Historical Development of Coal Ash Utilisation in South Africa

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INTRODUCTION

The South African fly ash industry developed in a unique, somewhat different manner to similar industries elsewhere in the world.

Recognising the ash opportunity, the research community provided the fundamental science and technology for sustainable ash applications well before either the power generators or cement and construction industries realised the value of coal ash. In coordinating their efforts and cooperating closely with each other various universities and research organisations ensured an effective unified approach that soon drew the attention, and ultimate involvement of industry.

This paper explains the scenario against which these developments took place that saw commercial ash sales rise from a few thousand tons in the 1980s to approaching 2,0 million tons today (2005).

THE POWER SCENE

The rapid industrial expansion within South Africa during the late 1970s and early 80s created a sudden surge in the demand for electricity. Given the vast coal reserves the additional capacity was provided by the erection of large (3000-3600 MW) pulverised coal-fired power stations.

These stations, situated at the mine itself, utilised coal of relatively low calorific value and high ash content which resulted in vast quantities of coal ash (3-6 million tons) arising at individual power stations.

The availability of inexpensive land at the mine enabled low-cost disposal of the coal ash. The power stations, were located a significant distance (100-250 miles) from the economic hub of the country and very far away (300-1100 miles) from other centres of industrial activity along, and adjacent to the coast. Being remote, public pressure to minimise the aesthetic and environmental impact of these dumps was muted.

The South African fly ash industry was thus born with a connotation of huge mountains of waste of little or no value.

Even where large-scale uses such as the backfilling of mines or structural fills for roads existed the economics of transport mitigated against usage.

RESEARCH PROGRAMME MANAGEMENT

Recognising their responsibility in investigating the ash 'problem' governmental research-funding agencies launched a nationally coordinated programme under the auspices of the Cooperative Scientific Programmes, the forerunner of the current National Research Foundation (NRF).

The funding was used to support both fundamental (university) as well as applied (CSIR and Mintek). The aim being to provide the scientific and technical information needed to fully exploit the resource potential of coal ash.

The driving force behind the development of the South African ash industry was one that required the ash be transformed from a waste to a product of technical and commercial value so that it could bear the cost of long distance transport and still be an economically viable resource.

The organisational structure utilised to evaluate the relevance of both solicited and unsolicited proposals needed to be objective. A two-tier committee system was used; an evaluation mechanism (advisory committee) was put in place to consider the potential value of the research proposal to the programme objectives, peer evaluation of participants, contribution to training and development of students and funding needed.

This advisory committee was drawn from academics, research managers both in the private and public sector as well as consultants. The funding was allocated by an independent national committee.

Initially, all funding was provided by the government but within two years many industrial firms were contributing either by auxiliary funding or sharing their in-house research findings.

The structure of the coordinated programme facilitated and encouraged industrial involvement which in turn provided a unique focus and ensured 'seamless' technology transfer. Industry was relatively quick in implementing technology where it made techno-economic sense. Identifying the necessity of beneficiating and processing the ash in order to carefully adapt its performance characteristics to meet the needs of the marketplace was perhaps industry's most significant contribution. The precursory research and development therefore focussed on developing specific performance products rather than aiming to maximise volumes used.

SCOPE OF RESEARCH

The research activities were widespread. Initially, all the sources of coal ash were characterised, chemically, mineralogically and morphologically.

Armed with this information a plethora of potential applications were investigated.

These included recovery of alumina, soil amelioration, waste immobilisation, refractories, clay bricks, road stabilisation, processing aids and fillers for polymers, zeolites, counteracting acid mine drainage, mine backfilling, functional fillers for rubbers and of course, the very backbone of the industry; usage in cement, concrete and allied products. Some of the findings, highlights and commercial applications that ensued during and subsequent to the lifetime of the programme (7 years) bears mentioning.

FLY ASH AS A CEMENT EXTENDER

The initial characterisation of all the sources of ash in South Africa established that the ash was high in alumina and silica, with moderate amounts of calcia and iron, and low in alkalis. Power stations like Matla, Kendal and Lethabo were found to produce fly ash with exceptional pozzolanic characteristics. This was due to the particular way in which the power stations operated.

The combustion technology employed at these stations required careful control in order to maximise energy recovery from the low-grade high-ash (30-40%) coal being supplied by the mine. The result was a consistent fly ash, low in carbon with a significant amount of amorphous phase - a typical pozzolan. Indeed initial tests in cement and concrete confirmed the pozzolanic potential of South African fly ash.

In its ‘raw’ state the fly ash, although of good quality, did not improve the performance of concrete to such an extent as to justify the cost of transportation over long distances. It was thus necessary to add value to the fly ash in order to enable transport to the market place and ensure a long-term economically viable and sustainable industry.

The amount of fly ash available in South Africa (20 million tons) significantly exceeds cement clinker capacity (10 million tons). Driven by the need to enhance the properties of fly ash the finer more reactive fraction was initially recovered from the last 3 fields of the array of electrostatic precipitators. Work on this product soon confirmed that it was an excellent pozzolan that, albeit variable, enhanced concrete performance.

