New Approach Towards Sustainability – The Global Efficiency Concept (GEff)

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Abstract: In the actual economical environment, business sustainability requires high-efficiency technological processes and new innovative developments. That is why the efficiency concept has to be present at all levels of industrial and financial activities. The proposed concepts in this paper could be further developed as a model for improving companies' corporate energy policies.

Nowadays, some purchase decisions for equipment are still driven predominately by the purchase price, and the full consequences of energy efficiency and the impact on the environment are not always considered.

In general relatively "low value equipment" purchase policy is still driven by purchase price only, in spite of the evidence that such price represents a maximum of 5 % to 7 % of the total expenses related to the total costs of ownership. In the minerals industry "low value equipment", like low-voltage motors (up to 1100 volts, 50/60 Hz), are found many times and in very large numbers, their efficiency and reliability influencing dramatically specific costs of technological processes.

Although with "major equipment" energy savings are considered more in the purchase decision, every growing importance on the environment of "Green House Gas" (GHG) emissions is still not a major factor when selecting equipment. Often more traditional equipment is purchased at the expense of new innovative technologies that in addition to providing energy savings can also be used as a tool for trading Carbon Credits in the financial marketplace. An example of such a technology is the IsaMill™ comminution machine, which is becoming more widely used in gold and general mining operations in South Africa and throughout the world. Comminution in the mining industry is one of the most energy intensive activities in the world, and the innovative use of "major equipment" saving power can also have a positive effect on the environment.

The paper presents descriptions of the essentials of the Global Efficiency (GEff) concept that has been promoted over the last years in South Africa. Price-efficiency criteria (as a corollary of GEff) are investigated for applications incorporating equipments that are driven by low and high voltage motors.

The paper presents theoretical and technical aspects analysing the economic and environmental impact, by reducing total cost of ownership with energy savings, for one "low value equipment" in typical applications largely used in mineral processing in the gold mining industry, and one "major equipment" purchase at a current operating gold mine where the innovative IsaMill™ comminution technology was installed as an alternative to traditional older technologies.

Besides the impact of energy savings with high-efficiency technological processes and new innovative developments, this paper suggests the general impacts of:

- Technical and economical performance improvements and competitiveness of mining corporations to international standards;
- Defusing incipient energy crisis in the gold mining sector;
- Improving environmental conditions;
- Creating new job opportunities in the gold mining sector.

Keywords: Process Efficiency, Energy Efficiency Policy, Electric Machinery, Mining, IsaMill™, Comminution.

1. INTRODUCTION

This millennium is marked by new trends in EFFICIENCY and SUSTAINABILITY. In the current business environment, sustainability requires high-efficiency technological processes. That is why the efficiency concept has to be present at all levels of industrial activities, not only when energy is being considered.

However, as common practice, this concept is still regarded equivalent to "energy efficiency" concept as mentioned in the Intergovernmental Panel on Climate Change [1], and specifically re-defined by the Federal Energy Management Plan [2].

The new monetary policies compounded with energy and materials crisis in the world has had a huge impact on industrial processes.

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New efficiency concepts are now breaking the old rules that dictate, "As long the initial price (investment) is cheap, it is good enough".

Generally, market industry is divided into two distinct tiers:

- Discerning product market and
- Non-discerning product market.

The "non-discerning market" is price driven and the initial cost is usually the chief driver of the purchasing decision. This market is not specification driven and its focus is not, at least, on Total Costs of Ownership (TCO).

The "discerning market" has made great strides recently in raising the bar in terms of product specifications. The modern technical terms are frequently mentioned in purchasing specifications. This market secures business sustainability and international competitiveness.

The Mining industry is very conservative, and new concepts and technologies are often slowly accepted (Jankovic, 2003), hence the "discerning market" is slowly increasing in size. [15]

2. TWO NEW APPROACHES TOWARDS SUSTAINABILITY – THE GLOBAL EFFICIENCY CONCEPT (GEFF) AND THE CARBON CREDIT SCHEME.

2.1. The Global Efficiency Concept (GEff)

Countless inspectors, engineers, accountants and clerks are monitoring industrial processes at different levels. Billions of Dollars are annually spent on investments, maintenance, monitoring, and repair activities in addition to electricity costs related to industrial processes and applications. Total costs of ownership (TCO) (which include production costs) are even more important and require a new global concept of efficiency to be considered at all horizontal and vertical levels (technical, economical, financial, etc).

The global approach towards the efficiency concept (GEff) [3] incorporates the following activities:

1. Study of the process (application engineering);
2. Energy efficiency policy promoting energy efficient equipment (currently standardised in some countries) and including R&D, products, software, etc.
3. Mathematical modeling by using multidisciplinary techniques (including statistic-probabilistic methods in estimating reliability);
4. Estimations of the total costs of ownership (TCO);
5. Planning, prediction and process efficiency control;
6. Co-operation of Unions and employees with management.

As a common characteristic of the mining industry it was found that in most of industrial applications improved efficiency has been firstly obtained by increasing the process speed. However, the rule of maximizing process productivity **"Π"** by increasing the process speed **"v"** must be applied in conjunction with adequate technical support. That means inside the process rated domain:

- The process productivity **"Π"** can be approximated as proportional to the process speed **"v"**;
- The global efficiency of the application (process) is function of the various costs and adopted policies.
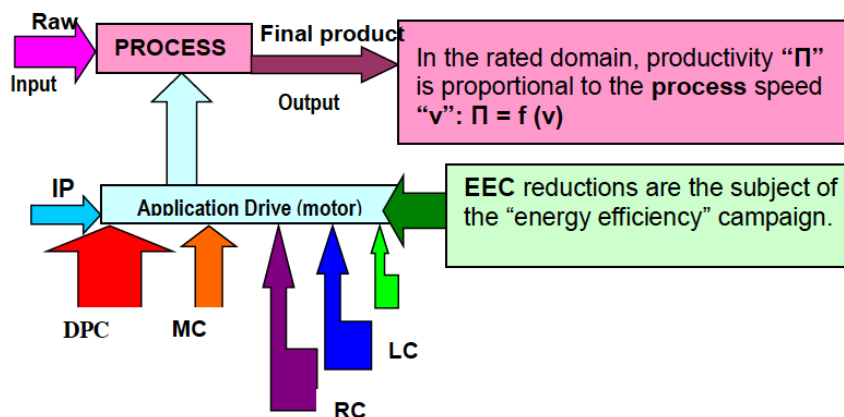

Figure 1: TCO structure of an application used for a particular mining process.

As shown in Figure **1** the following costs are part of Total Cost of Ownership **(TCO)** structure considered as main component of the global efficiency concept **(GEff).**

- Initial price (investment) **(IP);**

- Electric energy costs **(EEC);**

- Maintenance and monitoring costs **(MC);**

- Repair and replacement costs **(RC);**

- Logistic costs (**LC**);

- Direct and Indirect costs **(DIC);**

- Downtime production costs **(DPC).**

Process rated speed domain can be slightly extended (increasing productivity) without new investment or re-capitalization process being necessary. However, a consistent increase of productivity is always conditioned by a sound study of the process (application) involving the energy converters.

