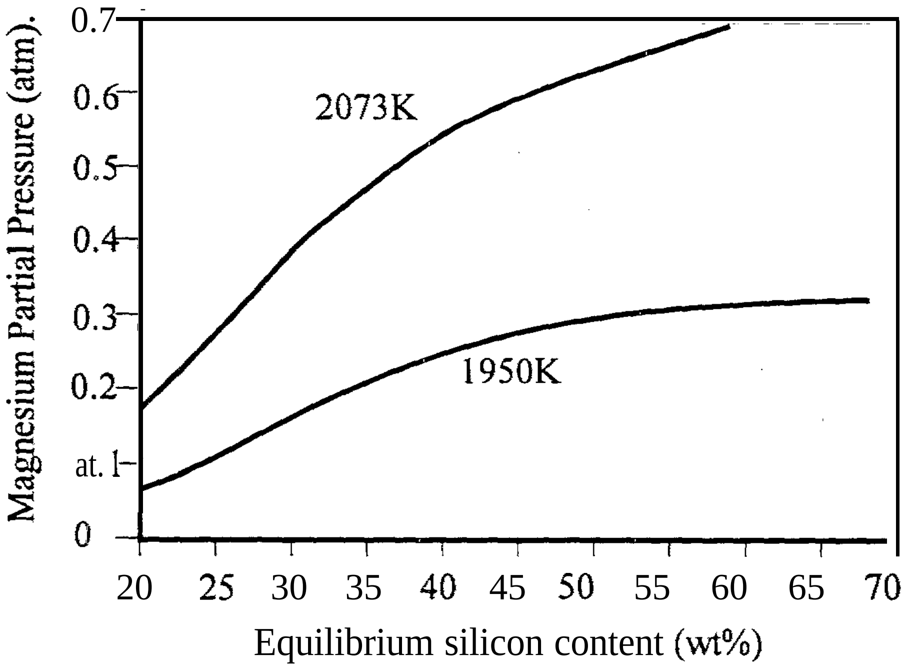


Figure 2 Equilibrium relationship between metal silicon content and magnesium partial pressure for a process employing Magnetherm slag composition at elevated temperatures.

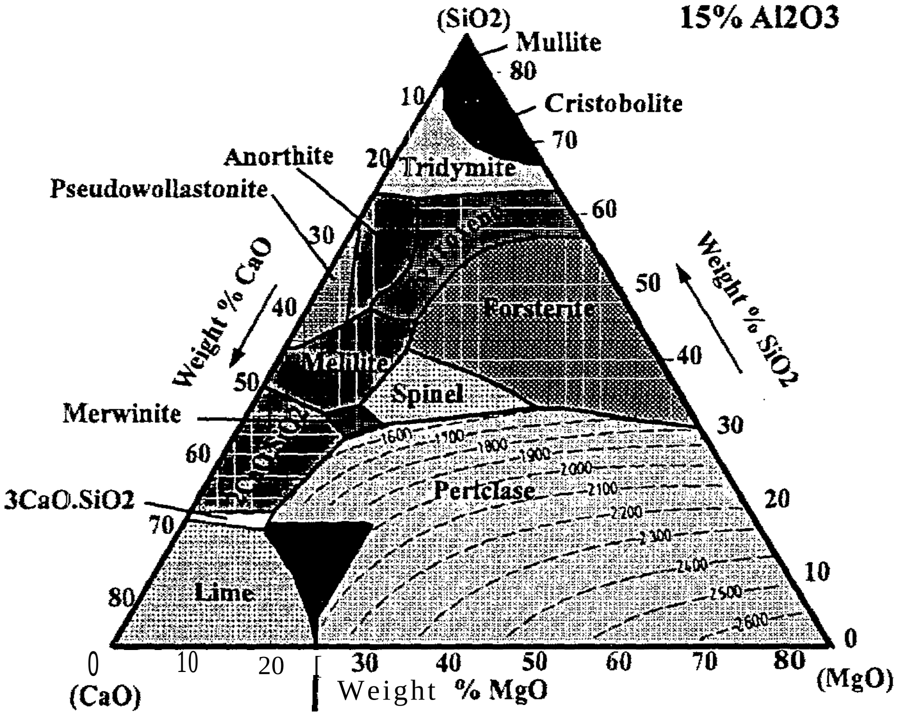
3.2 The MAGRAM process

MAGRAM is an acronym from “magnesium recovery from asbestos and related waste materials”. The process is being developed as a specific example of the environmental benefits derivable from a new magnesium smelting technology which operates under atmospheric conditions,

Cameron[5,6] has shown that the reduced pressure requirement of the Magnetherm process can be eliminated by the application of novel slag chemistry. The equilibrium constant, Equation 2, can be used to define suitable slag compositions in the following simple manner.

