Energy Efficiency with special lubricants in the steel industry.

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Abstract

This article aims to present a specific success case in a cold roll mill application in the steel industry. To achieve that goal, reliable methodology was used to determine the energy benefits, proving that it is possible to implement energy conservation measurements in motor-powered systems and to map the main process variables that influence energy consumption. The reduction of energy consumption and a positive financial result were accomplished by changing the lubricant, mineral oil, for a special lubricant. The result reached was 4.1 % less energy consumed with a payback of 20 months and the additional operational benefit of a reduction of the oil temperature by 15 °C, which allowed the operators to increase the production speed.

1. Introduction

The objective is to show results obtained in a steel rolling mill, demonstrating the achievement of energy savings through the substitution of mineral oils, as are currently widely used in the industry in most applications, by synthetic oils, evidencing the financial viability of the use of a seemingly more costly solution

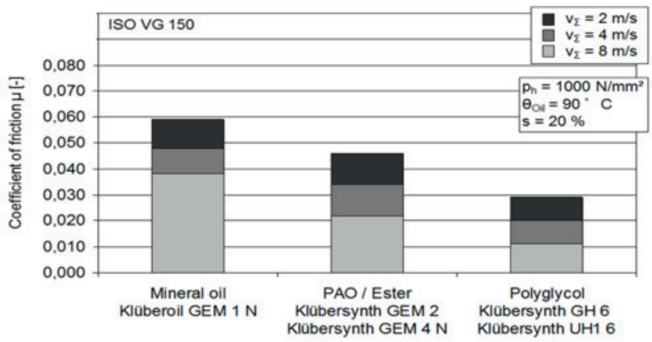


Figure 1. Friction Coefficients for Base Oils

coupled with other mechanical benefits increasing the return. The operational and mechanical improvement may even become a better argument than the energy efficiency itself.

The theoretical argument is that a high performance special synthetic lubricant from Klüber Lubrication increases the load bearing capacity and efficiency of a machine or a set of gears due to the lower coefficient of friction.

When using an oil with a lower coefficient of friction, almost half of the conventional mineral oils, the synthetic lubricant PAO (polyalphaolefin) and PG (polyglycol) oils have the capacity to increase mechanical efficiency, which theoretically results in lower energy consumption due to lower loses caused by friction.

To validate this theoretical argument, measurements and methodologies were adopted following the International Measurement and Verification Protocol (IPMVP- EVO 10000 - 1: 2018), which is recognized by main international organizations. The trial was conducted in a steel plant in Brazil and results were confirmed by the technical sector of that company.

The greatest motivation for this study and the application of our proposal is the fact that according to a 2018 IEA (International Energy Association) report, on average more than 60 % of the energy consumption of the equipment in the industry comes from electrical motors. These motors drive air compressors, machines moved by geared motors (rolling mills have the biggest electrical motors in a steel plant that drive gearboxes), chains that continuously move material during the manufacturing process. As a rule, the application of lubricants is required. Following the concept of replacing mineral oil based lubricant in these machines, at least a 4 % reduction of electricity consumption can be reached.

The equipment we discuss in this article is of great relevance in the use of lubricants and is responsible for 80 % of the energy consumption of the plant.

The retrofit and measurements were carried out at the ArcelorMittal (AM) Vega in São Francisco do Sul, Brazil, and the processing of the data obtained was done at Klüber Lubrication in Brazil.

2. Project Details

The measurements to determine the variables involved in the quantification of results were performed directly on the selected equipment. In addition to the measurement of the energy consumed, the production output of the equipment was taken into account to determine the specific consumption (kWh/ton). It is imperative to consider that there are other variables with a strong influence on energy consumption such as production process conditions, electrical and mechanical interventions. For comparison accuracy, all these variables and conditions must be the same in the baseline (mineral oil lubricant) and post-retrofit (Klüber Lubrication synthetic lubricant) periods. The measurement limit to assert the results is restricted to the powertrain equipment involved, through the continuous measurement of the energy consumed by it, the production of the equipment and other variables of influence.

