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Innovative Technologies for Industrial Wastes[1]

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ABSTRACT

This article is intended to provide several case studies of successful waste management of a few selected industries in their attempts to become "environmental-conscious" firms. In particular, this article examines the innovative waste-reduction and waste reuse processes undertaken by certain firms in the following industries - asphalt cement and concrete, ferrous metals, Portland cement and concrete, and some other that on the face of it somewhat isolated innovative technologies. For each case, the driver, the waste management technology or processes involved, as well as the associated economic benefits of the adjustments was highlighted. It is hoped that the findings of this article will provide the motivation or continue to motivate engineers and scientists to further explore processes that will help towards better management of industrial wastes.

Keywords: Innovative technologies, waste reuse, asphalt, cement, and concrete.

ABSTRAK

Artikel ini bertujuan untuk memaparkan kajian kes beberapa industri terpilih yang telah berjaya menguruskan bahan sisa buangan dalam usaha menjadi firma yang prihatin terhadap alam sekitar. Secara khusus, artikel ini cuba membuat penilaian terhadap inovasi mengurangkan bahan sisa serta proses penggunaan semula bahan sisa oleh firma-firma di dalam industri berikut–industri simen dan konkrit aspal, industri logam feros, indusrtri simen dan konkrit Portland, di samping beberapa industri lain yang terlibat dengan inovasi teknologi tersendiri. Bagi setiap industri yang dikaji, analisis ditumpukan kepada tiga aspek berikut-pemacu, proses atau teknologi pengurusan bahan sisa, serta faedah dan kos akibat dari penyesuaian atau inovasi setiap firma. Adalah diharapkan bahawa penemuan yang dibincangkan dalam artikel ini akan menjadi pendorong dan seterusnya menggalakkan para jurutera serta ahli sains untuk terus mencari penyelesaian ke arah pengurusan bahan sisa yang lebih berkesan.

Katakunci: Aspal, bahan sisa, konkrit, teknologi inovatif

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BACKGROUND AND SETTINGS

Industrial wastes are inevitable byproducts of every industrialized economy. What was once a major environmental concern in the developed countries, proper management of industrial wastes is now beginning to take center stage in most developing countries, particularly in those that have chosen the industrial sector as the engine of growth. In most cases, the gravity of industrial waste management issues is related to the quantity and types of waste that were generated.

To deal with the industrial waste issues, it can generally be stated that developing countries have a tendency to devise their policies and strategies that resemble those that have already been developed by the developed nations. This task is never easy largely because most developing countries have yet to establish an information system. Simply put, problems related to scarcity of information as well as a lack in effort to disseminate available technological solutions are perhaps the two most oft-quoted reasons hampering the efforts of most developing countries in addressing their waste issues. Take for instance Malaysia, where information pertaining to waste types and quantities as well as waste management technological solutions that are now being utilized are currently seriously lacking or unavailable.

With respect to information on how to effectively manage industrial wastes, we strongly believe that in addition to a good database on waste types and quantities, there must also be serious efforts to disseminate useful information regarding good technological solutions. Since we have regarded that the majority of the developing countries have the following- road-making, ferrous metals, and cement makers, we have therefore attempted to provide case studies of these industries in the developed countries that we consider innovative with respect to their waste management techniques. We hope that this article will illustrate how firms in these selected industries can adapt in reducing their respective industrial waste management issues.

LITERATURE REVIEW AND OBJECTIVES

As many would expect, the initial reaction to industrial waste management problems by most governments is to enact tough environmental laws. In the case of developed countries, the environmental issues began to move into the political, technological, and economic mainstream of most developed countries in the 1950’s and early 1960’s. In the United States of America (US) and most Western European countries, public concern for the environment initially led to enactment of new and tougher environmental laws that were subsequently accompanied with stricter enforcement of various environmental-related rules and regulations. A good example of successful environmental legislation is the introduction of stricter emissions regulations in the 1970’s that resulted in many older and higher polluting plants of certain industries to close or make others “modernize” their facilities.

