THE PROOF OF CONCEPT OF GROUNDBRAKING DEVELOPMENT TO PELLETIZING AGGLOMERATION: COREM LAYERED PELLETS®*

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Abstract

Pellets market challenging scenario has stimulated pelletizing experts to pursue innovative alternatives to process development in order to increase pellets competitiveness vis-à-vis sinter**.** When it comes to indurating process, pelletizing productivity is still limited and its OPEX inflated by the lower input of carbon into mixes due to quality impairment caused by magnetite formation in pellets core. This obstacle led to the rethinking of carbon distribution strategy within the green balls. To achieve such purposes, COREM through its precompetitive research program dedicated to its members, has proposed the layered pellets®, a two-stage balling technology. Balling in disc and pot-grate tests in COREM's pilot plant were carried out to proof the concept, support the arising technology and evaluate its potential. According to first results, while CCS strongly improved, tumble and abrasion indexes as well dynamic LTD must be further investigated. Tests on four classes of equivalent carbon content pellets to evaluate layering strategy gave very good perspectives concerning the increase of productivity, and the reduction of fuel consumption and GHG emissions.

Keywords: Layered pellets, pelletizing, agglomeration, COREM.

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1 INTRODUCTION

Pellets have been constantly under pressure of a high volatile iron ore market. Iron and steelmaking industries are always rigorously evaluating pellets price-performance ratio, i.e., their value in use (VIU), in order to select the most suitable/profitable composition to be fed into reactors. The seaborne trade of pellets can be considered as a niche market that has its own very particular scenario. If on the one hand, when the demand for iron and steel shrinks, it is not unusual to pellets to be shifted out because producers' choice turns to low productivity and cheaper sources of iron, e.g., sinter and lump ore; on the other hand, such industries can face periods of high demand/consumption for their products booming raw materials market and pressuring iron commodity price up to the point that many producers shift out pellets due their exorbitant figures.

This challenging scenario has stimulated pelletizing experts to pursue innovative alternatives to process development in order to increase pellets competitiveness vis-à-vis sinter. When it comes to pelletizing, the most important target, that still remains, is to reach lower OPEX by increasing actual productivity numbers as high as the practiced by sintering machines, 1.6-1.9 t/m².h (+20%), and at the same time, be able to maintain/improve quality standards of pellets.

In this arm wrestling between pelletizing and sintering, the former is undoubtedly handicapped by the unavoidable increasingly amount of fines generated in mining/concentration process. As high-grade deposits deplete, finer grinding and better selective concentration are necessary to beneficiate low-grade minerals. Nevertheless, when it comes to indurating process, pelletizing is still limited by the lower input of carbon into mixes, usually between 1.0 to 1.8%, while sintering straight grates easily works with carbon content up to 3.3-3.8%. Further addition of carbon in pellets feed is limited by reduction phenomena that take place in pellet core that impairs their resistance.

Current commercial pellets are made from iron ore concentrate in which carbon is distributed randomly by mixing and agglomerated into uniform green balls. When fed into induration machines, green pellets are exposed to oxidizing atmosphere where kinetics drive calcination of additives, oxidation of such solid fuel, slag phases formation and sintering reactions. Topochemistry can be split in three different phases: mass transfer through gaseous boundary layer (equation 1), mass transfer through solid porous product layer (equation 2) and chemical reaction at interface of reaction (equation 3):

$$-\frac{dN_R}{dt} = K_d . 4\pi r_o^2 . (C_G - C_{G/S}) \qquad \text{(Eq.1)}$$

$$-\frac{dN_R}{dt} = \left(\frac{4\pi r_i r_o}{r_o - r_i}\right) D_R(ef) . (C_{G/S} - C_{S/S}) \qquad \text{(Eq.2)}$$

$$\frac{dN_R}{dt} = K_d . 4\pi r_i^2 . k_f \left[(C_R)_{S/S} - (C_{RO})_{S/S}) / K_{eq} \right] \qquad \text{(Eq.3)}$$