Cold rolling mill	OEM: SMS -DEMAG
Number of Gearboxes	4 to drive the Mills + 2 Coilers
Oil Sump Volume (centralized system)	25,000 liters
Electrical Power (nominal of all motors)	27,000 kW
Oil in use (Baseline)	Mineral ISO VG 320 Temperature of Operation: 80 °C
New oil replaced (PAO basis)	Klübersynth GEM 4-320 Temperature of Operation: 65 °C

Table 1. Equipment information and products used

- Baseline (Mineral oil: 01/Jan to 31/May/2019
- Retrofit (Oil Change): 09/Jun/2019
- Post – retrofit (Synthetic Oil): 16/Jun to 15/Nov/2019

The variables analyzed with high influence on the energy consumption were:

- Electric Motor Power (kW) per stand;
- Oil temperature (ºC)
- Oil flow (7 bar – 1036 liters / min)
- Speed (stands # 1, # 2, #3 and #4)
- Production (ton / hour)
- Product (bar code)
- Thickness between stands;
- Cross section (thickness x widh)
- Time of production of coil
- Torque
- Weight of the steel coil

39 product codes representing 85 % of the portfolio produced in volume (tons) manufactured were analyzed.

2.1. Methodology used

The measurements to determine the variables involved in the quantification of the results were carried out in the field, for each lubricant, directly at the installation site, using data from AM Vega's data base systems. The measurements were made with the duration interval of 10 seconds of rolling of each coil and analyzed the same way.This data base was used to compare the power consumption profile of the main motors after the change from mineral oil to synthetic oil, this period is called post-retrofit. The baseline and post-retrofit measurement period was 150 days each.

In order to carry out the energy efficiency assessment of the oil replacement of the centralized lubrication system, it is necessary to build a model of energy consumption for the equipment responsible for the rolling power. For this, a set of equipment and production variables with mineral oil was first collected to build and validate a mathematical model.

Due to the high number of variables with influence, the complexity level for comparison was high. To solve this, a mathematic model was built, so a comparison with a high level of accuracy could be performed. The coefficient of precision found for this model was 0.997 (or 99.7 %).

With this, it was possible to predict the power consumed when data of the production was given (the independent variables).

Returning to the mill, we have a dependent variable, which is the Power for each roll and 24 more independent or explanatory variables. In this case the regression analysis is widely used as a descriptive method of data analysis without requiring any assumptions about the processes and other variable influences that allowed the data to be generated. The baseline was represented by a function / mathematical model that describes the efficiency of the Power unit and determined through regression analysis as a function of the variables X, Y, Z, up to N:

$$\text{Power} = f(X, Y, Z, \ldots N) \tag{1}$$

Once the coefficients for each independent variable were determined, it was possible to predict what the value of the dependent variable would be for any value read / known, respecting the limits where these values were obtained. With this, one can explain the phenomenon observed in a single mathematical equation, applying the coefficients. We can explain, or rather predict the value of the power for the baseline with only one equation.

$$Power_t = V_{1t}xCoef_1 + V_{2t}xCoef_2 + \ldots + V_{nt}xCoef_n \qquad (2)$$

These coefficients multiplied the values read for each coil / line / instant from the database to the corresponding "Channel" (independent variable) in the other periods, respecting the limits of "minimum and maximum values as well as the validation conditions". With this, it was possible to make the "prediction" of what the value of the "Total Power" of the current period would be for each coil, with no need to measure this variable, just perform a calculation. With this method, after changing the oil to Klüber Lubrication's oil, it was possible to say "what would have been the power read using Mineral oil if the change had not been performed".

This procedure was repeated for each stand (#1 to #4), respecting their own boundary measurement, in order to confirm the accuracy and results.

Channel	GenLSFitCoefficients
Tempo Laminação	1.33
Produção (ton\ hora)	4.17
ESP_SAIDA	-6.32E+03
LARG_SAIDA	1.96
COMPRIMENTO_METROS	-0.544
PESO_SAIDA	138.81
REDUÇÃO	-105.89
TCM_ESPESSURA_ENTRADA	764.90
VEL_MED_ENTR	-33.45
TCM_ESPESSURA_CAD_1	4980.65
VEL_MED_CAD1	29.43
TCM_ESPESSURA_CAD_2	-3.43E+03
VEL_MED_CAD2	-3.97
TCM_ESPESSURA_CAD_3	-2.21E+03
VEL_MED_CAD3	4.21
TCM_ESPESSURA_CAD_4	2064.16
VEL_MED_CAD4	33.42
VEL_MED_SAIDA	-24.05
TCM_FORÇA_CAD_1	0.203
TCM_FORÇA_CAD_2	0.111
TCM_FORÇA_CAD_3	0.194
TCM_FORÇA_CAD_4	-0.151
TCM_TORQUE_ENROLADEIRA	88.88