2.2. The Carbon Credit Scheme

Under the Kyoto Protocol Clean Development Mechanism, governments or companies in developed countries can generate carbon credits by investing in greenhouse gas (GHG) abatement projects in a developing nation. These credits, called Certificates of Emission Reduction or CERs, can be used to offset the company's own GHG obligations or can be sold on the international market. In 2007, the global Clean Development Mechanism - CDM market was worth over $US15 billion.

With its energy efficiency benefits, the IsaMill[TM] Project has the potential to be accredited under the CDM mechanism of the Kyoto Protocol. To achieve CDM accreditation, the IsaMill™ Project must deliver real, measurable, and long-term reductions in GHG emissions. Furthermore, the project must be shown to be 'additional' to business as usual.

3. THE ROLE OF APPLICATION ENGINEERING TOWARDS GEFF – FIVE ESSENTIALS OF APPLICATION ENGINEERING (EXAMPLE)

Engineering is nothing more than planning based on knowledge instead of guesswork. In this sense everyone in design, service, maintenance, and technical sales work is his (or her) own engineer every day. Using application engineering principles must do study of the industrial processes involving energy converters.

Consider a motor as an energy converter driving a load. The load represents all the numerical values of the electrical and mechanical quantities that signify the demand to be made at a given instant on a motor by an application. Proper application of electrical motors does take some fundamental knowledge requiring a strong technical background.

When selecting an energy converter (electric motor) for specific application **five essentials** of what is called **application engineering** [4] must be taken in consideration as shown in Figure **2**.

- Matching the load (application) or downstream required conditions;

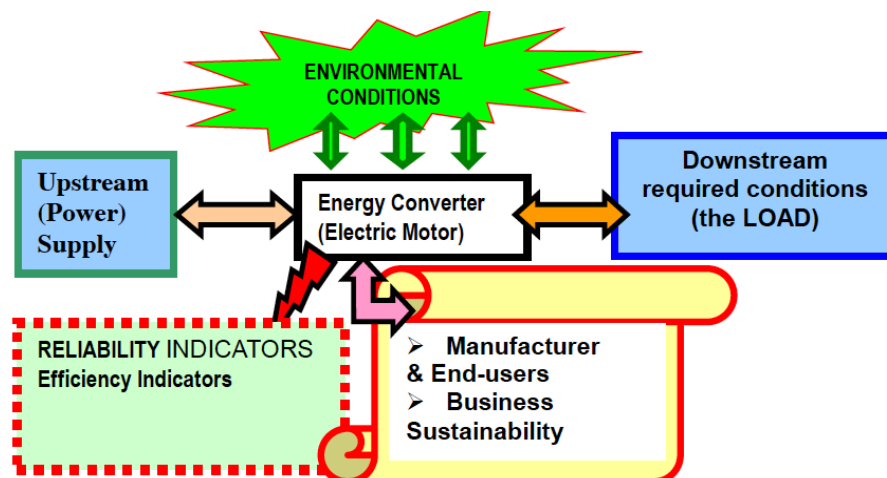- Matching the (power) supply or upstream conditions;

Figure 2: Applying FIVE essentials of application engineering when designing (choose) an energy converter (electric motor for a drive).

- Matching the environmental conditions;

- Matching the reliability conditions;

- Matching the business sustainability conditions.

- Matching the energy converter to the downstream required conditions (*i.e.* the motor to the load**)** is the most important – and the most complex - of the five areas to be considered.

- Matching the supply or upstream conditions (power supply) is related to fact the converter must comply with incoming energy conditions (the motor protection from power supply system but also to the motor's influence on the incoming power and electrical distribution).

- Matching the energy converter (motor) to its environment means the equipment must not be destroyed by its surroundings. Conversely, it must not in turn inflict damages.

- Matching the reliability indicators enable the end-user in planning the maintenance, repair activities, minimizing **DPC** (see also Figure **1**).

- Matching conditions of business sustainability ensure stability of the "discerning product market" as defined before, but also a price-efficiency decision.

These essentials are applicable for any equipment considered as energy converter.

By contradicting any of the five essentials of application engineering the business could become less competitive being exposed to financial losses [3].

4. THE ROLE OF ENERGY EFFICIENT POLICIES TOWARDS GEFF [5]

Various papers in international conferences stressed that energy efficiency improvement in industrial sectors play a key role in assuring a sustainable energy future and socio-economic development.

In order to change unsustainable patterns of energy use, developed countries enforced specific energy efficiency standards for various energy converters equipments. A typical example is the Energy Policy Act - EPAct introduced in Canada and USA in 2005 [18]

4.1. Influence of Limitation Laws of Efficiency on Power Converters

There are natural limitations related to efficiency of specific equipments. For energy converters, these limitations represent classic applications of the thermodynamics laws with their laws of efficiency limitations. Thermodynamic laws place limits on how much useful energy or work can be obtained from a given source [6].

That means the efficiency with which the input energy is converted in useful energy in a converter varies widely, but up to a maximum value (η_{max}) imposed by laws of limitations. However, maximum efficiency value cannot be technically achieved.

Asymptotic evolution of efficiency of this specific equipment type towards a "plateau" limit value (η_{max}) during continuous development activity is limited by natural limit of physical efficiency, and is imposed by:

1. Thermodynamic laws of efficiency limitations (these laws place limits on how much useful energy or work can be obtained from a given source).

2. Technical (including interface conditions) and economical constraints experienced by manufacturer and imposed by end-user.

3. Natural tendency of the technology towards equipments with higher efficiency values (evolution of the baseline known as natural conservation)

4. Limited number of such individual equipments to be replaced.

There are two natural limits imposed by physical laws, technical conditions and also by economical restrictions (price) imposed by the markets that are always present during entire lifetime of energy converter:

➢ η_{max} = Natural limit of physical efficiency (maximum efficiency) imposed by physical laws of limitations, interface conditions and other technical conditions, as defined above.

➢ p_{min} = Natural line of minimum price that represent a limitation imposed by business sustainability (regarded sometimes as a barrier by regulatory bodies)

In energy efficiency regulated market the efficiency barrier is also removed by acting towards price of equipments. The government or utilities are committed to pay incentives (price incremental) in order to stimulate introduction of energy efficient equipments with performances above regulated values.

A typical example of reducing energy losses by encouraging the end-users to choose energy converters with higher energy efficient performances is a program named Motor Management Plan that has been introduced by BC Hydro, Canada. British Columbia utility is paying incentives equal with incremental price between highly efficient motors (enacted by EPAct) and Premium™ motors as part of conservation policy promoted by Provincial Government and Natural Resources of Canada [7].