It is important to recognize that whilst environmental laws do cause permanent changes on how firms conduct business, there are also numerous cases where firms make changes to their ways of doing businesses more because of economic reasons. One simple but clear example is the oil price hikes of the 1970’s that led many firms to review the idea of energy efficiency. It is also important to be aware of the fact that all modifications and adjustments have not come without cost. Szekely (1995a) estimated that in most efforts by industries that take the form of “end-of-the-pipe” treatment, environmental-related modifications typically are about 20 percent to 30 percent of the cost of a new plant.

Through all of these, however, the less obvious benefits of environmental concern have come to pass. Today, there are many who are now advocating that environmental-conscious industries have a better public image, make better neighbors, and compared to industries of a couple of decades ago, are also producing products of higher quality and lower real cost (Szekely, 1995a). All of these efforts have lead to a great deal of discoveries of newer and safer technology as well as innovative ideas in the engineering world.

As was stated earlier, certain industries are capable of alleviating the waste management issues of other industries. Thus, the primary purpose of this article is to provide an overview of some of the innovative ideas of a few selected industries in their efforts to become "environmental-conscious" firms and in so doing, facilitate the overall reduction of the demand for industrial waste management. To prove this, this article will highlight the following elements for consideration: (1) the key drivers that make certain firms make adjustments or modifications, (2) the change in processes or "adjustments" undertaken by firms, and (3) the costs associated with each respective adjustment. We are obliged to inform readers that the above three industries - asphalt cement industry, the ferrous metals industry, and the Portland cement and concrete industry, were purposefully selected for discussions because we think that these industries are commonly labeled as major polluters. We also think that these industries are fundamental industries in all countries and are almost always in a good financial position to undertake modifications or changes to their production methods.

An implicit point of the case studies contained in this article is to highlight the facts that technological solutions to most types of industrial wastes in the majority of cases are already available and yet efforts to make such waste management technology to be widespread is lacking. Perhaps the most important point to be gleaned from each of the case studies illustrated is that a "win-win" situation is possible through innovative ideas of engineers and technocrats. The challenge, however, is to find the right drivers and incentives for the engineers and management to be more creative.

ASPHALT CEMENT AND CONCRETE INDUSTRY

When the first oil price hikes struck in the 1970's, it had a major impact on the production of asphalt cements for the use in road construction, particularly in the US. Such "oil crisis " had a tremendous impact on this industry largely because the majority of the roads in most countries were paved with asphalt products. In the case of the US, about 2.21 million miles of roads there were paved with asphalt products, and the road construction industry was consuming an annual average total of 0.3-0.6 billion tons of asphalt mixtures as well as 25-30 million tons of binders. This, according to Roberts et al. (1995) is twice what was used by the rest of the world and the road construction using asphalt was a US$15 billion-a-year industry (Roberts et al., 1995).

Given these facts and in the face of rising oil prices, the idea of reusing the old paved roads for the creation of the new, instead of overlaying or landfilling, became a very lucrative project and were soon undertaken by the US Department of Transportation. In the late 70's the Department of Transportation conducted many experimental procedures to determine the possibility, and feasibility of surface recycling of asphalt concrete pavements.

According to Barnes & Trammell (1977), one of the first such experiment to reuse asphalt was conducted on US Highway 281 and State Highway 336 in Texas. This experiment that involved the "old" asphalt was first heated to about 300 degrees C (using radiant heaters burning propane) that was later scarified up to a thickness of one inch. The scarified material was later collected and was reused in the patching of the new overlay. Table 1 shows that the process not only created a good quality asphalt pavement but also resulted in a savings in price and energy consumption.

Since that time there have been significant improvements in the control of using the recycled asphalt concrete, and in the technology of the milling machines now used to scarify the old road surface. This has lead to an increase in recycling procedures and in the stockpiling of the reclaimed asphalt pavement (RAP). From Roberts et al. (1995), the typical monetary values for such processes are shown in Table 2.

