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MICROWAVES FOR COAL QUALITY IMPROVEMENT: THE DRYCOL PROJECT

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ABSTRACT

Progressive advancements in mining technology have resulted in increasing volumes of Fine coal being presented for processing. This provides an ongoing challenge to coal processing plant managers, as the larger surface area of Fine coal enhances its capacity to retain moisture. In response, the capabilities of the various conventional coal-drying technologies with regard to removing moisture from Fine coal are limited. This paper describes the current stage of development of the “Drycol Project”, concerned with applying advanced microwave technology to more efficiently and effectively improve coal quality (remove water, Sulfur and other contaminants), as a large-scale, continuous process.

1. INTRODUCTION

1.1 Background

The “Drycol Process” is the name of the new industrial process[1], under development by way of the Drycol Project, for continuously improving coal quality by the controlled application of microwave (MW) radiation. The development is based on adapting existing industrial MW applicator systems, already in use in other industries, to provide a regulated and continuous drying of Fine coal fractions. The work has highlighted other potential benefits that may derive from the process, including the return of clean water, the reduction of Sulfur, and the potential for targeted reduction of Mercury, Potassium and Phosphorus. This paper provides a general introduction to the technology, its likely applications and potential benefits.

1.2 Concept

Figure 1 (below) illustrates the basic concept of the Drycol Process.

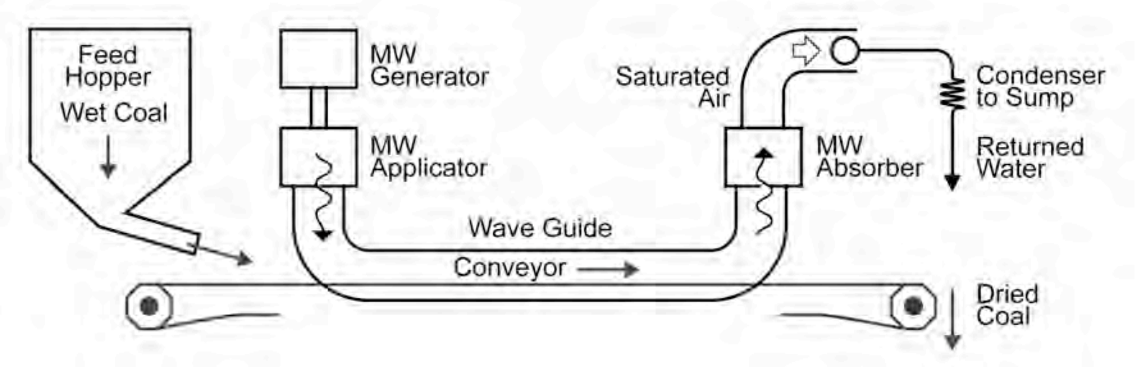

Figure 1 The Drycol Process for continuously improving coal quality

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[1] US Patent Application 20070151147; International Patents Pending

The Drycol Process is described as a method for drying coal using MW energy, to achieve a controlled aggregate moisture content target range, without starting combustion or degrading the coking qualities of the coal. Coal feed stock is first separated into Fine grade coal and one or more larger grades. The Fine coal is loaded onto a conveyor as a bed of fixed depth and conveyed continuously through a microwave-energized heating chamber for drying. The Fine grade coal is dried sufficiently so that when it is combined with the larger grade coals, the moisture content of the aggregate is within a target moisture content range. By volumetrically and uniformly heating the coal, the microwave heating chamber boils away the water without heating the coal above approximately 90°C. In this way, the processed coal neither combusts nor oxidizes, and its coking and thermal qualities are retained.

1.3 Technology

MW radiation is known as an effective exciter of water. MW ovens are commonplace in domestic and commercial kitchens. Microwave technology is also in widespread industrial use, for example for the small scale laboratory drying of coal samples, and on a larger scale in continuous applications such as in food processing and textile manufacturing.

Various past studies have addressed the potential of MW energy for de-watering coal[2]. It has also been observed in technical literature that exposing coal to MW radiation may result in a reduction of Sulfur and other contaminants[3]. For practical purposes however, the earlier work remained largely theoretical, because of the limited state of development of MW technology at that time. The current development has been made possible by the concurrent and continuing emergence of new, more powerful industrial MW systems capable of continuous, large-scale industrial processing.