ResultStatStdError: 4.82 kW ou 0.06 %

Table 2. Coefficients for Mill #2

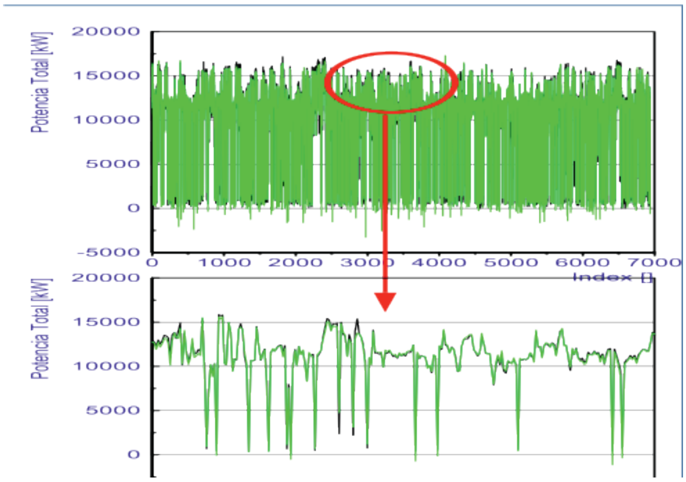


Figure 2. Accuracy of Model (green line)

In the comparison between the averages, the error was 4.82 kW or 0.064 % of deviation, using a determination coefficient (R2) equal to 0.997. Applying student's t-test, a result with 99 % of confidence compared to the means was achieved.

Because of the high number of product codes and repetition of the analysis, a software called EES was developed using the algorithm proposed to do the calculations and comparisons for each case "Product Code and # of Stand" separately.

The accuracy of the results stayed high, with 99 % of confidence, and determination coefficients (R^2), above 0.9, for every calculation executed.

3. Results and Discussion

Using the methodology defined and described in item 2.1, a comparison was made between the data measured in the Post Retrofit and in the Baseline. It was possible to see graphically the "before" x "after" (black line is mineral oil, orange line is Klüber Lubrication's oil) perceiving differences in Power under exactly same conditions / values for all variables during post retrofit period.

The first result shown below is a dashboard of EES for "all stands and all products", the result achieved was 4.1 % savings or 570.08 kW less power demand in absolute value.

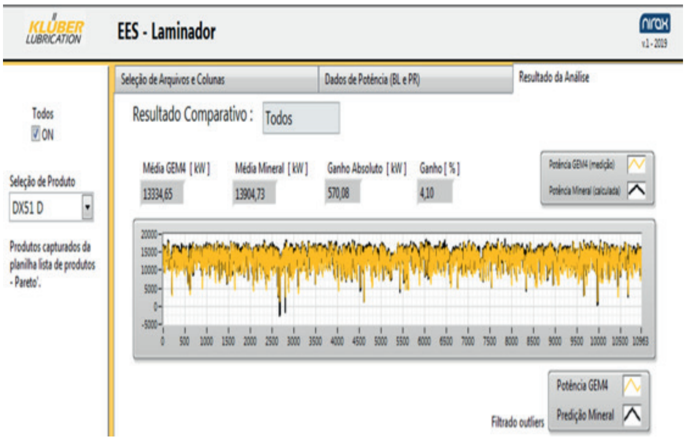


Figure 3. Results from software EES (all products & all stands)

For the calculation of each stand separately, a similar procedure was followed, resulting in savings of 4.06 % in weight average or 564.32 kW.