The desired operating temperature of the process determines the numerical value of the equilibrium constant. If the magnesium pressure is then set at 100 kPa and a_{Si} is that associated with the desired silicon content of the spent reductant, the equilibrium constant defines the critical ratio of a_{SiO_2} to a^2_{MgO} which must be maintained. Isoactivity curves for MgO and SiO_2 can be plotted on appropriate sections of the quaternary phase diagram and these map-out regions of slag composition satisfying the basic thermodynamic criteria.

Various means may be adopted to determine the positions of the isoactivity curves. For example, initial estimates can be obtained by reference to the measured data for the ternary CaO-Al_2O_3-SiO_2 system. This is justified by observations that, on a weight percent basis, and up to concentrations of at least 10%, the effect of MgO on silica activity is approximately equivalent to that of CaO, [7,8]. The liquidus lines of the periclase region of the phase diagram allow an estimate of the activity of MgO. Alternatively statistical thermodynamic models of the slags can be used to systematically calculate variations in the activities of the component oxides as a function of composition and temperature. Example plots of candidate slag compositions, derived from the thermodynamic model of Gaye[9] are shown in Figures 3 – 5.



Region of Potential
Slag Compositions.

Figure 3 15% Al_2O_3 section of quaternary phase diagram showing a region of slag compositions allowing atmospheric production of magnesium gas at 1650°C.

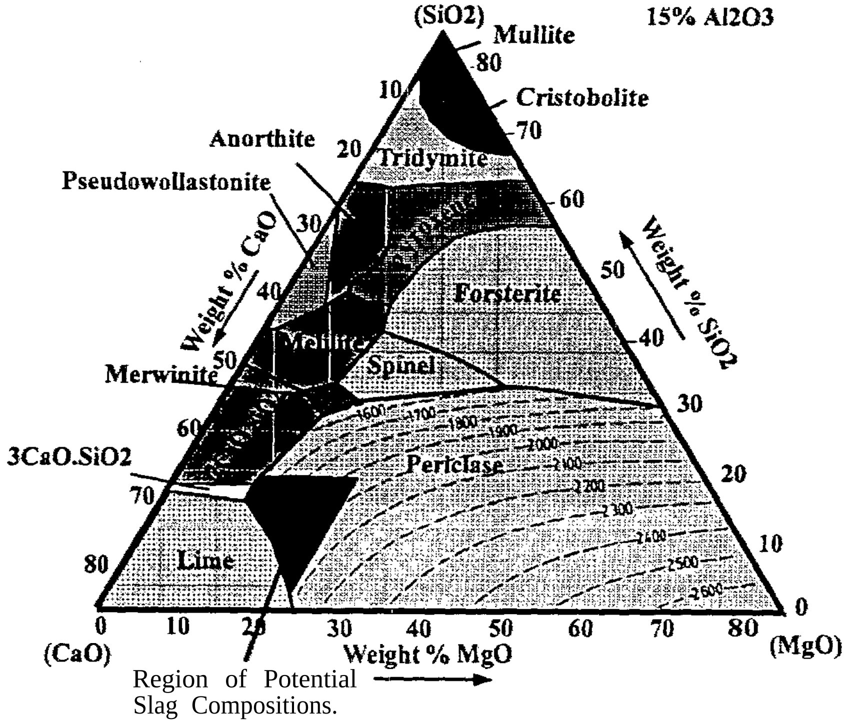


Figure 4 15% Al_2O_3 section of phase diagram showing slag compositions for atmospheric production of magnesium gas at 1750°C.