1.3 Evolution

The Drycol process was developed from R&D initiated, funded and undertaken from 2003 by DBAGlobal Australia Pty Ltd (DBAGlobal), an established organisation for delivering feasibility studies, engineering, project management and management support for (mainly) mining companies, operations and projects. The application of the process through the Drycol Project was supported in Australia by Anglo Coal, and also by way of partnerships with US-based technology developers that are connected with the established US industrial microwave industry. The technology that is the basis of the Drycol Process is patented, and its application to minerals processing (including coals) is the subject of current USA and International Patent Applications[4].

Since its commencement in 2003, the Project has progressed through various stages of testwork, analysis and engineering design, eventually to the construction and operation of a world-first commercial MW drying facility located in the USA, where a second, larger facility is currently under construction. The successful operation of the first commercial facility has demonstrated not only the viability and reliability of the technology, but also a range of potential benefits that are likely to apply as much to coal users as to coal producers. The current aim of the Project developers is to discover further commercial applications for the

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[2] (eg) Kalrash A. 2006. *Thesis: Dewatering of Fine Coal Slurries by Microwaves.* USA
[3] (eg) Wardle P. 2006. *Thesis: Advanced Coal Desulphurisation Techniques.* UK
[4] US Patent Application 20070151147; International Patents Pending

new technology, in particular where the Drycol Process may be applied to enhance the productivity and/or profitability of large-scale industrial facilities, including power stations, steel mills, coal mines and coal processing plants.

2. MICROWAVES FOR COAL DRYING

2.1 Microwave energy

Microwaves are a form of electromagnetic radiation. The term microwave refers to 'alternating current signals with frequencies between 300 MHz and 300 GHz' [5], with wavelengths approximately in the range of 30 cm (frequency = 1 GHz) to 1 mm (300 GHz). Domestic and commercial microwave ovens are commonplace in the developed world. They operate by passing microwave radiation through a target material, for example a food substance. Water molecules within the target material absorb energy from the radiation by dielectric heating, that is, by rotating rapidly as they attempt to align themselves with the microwave-induced alternating electric field. The molecular movement creates heat as the rotating molecules strike other molecules and put them into motion. The significance of molecular movement is demonstrated in that microwave heating is most efficient on liquid water, and much less so on frozen water where the molecules are not free to rotate.

2.2 Industrial microwave applications

Domestic microwave ovens generally operate at 2,450 MHz, while industrial microwave applicators used for the Drycol Process operate in the 915 MHz range. The depth of penetration of industrial 915 MHz applicators is about three times greater than a 2,450 MHz domestic-type appliance. With higher total system efficiencies, 915 MHz systems tend to have lower running costs than comparable 2,450 MHz units; one 100 KW 915 MHz generator tends to be about 50% cheaper than seven 15 KW 2,450 MHz units. 915 MHz generators can provide up to 100 KW from a single magnetron, and although they lose about 15% efficiency in producing electromagnetic energy from electric power, the particular configuration of the technology used for the Drycol Process results in the conversion rate of that energy into specific energy and latent heat of vapourization for water removal being frequently greater than 95%. This is the case for unbound water (or free moisture in coal) in particular, so that the total system efficiency is usually in excess of 80%.

2.3 Microwave versus Radio Frequency

Radio Frequency (RF) and Microwave (MW) are both forms of electromagnetic energy but differ in operating frequency and wavelength. Typically, industrial RF units operate between 10 and 30 MHz, with wavelengths of 30 to 10 metres, while industrial MW systems use frequencies between 460 and 2,450 MHz with corresponding wavelengths of 60 to 10 centimeters. Work completed by the Drycol project's MW technology partners indicates that the efficiency of power utilization is far lower in a RF generator than a MW unit, although the initial capital cost per KW of power output is likely to be higher for MW [6]. The choice between RF and MW heating generally depends on the physical properties of the products, as well as the process conditions that are required for the particular application. For example, RF offers a good solution where penetration depth in excess of 15 cm is required,

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[5] Pozar D.M. 2002. *Microwave Engineering*. J.Wiley

[6] Industrial Microwave Systems (IMS) USA. http://www.industrialmicrowaves.com

and the control of heating uniformity is not an important factor. However, where uniformity of drying and precise moisture control is essential, MW energy is the obvious answer. The Drycol Process is superior to RF for planar applications where the belt width is in excess of 100 cm, and where edge-to-edge heating uniformity is a fundamental requirement.