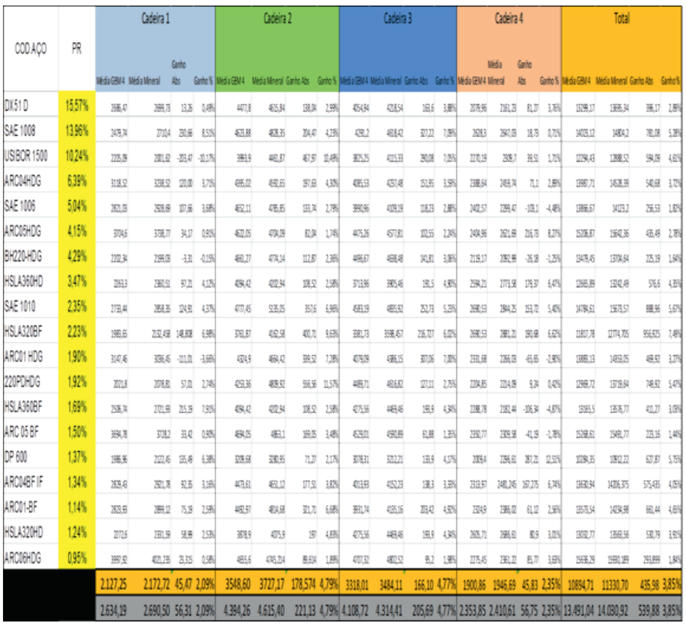
All products Analysis	Power Reduction	Savings
Rolling stand #1	140.99 kW	5.183 %
Rolling stand #2	182.87 kW	4.021 %
Rolling stand#3	189.00 kW	4.419 %
Rolling stand #4	51.46 kW	2.188 %
Total	**564.32 kW**	**4.06 %**

Table 3. Results for each rolling stand

Another analysis was made for all products and for each stand (#1 to #4) so that the comparison would also take into account the hardness and other physical properties of each product under the same process conditions.

Figure 4. Results from software EES in each stand.

A procedure was also made for each product code separately, the results are summarized in the table below. The average was a reduction of 589.0 KW or 3.85 %. Because of the large number of products (many rows), this table is available in png file to give more details for readers.



CODAÇO	PR	Cadeira 1				Cadeira 2				Cadeira 3				Cadeira 4				Total			
		Média GEM4	Média Mineral	Ganho Abs	Ganho %	Média GEM4	Média Mineral	Ganho Abs	Ganho %	Média GEM4	Média Mineral	Ganho Abs	Ganho %	Média GEM4	Média Mineral	Ganho Abs	Ganho %	Média GEM4	Média Mineral	Ganho Abs	Ganho %
DX51 D	15,57%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SAE 1008	13,96%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
USIBOR 1500	10,24%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ARC04HDG	6,39%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SAE 1006	5,04%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ARC05HDG	4,15%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BH220-HDG	4,29%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HSLA360HD	3,47%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SAE 1010	2,35%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HSLA320BF	2,23%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ARC01 HDG	1,90%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
220PDHDG	1,92%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HSLA360BF	1,69%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ARC 05 BF	1,50%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DP 600	1,37%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ARC04BF IF	1,34%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ARC01-BF	1,14%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HSLA320HD	1,24%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ARC06HDG	0,95%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		2.127,25	2.172,72	45,47	2,09%	3548,60	3727,17	178,574	4,79%	3318,01	3484,11	166,10	4,77%	1900,86	1946,69	45,83	2,35%	10894,71	11330,70	435,98	3,85%
		2.634,19	2.690,50	56,31	2,09%	4.394,26	4.615,40	221,13	4,79%	4.108,72	4.314,41	205,69	4,77%	2.353,85	2.410,61	56,75	2,35%	13.491,04	14.030,92	539,88	3,85%

Table 3. Results for all products and each Roll Mill

The methodology of analyzing "each stand & each product" presents greater detail, as it analyzes each stand considering the interference within the set between each mill and by separate products, technically the most accurate result because it involves more variables in the analysis. With this methodology the result was savings of 573.52 kW or 4.101 %.

As the product codes portfolio was very similar for both periods, we can assume that it's not necessary to analyze them separately, decreasing a lot the efforts and time for the next projects. The confirmation for this was obtained after doing a student's t-test with confirmed independence of the samples and accuracy of results with 99 % of confidence.