Where,
dN_R/dt is the molar flux of the regent gas
K_d is the mass transfer coefficient
r_o is particle initial radius
C_G is the concentration of the reagent gas
$C_{G/S}$ is the concentration of the reagent gas at the interface gas/solid

$C_{S/S}$ is the concentration of the reagent gas at the interface solid/solid
r_i is the unreacted particle radius
$D_R(ef)$ is the coefficient of effective diffusion which is dependent on Arrhenius relation, solid porosity and porous tortuosity.
K_f is the kinetic constant for the frontal reaction
K_{eq} is the equilibrium constant between reversible frontal and inverse reactions
$(C_R)_{S/S}$ is the concentration of regent gas at interface solid/solid
$(C_{RO})_{S/S}$ is the concentration of the produced gas at interface solid/solid

The second mechanism is of extreme relevance for indurated pellets because it has strong effects on their resistance. If at the beginning, the abundance of oxygen at pellets shell allow fully oxidation of carbon into carbon dioxide, as long as gaseous products are generated and diffusion into pellets core become harder, oxygen partial pressure continuously decrease. As consequence, at inner layers and core, monoxide of carbon is produced by the oxidation of carbon in a low oxygen atmosphere. Then, carbon monoxide reduces hematite (Fe_2O_3) into secondary magnetite (Fe_3O_4). Although an important proportion of the secondary magnetite is later re-oxidized into secondary hematite [1], some magnetite remains in pellets core and gives origin to a heterogeneous embrittled microstructure. Some authors have evinced the impact of higher addition of carbon on magnetite formation and the direct consequences of such detrimental phenomena to physical quality of indurated pellets [2,3].

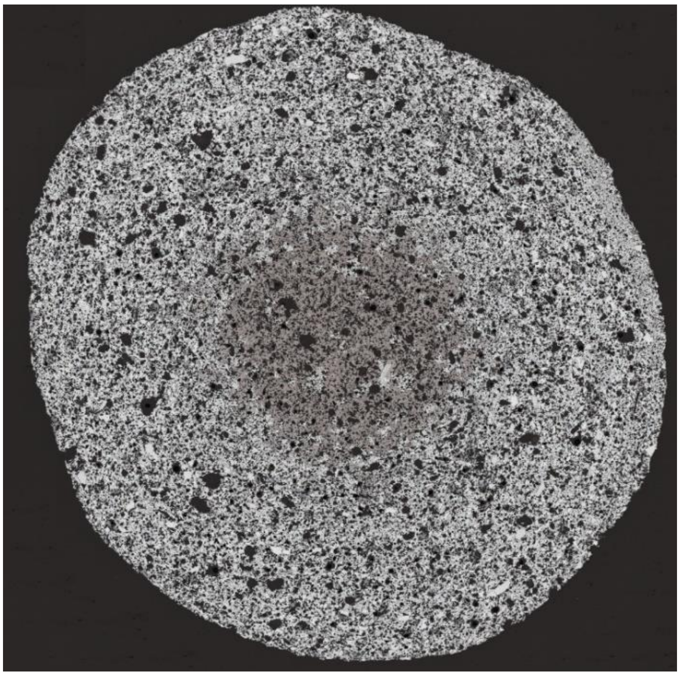


Figure 1. Heterogeneous structure of indurated: magnetite (dark gray) in the core and hematite (light gray) in outer zones.

This obstacle led to the rethinking of carbon distribution strategy within the green balls. To achieve such purposes, COREM, which is strategic positioned as the largest organization in Canada, totally devoted to mineral processing R&D and leader in pelletizing technology and products, has proposed the layered pellets®.

2 DEVELOPMENT

2.1 Objectives

The main purpose of the study is to avoid pellets embrittlement due to magnetite occurrence in indurated pellets. The strategy consists in segmenting the pellets carbon content in two distinct zones: core without (or low content of) carbon and high carbon addition in the external zone (shell). That way, the carbon would be rapidly consumed through a complete combustion reaction and carbon monoxide would not be available to produce secondary magnetite.

The present work aims to evaluate the impact of such changes in main operational key drivers' trade: grate factor, operational expenditures, greenhouses gas emissions and quality parameters.