2.4 Why MW energy is effective for drying coal

MW energy is effective for drying coal because water that is contained with and within the coal is preferentially heated by MW energy. The microwave energy is preferentially transferred to molecules that are free to oscillate or rotate within the microwave-induced electric field. This allows work to be done on the molecules and the temperature increases accordingly. Carbon atoms within the coal are tightly bound to the organic matrix and are therefore less free to move. Correspondingly the heating rate of coal is much less and linked to heat transfer via conduction from water molecules. Provided that the residence time of the coal in the MW applicator chamber is controlled such that the coal temperature remains less than 90°C, there is no opportunity for short chain hydrocarbons to volatilize from the coal matrix, and therefore coal quality does not degrade. In the case of inherent water where it is bonded to the coal matrix, these molecules are still able to oscillate within the microwave-induced electric field, and it is therefore feasible to remove inherent moisture from coal, albeit at a lower drying efficiency.

The following diagram (Figure 2) illustrates that, for the different forms of water retained in Fine coal, the effectiveness of the various conventional mechanical dewatering processes is limited to the EASY end of the FREE moisture category. On the other hand, MW energy is effective for removing moisture across the entire FREE-INHERENT moisture spectrum.

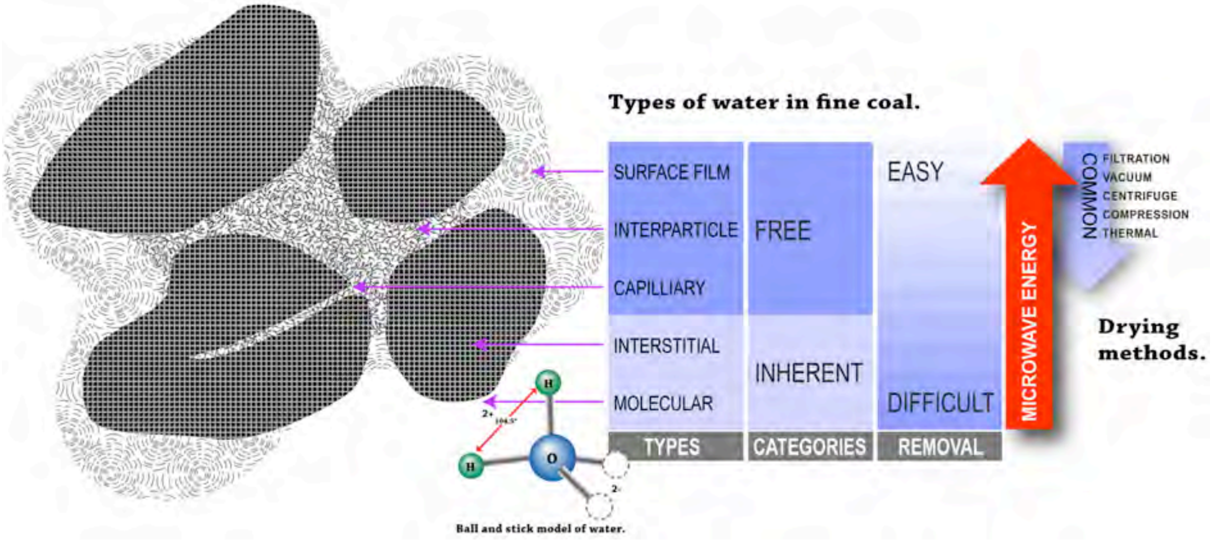

Figure 2 Forms of water in Fine coal, illustrating the relative effectiveness of various coal de-watering techniques versus microwave energy

The virtual transparency of coal to microwave radiation means that the energy is delivered directly to both FREE and INHERENT water.

2.5 MW energy versus other drying processes

In the first place, microwaves are a non-contact drying technology, so that coal may be processed without further crushing or disturbance of the structural integrity of individual particles. Secondly, the MW process is superior because it effectively removes inherent as well as free moisture, in a selective, controlled manner, and without necessarily overheating. The following diagram (Figure 3) compares the relative effectiveness of various conventional processes generally used for de-watering Fine coal. The chart plots the drying and re-wetting curves of fine coal (%TM) against the Pressure Equivalent (kPa)[7].