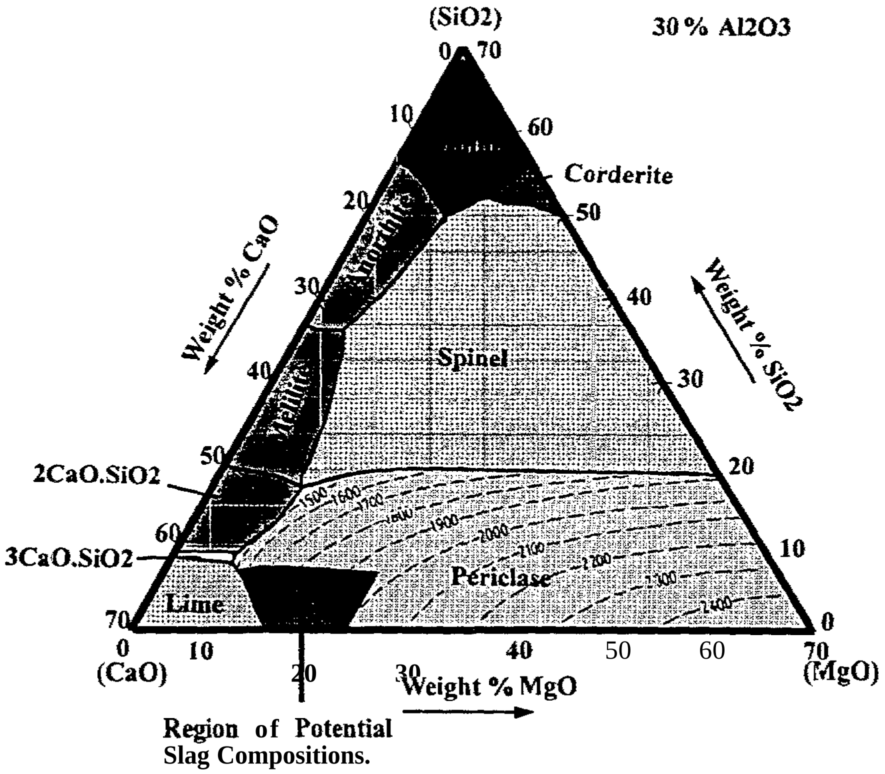


Figure 5 30% Al_2O_3 section of phase diagram showing stag compositions for atmospheric production of magnesium gas at 1650°C.

An advantage of this approach is that it defines an entire range of slag compositions and operating temperatures. Numerous mass balances can be derived and the optimum chemistry selected to suit the choice and availability of raw materials. The pyrometallurgical production of magnesium is thus a more flexible process than has previously been recognised. In addition to traditional raw materials it is possible to incorporate a range of non-conventional materials in the mass balances. Any material comprising one or more of the constituent axides is usable. Examples include wastes arising from the refractories/ceramics industries as well as the asbestos wastes being targeted in the current project. The replacement of part of the ferrosilicon reductant by aluminium can also, under specific circumstances, be advantageous.

Having determined the slag compositions of practical interest, Gibbs energy minimisation calculations were conducted to predict the purity of the evolved magnesium and to confirm the silicon content of the residual reductant. Such calculations suggest that a further benefit of atmospheric operation is improved product purity. This can be ascribed to the suppression of undesirable reactions which generate gaseous contaminants such as aluminium or silicon suboxides or metallic gases such as Mn or Ca. For example, predicted magnesium contents of the gas phase are > 99% and the effect of the higher pressure is to reduce SiO contents of the gas from around 0.7% for Magnetherm conditions to 0.170 for MAGRAM. The primary contaminant is Ca which is easily removed by standard refining techniques.

The basic predictions of the thermodynamic model have been generally supported by laboratory bench scale investigations of the process. In fact measured purities of magnesium product in the experiments were often higher than those predicted.

4 Pilot plant equipment

The arc heated reactor consists of a cylindrical steel shell lined with a high grade refractory that is chemically resistant to the slag melt. The base and sidewalls of the shell are cooled by water spray nozzles, whilst the removable flat roof section employs a double-skinned, water jacket.

The furnace is heated by a direct, current arc drawn between the tip of a 100 mm outside diameter tubular graphite cathode and the surface of the molten slag. A graphite anode is built into the hearth refractories, and is spring loaded into electrical contact with the graphite hearth. The cathode is located on the centre line of the furnace and enters through an electrically insulated fitting using a water-cooled packing gland seal arrangement. The seal is also continuously purged with argon during furnace operation to limit the possibility of formation of solid accretions around the cooled seal region by the condensation of species within the furnace atmosphere The electrode is raked and lowered within the furnace using a mechanical chain hoist mast/arm assembly.

Argon gas is injected down the the cathode bore to stabilize the transferred arc. Electrical measurements and visual studies of arcs on an intermediate scale of up to 800A have shown that only quite small argon flow rates (about 1 *(N)*L/min) result in a significant improvement in arc stability as indicated by minimised arc voltage fluctuations and by reduced flare and stray arcing.

The inner lining of the furnace is made from high quality graphite; this material was chosen as it is already used in the proven Magnetherm process. The roof and upper sidewall sections are separated by a course of electrically insulating magnesia bricks limiting the possibility for side-arc development between the graphite cathode and roof. The secondary lining is constructed from high-grade magnesia bricks. Insulating felt is used in the sidewall adjacent to the steel shell to lower heat losses through the walls, and to allow for thermal expansion of the refractory.

A schematic of the 3(XI kW plasma pilot furnace is shown in Figure 6.