On Northern American continent there are popular tools like: MotorMaster+, Pumping System Assessment Tool (PSAT), Fan System Assessment Tool (FSAT) promoted by DoE and NRCAN helping end-users to assess the energy savings and avoided costs.

4.2. Energy Efficiency Programs (EEP) influence on Cost – Efficiency Decisions

Designed for market transformation, the EEP types could be characterized by their goals.

Type 1: Introduction of energy converters with higher energy efficient features;

Type 2: Accelerate the adoption of new energy-efficient practices and technologies;

Type 3: Assessment of compliance to specification of the existent equipment;

Type 4: Influence market structural changes by behavioural, operational and maintenance practices.

When a specific energy converter type, (for example induction motors) is targeted by an EEP the efficiency and price of such equipment will have the following evolution:

➢ Phase 1: Efficiency is increasing to comply with EEP as a result of an intense R&D activity, but without major price increase

➢ Phase 2: Improved efficiency beyond regulated efficiency values, with further price increase

➢ Phase 3: Further efficiency improvement (with substantial price increase) with a tendency towards "saturation".

The EEP is implemented by using incentives paid by the government to the end-users, repairers and sometimes to the manufacturers.

However, "parallel" markets with equipments performing bellow regulated values are still present. Second-hand repaired products are also present on the market.

As shown in Figure **3**, a parabolic (natural) evolution of a specific energy converter price function of its efficiency, **p = f (η),** creates transitional situations even in a regulated market. Description of characteristic regions (segments of population) separated by different prices and efficiencies of induction motors are indicated in Table **1**. To mention that such classification can be applied to any other energy converters.

In Figure **3**, there are 4 (four) distinctive horizontal lines corresponding to various prices of the following types of equipments:

A. **"N-Reg"** denominates sub-standard efficiency equipments originated from:

1. Products purchased based on initial price by non-discerning market

2. Degraded products as a result of multiple repairs

3. Products that downgraded their performances as a result of sub-standard repairs

4. Second hand (from shelves) products discarded by end-users but re-introduced in circuit by repairers at cheaper price.

B. **"Std"** denominates the same equipments as above plus standard efficiency equipments still being used in non-regulated markets; their performances is sometimes used as baselines to calculate energy savings could be obtained by introducing equipments having superior values of efficiency.

C. **"Reg"** denominates products that have to comply with a minimum efficiency requirements imposed by Acts (like EPAct) in a regulated market; their performances are used as baselines to calculate energy savings that could be obtained by introducing equipments having superior values of efficiency.

D. **"Inc"** denominates equipments with superior performances, above the those stated by the Act; to promote introduction of such products, the utilities pay incentives equal to incremental costs [$p_3 - p_2$] (replacement of EPAct motors with Premium™ motors).
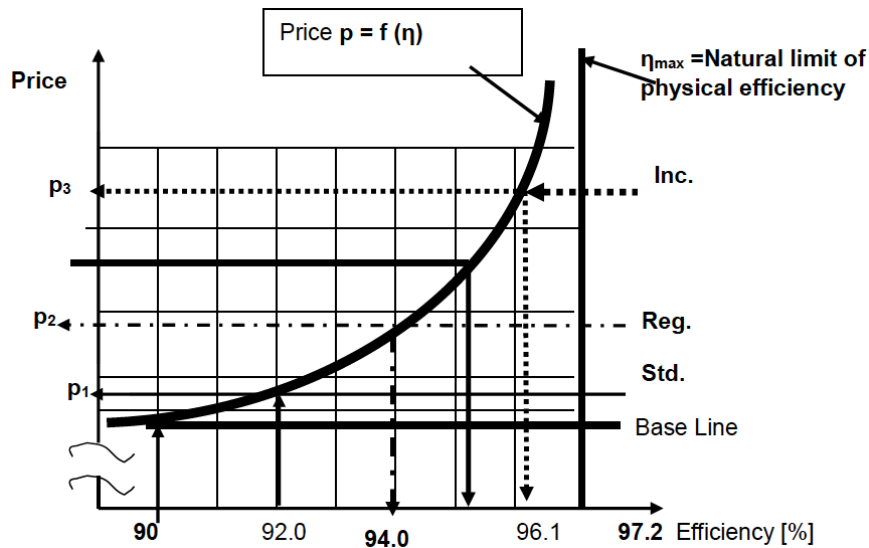
Figure 3: Typical price – efficiency relationship for electric energy efficiency motors in a regulated market.

Table 1:   Characteristic Segments of Energy Efficiency Motors Population in a Regulated Market

Region/prices	Product Population Definition	Class
Bellow Std.	Non-discerning market products, reused 2nd hand repaired equipments at cheaper price	Substandard
Std. to Reg	Non-regulated markets, repaired equipments	Std. baseline
Reg to Inc.	Regulated markets promoting equipments with performances better than regulated products	Regulated efficiencies as baselines
Above Inc.	Regulated markets paying incentives higher than [$p_3 - p_2$] to promote best efficiency	Premium™

The horizontal lines in the diagram indicating various price levels have the following significance: N-Reg = Non-regulated, Std = Standard, Reg = Regulated, Inc = Incentives

5. PRICE-EFFICIENCY DECISIONS ON "LOW VALUE EQUIPMENT" (CASE STUDY)

Auxiliary ventilation is vital in mining industry, where dilution of dust and gases and removal of heat are some of the primary reasons. Auxiliary ventilation is performed by hundreds of single stage axial fans powered by low voltage PAD motors, running 24 hours/day [8]. In spite of the fact they are considered "low value equipments" their total installed power could reach the order of MW. Two price-efficiency retrofit (failed) decisions have been taken before implementing GEff for the entire fan system:

- Phase 1: Retrofit with energy efficient electric motor (EEEM),

- Phase 2: Retrofit with high efficiency impeller (HEI)

- Phase 3: Applying GEff by using an energy efficient fan (ENEF)

5.1. Short Description of Application and Theoretical Background

Function of performance requirements, the auxiliary fan systems are installed in long or short ducts and are composed by various parts, all of them influencing the overall efficiency and price [9]:

i.   Casing (where all the components are installed).

ii.   Electric motor driving the impeller.

iii.   Impeller as such causing the incoming air to swirl.

iv.   Guide vans changing air direction to axial.

v.   Diffuser recovering some losses, and attenuation.

Electric motor is transforming electric energy in mechanical energy at the shaft facilitating the impeller rotation. The rotating impeller carries blades of some kind that exert force on the air, thereby maintaining the flow and raising the static pressure.