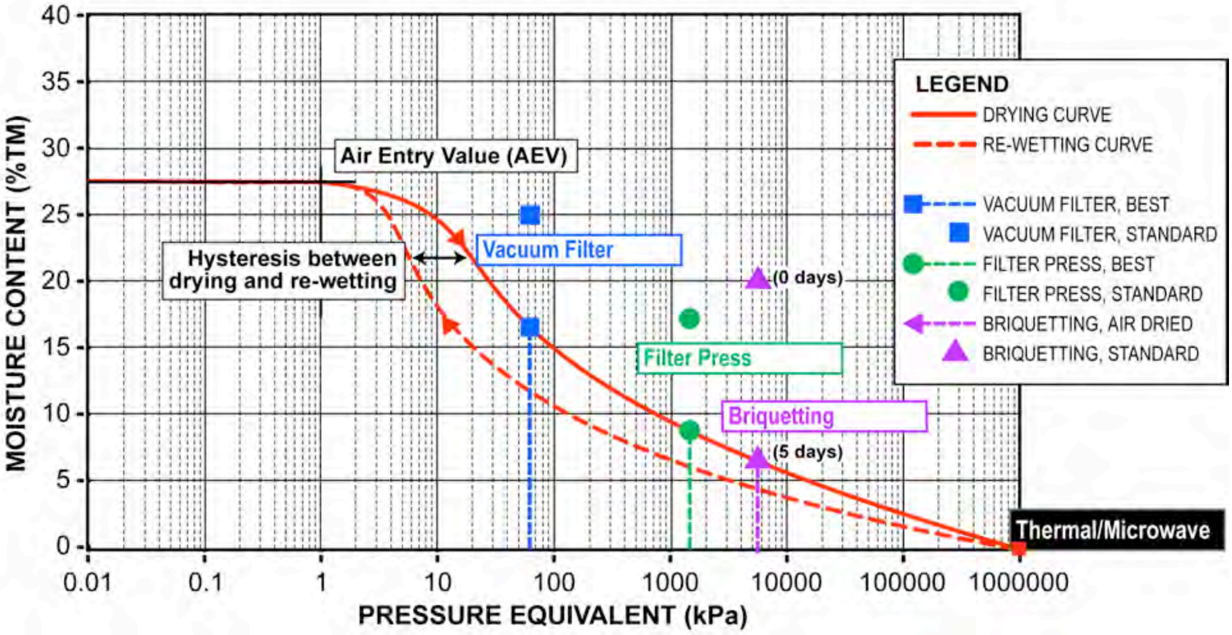

Figure 3 Coal water characteristics curves for drying and re-wetting (Fine coal)

The Air Entry Value (AEV) represents the point beyond which the coal is unable to remain saturated, and air starts to replace further moisture loss. The hysteresis between the drying and re-wetting curves occurs as a result of the coal re-saturating after drying, but at a much lower pressure than was required to drain moisture during the drying cycle. The chart also shows how only Thermal techniques (including MW energy drying) are theoretically capable of producing zero moisture. However, it should be noted that in comparison with MW energy drying, conventional Thermal processes incorporate significant disadvantages. The use of conventional Thermal drying is generally limited by a combination of high operating costs, environmental approval requirements, the risk of fire, and the risk of detracting from the dried coal's thermal and other properties by overheating.

3. EFFECTIVENESS OF MICROWAVE DRYING

3.1 Superior control

The Project testwork has shown consistently that MW energy may be applied to achieve specific moisture targets without diminishing the coal’s thermal and coking properties. More than six months continuous operation of the US facility has confirmed this feature. Application of the MW energy is precisely controllable and (as shown below in Figure 4) steady state drying can be achieved within 50 seconds of commencing operation. In the application of the Drycol process, the effect of applying the MW energy is monitored in real time by way of electronic moisture and product temperature sensors, and by a Control Room Operator using Supervisory Control And Data Acquisition (SCADA) equipment. Coal that has been MW dried acquires a distinctive "dried through" consistency, and tends to not re-hydrate readily because Inherent as well as Free moisture has been removed. Figure 4

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[7] (From) Williams Dr.David J. 2004. *Results of Laboratory Testing of Product Coal*

shows that coal passing through the MW drying zone is highly absorbent of the applied MW energy, so that the targeted product moisture reduction is achieved in a direct and efficient manner, with a low incidence of MW energy reflection.