Table 1
Costs and Energy Consumed Associated with Collection and Reusing "Old" Asphalt

Repair Type	Cost*(per yd^2)	Energy Consumed (BTU per yd^2)
USH 281	$1.00	46,771
SH 336	$1.29	66,627
Conventional Overlay	$1.13	115,900

*Note: These are monetary values from 1976.
Source: Barnes (1977)

Table 2
Costs Associated with Reclaiming Asphalt Pavement

Depth of Milling Cut	1989 Costs (per ton)
1 in	$ 1.86-1.88
2 in	$ 1.39-1.40
3 in	$ 1.04-1.13
4 in	$ 0.93-0.90

Source: Roberts (1991)

FERROUS METALS INDUSTRY

Similar to the asphalt cement industry, the metals industry has seen a decline in its energy use due to an increase in recycling. The energy needed to produce metal from recycled scrap is a fraction of that needed to process ore. Paradoxically, the primary processing plants in developed nations have virtually stopped being constructed because of this boom in recycling. As such, "mini-mills" that use scrap steel as their raw material has come into prominence in the steel industry. It is important also to recognize that the weight of materials consumed has actually decreased in the metals industry as heavier grades of steel are replaced with thinner gauge, higher-performance steel; steel is replaced with aluminum; and aluminum is replaced with plastics and composites. A full-sized passenger car built in 1994 needs 18 percent less steel than one built in 1964 (Szekely, 1995b). The price for a ton of steel has stayed at about 20 cents per pound for the last 20 years. Copper and lead are in the same boat. Aluminum has actually gone down in price in the last 20 years. This fact has lead many metal industries to look for alternate ways to increase their profit margins, which means resource recovery and waste recycling.

Other than the above, it is imperative to be aware of the fact that there has been almost a constant stream of experiments in using shredded automotive scrap to aid in the cementation of copper out of acid leaching wastes produced in the processing of low grade copper ores resulting in 91 percent recovery rates (Staker, 1976). Automotive scrap and the ferrous metal contingent of municipal solid wastes (MSW) have also been used to produce "gray" iron through a process called cupola. This met with limited but hopeful success producing a gray iron with a tensile strength of over 35,000 pounds per square inch (Spironello, 1979).

The following are excerpts of several case studies worth noting.

Magnetic International-Burns Harbor, Indiana

This manufacturing company has developed a commercially viable technology to treat and recover pickle liquor. Pickle liquor is the leftover residue that results from the cleansing of oxides and other impurities from steel sheets after they have been rolled. Steel makers do this by dipping the sheet in a highly acidic solution called a pickling bath. The leftover liquid is acidic and contains dissolved ferric chloride and other heavy metals. In the past, such leftover liquid was stored, lagooned, or injected into deep wells. But at Magnetics International, this liquid was sprayed at high pressure into a 100-feet tall "roasting" chamber that exceeds 1200 degrees F. Such processes allow ferric chloride to react with oxygen to yield a pure form of iron oxide. They then turn this into 25,000 tons of magnetic powder per year that can be used in electric motors, loud speakers, and refrigerator gaskets. The process also allows Magnetic International to reclaim hydrochloric acid with commercial value (Szekely, 1995b).

Inland Steel

Inland Steel is the parent company that owns Magnetics International. The process of pouring molten iron from ladle to ladle creates a black-gray powder called "kish". It is a mixture of graphite and iron oxide that has been regarded as a waste product. Inland, however, now collects the kish through air filters throughout its plant. Their kish then goes through a series of acid leachings to produce graphite flakes that can then be processed into lubrication products. The production of raw graphite is typically very expensive, and by doing so, the production of graphite flakes by Inland Steel turns out to be very lucrative for this company. It is estimated that kish recycling at all of its plants could easily yield about 1,500 tons of graphite a year; about 6 percent of the total US market (Szekely, 1995b).