2.2 Materials & Methods

In order to produce layered pellets at lab and pilot scale, the installations of COREM research center in Quebec City, Quebec, were used. The following procedures details pellet feed preparation and balling.

2.2.1 Green balls preparation

Mixture (concentrate, water, binders, additives and solid fuel) was prepared in paddle mixer. Two separated mixtures were produced: low and high carbon content.

Green balls were made in a 1 m diameter disc equipped with adjusted inclination and variable rpm where growth rate is constantly monitored and controlled.

Green balls smaller than the final desired size distribution were firstly prepared using the low carbon content mixture. The discs production was sieved and agglomerates ranging between 9.5 mm and 12.5 mm were picked up as core.

Shell layering was then carried out through a second balling stage where such low carbon cores were added to the disc concomitantly to a high carbon mixture. Fines feed was done through two different dosing conveyors. The layered green balls made were 9.5 mm to 16 mm collected for further firing tests.

2.2.2 Firing test

To simulate the induration of green balls in travelling grate and evaluate layered pellets quality, 40 cm height bed of green balls were load in a 0.1 m² pot grate (Figure 2). Layered pellets were prepared, submitted to the same firing profile currently in practice in industry. Four classes of pellets were investigated. Comparisons between their layered distribution with equivalent carbon and regular pellets were carried out. After firing and cooling, pellets were analyzed according to current international standards as presented in Table I.

Figure 2. Pot grate test.

Table 1. Standard procedures used to determine fired pellet properties

Determination	Procedure
Tumble	ISO 3271
Cold compressive Strength (CCS)	ISO 4700
R40	ISO 4695
Swelling	ISO 4698
Dynamic LTD	ISO 13930
R180	COREM
Linder	ISO 11257

3 RESULTS

3.1 Physical Resistance and Metallurgical Properties

The new strategy for carbon distribution was effective to avoid the magnetite occurrence and to improve pellets cold compression strength (CCS).It can be observed in Figure 4 that pellets with equivalent addition of carbon presented much lower occurrence of magnetite (darker gray zones) if the carbon is layered concentrated in the shell. Even at higher additions, no residual magnetite is measured in the fired pellets (Figure 3).