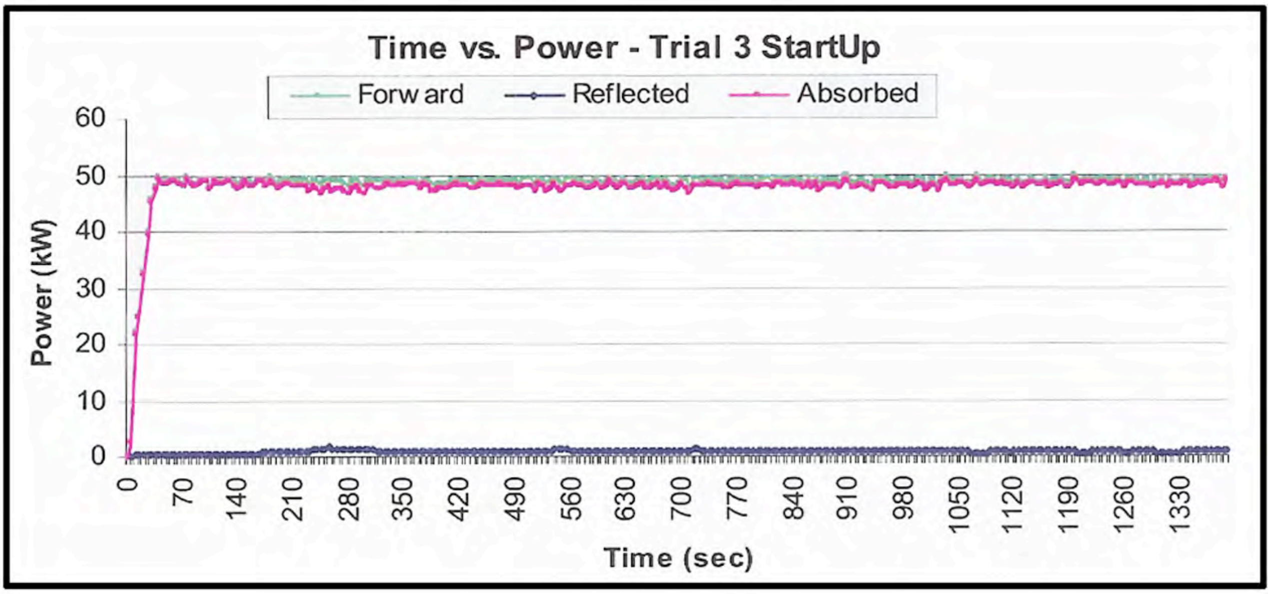
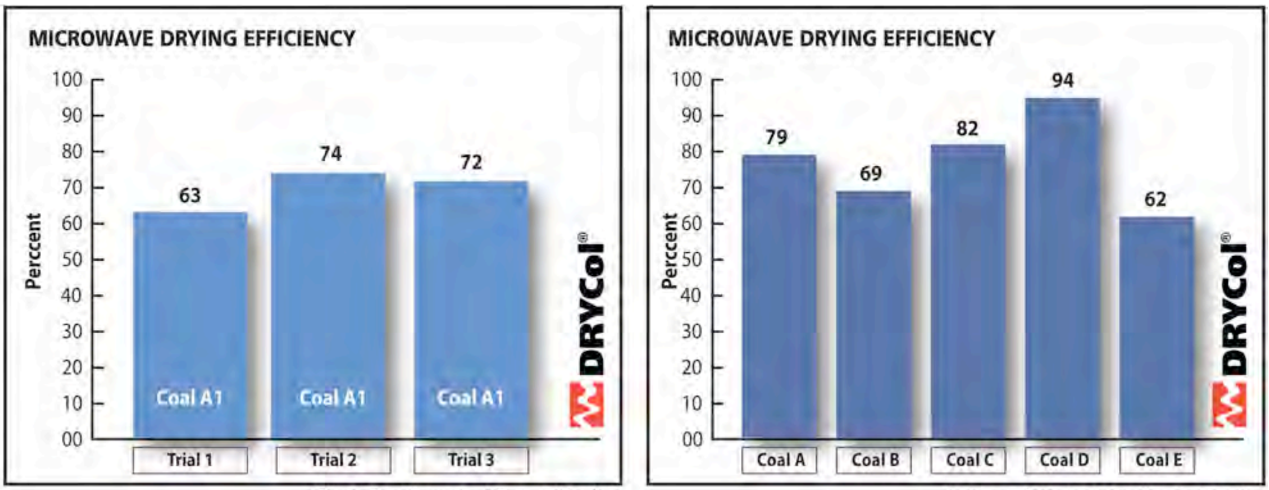


Figure 4 **Microwave energy absorbed in continuous application**

3.2 Coal drying efficiency

Figure 5 below shows variations encountered in the MW drying efficiency of various processed coal types. The chart on the left shows variations encountered during 3 separate trials of unwashed thermal product at 50mm topsize. The chart on the right shows averaged variations encountered for five different types of washed metallurgical coal. The work has shown that while MW coal drying efficiency is generally high, it is also likely to vary according to the coal type, as well as to a range of other factors including geological makeup, the uniformity of size fractions, and not least, the proportion of free to inherent moisture within the targeted reduction of total moisture (%TM).



