RED HERRINGS ON THE PATH OF TECHNOLOGY DEVELOPMENT: 
CAPITAL DESTRUCTION IN THE PURSUIT OF A BAD IDEA

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ABSTRACT

The history of extractive metallurgy is replete with examples of commercializing new processing technologies. The successes are widely reported, but failures seldom are. This is unfortunate, for usually we can learn more specifics on how to succeed in technology development by studying and thoroughly understanding their failures. Frequently one encounters a red herring that caused the whole effort to fail. A thorough and objective due diligence up front would have identified those red herrings and prevented the pursuit of a bad idea and the resulting destruction of capital. Due diligent analyzes performed before construction of three such bad ideas will be discussed. One is an EAF dust process, which pursued the red herrings of a poor understanding of the business, a naïve view of past experience, and false confidence in the technology. Another will examine the effort to commercialize a new pressure copper leach process that followed the red herrings of inadequate testing of the raw material, application of processing conditions that were inherently unsafe, and an improper assessment of the inherent advantages of past developments. The last is an alternative iron-making process, where the red herrings were incomplete and superficial assessment of prior pilot plant and demonstration plant tests, an assumption that the commercialization model of “build it and we will make it run” was viable, and a technology whose technical fatal flaws had already been identified. Unfortunately, capital destruction often also closes the window to more intelligent pursuit of technology development.
TECHNOLOGY COMMERCIALIZATION

The development and commercialization of new technology is a vital part of keeping industry profitable, able to deal with new sorts of feed stocks and current with economic, product, operational and environmental requirements. This is a difficult task in the best of times, and can be compounded when the developers become enamored of a particularly favorable characteristic of the project or of the product. These “red herrings” divert project focus away from the arduous path to success and, in the end, result in project failure.

The subject of the path to technology success has been assayed from two aspects — the number of attempts to commercialize a new process (McNulty, 1998), and from the concept of fatal flaws (Southwick, 2000b, 2000c). The former seems to be a common route developers take, working through various laboratory tests and pilot plants, building facilities and experiencing their demise, and as they fail the baton is taken up by other developers. In the second, a critical and objective analysis is made of the technology itself, looking carefully at past efforts with similar processes and equipment (perhaps from other industries even), examining pilot and other tests for a thorough understanding of just how the process can succeed and which operating problems arise and what causes them and how to resolve them. Further, it has been found that virtually all of the problems that lead to technology failure could have been seen in the earlier small scale tests and experiments.

The repeated efforts of the first route become in effect a “pin ball” or “roll the dice” method of solving process difficulties, but on a much too large and expensive scale. And often the window of opportunity closes due to exhaustion of financial resources or loss of management commitment before success can be achieved. A further problem is that often a complete analysis of the causes of failure is not done, the specific causes and sequences are not well understood and, worse, the details are poorly known within the developers’ staffs and only rarely are they communicated to others (Southwick, 2012a). Thus those that “pick up the baton” have little useful information upon which to improve their chances for success.

The second route takes a concerted, objective and thorough effort and a deep understanding of how processes work, or don’t work, and how to conduct and solve equipment and design scale-up issues. Also, in the minds of many, the second route consumes unnecessary costs and they have confidence their plant staffs can solve any problem which arises in the prematurely constructed plant. “Build it and we will make it run”. Except they cannot — equipment and operational sequences are too large to study or replace readily or in detail, new ideas become equally large and expensive to test and install, and cleanup of spilled feed stocks and off-spec materials in process must be moved around and disposed of to provide room for continued operations.

Further, the first is more frequently practiced because it is easier for management and staffs to be convinced by the shambles and disorder of a collapsed process concept than to believe in a somewhat abstract scientific and engineering exercise. Ruptured equipment, fires, debris, and economic devastation are more convincing, though the companies would be greatly benefitted if their capital funds had not been dissipated on what can be proven scientificaly and by resort to other examples to have been a losing cause.

It is for this last reason that the second route should be preferred, and although the author has spoken on this topic for many years with a myriad of examples, the “fatal flaw” route is not well understood or believed. Failed processes seem to attract imitators like flies and carrion birds, hoping another more grandly mounted but no less poorly informed effort will succeed this time around. Their only reward is being second (or third) on the trash heap of failed processes. The following examples are thus being offered as substantiation that such analyses can indeed be done before a commercial plant is built, and with meaningful results. In all of these cases a conclusion was reached that the plant should not be built (or should not be started up without changes), and in all these cases the plant was operated, and in all these cases the technology has failed or is in the process of failing.
In some of these cases, large companies are involved and the debacle can be paid for – in some the losses will likely result in collapse of the company, or at least reorganization. Yet even when the capital loss can be covered, the project was funded on the basis of a projected capital gain, but was pursued with false expectations that could have been better extended to a technology that had a reasonable chance to succeed. Even when other goals might be achieved, such as in the case of HiSmelt in Australia where benefits were claimed in placating government edicts (Burke, 2008), the non-Australian parties who sank their money into the project gained no such benefits, their financial contributions being used to fund the lead company’s unique goals.