Oregon Steel-Portland, Oregon

In Oregon Steel's processes for treating the dust that was produced as a result of the melting scrap metals in electric furnaces, it is the case of the glass-making industry that gets the benefit. Because the dust that was produced contained zinc, lead, and cadmium oxides, the United States Environmental Protection Agency (USEPA) therefore classified the dust as a hazardous material/ waste. In the Oregon process to treat their dusts, they melted this hazardous byproduct together with glass-forming chemicals in their electric furnace. The inert glassy material that results can be used to make a variety of ceramic products such as tiles. The hazardous waste aspect is taken care of because glass is inert and meets the leaching tests set up by the USEPA for encapsulating and disposing of hazardous wastes (Air and Waste Management Association, 1992).

PORTLAND CEMENT OR CEMENT INDUSTRY

Producing cement is essentially a process of mixing limestone, and silica in a ratio of about 3:1 in a long, rotating kiln. This blend is then gradually heated to a temperature of about 1,500 degrees C by the burning of coal, oil, or other fuels. Cement kilns are large, stable systems; typically 100-150 m long, and 3-5 m in diameter, which process large volumes of materials. The high temperatures and long residence times in the combustion zones of cement kilns have been used for over ten years to burn flammable liquid hazardous wastes, like solvents and waste oils. Increasing government regulation of this technology and of the wastes burned in the kilns has actually lead to increased use of the facilities as more cement manufacturers and waste generators become more comfortable with the technology. Laboratories at both cement kilns and the generating/processing plants have lead to increased quality control of such technology.

In an incinerator there is no other reaction that takes place except those directly by incineration, which is oxidation. Gases exiting the incinerator therefore tell exactly what is happening in the combustion chamber. The gases are also moving in the same direction as the solids and liquids, and this pushes phase equilibrium towards the gaseous state and produces more emissions, such as metals. This also affects the thermal capacity and thermal stability, and makes them quite low. This instability can lead to quick upsets that may allow organics to escape in the upset time. This can be caught with an afterburner (Gossman, 1992).

In the cement kilns, the dehydration and calcination steps typically generate lots of gas that can mask the gas produced in the combustion section of the kiln. Almost half the raw materials that enter a wet process kiln leave the kiln as gases, mainly as water vapor and carbon dioxide, but these ought not to be considered as products of combustion. The counter current flow of gases and solids/liquids tends to entrain metals in the clinker by the process of recirculating loads. This has lead to other questions about the leaching possibilities of the clinker that will be discussed later. If metals do manage to reach the cooler sections of the kiln before the condensation of the gases, they are most likely to leave the kiln as airborne particulates because of the low exit temperatures. The vast quantities of material in the kiln at any given time leads to a much more stable environment than that found in an incinerator. The high temperatures in the kilns also eliminate the need for an afterburner. With flame temperatures of 3,400 degrees C that heat the raw materials to around 2,700 degrees C there is little that does not combust. Those temperatures are: 20 percent hotter than molten iron, 30 percent hotter than a commercial waste incinerator, and 40 percent hotter than a fossil-fuelled electric power plant (Air and Waste Management Association, 1996). Table 3 below displays the comparison of several key parameters between cement kiln and a typical incinerator that could make the former a better technology to treat certain industrial wastes.

Table 3
Cement Kiln vs Incinerator: Some Selected Parameters

Parameter	Kiln	Incinerator
Max. gas temp.	> 2,200 degrees C	< 1,480 degrees C
Max. solid temp.	1,420-1,480 degrees F	< 1,370 degrees F
Gas retention > 2,000^{O}	6-10 sec	0-3 sec
Solid retention > 2,000^{O}	20-30 min	2-20 min
Oxidizing conditions	Yes	Yes
Turbulence	> 100,000	> 10,000

Source: Grossman (1996)

The cement industry can utilize wastes in at least these three ways: (1) by substituting a by-product or waste for an original input to the feed stream, (2) by using a waste as a fuel for the kiln, or (3) by incorporating the waste into the cement itself without impairing the quality of the cement product (Szekely, 1995a).