As news of these findings by the research community reached the building and construction industry, ash became more widely investigated, its benefits quickly appreciated and its utilisation implemented. Demand grew rapidly and it was soon apparent that reliance upon a product selected from the precipitators was inadequate both from a volume and consistency point of view.

It was therefore decided to install equipment to beneficiate the fly ash by air classification. A plant was commissioned in the early eighties (Matla) with a capacity of about 250 000 tons. The site was selected on the grounds of the fundamental chemical and physical properties of the ash as published by the members of the coordinated research programme. An air classified fly ash with 90% below 45 μm and a carbon content of less than 1% became the industry norm (SABS 1491-2.). The coarse fraction was disposed to the dump in conjunction with the ash not used. This station produces about 3 million tons of fly ash annually.

As participation in the programme became more widespread it was soon established that classified fly ash was eminently suitable for cement extension since it is:

- spherical
- pozzolanic
- low in alkalis
- non-expansive
- of consistent quality and reactivity; and
- the carbon content is low

The effect of the abovementioned properties is that less water is required to make concrete. This results in less shrinkage (cracking), improved density and easier placing. The low carbon meant that mineral admixtures used to modify concrete behaviour (delay setting, aid flow etc) are not affected by fly ash.

The pozzolanicity of the fly ash means that the ultimate strength of the concrete exceeds that of portland cement only concrete. Contractors soon started using innovative concrete mix designs to produce equivalent strength concrete with less cement.

It was at this stage (the late 80s) with the cement industry facing capacity constraints, that perhaps the definitive deciding step in the establishment of an ash industry in South Africa took place when the cement manufacturers themselves decided to introduce fly ash blended cements. This move not only counteracted the ever-increasing volumes of blended cements being supplied to contractors and the ready-mix industry by entrepreneurs who bought portland cement and fly ash separately, blended them at various ratios and sold extended cements. It also presented the cement manufacturers with the opportunity of increasing capacity with minimal capital expenditure. The fact that the fly ash was of such a consistent quality meant that interblending rather than intergrinding took place.

This sequence of events provided a steady conduit for ash utilisation and ensured more widespread use as ash rode on the back of the cement distribution network.

The end result was the introduction throughout the country of blended cements containing between 15 and 35% classified fly ash. These products are currently marketed by the cement producers under various brand names.

While the blended cements became the general purpose product, civil engineers soon realised that one could 'engineer' the properties of concrete by using higher ratios of fly ash or by reducing the amount of cement. This had many repercussions, not least of which are dams, both rollcrete and mass pour. Here the amount of fly ash used was adjusted to provide better compaction and lower head of hydration. The Knellpoort Dam, the first roller-compacted arch-gravity dam in the world made extensive use of fly ash.

The Lesotho Highlands Water Project used up to 40% fly ash so as to limit heat build-up and reduce the likelihood of cracking.

Perhaps the most compelling reason advocated for using fly ash along with portland cement is the aspect of durability. In an extensive research programme involving domestic and foreign participation by universities, research organisations, and cement manufacturers it was proven that concrete containing fly ash was significantly more durable than the “standard” cement-only concrete. The reason for this is two-fold; removal of excess $Ca(OH)_2$ and the densification of the concrete’s matrix. In particular the ingress of chlorides and sulphates are reduced.

Once of the problems encountered in concrete is the long-term interaction between siliceous aggregates (acidic) and the cement (alkaline). The pozzolanic reaction removes excess $Ca(OH)_2$ and prevents the alkali-silica reaction often referred to as concrete cancer.

The confidence the research findings instilled in the marketing and use of fly ash cannot be over-emphasized. Recognising this, industry implemented the technology as a means of producing more cost-effective products.

Current applications of fly ash include pre-cast products such as tunnel linings, dolosse, railway sleepers, autoclaved fibre cement sheets and pipes.

Masonry units (bricks and blocks) make use of bottom (clinker ash) as well as fly ash.

As a result the growth in consumption has been phenomenal from about 20 000 tpa in the early 80s to over 1.65 million tons by 2004.

The success achieved in using classified fly ash as a cement extender has been followed by the introduction of an ultra fine fly ash. Originally manufactured as an ultra fine filler for the polymer industry the use of this particular fraction has proven to be almost indispensable in high-performance and self-compacting concrete. By careful control of the particle size distribution the ultra fine fly ash emulated the performance of silica fume without the handling difficulties associated with the latter. This fraction enhances the performance of concrete to meet the demands of modern construction technology where 100-150 MPa concrete is the norm.

This product is being exported from South Africa to the Middle East where it is being used in prestigious buildings eg The Jumeirah Beach Resort Complex (the height of the hotel is 60 m less than the Empire State Building and is higher than the Eiffel Tower).

FLY ASH IN POLYMERS

As mentioned earlier, the investigation into uses for fly ash was multi-faceted and besides the construction industry involved a number of non-conventional applications.

The polymer industry makes extensive use of limestone, talc and other inorganic minerals as functional fillers.