The electric motor shaft power P_{shaft} is the quantity of mechanical power delivered by electric motor and required by impeller:

$$P_{shaft} = \eta_{motor} \times \sqrt{3} \times U_{line} \times I_{line} \times \text{Power factor} \qquad (1)$$

Where: η_{motor} is motor efficiency

U_{line} and I_{line} are line voltage and line current

The impeller power measures the work intensity done to drive the impeller round against the aerodynamic forces and is the useful work intensity required from the axial fan for practical purpose. The impeller power, as fan output (air) power P_{fan} is the product between airflow $Q[m^3/sec]$ and static pressure P [Pa] (depending by air density "ρ ").

$$P_{fan} = k \times Q \times P \qquad (2)$$

Where: k is compressibility factor, in this case approximated as unit

Impeller efficiency η_{imp} is:

$$\eta_{imp} = P_{fan} / P_{shaft} \qquad (3)$$

Currently standard impeller efficiencies [10] are in a range of:

$$\eta_{imp} = 50\% \text{ to } 62\% \qquad (4)$$

It result that fan overall efficiency η_{fan} is:

$$\eta_{fan} = P_{fan} / \quad [\sqrt{3} \times U_{line} \times I_{line} \times \text{Power factor}] \qquad (5)$$

Standard electric motor efficiencies [11], [13] are in a range of

$$\eta_{motor} = 87\% \text{ to } 93\% \qquad (6)$$

For single stage 45 kW axial fans, the fan overall efficiency can be estimated as:

$$\eta_{fan} = \eta_{motor} \times \eta_{imp} = 43.5\% \text{ to } 57.7\% \qquad (7)$$

According to specifications [10], for standardized single stage axial "F" type 45 kW the fan characteristic point at 1.2 kg/m^3 air density has the following required values of the basic parameters:

- Electric input power P_{in} = 42.8 kW

- Fan static pressure P_s = 2000 Pa

- Fan air flow Q = 12 m^3/sec

- Fan output (air) power $P_{fan} \approx$ 24 kW

It results that specifications accept an average efficiency of 56% for the 45 kW standard axial fans. This value confirms the average data estimated by equation (7).

5.2. Why Retrofitting Attempts to Improve fan Efficiency Failed?

Electric Motor Retrofits

Attempts of increasing fan efficiency by improving electric motor efficiencies (using EEEM) failed due to reduced fan system overall efficiency increases vs. the premium paid for the motors. For an EEEM with η_{motor} = 94%, fan overall efficiency will insignificantly increase with 1 %, as per equation (7):

$$\eta_{fan} = \eta_{motor} \times \eta_{imp} = 44\% \text{ to } 58.3\%.$$

Low overall fan efficiency values are due to the poor impeller efficiency – equation (4).

Impeller Retrofits

The Law of maximum efficiency indicates that consistent improvement of the overall efficiency of a system could be obtained based on price increment per unit of efficiency of its components [6].

The price – efficiency criterion indicates which technical-economical measure ensures a consistent gain in efficiency of a complex system. Sometimes the maximum efficiency gain could be obtained by improving the equipment with lower efficiency and not by improving the equipment with higher efficiency- as shown in Figure **4**.

As presented in Appendix 1, by improving electric motor efficiency with average increments of 2 % the price increment varies between R 1000 / 1% and R 3350 / 1% (highlighted red column). This is because the price – efficiency relation $P = f(\eta)$ is non-linear. The incremental price increases (defined as **$\Delta P_i / \Delta \eta_i$)** are different for the fan components. The law of maximum efficiency indicated that improving impeller efficiency will ensure maximum efficiency increase with minimum expenses (Table **2**).
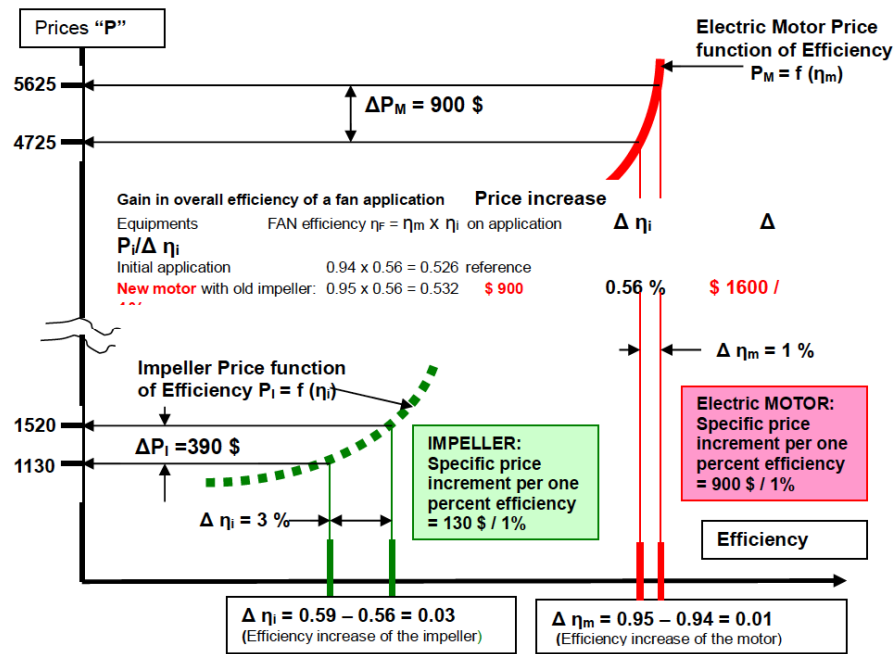
Figure 4: Price - efficiency graphs of two fan components (EEEM & HEI).

Table 2:   Efficiency Limitation and Overall Efficiency Law Applied to a Fan System

Item	η_{motor}	$\eta_{impeller}$	η_{fan}	Δη gain	Δ P	Improvement cost
Initial application	0.94	0.56	0.5264	Baseline	Zero	$\Delta P_i/\Delta \eta_i$
Improving η_{motor}	**0.95**	0.56	0.532	0.0056	$ 900	**1600 [$/1%]**
Improving $\eta_{impeller}$	0.94	**0.59**	0.5546	0.0282	$ 390	**138 [$/1%]**

Note: These are average test data performed in various conditions.

As a result, a high efficiency impeller (HEI) has been promoted. However, when tested with some motors, the impeller did not perform at stipulated efficiency. Further tests in aerodynamic tunnel revealed that sudden changes of the cross-sections profiles along the standard axial fan do not ensure a streamline regime. The air fillets are approaching the impeller blades with a large amount of turbulence like: eddy, swirls and blow by effect, reflections, flow reversals and pulsating pressure waves. The pulsating waves are inducing vibrations that stress the welded joints of the impeller blades as shown in Figure **5** and **6**, reducing the impeller lifetime.
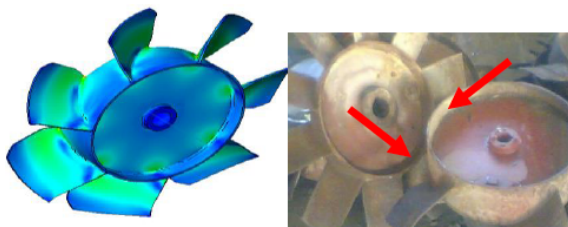

Figure 5: The edges placed on inlet side of the hub enhance the hub losses by "flow reversals" (right)**.** Nodal stresses & vibration areas of a standard impeller (left).
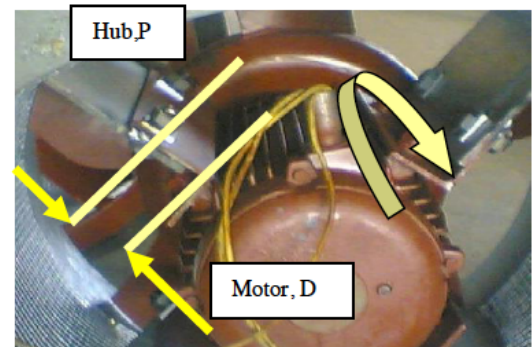

Figure 6: Difference between hub and motor diameters enhanced stray losses.