(Single Type Unwashed Thermal Coal)

(5 Types of Washed Metallurgical Coal)

Figure 5 **Variations encountered in microwave drying efficiency**

Figure 6 below illustrates the results of earlier testwork, where the Drycol Process was used to dewater five different Fine metallurgical coal types to suitable levels for moisture control. The dried coal was compared by analysis with control samples, proving that in each case the Process had significantly lowered the %TM.

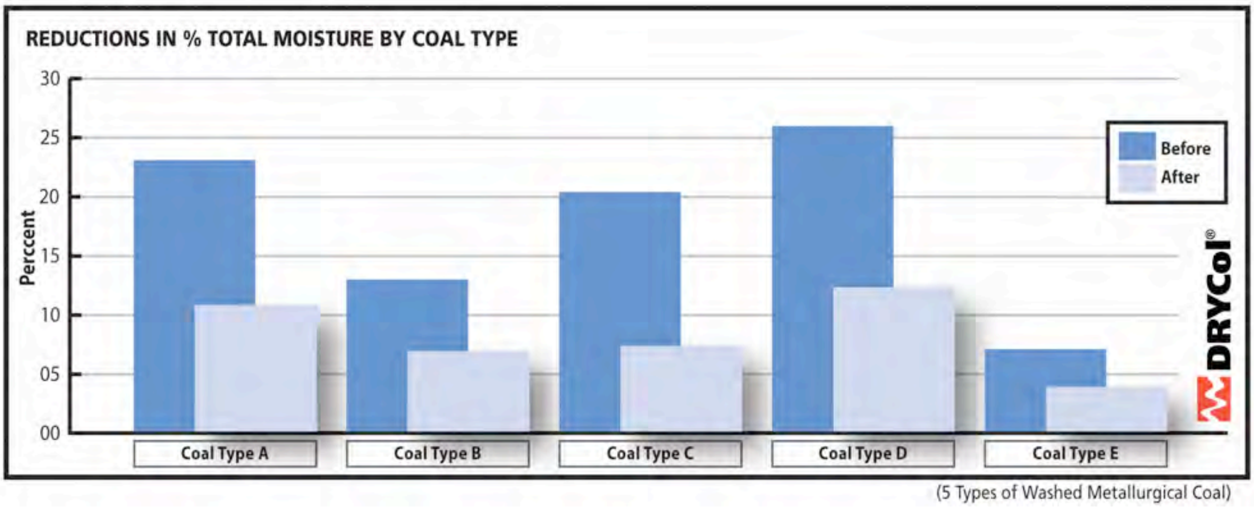


Figure 6 Averaged %TM reductions for 5 types of washed Fine coking coal

4. MICROWAVES FOR REDUCTION OF COAL CONTAMINANTS

4.1 Removal of Sulfur by microwave energy application

The analysis that was conducted on the tested coal types (see Figure 6), to establish the level of moisture reduction and to confirm that dewatering had been achieved without detracting from the coal's coking and thermal properties, also showed that a reduction in Sulfur had occurred (see Figure 7), in one of the samples, Coal Type C.