Just because a technology makes the desired product and which has beneficial properties does not in and of itself assure that the plant will be either technically or economically feasible. Until those aspects are proven, the technology is just a scientific curiosity. To be technically feasible the commercial plant must be able to meet production rate and quality goals with adequate onstream and reasonable maintenance requirements. To be economically feasible it must meet these goals and make money doing so. A fatal flaw is evident when there is an aspect within the process sequence which inherently cannot meet goals, such as a furnace with continual and recurring refractory issues, or requiring unique feed characteristics which cannot be maintained, or when all operational abnormalities migrate to one part of the process, or if the equipment or operating modes have serious safety issues. The examples discussed below will fall into one or more of these categories.

**FREE ZINC**

In the making of steel by melting scrap in an electric arc furnace (EAF), the dust emitted contains mostly iron but also volatile metals such as zinc, lead and cadmium. It was because of these that beginning in 1988 regulations in the United States were developed that designated EAF dust a hazardous waste, a designation which has since migrated around the world. Environmental regulations require that the dust be processed for removal of these metals, and so an industry has built up over the last 20+ years to provide those processing facilities. Before the regulations, some of these wastes were processed for economic reasons to recover the valuable metals, but this was only for dusts of higher zinc concentrations, which were purchased as mill feed. After the regulations, since the dusts had to be treated, new capacity became necessary which could be justified since it was now possible to charge for that processing since the steel industry had no other choices.

Better than free zinc, the perceived instant profits and the sudden and burgeoning supply of new feed stocks attracted a great many who ignored the established technology, Waelz kilns, and attempted to develop new processes (Southwick, 1998). Virtually all of these new processes failed, with Horsehead, the original US dust processor, now having a monopoly. Thus the “lowly” 75 year old Waelz kiln became the industry and regulatory standby (Southwick, 2010a). Dust is fed with reductant (coal or coke) to the kiln, the heavy metals fumed off and the irony residues discharged. Furne is processed to separate and purify heavy metal products, while the residue has various low value markets, generally site specific. Over 35 kilns are in operation around the world, having processed tens of millions of tons of dust, recovered million of tons of zinc, and accumulated millions of hours of documented regulatory-compliant operation with hundreds of regulatory agencies. These plants are owned by independent service providers, who must operate at a profit.

None of the new processes were profitable. They were also technical failures, never reaching production goals or product objectives. Many technical issues arose, some due to unfamiliarity with zinc processing or with dust characteristics, such as it variability, contained chlorides and fluorides, ferrite content and associated processing problems, and substantial iron content.

**Rotary Hearth Furnace**

However, even before the regulations changed the economic picture, a new technology, the rotary hearth furnace (RHF), was applied at Inmetco to stainless steel EAF dust. This is a flat, donut shaped
circular hearth that is heated by gas burners located around the inner and outer periphery, firing into the freeboard space. Stainless steel dust contained residual amounts of nickel and chromium used in making this specialty alloy, as well as some zinc, though at lower levels. Prices of ferro-nickel and chromium alloys are very high, and thus the plant was profitable without the regulations. Dust was blended and pelletized with coal or some other reductant, and fed to the RHF. Zinc was fumed off, which was of nominal value, and the iron material pre-reduced and drawn off with a discharge screw. These hearth residues were then final reduced and melted in a submerged arc furnace, SAF (Hannewald, 1992). When the EAF dust regulations came along, stainless steel dust required separate processing because of the added hazards of chromium. This meant even higher processing fees.

Thereby the RHF gained a tenuous reputation as a readily profitable method of processing dust and became the Lorelei that attracted other applications. The plant was credited with profitable operation, poorly conducted tests indicated pellet layers at least three deep were satisfactory, that 15 minutes was adequate, and by extension then what was hoped for in later applications was assumed doable (such as good iron reduction, good zinc fuming, and trouble free SAF operation). This is a complex subject which is covered fully elsewhere (Southwick, 2011), but we will turn now to one of those applications – processing carbon steel EAF dust. Unless otherwise quoted, the references for this discussion can be found in another paper (Southwick, 2012b).

The primary factor that led to the development of the RHF for the processing of irony materials was the rapid reduction rate that would result from the blending of reductant and feed to be oxidized. The briquetting of fines (such as those generated in flotation circuits) and residual dusts (such as in exhausts from smelting furnaces) had been practiced since the 1890’s (Anon, 1900). The concept had been extended twenty years later (Johnson, 1918) to mixing, grinding and briquetting reductant and zinc ores together as preparation for feed to zinc retorts. The intimate mixture assured that the carbon monoxide content in the retort was maximized which then gave more complete reduction fuming and recovery of the zinc.

**Carbon Steel EAF Dust**

In the 1960’s Donald Beggs discovered that blending reductant and iron ores together into a self-reducing mixture allowed their reduction on a RHF to sponge iron (or direct reduced iron, DRI) to occur in less than 20 minutes, much faster than the two hours or more required in the blast furnace. While the iron reduction application took a while to fester and take hold, the success of the Immetco plant a dozen years later led directly to the application of the RHF to carbon steel dust. In the second generation of new technology attempts after the EPA regulations took effect, two RHF furnaces were built, one for Metals Recovery Technology at AmeriSteel in Jackson, TN, and the second for Allmet at Nucor in Blytheville, AR.