5.3. Applying Global Efficiency Concept to Improve the fan Performances

Investigations of the shaft power conversion process into air power for various standard "F" type fans were performed in aerodynamic tunnel revealing shortcomings of the existent applications, *i.e.* four regions of air turbulence as shown in Figure **7** [12].
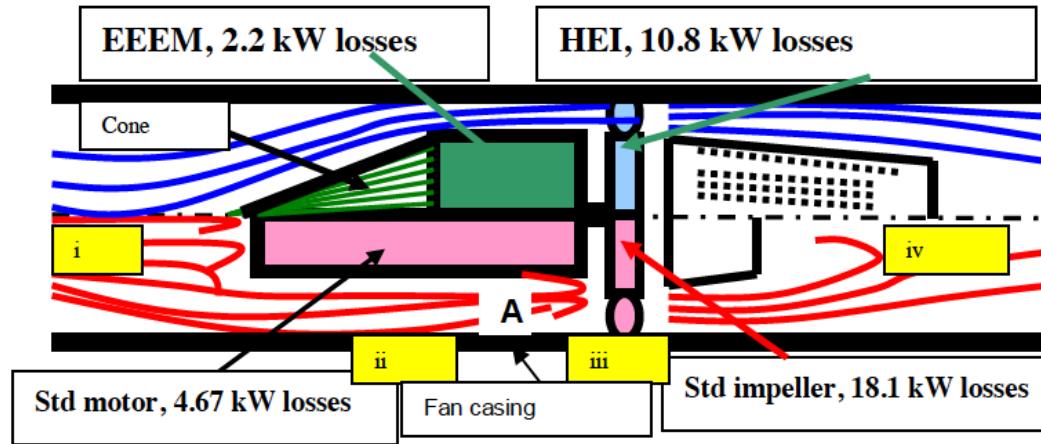
Figure 7: Schematic distribution of the air turbulence around profiles of a standard axial fan (bottom) and air streamline regime around ENEF (top) with energy efficiency electric motor EEEM & and High Efficiency Impeller – HEI.

In the turbulence area "i" at the motor impact the air fillets creates a "blow by effect" (deflection losses) and an overpressure at the motor edges. Further on, the air stream will approach the annular area "ii" bouncing between motor and fan casing approaching impeller blades with heavy turbulence (no streamline regime).

In the "ii" area the air fillets bounce with one or two reflections in the annular shell "A" (deflection losses) due to motor length and initial disturbances induced in "i" area.

The difference between motor outside diameter "D" and the diameter of the impeller hub "P", (shown in Figure **6**) produce further air turbulence (hub losses due to flow reversal) in the "iii" area being enhanced by the previous air fillets reflections and turbulences. The hub profile itself with edges generates major losses by flow reversals, shown in Figure **5**. In the "iv" area the turbulence is due to "flow reversal" (related to diffuser length).

The "*air stray losses*" are reducing the fan overall efficiency. This is the reason why the electric motor requires more electric input power to overcome such "*air stray losses*".

5.4. Design Conditions of the Energy Efficiency Fan

Energy Efficient Fan (ENEF) design target was to minimize the "air stray losses" by improving the fan **streamlined flow** [12]. The goal of an easy implementation of the product was considered achievable by imposing technical and economical conditions:

➤ Reducing "air stray losses".

➤ Ensure streamline regime enabling HEI to perform a higher efficiency at the same air power with lower vibrations and noises level.

➤ Electric motor designed as a dedicated energy efficient electric motor (EEEM) or Premium™ [13].

➤ Increased reliability of the components in order to increase the product reliability, reducing total cost of the ownership (TCO).

➤ Keeping the same overall interface conditions, including position of the pad fixing rods, shaft sizes and fan overall sizes (diameter and length) as existent standard axial fans to allow an easy replacement of the existing fleet.

➤ Keeping a market orientated competitive price.

A salient feature is the performances stability of the equipment after repairing process. The standards accept a performance degradation of the rated efficiency in a range of 1.5% after every repair activity [14]. A reduced number of repairs (because of the lower level of the temperature rises on the winding and bearings) will avoid performances degradation of the motor. Comparative estimations of the energy savings between a standard axial fan 45 kW and the ENEF running at 1.2 kg/m^3 air density are shown in Table **3** [12].

Regardless the air density (depth of the shaft level), the ENEF manufactured at very competitive prices will run safely paying for itself in a very short time: payback period for the ENEF is 0.5 years.

Table 3:   Comparative Performances & Energy Savings

Fan/Motor Performances	Standard	ENEF/EEEM & Comments
Rated output	45 kW	35 kW (77% demand)
Overload factor	1.0	1.25 (see temperature rise)
EEEM Efficiency	90 %	94.4 %
Power factor	0.9	0.94
Temp rise/insulation class	105°/F class	70°/H class
Input power @ 1.2 kg/m^3	42.8 kW	37.0 kW
Shaft power [kW]	38.52 kW	34.78 kW
Fan output (air) power	23.9 kW	24.0 kW
Fan overall efficiency	**56 %**	**69 %**
Average energy annually saved	NIL	25MWh
Saved power / unit fan [kW]	NIL	~ 5.8 kW (power demand)
Air Quantity ventilated (delivered)	~ 450,000 tons @ 1.2 kg/m^3 density/year	
Specific cost of a ventilated ton of air	$0.059/ton	$0.050/ton of air (15% reduction)
Annually savings/fan unit [$]	**NIL**	**$ 4,050/year**
Price (units)	**1.0**	**1.15, pay back period = 0.5 years**

6. APPLYING GEFF IN COMMINUTION PROCESS - CASE STUDY – ISAMILL™ TECHNOLOGY

IsaMill™ Technology[1#] will be used as a case study of the global efficiency concept for the "discerning market" mentioned in the introduction by considering each of the following activities in turn.

6.1 Study of the process (application engineering)

6.2 Energy efficiency policy

6.3 Mathematical modelling

6.4 Estimation of total costs of ownership (TCO)

6.5 Co-operation of Unions and employees with management

6.1. Study of the Process (application engineering)

When a Reputable Mining Corporation (RMC) expanded its gold operations to include a new deposit (ND NEW), it was required to process the mine's refractory gold ore deposit. RMC had been operating an open-cut mine at its previous sites (PS Old) processing the ore on site.