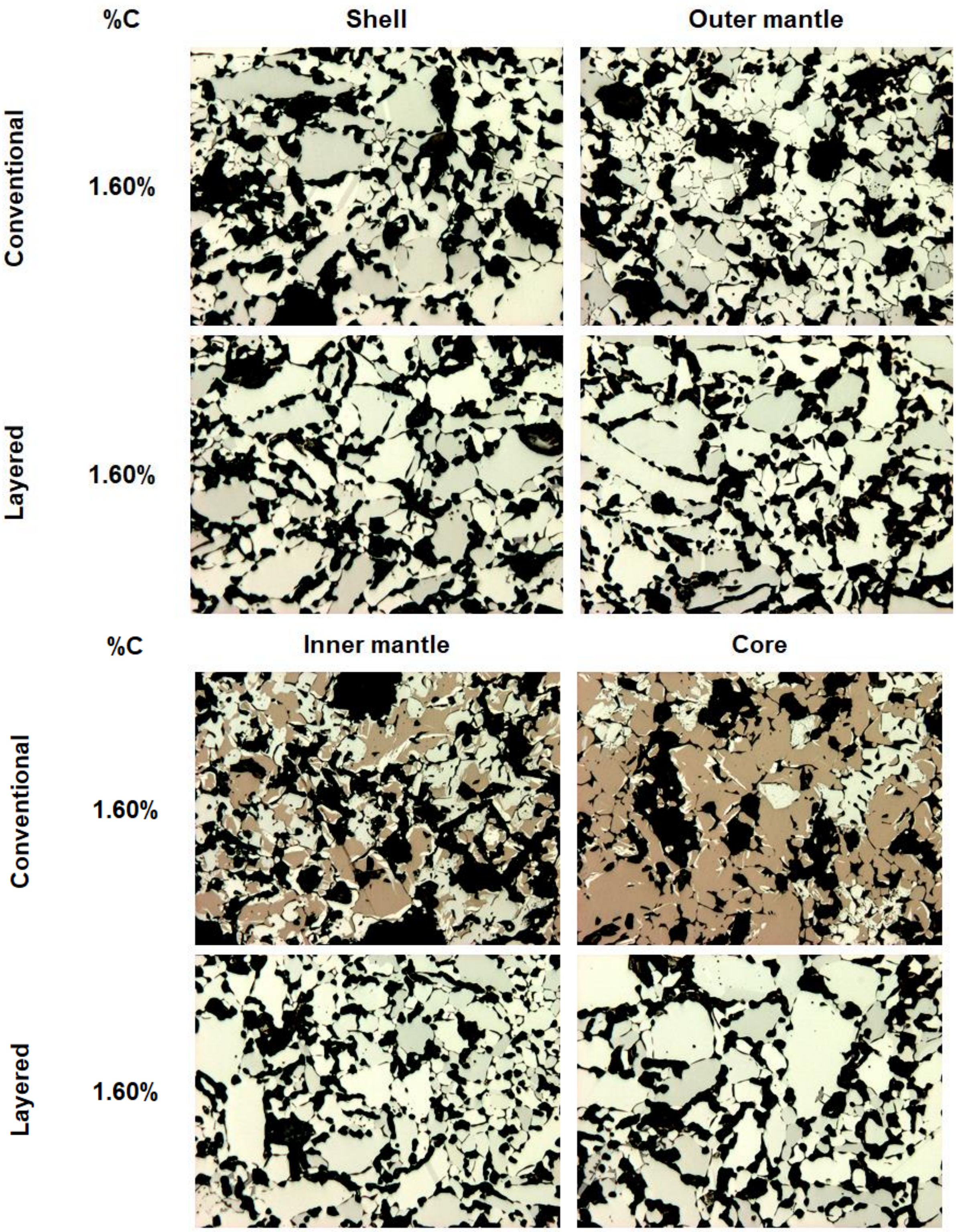


Figure 3. Optical microscopy of Type 1 pellet – conventional and layered carbon distribution.