The MRT furnace was to fume zinc from briquetted feed and reductant, and then the recovered oxide was to be upgraded by a special re-precipitation route to high grade oxide. This was the second attempt for this upgrading technology, the first example (part of the first generation of EPA-induced processes) had failed, partly because without a fuming furnace, much of the zinc remains unrecovered in the residue since it is tied up as unleachable ferrites (a spinel, ZnO\(\cdot\)Fe\(_2\)O\(_3\)). Missing this issue that is a well-known fact in the zinc industry was typical of the newcomers to dust and zinc processing that the EPA attracted. In the second plant, the furnace was addec to break down and fume the zinc. Then it was found that the upgrading portion of the process had not been working anyway.

So the oxide part was abandoned, MRT went bankrupt, and the steel company operated the RHF for a while, fuming off zinc and selling the CZO (crude zinc oxide, mixture of zinc, lead and cadmium oxides) to Big River Zinc. The iron residues went back to the EAF melt shop. The residue was in poor form for feeding to an EAF, the briquettes were only partly reduced and many had broken apart. After a couple of years of torturing EAF operations, HRD, the primary US dust processor, came in and made a better deal for processing the dust.
The plant was to process 24,000 tpy of dust, plus some mill scale, but throughput averaged less than 50%, partially due to inadequate burner capacity, hearth accretions (from fused wustite and slag), and generally excessive downtime. Much of the downtime was caused by the used equipment with which the plant was built, and the resulting operational issues. Analyzes of iron residues often showed high residual zinc (~12%) and lead (~2%), with only 35% metallization. The self-reducing briquettes break apart caused by reduction of oxides, fuming of metals, and swelling from contained zinc, halides and alkalis. The latter three factors were discover to cause similar problems in iron ore oxide pellets and were to be avoided. Once the feed blend broke apart, reduction slowed down and thus the reactions could not be completed. Another issue is the dustiness of the hearth freeboard space, from the broken pellets, as well as fumed metals reoxidizing. This means that the burners cannot be as effective in getting heat down to the hearth as computer modeling implied they would.

The Allmet plant had even more problems. It was sized for 40,000 tpy of dust, with twice that much mill scale, but never processed any scale and only a small amount of dust. It incurred similar hearth problems, serious down time in feed blending, mixing and pelletizing areas (this plant used a disc pelletizer), and in backend recovery of CZO. The back end had serious corrosion problems from the wet chloride gases. The oxide product was to be refluided in a second furnace and the metals were to be condensed in a lead splash condenser. This tail end segment never started up.

There are two small pilot scale RHF’s on carbon steel dust in Japan, one at Asahi Steel and one in the Kobe plant at Kakogawa. The Asahi plant, 10,000 tpy, started up in 2007, and while information is limited (Nakayama, 2011), it seems as though commissioning to full capacity was a lengthy process and is not yet totally satisfactory. The Kakogawa plant, 20,000 tpy, was built in 2005 expressly to test carbon steel dust and was funded by Japan’s Ministry of Energy, Industry and Trade (METI) to obtain design information. Again details are limited, but conclusions are that residence time for the hearth must be longer than expected (i.e., seemingly 25 – 30 minutes rather than 10 to 15). These figures are consistent with the poor results at AmeriSteel and Allmet.

Iron Units

There have been three other RHF’s built in the US, one for integrated plant steel dusts at Rouge Steel in Dearborn, MI. Two others were to supply iron units to an EAF, one at Iron Dynamics on iron ore in Butler, IN, and one at Mesabi Nugget in Hoyt Lakes, MN, both owned and operated by Steel Dynamics. The Rouge plant shut down after about a year of fighting operating problems and fires, and never exceeded 50% of capacity. The IDI plant has run for over 12 years, has been down for extended periods for repairs and fires, and recently gave up on reducing iron (an SAF melts the DRI from the RHF, producing pig iron for the adjoining EAF plant). It now processes only mill scale, boiling off the oil and water in the RHF and then melting it in the SAF. The plant in all of its years of operation never reached 50% of capacity (Hansen, 2012).

The Mesabi Nugget plant started up in January, 2010, and has yet to reach 50% of capacity. Operating at higher temperatures, 1450 °C vs. 1325 °C, the iron reduces and melts, forming nuggets of pig iron. These are a first rate source of iron units for the EAF. These pretty little "nuggets of opportunity" (Cable, 2010) have been anything but that because unfortunately, there have not enough of them – another Red Herring. These have been a great many equipment problems, myriad issues with the “hearth management system”, and in general lots of downtime such that the longest continuous run lengths is only 7 days (Hansen, 2012; Bednarz, 2012). The hearth management system includes using a protective layer of coal on the hearth, to prevent accretions, and a second screw to level this layer prior to placement of the feed pellets. This system has recently been modified and hopes are high that production will improve. There was also an “explosion and fire” that blew off a panel and injured a worker back in December, 2011, and while the cause has not been announced, considerable rebuilding of the offgas system was also undertaken at the same time.
There are perhaps a dozen RHF's in the Far East and Italy processing generally integrated plant oxides. These take the zinc-containing wastes, as well as pellet fines and fine iron ore that a sinter plant cannot process, and prepare a partially reduced DRI that is briquetted for feeding mostly the blast furnace. There is no data on actual production rates, although some information implies two of the units are doing no better than were Rouge or IDI. In general, without actual data, design capacities of these units cannot be accepted as economic or technical proof of concept for the RHF in any sort of iron-related service.