However, the situation was slightly different at the ND goldfield. Although ore from that mine is treated at an adjacent 1.0Mtpa plant, the gold concentrate is sent 800 kilometers by rail to the PS Old) pressure oxidation plant for final processing. This proved to be more of a challenge than initially expected, as regrind limitations at PS OLD meant the mill could not handle all the ore from ND NEW. Without adequate regrinding ahead of pressure oxidation gold recoveries would be lower than forecast.

The processing at PS OLD utilizes a grinding and flotation circuit employing SAG and ball mills, followed by a sulfide flotation, fine regrinding, a pressure oxidation autoclave and then a carbon in leach circuit for the gold extraction. While there was some capacity in the autoclave to treat ND NEW product, the mill did not have the regrind capacity to handle the mine's ore. RMC needed to source additional capacity for regrind.

The company wanted a grinding mill that:

i.   could achieve a very fine grind size,

ii.   was power and energy efficient, and

iii.   had a low capital cost.

[1#] The **IsaMill** is an energy-efficient mineral industry grinding mill that was jointly developed in the 1990s by Mount Isa Mines Limited ("MIM", a subsidiary of MIM Holdings Limited and now part of the Glencore Xstrata group of companies) and Netzsch Feinmahltechnik ("Netzsch"), a German manufacturer of bead mills [19] The IsaMill is primarily known for its ultrafine grinding applications in the mining industry, but is also being used as a more efficient means of coarse grinding [20,21] By the end of 2008, over 70% of the IsaMill's installed capacity was for conventional regrinding or mainstream grinding applications (as opposed to ultrafine grinding), with target product sizes ranging from 25 to 60 µm [22].

Ideally, they also needed something that was simple to operate, as well as a small layout, as space limitations restricted the use of a lot of ancillary equipment normally associated with other grinding methods.

Using a traditional ball mill would have required a set of cyclones, pumps pumping large re-circulating loads and thickeners, which would not have fitted at the site. That is when they began to consider the IsaMill™, marketed by Xstrata Technology, and developed with Netzsch.

In summary the development of the IsaMill™ technology was driven by the metallurgical requirements of fine-grained lead/zinc deposits.

The complex nature of both deposits required ultra fine grinding to sizes that were not possible to do economically with existing technology in the early 1990's. Both mines had a similar problem, due to different circumstances.

The ore at one of them was seeing a decrease in liberation size and increase in amount of refractory pyrite. This resulted in recovery decreases from 70% to 50%.

At another mine the ores were already mineralogically complex requiring regrinding down to 7 um to achieve sufficient liberation to allow the production of a bulk concentrate. The available technologies using conventional ball and tower mill were uneconomical, as well as resulting in a high rate of steel media consumption which contaminated the mineral surfaces with iron hydroxide, resulting in poor downstream flotation response.

A real need had arisen for technology that could grind to ultrafine sizes in metallurgical operations economically and without serious contamination of mineral surfaces and pulp chemistry. However, in 1990, there was no generally accepted technology for regrinding economically to such sizes in base metals.

So, test work was undertaken at the time into high speed horizontal stirred mill technology, which was used in pigment and other industries. It was shown that such mills could grind down to the ultrafine sizes required for mineral liberation. As a result of the initial testing a program of major mechanical modifications of horizontal stirred mill technology was undertaken between the mines and Netzsch-Feinmahltechnik GmbH, the manufacturer of the stirred mill technology. The focus was to make the technology more applicable for the mining industry.

After many prototypes, the first full scale model was developed and installed at the one mine in 1994. The was the M3,000 IsaMill™ with a 1.1 MW motor.

6.2. Energy Efficiency Policy: The Power Intensity

As mentioned earlier the company wanted a grinding mill that could achieve a very fine grind size, was power and energy efficient, and had a low capital cost. Ideally, they also needed something that was simple to operate, as well as a small layout, as space limitations restricted the use of a lot of ancillary equipment normally associated with other grinding methods. Using a traditional ball mill would have required a set of cyclones, pumps pumping large re-circulating loads and thickeners, which would not have fitted at the site.

A complete review of the potential sources of grinding mills including the standard regrind ball mill, the tower mill, and the IsaMill™ was looked at. One of the larger factors in evaluating the efficiency of the equipment is the power/energy intensity as summarized on the following Table.

As shown in Table **4** the Energy Intensity of the IsaMill™ is significantly higher than any other commercially available grinding equipment. Combining the energy intensity and the high grinding efficiency leads to a compact mill. The IsaMill™ is able to achieve the high energy intensive environment due the high tip

Table 4:   Comparative Grinding Mill Power Intensities

	Installed Power (kW)	Mill Volume (m^3)	Power Intensity (kW/m^3)
Autogenous Mill	6400	353	18
Ball Mill	2600	126	21
Regrind Mill	740	39	19
Tower Mill	1000	12	42
IsaMill™ – M10,000	3000	10	300

speed inside the mill. The grinding action in the IsaMill™ is based on high intensity stirred milling, with the shell being stationary, while inside discs rotate on a central shaft at speeds up to 20m/s. Compared with conventional grinding, the IsaMill™ reduces the energy usage, media cost and capital cost of fine grinding.

There are three factors that determine energy efficiency in grinding mills:

1.   Ore characteristics

2.   Media size and type

3.   Classification efficiency

The ore characteristics are not something that can be controlled but do dictate what is required for the optimization of the downstream processes.

The media used in the IsaMill is a ceramic media, which transfers the energy to the rock without absorbing then energy itself as steel grinding media does. The ceramic media is also inert, which does not negatively affect any downstream processes.

The use of steel balls do result in releasing Iron Hydroxide (as the media wears) which coats the minerals resulting decreased flotation and leaching circuit performances.

The media that is used for the IsaMill™ is as fine as 1.5 mm to 2.0 mm. The smaller the media the more efficient the grinding circuit is. The smallest media the other technologies can use is 12 mm steel media, which is much less efficient.

The IsaMill™ has a patented Product Separator on the end of the mill. This is a very efficient separation system resulting in the grinding power being used mainly on the coarser fractions that require grinding without overgrinding the fines. This results in a steep grinding curve.

6.3. Mathematical Modelling

One of the challenges of the ND NEW project was the concentrate sizing. The company planning for 70 to 80 micron feed size known as the F80 (80% passing 70 to 80 microns) made allowances in the design for it to go coarser. The feed size of the concentrate from ND NEW ranges between 90 and 180 microns and 17 to 26% Sulphur. As well RMC required the technology to run the mill over a wide range of pulp densities. The concentrate regrind product size is required to be in the 15-18 micron range.

To accurately design full scale IsaMill's™ a developed laboratory procedure was utilized. The relationship between product size and energy input remains constant during scale-up of IsaMill technology.