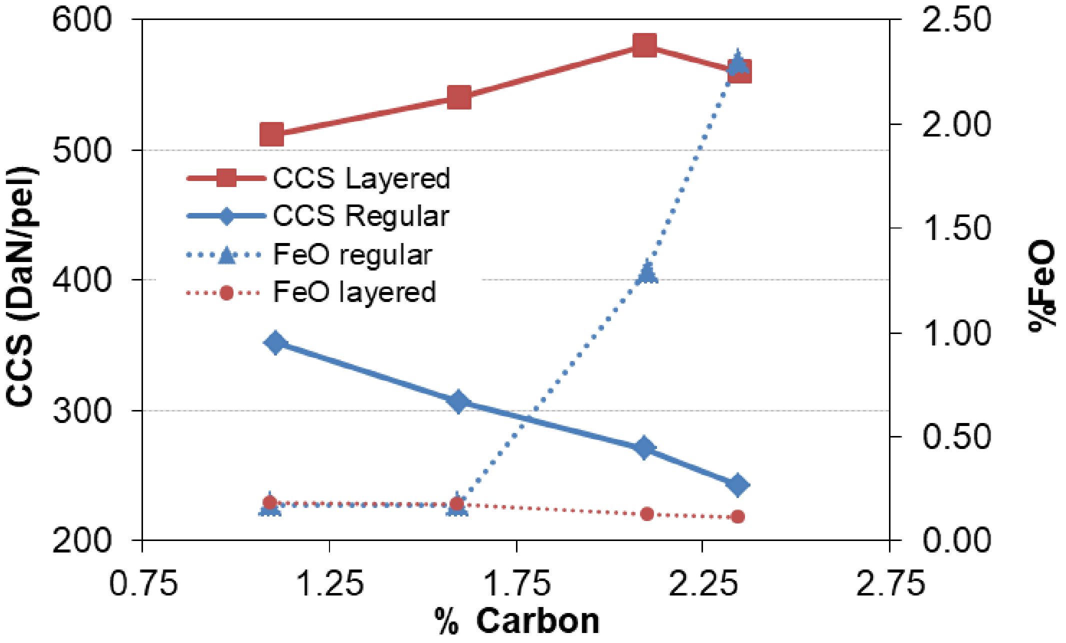
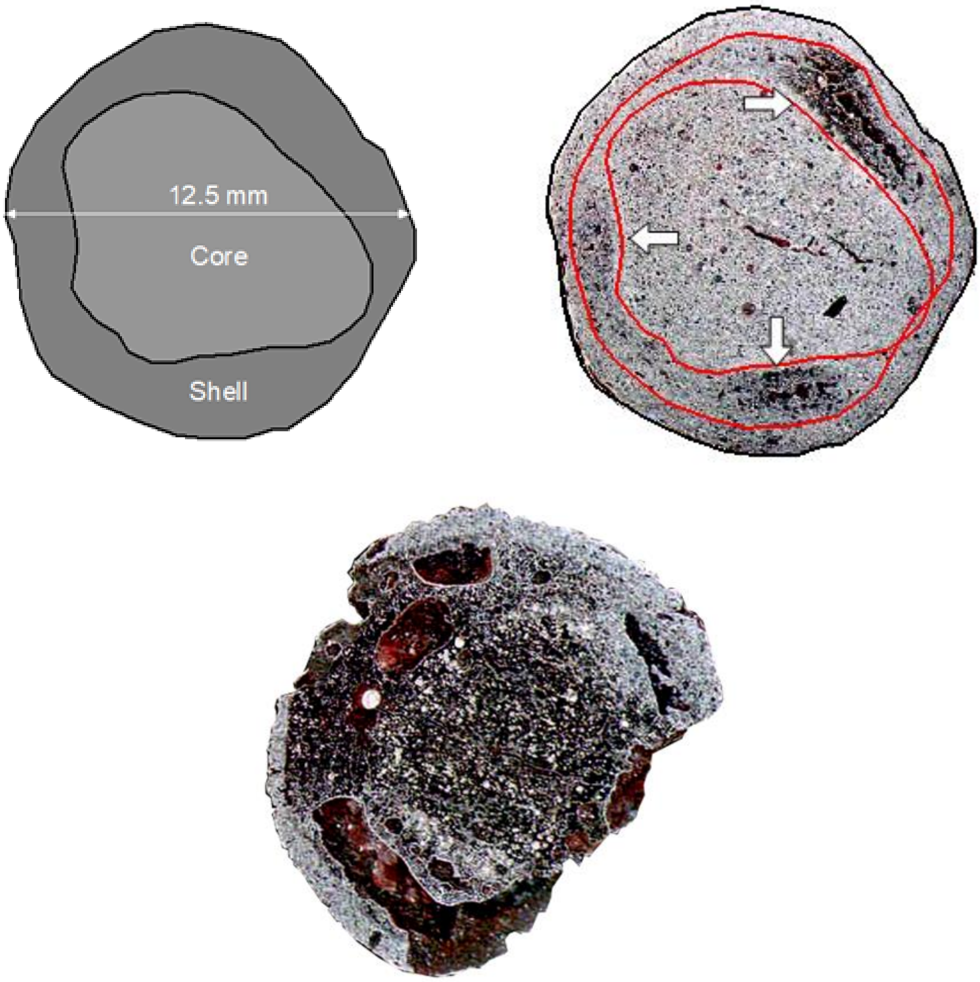


Figure 4. CCS and FeO for type I regular and layered pellets.

However, tumbler and abrasion were slightly impaired by layering of carbon. According to investigations, it is believed this could be due to the following possibilities: the inherent occurrence of larger pores at pellet’s surface and/or the batch balling process. The latter suggests that the problem might arise from the making of deformed cores [4]. Between balling stages, cores were preserved aside in buckets where their own load induced deformations by compression. During the second balling, such misshapen cores, under rolling action, agglomerated high carbon mixture fines and returned to spherical/round shape. However, the shell was unevenly distributed presenting thicker width at some regions. In such thickest zones, the excessive heat input promoted reduction and partial fusion (very extreme cases) as it can be verified in Figure 5. Areas where the thickness of the shell was uniformly distributed presented stable and homogenous microstructure.