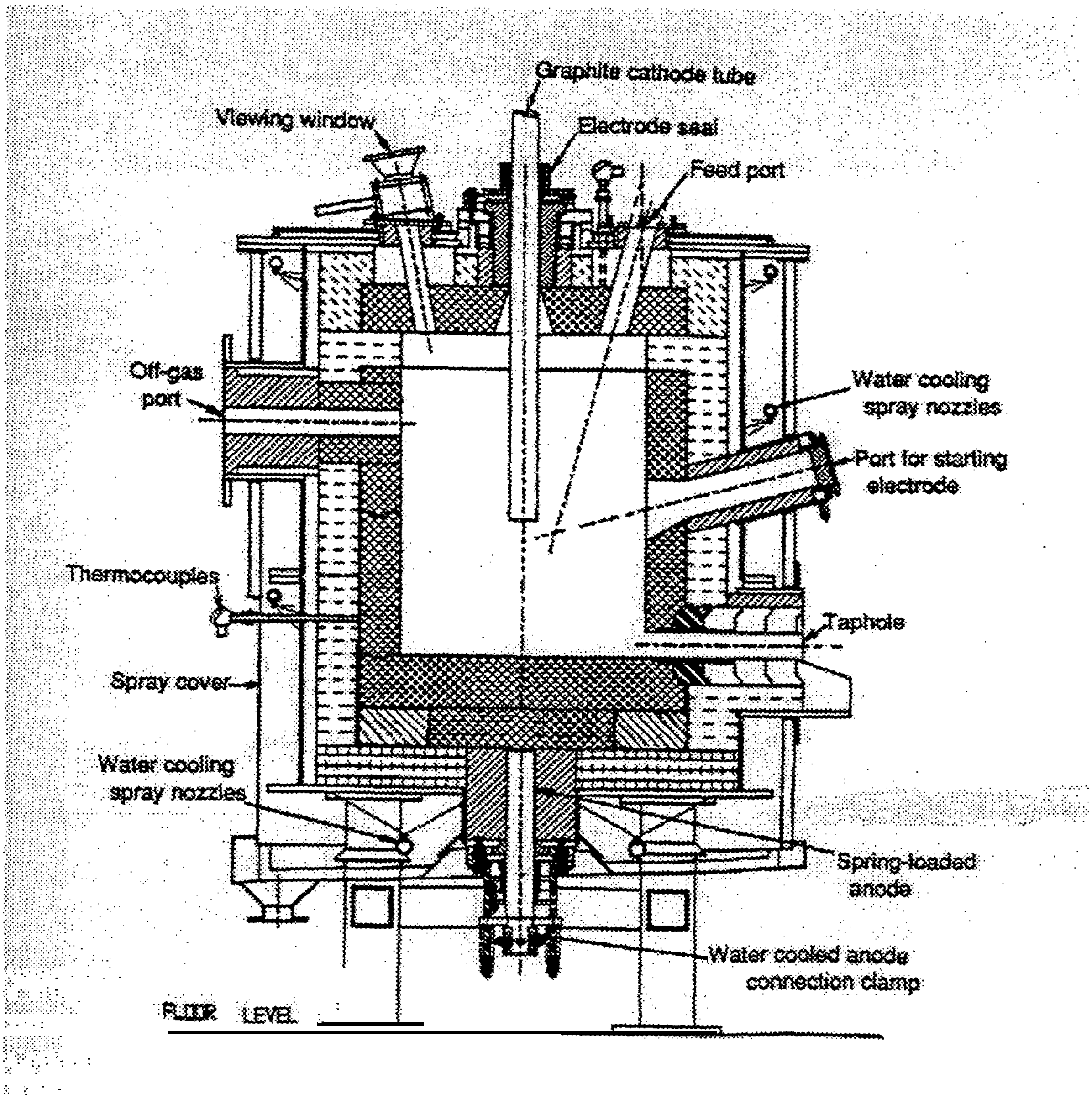


Figure 6 Schematic diagram of the MAGRAM experimental pilot plant furnace.

The main process specifications are given in Table 1. The system is designed to handle around 100 kg/h of raw materials feed, generating up to about 20 kg/h of magnesium vapour. For pilot plant operation the raw materials calcination stage was not available on-line and the feed materials were either obtained as calcined products or the raw materials (particularly the asbesto-containing wastes) were calcined in batches in a separate furnace.

Table 1 Pilot plant process specifications.

Plasma power rating	300 kW
Maximum arc current	1500 A
Maximum arc voltage	200 V
Maximum raw feed to furnace	135 kg/h
Maximum magnesium production rate	20 kg/h
Baghouse filter area	75 m^2
Baghouse gas handling capacity	3800 (N)m^3/h

The furnace is fed from a gravimetrically controlled stainless steel screw feeder, which enables accurate feeding of the pre-blended, pre-calcined raw materials to the furnace. Rigorous operating and monitoring procedures must be enforced for the treatment of asbestos-containing waste materials and air sampling monitors are installed around the feed unit area to check for the accidental release of asbestos fibres.

In the initial trials reported here the magnesium condenser was not installed on-line and the magnesium product was burned with excess air in a combustion chamber close-coupled to the furnace off-gas port. The magnesium oxide fume was subsequently collected in bag filters before the off-gases were vented to atmosphere.

A prototype magnesium condenser has been developed and this will be commissioned in subsequent trials. The condenser, which is designed for continuous operation, will condense magnesium vapour to the liquid state and provide collection of the metal for subsequent periodic removal by ladle.