As the diameter of a particle is halved, the surface area of its progeny is doubled. Within reasonable reduction ratio's, the log of size plotted against the log of energy produces a straight line. This line can be extrapolated within the limits of media efficiency and viscosity. This plot is referred to as a signature plot, and is unique to the ore, pulp conditions, and media selected. The development of the signature plot is used to design full scale IsaMill's™. Most full-scale installations have been designed from a signature plot developed in a 4 litre laboratory continuous mill. The 4 litre test must reflect the media and pulp conditions planned for full scale operation, or full scale design can be based on the most efficient signature plot developed during test work.

The standard method of grinding is controlling/maximizing the power input into the grinding mills. This is with standard technologies due to the power inefficiency of those technologies. With the IsaMill™ the specific power required to grind to a defined product size is determined in the signature plots previously mentioned. This allows for more refined control of the power input and resultant product size.

The power input into the mill in terms of kWh/t can be monitored and controlled. This is a much more efficient method to control the power input and to ensure the desired product size is obtained.

The flexibility was a key factor in the purchasing of the IsaMill™. The feed size of the concentrate from ND NEW mine ranges between 90 and 180 microns and 17 to 26% Sulphur. The IsaMill™ allows RMC to run the mill for a wide range of pulp densities, plus the speed and power draw can be changed, which means the mill can maintain the same feed rate and product size regardless of how coarse the feed is. Another advantage is that the mill runs in a single line open circuit to achieve the final product. Using a ball mill in this situation would have required balsa mill, cyclones, large pumping and re-circulating load and product thickening.

The concentrate feed size has an F80 of 180 microns in size and the IsaMill™ is able to get it down to that 15-18 micron range. In a conventional mill it would be a struggle to do that, it may have required a

two-stage grinding operation, potentially resulting in a much higher power consumption.

6.4. Estimations of the Total Costs of Ownership (TCO)

RMC wanted a grinding mill that could achieve a very fine grind size, was power and energy efficient, and had a low capital cost. Ideally, they also needed something that was simple to operate, as well as a small layout, as space limitations restricted the use of a lot of ancillary equipment normally associated with other grinding methods. Using a traditional ball mill would have required a set of cyclones, pumps pumping large re-circulating loads and thickeners, which would not have fitted at the site.

The costs of operating the grinding mills, ownership, covers the actual operating costs of the units, the power requirement, the required ancillary equipment, manpower, maintenance, and the effect on downstream processes.

The above chart is called a signature plot, showing a good level of reproducibility for each technology, the IsaMill™ and the Tower Mill [23].

The IsaMill™ was able to reduce the top feed size at an F80 of 130 microns down to a product size, P80, of 13 microns. The Tower Mill treated the same feed but could not produce a product size below 31 microns. Additionally to reach the product size of 35 microns the Tower Mill required 32 kWh/t where the IsaMill™ only

required 18 kWh/t of power, a 45% decrease in power consumption. The flatter curve in blue for the IsaMill™ indicates less energy required to achieve grind size, than the steeper curve (in red) that was obtained with the Tower Mill.

The operating layout required for the IsaMill™ has a small footprint, since it is a horizontal, rather than vertical piece of equipment, and because it does not need cycloning equipment, less space is needed for set-up. To handle the same material with a ball mill with its associated cycloning and thickening equipment would mean that at least three times the area of ground for the equipment would have been required. The IsaMill™ has been designed to keep maintenance simple [24]. The shell of the mill is simply rolled away from the mill on a set of rails, enabling the disc and internal ware surfaces to be examined and changed if required. Wear within the mill is determined by the specific size reduction of the mill, as well as wear characteristics of the minerals. It is common for IsaMills™ to be operating with availabilities of 96% and higher.

IsaMill Technology has a lot of benefits, especially for downstream processes such as flotation and leaching. Ceramic media is used as the grinding medium. The use of this inert grinding media improves the kinetics in leaching and flotation circuits. Depending on the application, grind sizes as small as seven microns are achievable with a float of 92 to 96 per cent recovery. The action inside the mill produces a sharp
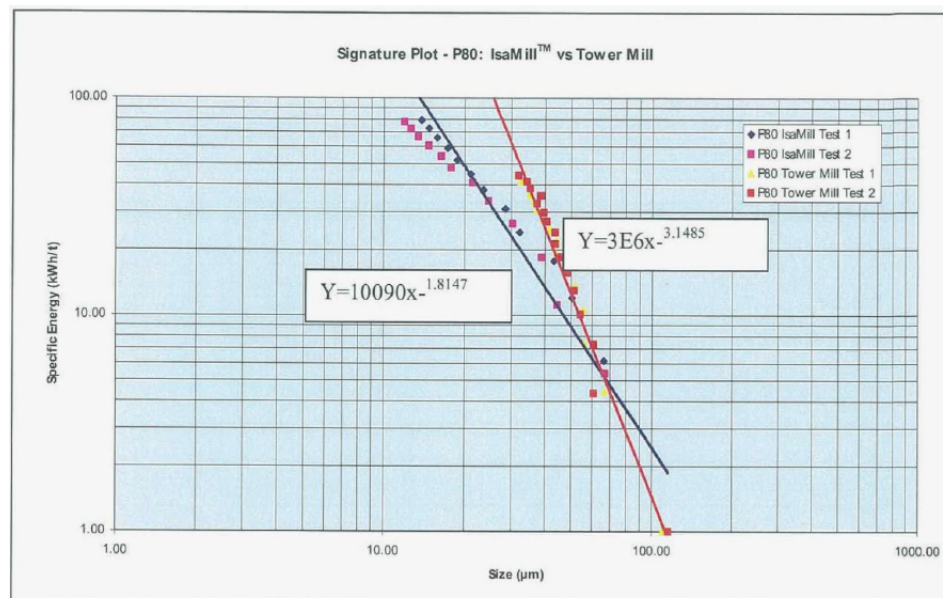

Figure 8: Size versus Specific Energy – M4 IsaMill™ and Tower Mill.

discharge sizing curve, with minimal slimes, even at these fine product sizes. The more grinding power used, in the IsaMill™ the particle size distribution curve steepens without overgrinding. This results in lower downstream costs with reduction in reagents, as for PS OLD cyanide for leaching, and with improved kinetics a potential reduction in equipment required for recovery of metals downstream from the regrinding application [25].

At PS OLD the regrind circuit would additionally require a full-time operator whereas with the IsaMill™, the operator that looks after the mill also runs the autoclave.

6.5. Co-operation of Unions and Employees with Management

As mentioned above the operation of other grinding technologies would have required a full-time operator whereas with the IsaMill™, the operator that looks after the mill also runs the autoclave.

From an operational point of view, the mill has proven to be a winner as well. It's simple to operate. Most of the operational and maintenance challenges over the last two years at PS OLD haven't been related to the IsaMill™. It's been related to the concentrate handling, not in getting the mill to grind.