(a) (b) (c)

Figure 5. (a) Schematic view of deformed core (b) optical microscopy of layered pellet (c) extreme case of damage caused by excess amount of carbon in thickest layered zones

Table 2 presents the properties measured for layered pellets in comparison to regular pellets for four classes of pellets: type I – low silica content; type II – blast furnace pellets; type III – limestone semi-fluxed pellet; type IV – fluxed pellets. Excluding the dynamic LTD, all properties remained on the same level or slightly better. The dynamic LTD, just like abrasion, is a test that measures superficial breakage due to abrasion mechanisms and it is believed that it was impaired by the same aforementioned causes.

Table 2. Summary of metallurgical properties for layered pellets

Test	Type I	Type II	Type III	Type IV
R180	Slightly lower			
R40		Equal	Slightly better	Equal
Linder	Better			
Dynamic LTD		Twice the amount of fines	More fines	Few more fines
Swelling			Lower	

3.2 Impacts on sintering

Table 3 summarizes the results of pot grate tests for the four classes of pellets. In order to compare layered and conventional pellets, the same flow rates were pursued for both cycles. Temperature profile was also kept constant. For layered pellets, the cycles lasted less in order to reproduce different levels of productivity. Results are in relative comparison to regular grate factors for each conventional type.

Table 3. Summary of pot-grate tests scenarios by type of pellet

	Type 1		Type 2	
	Conventional	Layered	Conventional	Layered
Solid fuel (%)	1.6		1.8	
Tumble (%)	97.0	94.0	97.0	94.4
Abrasion (%)	2.9	5.4	2.9	5.2
CCS (kg/pel)	314	378	266	368
Porosity (%)	26.5	26.8	25.9	25.6
Fe II (%)	0.8	0.4	2.5	1.8
R180	93.0	92.1		
R40 (O_2/min)			1.02	0.97
Linder [-3.15 mm] (%)	0.7	1.4		
Dyn. LTD [+6.3mm] (%)			84.9	77.2
CSAR* (kg/pel)	71	57	82	139
Productivity	-	+20%	-	+17%
Bunker consumption	-	-39%	-	-25%
Greenhouses gases	-	-12%	-	-7%

**Compression strength after reduction*

	Type 3		Type 4	
	Conventional	Layered	Conventional	Layered
Solid fuel (%)				
Tumble (%)	97.0	95.4	96.8	95.8
Abrasion (%)	2.7	3.8	2.9	4.0
CCS (kg/pel)	327	362	294	334
Porosity (%)	25.5	25.4	26.5	28.3
Fe II (%)	0.2	0.5	1.3	0.9
R180				
R40 (O_2/min)	0.53	0.64	1.14	1.13
Linder [-3.15 mm] (%)				
Dyn. LTD [+6.3mm] (%)	91.5	84.6	89.4	85.5
CSAR* (kg/pel)				
Productivity	-	+12%	-	+7%
Bunker consumption	-	-20%	-	-43%
Greenhouses gases	-	-7%	-	-16%

In average, productivity levels increased around 10-15%. Due to fully combustion of carbon and rapidly heat exchanges, bunker consumption dwindled around 20-30% depending on pellet type. Greenhouse gases also presented an important reduction of the order of 8-12%.

3 CONCLUSIONS

Preliminary studies have unveiled great potential of the new strategy for carbon distribution. According to first results, while CCS strongly improved, tumble and abrasion and dynamic LTD must be further investigated. Preliminary findings in pilot plant suggest that balling control of core and layering steps is necessary to avoid negative impacts on properties measured by surface breakage.

Tests on four classes of equivalent carbon content pellets to evaluate layering strategy gave very good perspectives concerning increase of productivity, reduction of fuel consumption and of GHG emissions.

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