Extensive R&D indicated that specially manufactured fractions of fly ash (Plasfill 5, 15 and 5/45) can be used to replace (partially or completely) some of these functional fillers.
The main advantage gained by using the Plasfill is the ease of processing and compounding. The spherical nature of the fly ash promotes flow during extrusion and casting. Reduced shrinkage and lower processing temperatures allow more accurate manufacture and limits wastage. In most cases the physical characteristics are similar or enhanced. Compatibility between the organic matrix and inorganic filler needs to be facilitated for successful application.

In rubber the synergistic effect between fly ash and the other fillers to produce superior products has been demonstrated.

Many of the commodity plastics marketed in South Africa contain special grades of fly ash as the function filler. These include garden hoses, electrical conduit, water pipe, shoe soles, sanitary ware, etc.

AGRICULTURE

Fly ash is essentially the calcined remnant of inorganic inclusions in coal and can be regarded as a ‘natural’ addition to soil.

With much of the agricultural land in the proximity of the power stations being acidic, the addition of fly ash as a soil ameliorant has proven to significantly increase crop yield.

Field and laboratory trials have shown that after an initial addition of ash the vegetative yield has been maintained for several years at levels elevated well above that of other treatments. Various crops have been tested (corn, beans, legumes, grasses, etc.)

This finding has led to work on the rehabilitation of coal mine spoil. Test work currently underway has shown that after an initial application of ash the vegetative cover was rapidly established and maintained.

The rehabilitation of gold mine spoil with fly ash has proven to be more cost-effective than the conventional method using limestone.

The use of fly ash to pasteurise sewage sludge has been demonstrated. The resultant product has also proven to be an excellent soil ameliorant. Although not yet commercialised in South Africa, similar technologies are being successfully applied elsewhere in the world.

MINING

The use of fly ash in underground mine supports on the gold mines was one of the first commercial uses of ash in South Africa. Gold mines operate at depths of over 10 000 ft which requires the use of woodpacks to keep the stopes open to allow for the extraction of ore. It was, however, found that packs consisting of cement, tailings from the gold extraction plant and fly ash is just as effective. Obviously, this application conserves forests. Furthermore, fissure grouting also utilises fly ash to reduce the viscosity and enables more effective sealing.

Besides rehabilitating coal mine spoil ash can also be used to counteract acid mine drainage. An innovative project currently underway shows great promise for the neutralisation of acid mine drainage and the simultaneous manufacture of zeolites. This could be a vital on-site use of ash that enables the mining houses to comply with environmental legislation.

Stonedusting is a technique used extensively in underground mining. Normally finely milled limestone is sprayed onto the walls of the tunnel and small bags containing the same are hung from the ceiling. In the event of a methane explosion the coal dust is diluted with limestone. In addition, the bags are shattered releasing more inert powder that then quenches the further propagation of the fire. Research indicated that fly ash could be used to replace or augment limestone for stonedusting. Although slightly higher doses are required the close proximity of the ash to the coalmine considerably reduces the cost of transport making stonedusting cheaper.

REFRACTORIES

The relatively low concentration of alkalis and alkaline earths in some of the fly ashes result in fairly high melting points (2600-2750 °F). This enables the use of fly ash as part of the formulation for refractories used at temperatures around 2200 °F.

RAW MATERIAL

The alumina content of South African coal ashes is fairly high. Once source (Lethabo) with a content in the range of 32-35% is used as a replacement for shale by the large international cement company as a source of alumina in the manufacture of portland cement. Once again this conserves natural resources.

Like elsewhere in the world, the composition of fly ash with its plethora of elements attracted attention especially as a source of alumina. In South Africa research has focussed on the recovery of trace elements that are leached from the surface of the ash particles. A conceptual process for the recovery of boron and an array of trace elements has been developed. The use of electrochemical methods to separate the various metals recovered was suggested.

SUMMARY AND CONCLUSION

South Africa currently uses fly ash in diverse applications in a number of different industries. The genesis of the fly ash industry was a concerted, coordinated R&D effort on the part of participants drawn from a spectrum of disciplines and backgrounds. This national programme, which served as a technology incubator, lasted but 7 years (1980 – 1987). It left behind a legacy of innovative applications that developed into a thriving industry. Besides the contribution of the participants its success owes as much to the economic scenario against which it unfolded – shortage of cement in a booming economy - as to the fortuitous availability of large volumes of high quality fly ash of consistent composition.

Today, ash utilisation is a sustainable business providing cost-effective solutions to pertinent problems. It contributes significantly to the economy and growth of the country as well as resource conservation and the amelioration of pollution (less CO_2 emission, conservation of forests and preventing pollution).

The application of ash is not a static state of affairs. The country is currently pursuing large-volume uses in mine backfill, structural fill and road stabilisation. This is contrary to many other countries where, driven by disposal considerations, volume utilisation was paramount.

There is, however, still much left to be done. Beneficiation and modification of fly ash itself, exploitation of its unique chemistry, etc will ensure the continued bright future for coal ash. This is especially true as the research community turns its attention to new generation coal ashes such as those from gasification and flue gas treatment.