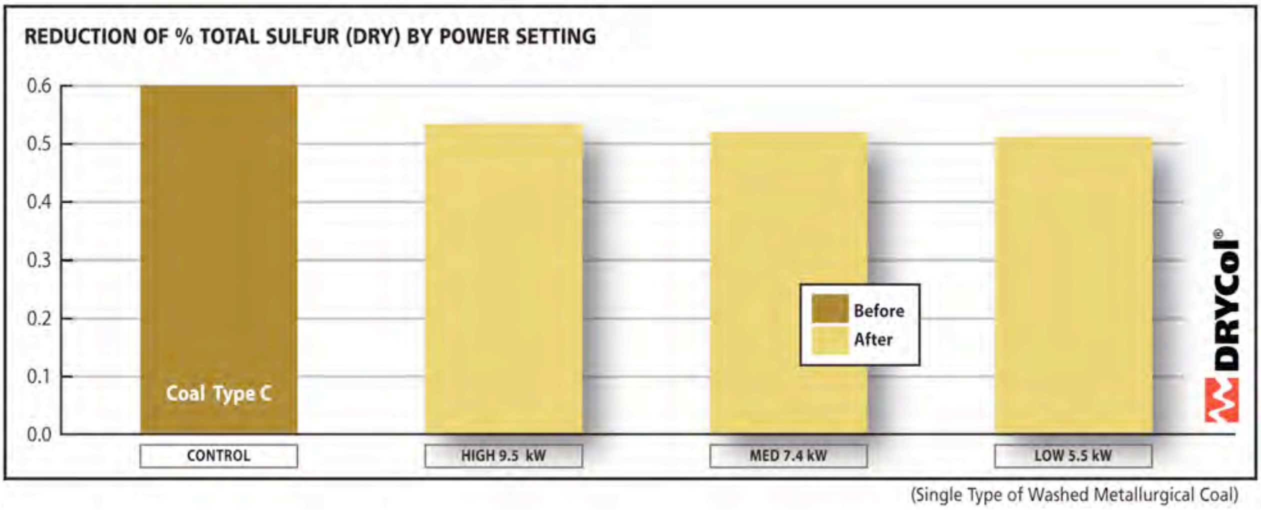


Figure 7 Sulfur reduction by microwave energy for Coal Type C

In considering the analysis, the following conclusions were drawn: (1) The Sulfur reduction had been specific to one coal type (Coal Type C); (2) The greatest reduction had occurred on the 'Low' power setting; and (3) That further investigation is warranted.

The hypothesized mechanism for Sulfur reduction is described as follows:

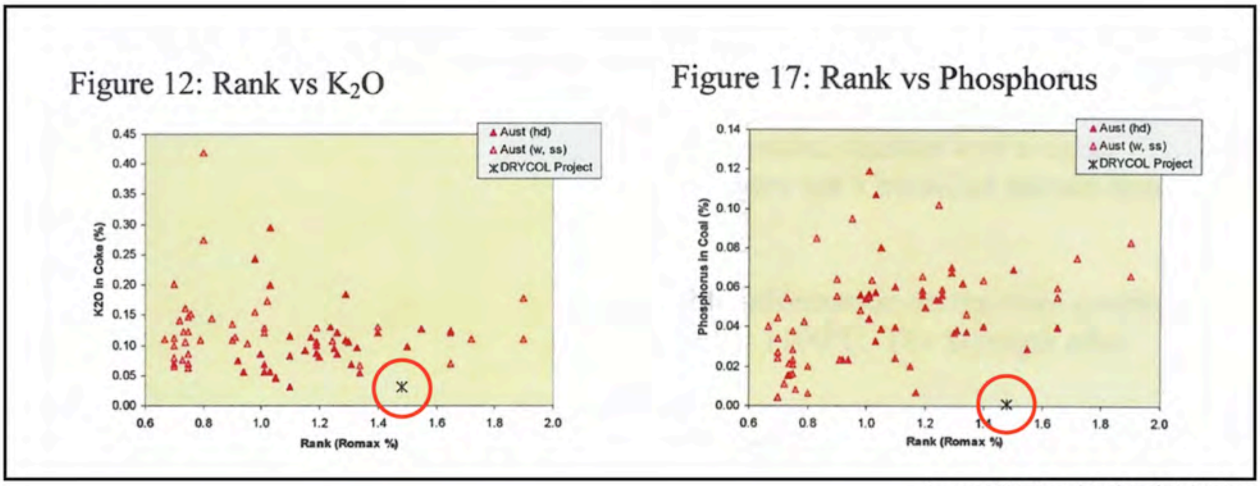
1. Some mineral components within coal have relatively higher dielectric constants to other components which means that their temperature increases relatively faster;

2. In particular, the MW energy excites pyrite (Iron sulfide) at higher rates than other coal components (eg. Pyrite rate > 5 x Carbon rate);

3. Pyrite is reduced during the application of MW energy (eg, pyrite to pyrrohtite) and sulfur is released. Pyrrohtite may also be removed by secondary processing.

4.2 Reduction of Potassium and Phosphorus

Potassium and Phosphorus reduction was also noted during initial moisture reduction testwork, after MW dried samples of coal had been coked and analyzed to confirm that the Drycol process had not caused degradation of the metallurgical coal properties. The magnitude of the reduction reported in the original testwork is shown below in Figure 8.



Source ACIRL. Drycol Coal Analysis Report

Figure 8 Reduction in Potassium and Phosphorus

4.3 Future work

While the testwork showing measurable reductions of coal contaminants by MW was of interest in the context of the Drycol Project, commercialization of the Process for dewatering coal has remained the primary focus. Now that this stage has been completed, further work will be undertaken to quantify the reduction of contaminants.