When substituting a waste into the feed stream, the introduction of such waste should leave the composition and performance of the cement product unimpaired, or even improved. It is in the opinion of the author that spent sand from a metal foundry, or even better, blast furnace slag is good potential for this type of waste utilization. Blast furnace slag is considered a good candidate largely because it supplies iron, which is needed in cement production, and it also contains lime and silica in about a 3:1 ratio. Calcium sulphate, or gypsum, is also an example of thistype of waste utilization. It can be mined directly, or it can come from the scrubbing operations that are in use at most power plants.

The utilization of wastes as fuel for the cement kilns has raised a lot of questions about safety concerns around the kilns. Thus far, alternate fuels that have been considered include waste oils, organic sludges, petroleum and petrochemical wastes, and spent solvents such as carbon tetrachloride, trichloroethane, and toluene. Pilot experiments have shown that these alternate fuels actually burn cleaner than coal with respect to nitrogen oxides and sulphur oxides. With cement demand stagnant, and increasing regulations, cement manufacturers are looking to these alternate fuels as a way to make ends meet. In fact, not only will cement manufacturers get waste fuel at no cost, but often times they might get paid to dispose of a potentially hazardous waste (Szekely, 1995a).

Incorporating the waste into the cement itself does not contribute to the combustion process, or the composition of the final product. The burning of certain toxic wastes leads to the breaking down of these compounds into benign elements that would be harmlessly encapsulated into the cement. Since 90 million tons are produced a year this could be a very large area of the waste stream. The use of cement in this way has lead to questions being asked about the potential leaching or air emission of heavy metals. There really is not enough data at this present time to say whether the heavy metal concentrations that are sometimes found in the cement clinker are detrimental to the cement itself. With regard to this, there is a need to carry out in-depth investigation of the effects of certain compounds, such as silver, arsenic, cadmium, chromium, mercury, and lead, on the cement, as well as the effect of these compounds on the treatment of the cement kiln dust (CKD) as a hazardous waste (Kleppinger, 1993). As it stands right now, at least in the US, the cement kilns are exempt from the boiler and industrial furnace regulations set up by the USEPA due to the fact that most of the heavy metals stay in the CKD or in the clinker. The clinker and the CKD could possibly become hazardous wastes themselves if it is ever found that the heavy metals, found in very high concentrations in the clinker and CKD, are capable of leaching out (Kleppinger, 1993).

In many other developed countries around the world the potential of cement kilns has already been realized. In Japan and several countries in Western Europe where energy is more expensive and landfill space is restricted, the use of cement kilns as a waste alternative has been in full effect. Mitsubishi Materials burned more than 23,000 tons of tires at its own cement plant in 1992 (Szekely, 1995a). In England, the Pollution Inspectorate HMIP has since January 1995, authorized six cement kilns and one limestone kiln to carry out trial burns of a highly calorific fuel called *Cemfuel*. *Cemfuel* is a processed replacement fuel for cement kilns that is manufactured to specific requirements. It must have only 0.5 percent sulfur, four times lower than coal and 12 times lower than petroleum coke. The major concern with *Cemfuel* is dioxin production, which the cement manufacturers declared at 2,000 degrees C flame temperatures and its relatively long residence time that will be able to keep organic emissions to a minimum (Goldsmith, 1998).

CONCLUSION

The main purpose of this article is to provide an overview of some of the innovative technologies of the following commonly found industries worldwide, that is asphalt, metals and the cement industry. The case study methodology was utilized to highlight the efforts of selected firms in these industries towards becoming environmentally-conscious firms. For each case study, the three elements discussed were the drivers that caused the adjustments, the technical adjustments involved, and the financial aspects associated with the adjustments.

It must be noted that without doubt, there are many more innovations in fields that are not covered in this article. The influx of new ideas surrounding the use and reuse of the wastes that industries produced has made possible for engineers and scientists to go where once they did not think they could go. Instead of analyzing already existing theories and expounding on them, they were able to break new ground in the technology that would suit their respective problems, or meet their respective goals. Hopefully, at least the author hopes so anyway, this trend will continue, so that the inventive part of the engineer and scientist can prevail.

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