Pilot plant operation is monitored using a PC based data logging system. The parameters recorded include arc current, arc voltage, electrode height, feed rate, furnace water temperatures and corresponding heat balances, furnace refractory lining temperatures and off-gas temperatures. The furnace melt temperature is measured with an optical pyrometer viewing the melt surface through a sight port in the roof.

The furnace is periodically tapped via a single taphole located in the sidewall, level with the furnace hearth. The furnace is tapped when a maximum slag height of around 400 mm (i.e. about 600 kg) is obtained.

5 Experimental pilot plant operation

The principal objectives of the initial pilot plant trials were to demonstrate the recovery of magnesium from feed mixtures incorporating a proportion of asbestos-containing wastes and the simultaneous destruction of asbestos fibres.

The MAGRAM process demands a relatively well-controlled slag composition for the successful generation of magnesium at atmospheric pressure. During the warming-up period, in which the furnace temperature is slowly raised to operating temperatures, it is therefore convenient to feed a “starting charge” that results in the formation of a molten slag with the same composition as that corresponding to the end-point slag composition for the magnesium generating process. The slag composition for this first trial was selected to lie well within the permissible range for atmospheric pressure magnesium generation.

Once the equilibrium thermal conditions were approximately established (after some 36h), the materials feed was adjusted to the MAGRAM feed composition. In these first trials the feed mixture was formulated to give some 36% MgO with approximately 11% of clean, dry aluminium swarf as reductant. Initially the recipe included only conventional materials (calcined dolomite with supplementary magnesia) but for most of the trials the recipe incorporated 16 mass% of calcined Italian asbestos mining wastes together with calcined dolomite. Typical compositions of the calcined feed materials are:–

dolomite: 57% CaO, 41% MgO, 2% SiO_2,
asbestos cement wastes: 65% CaO, 5% MgO, 27% SiO_2, 3% Al_2O_3,
asbestos mining wastes: 3.5% CaO, 43% MgO, 51% SiO_2, 2.5% Al_2O_3.

A summary of the results obtained in the first trials is given in Table 2.

Table 2 Summary of initial trials with the experimental pilot plant.

Feed composition by mass	16% mining wastes
Feed rate	33.4 kg/h
Total charge of feed mixture	300 kg
Total oxidic dust recovered from bag filters	40.95kg
Total magnesium recovered (as oxide)	22.15 kg
Total slag mass formed (i.e. total feed charge less Mg product)	278 kg
Overall mean slag/Mg ratio	12.5 (.S.6 *theoretical)*
Best magnesium product purity	96.31%
Maximum magnesium production rate(and mean over 13 h)	5.7 kg/h, *(1.6 kg/h mean)*
Mean arc power	118.6 kW
Specific energy consumption at max. Mg production rate	21.6 kWh/kg *(Mg)*
Graphite consumption (mean over complete campaign)	0.026 kg/h

An analysis (by X-ray fluorescent spectroscopy) of the bag falter dust sample representing the highest magnesium purity observed during these trials is shown in Table 3; the 7.7 kg sample of dust was collected over a period of two hours. The analysis indicates lower purity than obtained from the small scale trials but this is typical of pilot pkmt experimentation where sampling difficulties and feed material fugitive dust combine to give a pessimistic view of the product composition.

Table 3 XRF analysis of the highest purity sample of bag filter dust from the first trials with the experimental pilot plant. Data in mass%.

MgO	CaO	Al_2O_3	SiO_2	Fe_2O_3	MnO	Na_2O	K_2O	P_2O_5	LOI	Total
96.58	1.94	0.25	0.62	0.31	0.17	0.09	0.01	0.02	0.82	100.81

The final slag product from these trials decrepitated on cooling. The mineralogical phases detected in the decrepitated slag are larnite (Ca_2SiO_4) with some merwinite ($Ca_3Mg(SiO_4)_2$) and a trace of akermanite ($Ca_2MgSi_2O_7$). No evidence of chrysotile was found and, correspondingly, the twin aims of magnesium production from a feed composition incorporating asbestos mining wastes and the complete destruction of asbestos fibres have been demonstrated.

Unfortunately the occurrence of a stray arcing malfunction in the furnace necessitated a modification of the refractory configuration in the furnace cap and a demonstration of pilot plant operation with a feed composition incorporating asbestos cement wastes has been delayed. However, arc studies on the intermediate scale experimental plant, with arc currents up to 800A, included observations of the effects on arc stability of the introduction of typical MAGRAM feed formulations. Magnesium vapour was generated as expected in the furnace and no indications of any exceptional behaviour associated with the asbestos cement feed were detected.

6 Commercial considerations

6.1 Introduction

There is no doubt that the MAGRAM process offers a cost effective method for the disposal of asbestos wastes. This is best understood by consideration of the technology as a new method for the production of magnesium metal and by comparison the projected operating costs with those of the traditional Magnetherm process.