In particular, based on the results of the Project testwork, together with incidences of Sulfur reduction through the application of MW energy that is cited in the literature, future work is likely to focus attention on optimizing the reduction of Sulfur.

5. CURRENT COMMERCIALISATION

5.1 Initial development

The initial MW drying plant is based on the concept of drying unwashed Thermal product (high inherent moisture) from ~28%TM to ~12%TM (see Figure 9, below), as replacement for coal destined for power generation. The 15 tph plant has operated commercially for more than six months, providing its owners with a useful test facility, a financial return, and clear justification for investment in a larger, adjacent facility.

Figure 9 MW-dried coal emerging continuously from the drying zone

5.2 Full scale plant development

The second, 50 tph plant is to be commissioned Q4, 2007. A number of additional plants are currently under consideration.

6. THE FUTURE FOR MICROWAVE TECHNOLOGY

6.1 Summary of benefits

The Drycol Process provides an effective method of moisture control that allows contractual moisture and energy specifications to be met, permitting the maximization of product value. It enhances the potential of miners and processors to utilize finite coal resources more completely, and of coal burners to maximise the thermal efficiency of their fuel.

Where the availability of water is an operational issue, the Process offers the potential for the return of clean water, in significant quantities.

In addition, the Process offers a no less significant range of benefits in its potential to reduce coal contaminants, for which the “Prizes” may include the following:

A. For Coal Producers and Steel Makers:

a. Sulfur Reduction

- Reduction in SOx emissions;
- Savings in sulfur trading; and
- Mitigation of environmental license requirements.

b. Alkali Reduction (Potassium)

- Possible reduction in coke usage per tonne of hot metal; OR:
  - Reduction in cost for cheaper (high alkali) coke blend coals; and
- Higher CSR and lower CRI adding value to weaker coking coals.

c. Phosphorus Reduction

- Reduction in de-phosphorizing costs in downstream steel making;
- Reduction in cost for cheaper (high phosphorus) coke blend coals; and
- Strategic use of higher phosphorus iron ores (Domestic or cheaper).

B. For Power Stations (coal burning):

a. Direct Load Control

- Load shedding of up to 20MW during peak periods;
- Maximize off-Peak drying of up to 20MW; and
- Potential to minimize spinning reserve for the network.

b. Sulfur Reduction

- Reduction in SOx emissions;
- Potential savings in emissions trading; and
- Potential to mitigate environmental license requirements.

c. Sustainable Development

- Transition from Clean Coal Technology to Zero Emissions Technology;
- Water recovery from coal drying;
- Recycling of site water as dust suppression; and
- Research potential to dry and utilise biomass or other low-value fuels.

6. TYPICAL DRYCOL PLANT PROJECTS

6.1 Concept for value-adding lignite or sub-bituminous coal

- Power stations (generating stations or power plants) that are designed to utilise lignite or sub-bituminous coals generally operate at lower efficiencies and burn greater tonnages of coal to generate the same power output.

- While lignite may have the property of very low ash, the moisture content is excessive. Other sub-bituminous coals will have less moisture but greater ash.

- Depending upon local market dynamics and transport logistics, it is possible to take (for example) a lower-value Powder River Basin coal and replace Appalachian coal destined for power generation.

6.2 Concept for vitrinite concentration

- The CSIRO (Australia) through Graham O'Brien et al have identified a characteristic of conventional froth flotation, that vitrinite is floated in preference to all other coal maceral types. The value of concentrating a semi-soft coking coal from ~30% vitrinite to a hard coking coal product >50% vitrinite is in the order of USD $30/tonne.

- Unfortunately the moisture content of 100% flotation product that has been conventionally dewatered with mechanical drying techniques is in the order of 20-25%TM. Solar or thermal drying techniques would allow a moisture specification of 10%TM to be achieved, but at the cost of degrading the coal quality (fluidity and volatiles) that the flotation cells have painstakingly upgraded.

- The Drycol Process is able to meet the required moisture specification, without degrading the coking qualities.

7. IN CONCLUSION

7.1 Proven technology

The Drycol Process offers a range of benefits as likely to apply to coal users as to coal producers. The successful operation of the initial commercial plant has established a sound platform for a growing acceptance and wider application of the technology.

7.2 Developer's objectives

The developer's current aims include the promotion of a greater understanding of the technology, together with the discovery of additional commercial opportunities, particularly outside the USA, where the Process might be applied to enhance the output and/or profitability of large-scale industrial operations including power stations, steel mills, coal mines and coal processing plants.

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