Fatal Flaws

A review of the application of the RHF to EAF dust processing, supplemented by information on the other applications, indicates a number of fatal flaws in the concept. These include formation of accretions on the hearth, poor heat transfer from the burners down to the hearth, breakdown of feed agglomerates, excessive downtime, difficulties in maintaining a uniform layer of feed no more than one pellet deep, and design residence times of 15 minutes or less only allow minimal adjustments for problem materials.

One way to look at the RHF is to consider that one of the more important fatal flaws is gravity. Gravity compounds all the problems: it causes broken pellets to fall down to the hearth, it means accretions will form on the hearth, it means those accretions will increase, causing excessive wear and tear to the discharge screw, and it promotes the separation of reductant and oxide. Alternatively, gravity is a blast furnace's friend: it promotes countercurrent gas and solids flow which enhances heat transfer, allows reducing gases more time in contact with oxides, separates iron and slag, allows slag accretions to form on vessel sidewalls, thus protecting refractory from attack by slag and fluid flows induced by gas bubbling, and moves product out of the furnace without troublesome devices like discharge screws.

ZincOx

So now we come to the latest seeker of free zinc, ZincOx, with a twist. While others charged a tipping fee to process their free zinc, this company decided they could make money without that lift—they charge no tipping fee. So in addition to using a fatally flawed technology, the RHF on carbon steel dust, they propose to do it for only funds realized from CZO sales and iron unit credits, of which they claim the first will be of superior quality and the other ready for the EAF. All supported by laboratory and pilot plant data. Products several operating facilities have already proven the RHF cannot make, and further that while every prior plant also claimed superior performance based on similar lab data, none of those projections came true.

This company is experienced with grandiose plans that did not come true. While their participation in the Skorpion project (Namibia) netted a large profit, and interest in the Shamarin zinc mine (Kazakhstan) was sold for a high price, this largess has now been mostly lost. Following these successes have been losses from a failed zinc mining project at Jabali in Yemen and suspended efforts to process EAF dust in Turkey and the US. The latter occurred when their partner sold the dust processing contracts to HRD without ZincOx knowing about it for perhaps two months. Interestingly, HRD is also "taking" something else from ZincOx—the Technicas Reunidas new SX technology TR got running for the Skorpion project. ZincOx was planning to use this for their "Zinc-Iron Recycling of Ohio" project (ZIRO), but now HRD will be using it in their new plant in North Carolina being built to replace their Monaca, PA, zinc smelter.

ZincOx stock has fallen off over 80% from those halcyon days, and they have had to borrow almost half of the $110 million to build and startup their latest venture. There was only $12 million left at the beginning of the year to get the plant up and running so that cash flow can be generated (ZincOx, 2012).

The earlier failed Rouge RHF was purchased for a fraction of its installed cost, then it was refurbished and moved over to eastern Korea near Pohang to satisfy a contract for 200,000 tpy of dust. This first plant is called Korea Recycling Plant #1 (KRP-1), and a second plant is in the offing when this one gets rolling to handle the full contract of 400,000 tpy of dust. It will be called KRP-2. These contracts had been
won in the first place because they bid a zero tipping fee, the other bidders dropping out recognizing the folly of this in a region where landfill fees are in the range of $180.

![Figure 1 – ZincOx rotary hearth furnace typical plant layout](image)

Figure 1 – ZincOx rotary hearth furnace typical plant layout

Cold commissioning began back in November, 2011 and first feed was brought to the plant at the end of January. That dust could not be processed until late April due to problems in the feed preparation area, getting the burners on the furnace to light, and other items. It was also revealed at that time that only after the plant demonstrated that it could process dust would they be awarded an operating permit. So the net total of CZO produced is from that perhaps original 100 tons of dust, and there has been no news of additional production since then, so further difficulties must be arising. The RHF is probably using the hearth protective layer developed at Rouge, calcined dolomite. How well that performed earlier is not known, but examples from other plants elsewhere with other materials have not performed well. Just hearing about the hearth management issues at Mesabi Nugget is convincing evidence that hearth accretions, short run periods, and long outages will be a fact of life for this plant.

One of the problems seems to be the lack of experienced personnel to complete complex startup procedures, deal with poorly functioning equipment and troubleshoot plant operating difficulties. This is to be expected since only in their last annual report, issued in May, have they even acknowledged that plant startup was a potential risk. Their answer was that they felt that was balanced by the experienced staff. Further, a recent financial analysis of the project (Daniel, 2012) had absolutely no mention whatsoever of potential risk from startup and operation issues. Obviously few if any involved in this project did their homework.

Their literature and that of their advisors is filled with comments like the RHF is a “signature technology”, the plant has been “optimized” and is “ready to go”. It represents a “remarkable breakthrough”, a “blueprint for future plants”. Apparently the conclusion that the RHF applied to EAF was a technology whose time “would never come” was lost on them, though a copy of that paper had been sent to the company ten years ago (Southwick, 2000c). Production of CZO product as a “fine white powder” is just “on the horizon”. None of the other RHF’s have made such a product, and in fact the photo in the latest ZincOx annual report shows CZO just like everyone else’s, brownish yellow. They have emphasized that the RHF would have lesser emissions than the Waelz kiln, but have yet to demonstrate that. As related earlier, there is a huge volume of satisfactory compliance data on the Waelz kiln and virtually nothing on prior EAF dust RHF plants.
Thus ZincOx must relearn the mistakes others have long since pioneered, yet will still end up at the same place. Likely by the time this paper is presented, remaining funds will be exhausted and the plant will be owned by their partner, Korea Zinc. The plant should never have been built. Even with a tipping fee, the plant cannot make CZO deserving of a premium, they will be lucky they do not have to landfill the iron residues (at a cost equal basically to what it would have been had the dust not been processed), the commitment of the Korean government in providing a free enterprise zone site to the project will have been wasted, and the company’s capital will have been wiped out.