There have been a number of recent studies of the magnesium industry and these suggest a cash operating cost for Magnetherm plants of the order $2.31 to $2.64 per kg of metal. The authors are of the opinion that these estimates are slightly high and that actual operating costs are in the range $2.20 to $2.42 per kg. Regardless of the exact figure, which will of course vary from plant to plant, it is readily demonstrated that the major cost component is raw materials, accounting for approximately 50% of the total operating cost. Power consumption is also a significant factor and contributes 20 – 25% of the operating cost. Although substantial economic benefits accrue from atmospheric pressure operation, it is essential that the cost structure be retained and that the new process is not disadvantaged by increased raw materials or power costs relative to Magnetherm plants.

The reduction reaction is known to take place at the surface of the slag. The adoption of arc heating in the new process is therefore expected to reduce power consumption by:

(a) improved heat transfer to the reaction zone, and

(b) elimination of the submerged composite copper/graphite electrode used in the Magnetherm process. The upper (copper) section of this electrode is water cooled and represents both a safety hazard as well as a significant heat loss from the process.

The potential impact of the novel slag chemistry on operating costs can be assessed by comparing the mass balances of the traditional and new technologies with specific reference to slag/metal ratios and raw material costs. Slag/metal ratios will, of course, impact on the power costs of the process.

6.2 Mass balances

The initial feedstock material for the MAGRAM furnace comprises of a mixture of dolomite and asbestos-containing wastes. In order to generate the required slag composition it is necessary to add other raw materials to the feed, and these additions are calculated by setting up a mass balance. On the basis of this mass balance it is possible to determine the raw materials costs and the amount of slag produced per kilogram of magnesium generated (slag/Mg ratio). The mass balance calculations are based on the use of either ferrosilicon and/or aluminium as the reductant with the overall reactions being

$$2Mg0 + Si \rightarrow 2Mg + Si0_2$$

and

$$3MgO + 2Al \rightarrow Al_2O_3 + 3Mg$$

Calculations have been conducted for a wide range of slag compositions which all lie well within the operating window for magnesium production at atmospheric pressure at 1650°C and 1700°C. The alumina content of the slags ranged from 10%-30%. For each composition the slag/Mg ratio is determined along with the raw materials costs per kg magnesium produced. The raw materials costs include a calcination cost for the initial asbestos and dolomite feedstock.

6.3 Effect of amount of asbestos in feed on slag/Mg ratio and raw materials costs

The variation in slag/Mg ratios and raw materials costs with increasing asbestos content in the feedstock and increasing alumina content of the slag are shown in Figures 7–10. The graphs represent the production of a specific slag using either cement based asbestos waste or mined asbestos with Al being used as the main reductant. For comparison a line has been drawn on each graph representing the data reported for the Magnetherm process. It is important to note that this economic analysis does not take account of any fees obtained for the treatment of asbestos wastes.

For both the asbestos cement wastes and the asbestos mining wastes, the slag/Mg ratio and the raw materials cost per kg Mg increase with increasing asbestos content of the feed and decrease with increasing alumina content of the slag. The decrease of the slag/Mg ratio and the cost with increasing alumina content can be explained simply by the stoichiometry of the reduction reaction i.e., for every mole of alumina produced three moles of Mg are generated. consequently the more alumina required the more magnesium generated and hence a lower slag/Mg ratio.