7. CONCLUSIONS

Global Efficiency concept is a new concept of approaching a system and various activities (R&D, manufacturing, usage & maintenance). By using

characteristic laws of efficiency in performing price-efficiency decisions could lead to a completely new product.

The new energy efficient single stage axial fan (ENEF) design was based on the global concept of efficiency GEff. Increased overall efficiency of ~120% higher than existent fans currently in use was obtained by identifying and eliminating the "air stray losses" that overload unnecessary the fan system. For a typical 45 kW fan, at the same delivered output air power required by standards, a save of 5...6 kW per fan is obtained (the fan performances are unchanged when the motor consumes less electric input power).

For an underground gold mine that has an average of 200 units working 24/7 hours, it result an amount of 5...8 GWh/year energy savings.

As "low value equipment" ENEF could offer a boost and a global solution for auxiliary ventilation systems (high efficiency and reliability) saving power and energy without frame alteration of the existent ventilation systems. With longer lifetime and a payback period of 0.5 years, ENEF could become part of any company corporate energy policy.

The use of the IsaMill™ has enabled the mining corporate to achieve its goals. These goals were to:

i.   have a mill that could achieve a very fine grind size,

ii.   was power and energy efficient, and

iii. had low capital and operating costs.

Appendix 1

PRICE – EFFICIENCY DECISION BASED ON GLOBAL EFFICIENCY CONCEPT (GEFF)

In the real life the equipment with maximum efficiency is not accepted by the market (unless incremental cost on purchase price is paid by the utilities as incentive). Preferred equipment with a lower efficiency value denominated as an optimum efficiency "η_x" is decided as a trade off.

How the manufacturer and end user agree on the optimum efficiency value "η_x"?

At the manufacturer the equipment price **"p"** is function of its performances (the chief driver being efficiency) as shown in Figure **3** and **4**:

$$p = f(\eta) \qquad (1)$$

Consider annually savings on Total Costs of Ownership "**Δ S**" (approximated by annually savings on energy costs) as function of the required (unknown) optimum efficiency η_x, *i.e.* **Δ S = φ (η_x)**:

$$\Delta S = [(P) \cdot LF \cdot T_w \cdot \tau \cdot (\eta_x - \eta_0)] / [\eta_0 \cdot \eta_x] \qquad (2)$$

Where:

P   = Output (shaft) power [kW]

LF   = Load factor [%]

T_w = Annual time duration of working hours [hours/year]

τ   = Tariff, energy cost [Rand/kWh]

η_0 = Standard efficiency

η_x   = Optimum efficiency decided by the market

Optimum efficiency "η_x" value is function of Pay back Period (PbP) value decided by the market as a function of the equipment price increase **Δp = p$_x$ – p$_0$** and annually savings on energy costs **Δ S = φ (η_x):**

$$\frac{[p_x - p_0]}{\{\Delta S = \varphi (\eta_x)\}} \leq PbP \qquad (3)$$

Where:

p_x is the price of the equipment performing the optimum, trade off efficiency p_x = f (η_x) (unknown η_x) that is required by PbP

p_0 is the standard price of the equipment performing standard value of efficiency η_0.

Formula 3 is a useful predicting tool for designer (manufacturer) and end-user when decisions on optimum price – efficiency for "low value equipments" (produced in high quantities) are to be taken. In spite of the fact that their cost (and absorbed energy)/unit is very low comparing to high power motors, their total energy consumption is considerable high. That is why the energy savings have considerable values even for a small fraction of their efficiency performance improvement [11].

Consider a standard 45 kW PAD motor of 90% efficiency (corresponding to natural line of the minimum price) as a base line (**B**). Three versions (prototypes) of the same motor type with average incremental efficiency increase in ratio r = 1.0222 have been designed (η_i = 92.0%, 94.2% and 96.5 %) and tested for this particular application. Obviously, they have different prices (as shown in Table **4**)[2#]. It was found that the selling price "p" is increasing parabolically-asymptotic in report to linear efficiency improvements towards the natural limit of efficiency (η_{max} = 97.2 %) as shown in Figure **3** and **4**.

Table 4:   Technical and Economic Indicators of a 45 kW Electric Motor for Incremental Increase of Efficiency

Type	(η_i) Efficiencies of various prototypes	Δ η [%] (η_i – η_0)	Price "P_i" [R]	Δ Price (P_i – P_0)	Δ P_i/Δ η_i [R/%]	Input [kW]	Energy cost/year	Annually Savings	PbP [y]
# 0	**STD**: η_0 = 90%	Base line	13,500R	Base		40.00	61200 R	Zero	
# 1	η_1 = **r**x90 = 92%	2.00 %	15,500R	**2000 R**	**1000R/%**	39.12	59850 R	**1350 R**	1.48
# 2	η_2= **r**x92=94.04%	2.04 %	18,900R	**5400 R**	**1666R/%**	38.28	58570 R	**2630 R**	2.05
# 3	**r**x94.04=96.13%	2.09 %	25,900R	**12400R**	**3350R/%**	37.45	57300 R	**3900 R**	3.18

How the manufacturer and end user agree on the optimum efficiency value "η_x"?

[2#] The currency used was the Rand.

The estimation **P = f (η)** as per formula **(1)** is shown in Figure **4**:

$$P = 1659\,\eta^2 - 2917\,\eta + 1297 \text{ [kilo Rand]} \qquad (4)$$

The **PbP** influenced by the **Δ P**rice = **(Pi – P0)** and annually savings **Δ S** will decide the *optimum efficiency* of the motor (*bellow* the natural limit of physical or *maximum efficiency*) and subsequently the motor price.

Annually savings of energy function of efficiency **Δ S = φ (η),** are calculated as per formula **(2)** in penultimate column of Table **1**.

Applying formula **(3)** for an imposed **PbP = 2.5** years we will obtain an equation giving optimum efficiency **ηx** (bellow the value of the natural limit of physical efficiency or *maximum efficiency* **NLPE**):

$$\frac{1659\,\eta_x^2 - 2917\,\eta_x + 1297 - 13.5}{45.0 \times 0.8 \times 8500\,h \times 0.18\,R/kWh \times 10^{-3} \times (\eta_x - 0.9)\,/\,[0.9 \times \eta_x]} = 2.5 \qquad (5)$$

The equation **(5)** becomes: $1659\,\eta_x^3 - 2917\,\eta_x^2 + 1130.5\,\eta_x + 137.7 = 0$

It results an optimum efficiency of $\eta_{optim} = 0,9575$ or 95.75%

However, this efficiency could not be exactly achieved due to various reasons like deviations from standard of the manufacturing process and materials imperfections. Therefore the optimum efficiency of the motors will be found in a range of +/- 0.5%, with $\eta_{minim} = 95.25$ %.

According to formula **(4),** the cost price of such motor shall be **R 22500**, performing estimated annually savings of **R 3600**. Successive iterations on formula **(2)** give a round value of **ηO = 95.3%**.

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