CHEAP ELECTRICITY

The Fiords of Norway provide abundant, cheap hydroelectric power. An earlier plasma process for stainless steel EAF dust was a success at Landskrona in recovering chrome and nickel ferro-alloys. So once again a successful stainless steel process snared the uninformed interested in processing carbon steel EAF dust. In this case, the red herring was the cheap electric power and the beauty of a plasma arc process.

The ScanDust process is a plasma fired blast furnace; after all it is making an iron product. As long as the top is hot enough, the zinc fumes will come out, and even if they don’t do that so well there is plenty of funds to cover costs. However, for carbon steel EAF dust, a new design was developed - basically a plasma fired bath smelter. ScanArc called it ArcFume, for that is what it did, fume zinc etc. out of a bath of molten iron and slag. Heavy metal fumes flow out the top, then are oxidized and recovered in a CZO baghouse. Unfortunately, the industry had been there and done that. Back in the 1980’s a company called PlasmaTech tried it in Houston, Texas, but it failed. Two units built by Tetronics crashed and burned in the mid 1990’s as part of the US, EPA’s flawed efforts to develop new technology, and an electric furnace developed by Elkem also failed in the same mad rush to cash in on captive customers. There was also a large pilot plant for a plasma process developed by Mintek and Pyropower in South Africa, known under the name of Enviroplas. It was never commercialized.

All five of these units tried to recover zinc in lead splash condensers, as had ScanDust, and so all six provided definitive proof of how bad that idea was. The Elkem unit had a number of serious refractory breakouts and fires; the plant failed to perform and was taken over by the steel company (Laclede of Alton, IL). They established the operating costs to be 6 or 7 times that which HRD was charging, so after the last fire it was shut down and dust processed by HRD. The two Tetronics plants (Florida Steel, Jackson TN, and Nucor, Blytheville, AR, both operated by International Mill Services) were difficult to run, they had the condenser, cost and on-stream problems as well, and so they too shut down in the mid-1990’s. Information on all these units can be found in the EAF dust workshop held at Lead/Zinc 2010 in Vancouver (Southwick, 2010b).

ScanArc

So in 2005 it was time, since electricity was really cheap, to try again, in Norway, scene of the lone plasma successes. ScanArc, inheritor of the ScanDust technology, though that plant was sold to Befesa, the major dust processor in Europe, built an ArcFume bath smelter in Hoyanger fired by two plasma generators. It is one thing though to use a blast furnace to melt iron, in which case as noted earlier one can readily form slag layers on the walls of a blast furnace, through which maintaining long refractory service becomes manageable. Not so in a splashing, bubbling bath smelter. (References include Heegaard 2008, 2010; Scan Arc 2008, 2010, 2011).

The unit finally got started up at the end of 2006, operating under the name Eras, and for the next 4 1/2 years lost money every fiscal quarter. The big issue was that they could not attract enough dust clients out of Europe to ship their dust up to Norway for processing. There were equipment issues such as a slag breakout of the furnace and resulting fire. The plant was cited for excessive mercury and hydrofluoric and hydrochloric acid emissions and forced to shut down for several months until modifications could bring emissions back under permitted levels. The sales brochures on new technologies always cite superior environmental performance.
Figure 2 – ScanArc submerged plasma system thermal unit flow sheet

It was thought that the slag residues would be more environmentally friendly than Waelz residues, but in fact it had to be stockpiled on site since start-up since no market had been developed for this material, called “Eras iron silicate”. It is vitrified by the plasma and met all EU standards as filling material and in asphalt. Still there is no market. Entering the asphalt aggregate market with alternative materials is not a given. Just because some government lab judges the material satisfactory, they will not take responsibility for problems, and if the permit writers are in a different group, permission could well be difficult to obtain.

The plant, sized for 40,000 tpy of dust, averaged less than 50% utilization. Part of the problem was a severe downturn in European steel production, and further it never seemed to have been able to penetrate a market dominated by Befesa, the Waelz kiln juggernaut of Europe. So Eras received a lot of poor quality dust with low zinc content, which led to high expenses and low revenues. Being a plasma process, it was also necessary to have low cost electricity. Plans to build another furnace at Hoyanger and three more at a location in Calais, France (called Eras France), were dropped. Eras France has since been phased out of existence.

An attempt to develop an improved process, called PolyArc, resulted in the delivery of one plant. This had difficulties meeting performance specifications, and the customer later declared bankruptcy. Further attempts to develop that technology improvement were halted.

The Eras plant was finally sold at the end of September 2011 to ProVal of Switzerland. They also assumed ownership and liability for the stockpiled slag residue. It is believed that this plant has been shut down. ScanArc became strictly an investment firm. While adequate details were not available, based on similar examples it is likely that the plant could never have met production and time on-stream goals, and costs would have been excessive. Land-filling costs in Europe roughly equals dust processing costs, so without a market for the silicate residues, the technology is a non-starter. Waelz iron product, WIP, too has a limited market, but there are enough local applications to find a buyer, their confidence backed up with the long history of such uses.