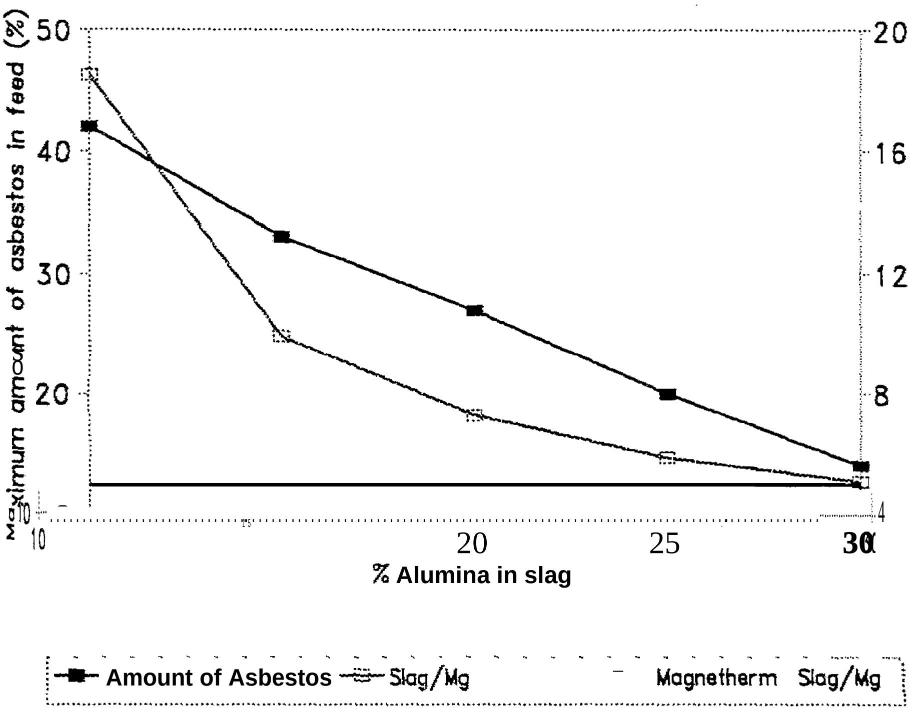


Figure 7 Effect of alumina content of the slag on the maximum amount of asbestos mining wastes which can be incorporated into the feed and on the slag/Mg ratio.

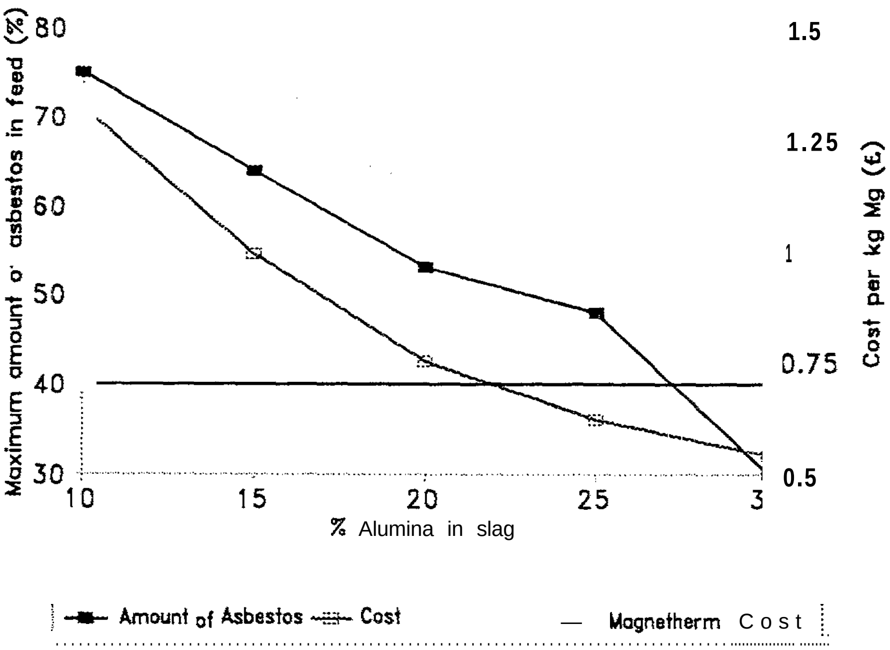


Figure 8 Effect of alumina content of the slag on the maximum amount of asbestos cement wastes in the feed and on the raw materials costs per kg Mg produced.

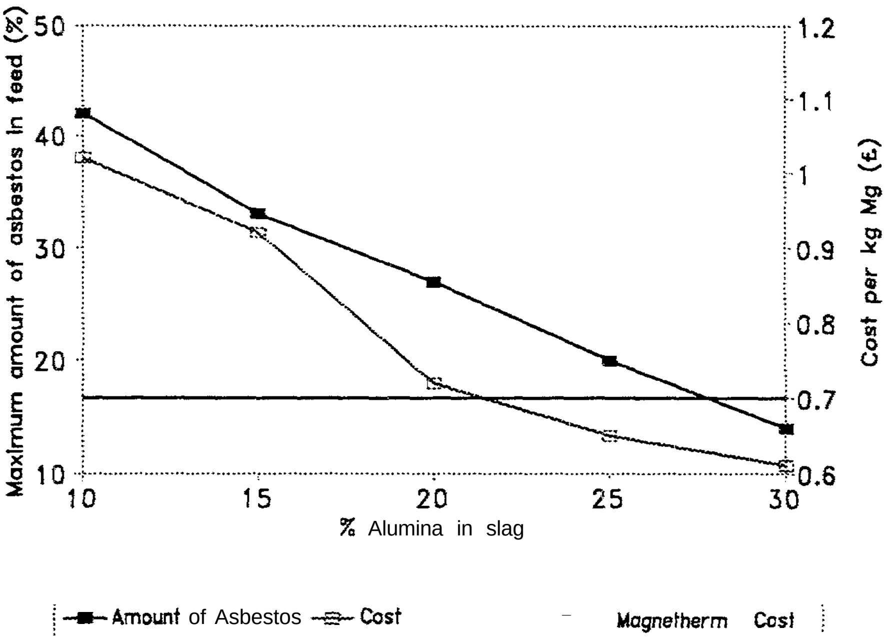


Figure 9 Effect of alumina content of the slag on the maximum amount of asbestos mining wastes in the feed and on the raw materials costs per kg Mg produced.