T-Test

[DataSet2]

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Potencia Total LB	6269,019893	729743	4549,633224	5,3258805
	Potencia Total PR	5903,224902	729743	4724,645381	5,5307528

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Potencia Total LB & Potencia Total PR	729743	-,002	,044

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Potencia Total LB - Potencia Total PR	365,7949912	6566,792653	7,6872027	350,7283305	380,8616519	47,585	729742	,000

Figure 5. T-test results ran in SPSS Statistics Software

Out of conservatism and to increase the reliability (repetition), for financial evaluation the lowest absolute value verified (in kW) will be adopted as the final result of the analysis, this was the one with the methodology by product with all rolling mills.

Result Adopted: Average reduction of 564.32 kW or 4.06 %

This result was achieved using same methodology in different ways of process in order to do a cross check and confirm the size order of the saving verified. The statistical analysis (t-test) also can be used in the simplest way to reach the final results.

The more detailed analysis, using all variables of the process, eliminates all doubts about the comparison in same conditions, despite the big variation among them.

3.1. Financial analysis

Financial analysis found a payback of 20 months, that is a very attractive investment with fast return.

Nominal Power	27.000	kW	Internal Rate	15%
Average Load	49,4%		Operation Tiime / year	7500
Oil Reservoir	20.000	Liters	Service Life(years)	10
Energy Price	0,03	Euro / KWh	# Gear Boxes	6
Amount of Analysis	1		Temperature	65

	Mineral	KLUBERSYNTH GEM 4 -320
Oil Price (in taxes)	1,80 Euro	10,50 Euro
Energy Saving		4,06%
Power Demand Reduction		564 kW
Energy Saving / year		4.232.400 kWh
Economic attractiveness		
Expenditure to replace Oil	36.000,00 Euro	210.000,00 Euro
Annual Expeditures (Oil + Reposition)	5.760,00	27.300,00
Annual Energy Saving	€ 0,00	-€ 126.972,00
Simple Payback		20 Months

Figure 6. Financial analysis of the savings achieved

It is important to consider also the sustainability benefits. The use of synthetic oils manufactured by Klüber Lubrication enabled the mill line, with comparable volume of steel produced, to significantly reduce its CO_2 emissions.

Sustainability Analysis

Category	Mineral	Klübersynth GEM 4-320 N	Saving per year
Lubricant FootPrint (Oil Sump)	307.500 kWh	415.110 kWh	-107.610 kWh
Lubricant Consumption per Year	166.050,00 kWh	107.928,60 kWh	58.121 kWh
Water Consumption	675 liters / year 810,00 kWh	325 liters / year 390,00 kWh	420 kWh
Labor Force	2,36 kWh	0,21 kWh	2,15 kWh
Parts	96.000,00 kWh	24.000,00 kWh	72.000,00 kWh
Transport	5.500,00 kWh	2.648,15 kWh	2.852 kWh
Energy		4.232.400,00 kWh	4.232.400 kWh
Total Emissions Reduction	4.365.795 kWh		
	420,75 ton CO2 / year		200 Trees / year

Figure 6. Sustainable benefits consolidated in kWh eq. (Brazilian carbon conversion: 1 MWh = 96 kg CO_2)

It is important to consider also the sustainability benefits. The use of synthetic oils manufactured

4. Conclusion

The result of a 4.1 % reduction of energy consumption in a rolling mill represents a financial benefit that should not be ignored by companies that seek to increase energy efficiency in their processes and shows that the practice of adopting high performance synthetic lubricants is a very good alternative among the energy efficiency solutions available.

This concept can be applied to any other gearbox with the same benefit, but in different orders of magnitude. In the steel industry, in which its machines work with peak loads closer to the nominal capacity, the result of replications could be even better.

It should be emphasized that financial gain with energy could be secondary for the company, since in many cases, the gain in productivity turns out to be far more relevant.

In addition to the financial benefits with the reduction of specific consumption there are other operational benefits obtained with the reduction of friction:

- Increased efficiency of gear pairs
- Less wear of gear pairs, less maintenance costs
- Increased efficiency through better agitation of the oil
- Reduced operating temperature
- Increased lubricant life (5 times longer than mineral oil)
- Greater oxidation stability, less waste in the tank

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