PRESSURE LEACH SHORTCUTS

Phelps Dodge built a copper concentrate pressure leach system in Morenci, Arizona, in 2007. It started up in October 2007 and ran until July 2008 when operation was terminated by a fire and violent release of pressure on one of the autoclaves. A four paper series of articles had been prepared on the process and its development, with publication scheduled for the November 2007 issue of Minerals and Metallurgical Processing. I was sent a copy of the fourth paper in the series, on the process design for editorial review (Marsden 2007a).
I found a number of issues that made me question the safety of the design and the ability to reach some of the design goals. The safety issue identified in the review was the cause of the fire and pressure release, and a number of other factors also had validity for the operations. This review was completed on August 23, 2007, and a copy was given to the authors at the Copper 2007 meeting later that month. These comments represent what a typical objective due diligence review should include. No changes were made to the paper or to the design.

The comments are presented below pretty much as they originally appeared, with clarification added only when necessary. There is an introduction regarding the impetus of the project, and a few comments from the project review prepared by Freeport McMoRan (owners of the facility at the end) for the SME annual meeting in Denver on Feb 2009 (Cole and Wilmut, 2009). Had my comments resulted in another pass at a HazOps review, the required changes would have altered plant economics adversely. In any case, the various problems at the plant caused operations to be cancelled and the service of the reactors changed.

![Diagram](image)

Figure 3 – Morenci concentrate leach process flow sheet

**General Comments**

The flow sheet was conceived as a medium temperature pressure leaching and direct electrowinning process for leaching of copper concentrates. Medium temperature limited acid production and direct electrowinning eliminated the SX circuit. In other words, in many ways this was a step back to the leach-DEW technology of 40 years earlier, before SX systems reached wide acceptance, and would have purified electrowinning feed with the earlier solid precipitation procedures. The former precursor roasting systems was of course replaced by the oxidative pressure leaching autoclaves.

The processing concept as conceived here might be considered to have four parts: (1) pressure leaching, (2) pressure letdown and cooling, (3) solids-liquid separation, and (4) direct electrowinning.
What follows will address each of these sections in turn, with page references as appropriate (corrected to the paper as it appeared in M&MP). Some of these questions or comments may have been addressed in the first three parts of this series of papers, but they were not available for comparison at the time. Specific corrections or issues that were felt important enough to address are highlighted in *italics* below.

Helpful in this review were the following references (Cole et al., 1995; Simmons 1995; Anderson et al., 1973; Ammann et al., 1976).

**Pressure Leaching**

In step (1), the unique features appear primarily to be (a) use of medium temperatures, 160°C, *vs* say the more normal 225°C, (b) 200 psia oxygen "overpressure", which I assume is the same as oxygen partial pressure, *vs*. what appears to be ~100 psia oxygen partial pressure (based on earlier studies and publications of this group), (c) new reactor cooling parameters, (d) new developments with refractory design, and (e) other new design considerations.

**Temperature**

The rational etc. of the lower temperature is well presented and understood. However, what constraints and requirements on temperature variation does that place on the control system?

A discussion of closeness of temperature control required, comparing it to higher temperature operation as well as in other PL systems would be useful here. To compare previously installed systems to the new one is to better understand how much, if any, this new system will differ from earlier ones.

**Oxygen**

It is not clear why the higher pressure (200 psia vs. 106 psia) is being utilized (Abstract, page 1 and page 6) compared to that for the higher temperature (225 °C), or that in fact that it is intended to be higher than "normal". Higher pressure would give higher sulfur oxidation rates, but it is also being emphasized that the process purposely is oxidizing less sulfur, to make it autogenous in acid generation and utilization. Total pressure is still less, since steam pressure is 90 psia at 160 °C vs 358 psia at 225 °C. But now the gas is 2/3rd oxygen (200/290) vs. 2/9th (106/454) – these ratios are the oxygen pressure divided by steam + oxygen pressure.

The rationale, justification and impact on yields, control, other operations and safety of the apparent pressure difference needs to be explained. Further, if this pressure difference is indeed intended, and the unit is operated at somewhat higher pressure to prevent undesired flashing of steam in the reactor, what then is the content of the gas in the vapor space of the pressure vessel? Steam partial pressure cannot be above its vapor pressure, 90 psia, and if the reactor is operated at say with a 10% safety factor, then 1.1x(90 + 200) = 309 psia. Is the difference, 309-90, not now all oxygen? Or over 70% oxygen. I suppose nitrogen could be used to make up the difference, but if so some discussion here would still be useful. How are copper and gold/zinc pressure leaching concepts different in this respect?

Further, what is the dissolved oxygen in the leach liquor? When this liquor is flashed in the pressure leachdown vessel, what sort of additional vapor velocities and fire hazards does that represent? (See also the flash system comments below)

As stated in one of the references regarding earlier work (Brewer, 2004), oxygen control is important (a) in the progress of oxidation stage to stage, (b) the generation of heat from more or less rapid chalcopryrite oxidation rates, and (c) formation of ferric sulfate precipitates. There are indeed a variety of control means available, but a discussion of how well such means have worked in other PLV installations and the size and nature of process control variations they have addressed and how they compare to what might be expected here would be useful.
Cooling

It appears that direct injection of cooling water into the PLV is contemplated.