It appears that fur the maximum amount of asbestos to be incorporated into the feed a lower alumina slag is needed. This, however, results in a high slag/Mg ratio and high raw materials cost per kg Mg produced. For each slag composition, reducing the amount of asbestos in the feed also reduces the slag/Mg ratio and the raw materials costs. Figure 10 shows the variation in slag/Mg ratio and raw materials cost with increasing asbestos content of the fee-d for a 10% alumina slag.

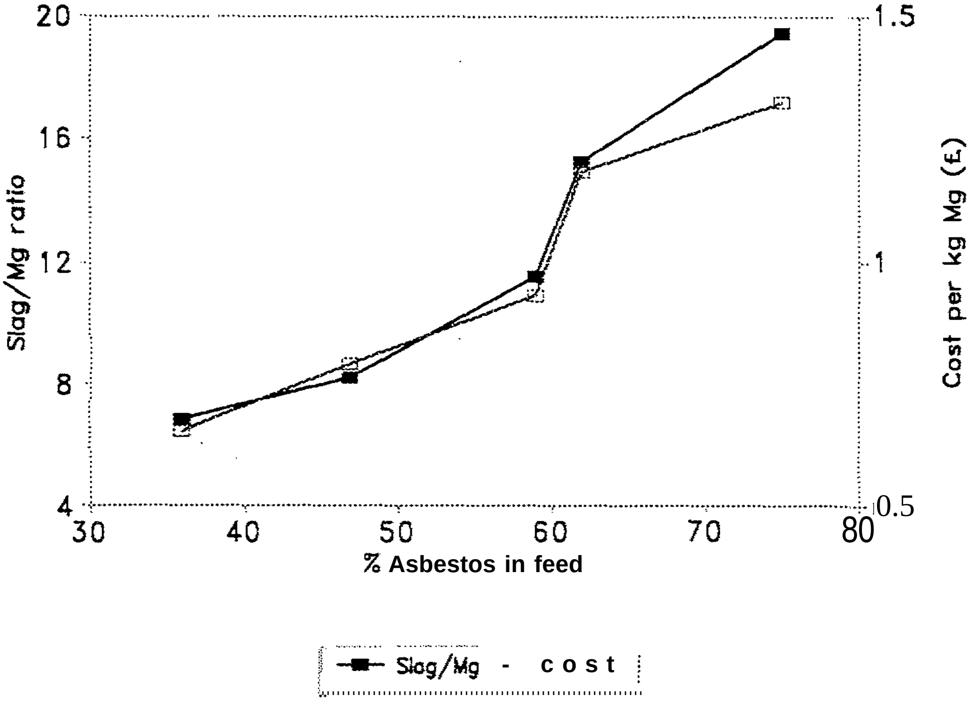


Figure 10 Variation in slag/Mg ratios and raw materials costs with increasing asbestos cement waste content in the feed for a 10% alumina slag.

It is evident from Figure 10 that, ignoring any cost benefit for treating asbestos, it is economically more favorable to reduce the amount of asbestos in the feed as this results in lower slag/Mg ratios and lower raw material costs. Comparison of this figure with Figures 7 and 9 shows that lower slag/Mg ratios and raw material costs are obtained with higher alumina content slags. For example, when a 25% alumina slag is used, the feed may contain 48% asbestos cement wastes but still generate slag/Mg ratios and raw materials costs which are lower than those for the Magnetherm process. To generate similar values to the Magnetherm process for a 10% alumina slag, the amount of asbestos would have to be dropped to about 30%.

7 Summary and conclusions

A 300 kW d.c. transferred arc furnace, forming part of a pilot plant facility for a novel magnesium production process, has been successfully commissioned. The process is characterised by flexible slag chemistry which facilitates the incorporation of a range of unconventional raw materials in the process mass balance. The MAGRAM process is a version of the technology which destroys asbestos waste materials, whilst simultaneously recovering metallic magnesium.

Extensive computer modelling of both the thermodynamics and economics of the process has been undertaken. The results suggest that magnesium purity will be higher than that obtained in the traditional Magnetherm process. When utilising asbestos wastes the lowest slag/Mg ratios and raw materials costs are obtained from relatively high alumina content slags. Slag/Mg ratios and raw materials costs are similar, and in some cases lower, than those of the Magnetherm process. The technology will therefore be competitive with traditional magnesium production facilities. This is an important contrast with technologies for disposal of asbestos wastes which rely on simple vitrification and consequently provide less financial incentive for the treatment of these hazardous materials.

The MAGRAM process has the potential to make the treatment of asbestos and similar wastes profitable even *in the absence of any economic benefit accruing from the treatment of the waste. If* operators of the technology were to charge a fee based upon existing landfill costs the profit margins would be increased further.

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