Is that indeed the case? Further, what quantities of flows are contemplated and how do they compare to overall leach liquor flow? How will this cooling water impact control of leach liquor residence time, dissolved oxygen, progress of oxidation and flash tank operation?

Refractory

The autoclave refractory design (page 235) is somewhat different from the Strebins design described in Brewer (2004), although the Pyroflex material was mentioned earlier as an alternative. Strebins used refractory brick, with some heat insulation factor, whereas the new design appears to be strictly acid resistant to protect the steel shell.

Why the change? Was reactor cooling control a factor, cooling water injection vs. vessel heat losses? What about vessel expansion and refractory spalling from the Bagdad experience? A discussion of the design change would be helpful here. Why so soon in the implementation of a new technology (copper pressure leaching) is a change being made - the reasons may be fully justifiable, but spelling out the learning curve is most helpful.

Other

One of the shortcomings with copper leaching processes is that they cannot readily recover precious metals. Often too the cost of producing a concentrate is justified by having precious metals in the ore which can then be recovered by smelting. One expects that the solvent extraction step was eliminated partly because there was insufficient precious metal or other value in the ore to pay for its recovery in addition to the cost of concentrating the ore. (See also the discussion below on DEW)

A note regarding precious metals in the ores chosen needs to be made, as well as some further discussion perhaps of what criteria should be used in determining for what kinds of ores this process might be viable and where it might not.

The discussion on pages 230 – 232 is helpful, but it also fuels the concerns expressed below regarding operation of the DEW circuit. The performance information on the test program with the various ores (pages 227 – 228) is also helpful.

However, it would be useful to show the variations in liquor concentrations from the leaching of each ore type. It was noted that impurities were tracked and that potential "bad actors" noted. Some discussion of what those were, how variable they were within a run on a particular ore, as well as how they differ from ore to ore, and how they might impact operational issues as ore type varies during an operational day. For example, will stockpiling and blending, or campaigning, of different ore types be necessary?

In an earlier study the reviewer did on copper ores in this region (Southwick, 1997), some are characterized by a gangue that is leachable (pyrite) and some by one that is inert. While the concentration method here (flotation) obviously separates out the pyrite-based fraction, if the copper is disseminated within an inert gangue, only fine grinding will liberate it. It appears that the latter may be the reason for the very fine grinding planned for Morenci. Or in other words, for all of the pyrite/chalcopyrite fraction to be available for pressure leaching, extremely fine grinding is required.

There is also the kinetics involved in the leaching itself - diffusion within a leaching particle vs. in the solution vs. reaction rate control. Fine grinding boosts the first and can assist the second, as well as providing more surface area for leaching.
A discussion of the reasons for this choice of very fine grinding and comparative and relative benefits would be helpful. The grinding is a large cost item and must have had a high "justification factor" - what was it? What part did the desire to limit oxidation play in the need for fine grinding?

**Pressure Letdown**

The pressure letdown system is really not discussed in this paper. It is though in one of the references (Brewer, 2004). Reference there is made to a double choke system that "has been used elsewhere in the pressure vessel industry".

Question is where - gold and zinc, or nickel (laterite) and aluminum?

These are two very different sorts of systems - one set is flashing from an oxygen-rich environment, the other set from a nominally "steam only" environment. And even within the second set, a recent attempt to use flash vessel technology from one (aluminum) in the other (nickel) resulted in some rather gross mis-designs and failures. Those "borrowed" designs had to be totally rebuilt.

So adapting technology from another industry for flash vessel design without noting both process differences as well as mechanical design features is an exercise fraught with difficulty and a high potential for mischance.

Thus, it would be useful here to revisit the flash vessel design aspects. Especially relating to the oxygen partial pressure in the above section, its impact on dissolved oxygen in the flashing liquor and the resulting oxygen content of the flashed gas. From a safety viewpoints, as well as gas velocity and the expected velocities within and around the flash vessels themselves. Including a diagram at least of the reference system would also be helpful, with comparison to what is used in the gold and zinc industries if they are different.

**Solids/Liquid Separation**

Similarly, the solids liquid separation step does not receive much attention here, reference to Brewer (2004) being again helpful for determining some of the testing and design details. However, S/L separation is a very important system since separating iron precipitates and fine solids, as opposed to perhaps larger gangue solids, is a critical part of the success of the DEW step, as outlined below.

Especially so since it was such suspended iron fines and dissolved solids that cause great difficulties in earlier DEW systems and is a major factor that led to the virtually total acceptance of SX/EW combinations.

Therefore, what would help here is to discuss how this new process's solid-liquid separation system will be an improvement over those of 40 years ago during the heyday of Roast/Leach/Electrowin and similar combinations. What were the specific problems from earlier relating to fine particles and how are they addressed here? If there is no improvement, then concerns that unresolvable problems will arise in the DEW must be considered. And especially noting the differences old to new in solids removal from DEW feed given that super fine grinding is being contemplated (page 230/235). It sounds like a critical unit operation (DEW solutions prep) is being asked to do even more than before - that would be a major concern.

**Direct Electrowinning**

This step is the most unique part of the process, the greatest departure from normal practice. Of course, 40 years ago, before the advent of solvent extraction upstream of electrowinning, it was the normal route for a roast/leach/electrowin circuit. It was also the problems that were encountered in direct electrowinning that led to the virtually total acceptance of solvent extraction as a solution purification step and replacement for DEW.
Solvent extraction improved deposit quality, increased current efficiency, and allowed higher current densities by eliminating or minimizing problems with impurities, dissolved salts, suspended particles, agitation, temperature and acid corrosion. One of the worst actors was dissolved iron, which will be a factor here.


In any case, that review covered a good deal of information regarding the impact of the various variables mentioned above, striving to show where optimums lay and the interactions between variables. Even if optimum regions of productivity and operability have not shifted from that review, it is not at all clear how well they can be achieved here and how steady and regular will be the characteristics of the solution produced by the new process.

This paper needs a discussion, and perhaps data plots, to show how variable the operations were regarding solution parameters of iron concentration, acid strength, calcium and aluminum, other impurities, temperature and so on. The description of how a bleed steam will be used to control some of these needs more detail. General statements of producing certain quality copper cathode needs more specifics, and also details regarding how much off-spec product was made and why. What about starter sheet production - was this tried? The 9 to 12 hour pilot test runs (page 228) seem somewhat brief - what sorts of longer runs were made?

In general, the DEW step seemed to have received the least amount of attention in the paper. Reinstating a process step that was discarded by the industry 30 years ago would benefit from more objective and full discussion. Can the impact of the variables eliminated by adding SX be more adequately addressed this time around, and if so what comparisons can be made and specifics presented to confirm improved DEW operation approaching SX/LW combinations?

The "comprehensive testing" from 2003 mentioned on page 229, as published, does not contain the details outlined above, although it did apparently address some of them. Much of the discussion in this paper focused on the lean electrolyte bleed, which while of interest would not appear to have the economic impact the above problems will.

**Fatal Flaws**

The process sequence appears to have two potential fatal flaws, and a possible third one. The most serious is DEW, and second in the flash system design, and the third would be solids/liquid separation (primarily in getting the suspended iron and fine particles generated from grinding out of the DEW feed). The discussions presented here do not seem to contain sufficient detail to address those concerns.

Finally, cost. Obviously an SX system up front of the DEW would address many of the above issues. But how to pay for it? Costs have already been somewhat increased by preparation of a concentrate, perhaps by some loss of precious metals (or at least any cost associated with the inability to feed PM containing concentrates to this unit), and by inclusion of very fine grinding. However, for the earlier DEW systems the added cost of the SX system was justifiable from operational reasons. One might logically conclude that a similar comparison should be relevant here. Apparently the information generated during the process development program showed that an SX system was not justified. Or else that to add a further cost threw the whole concept into an uneconomical framework.

A discussion of those comparisons would be useful - i.e., if SX were to be found necessary, then the whole concept goes out the door. Medium temperature pressure leach of a copper concentrate with DEW will only be economical on these feeds if projected yields can be achieved by a performance of the systems that is better than it was in earlier times.
Given that a "fatal flaw analysis" was performed (page 236), the above concerns may be overstated. However, the details of that analysis were not provided. In any case, since the Morenci unit is planned for startup shortly, the significance of all the above will soon be quantifiable.

**Freeport McMoRan First Year Review**

Prior to the fire in July, the plant had quite a number of problems relating to poor copper extraction due to the inadequate grinding obtained from the ISA Mill. This came about due to the need to do process development testing on a surrogate concentrate which turned out to be softer than the design Morenci material. Thus the normal concentrate was too coarse and Cu recoveries suffered. This impacted pressure leaching performance and in the end also an SX system was employed in front of the electrowinning circuit.

Thus the revisiting of DEW apparently was not done, though the discussion is not clear as to the factors, for example, that brought about implementation of SX, especially not in light of earlier era problems. In other words, was DEW a good idea after all for the Morenci plant?

As to the oxygen and steam partial pressures, why was the higher oxygen pressure adapted in the first place, especially since it seemed most of the earlier work was emphasizing the lower pressure? It was noted in the after-project review that in the future high oxygen pressures relative to steam pressure would be avoided. In effect, the higher steam helps "quench" any tendency for fires.

Another question not answered was did the lower temperature really help control the oxidation extent adequately to result in the desired diminution of acid generation?

**CONCLUSIONS**

A few thoughts on the "Adoption of a New Process", published in 1905, would be worth remembering here (Anon, 1905).

"When new metallurgical processes are to be introduced on a commercial scale, it is important that all the details be worked out prior to making an expensive installation. But this, unfortunately, is not always done. In such event the company's plant becomes a school for experiment, not only for the perfection of the chemistry of the process, but also for evolution of a satisfactory and economical means to apply it. Sometimes it occurs that after a plant has been installed its defects are realized, and it is seen that had a different course been pursued, success might have resulted, but the funds are exhausted and the process is condemned, when a more fortunate application of the ideas might have brought success. It sometimes pays better to defer the construction of a plant. Such experience stands as an example of the need for care in installing innovations which have not been worked out to a successful conclusion."

In the instances discussed above, Red Herrings have indeed led the process developer astray, either through lack of sufficient knowledge and preparation, through an excess of attention on only one aspect of the technology, or because no truly objective review was made. Even though substantial resources can be committed to a project, that does not mean one should do so in absence of technical, business, and economic due diligence. Capital should be spent in reasonable and promising expectation of it generating additional capital. The above examples demonstrate that hindsight is not necessary to determine when a new technology is a bad idea.

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