International Journal of Theoretical & Applied Sciences, 14(2): 04-11(2022)

ISSN No. (Print): 0975-1718
ISSN No. (Online): 2249-3247

Study of the Impact of the use of Alternative Fuels on the Process and the Finished Product

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(Received 25 May 2022; Accepted 24 July 2022)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Since 2010, SCB-LAFAGE has been using alternative fuels. It is of utmost importance for the plant to examine the changes brought by the use of these fuels. The present work consists in studying of the impacts of the use of alternative fuels on the process and the finished product. At the same time, the study allows to specify the impact of the switch to 50% alternative fuels by 2023. Prerequisites such as the mastery of process and finished product simulation tools, the transformation process of raw meal into clinker and the knowledge of the chemical composition of fuels have allowed this work. From this study, it appeared that the volumetric dosing systems of the alternative fuels must be replaced by weight dosing systems in order to control the thermal input in the kiln. The impact on the finished product reveals a variation of 0.1% in the SO_3 content of the clinker. As for the impact on the process, the alternative fuels are responsible for the formation of concretions in the preheater, due to their incomplete combustion. The concretions are, in turn, responsible for the reduction of the substitution rate of alternative fuels upstream of the kiln. To achieve these results, the study of alternative fuel dosing systems was carried out, and simulation models of the finished product and process were also used to analyze the impact of alternative fuels on the finished product and on the process. In order to achieve a 50% substitution, the optimal volume of the smoke box would have to be maintained and the alternative fuel plant would have to be adapted to the available alternative fuels. Finally, the study shows that alternative fuels allow us to make a gain of 1437 FCFA per ton of clinker produced, and encouraging the collection of waste oils would allow us to gain 115,775,782 FCFA per year.

Keywords: Alternative, process, impact, smoke box, concretion, nozzle.

I. INTRODUCTION

Clinker is a constituent of cement, which results from the firing of a mixture of limestone and clay [1]. It is produced by firing the raw meal in a kiln at 1500°C [2]. To obtain this temperature inside the kiln, a large volume of fuel is required. This is usually fossil fuels, which are an increasingly expensive source [3]. The global demand for energy will increase by a third in the next twenty years and energy prices will certainly increase as energy reserves decrease [4].

By seeking to obtain the most economical and least polluting fuel mix possible in the cement manufacturing process [5]. SCB-LAFARGE has opted since 2010 for new energy resources and favored those with low carbon emissions [6, 7], called alternative fuels because they replace fossil fuels in the cement manufacturing process [8]. In general, they are derived from industrial, agricultural, commercial, municipal or domestic waste.

At present, there are different ways of supplying alternative fuels to the rotary kiln, among which there is the supply in the combustion zones of the kiln, and in the preheating system, specifically in the riser pipe and in the precalciner [9].

Since alternative fuels do not have the same chemical composition and properties as fossil fuels [10], studies must be conducted on the impact of using these alternative fuels on the finished product and the process in order to see the changes made to the quality of the cement and the process. Our study fits into this context.

II. MATERIALS AND METHODS

A. Materials

In order to approach the present work, which is limited to the study of the impact of the use of alternative fuels on the process and the finished product, we have resorted to some equipment such as the mechanical balance (Fig. 1 (a)), the moisture meter (Fig. 1(b)), the calorimeter (Fig. 1(c)). Simulation models of finished product (Fig. 2) and process (Fig. 3) are also used.

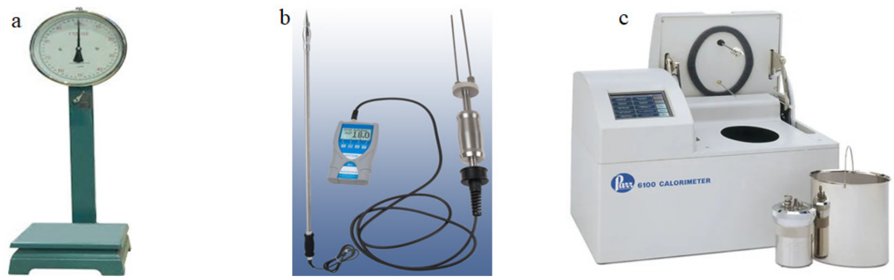

Fig. 1. Equipment used (a): Mechanical weighing scale 500kg (b): Universal moisture meter for biomass (c): Calorimeter 6100.

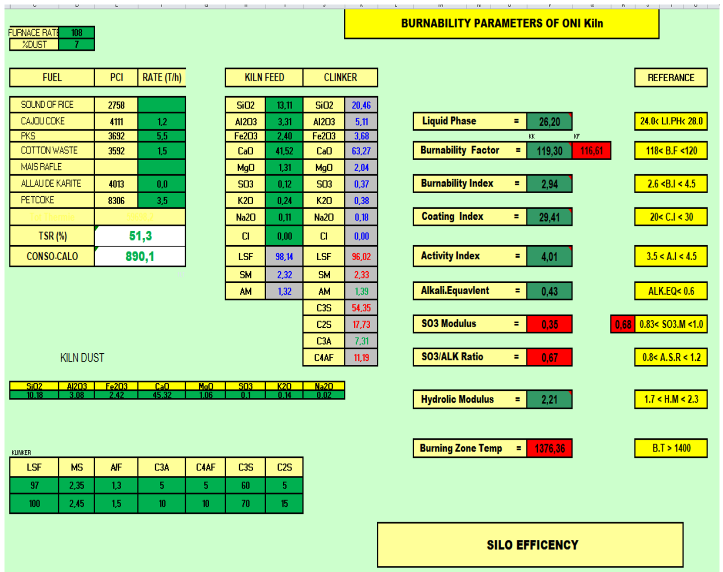

Fig. 2. Finished product simulation model.

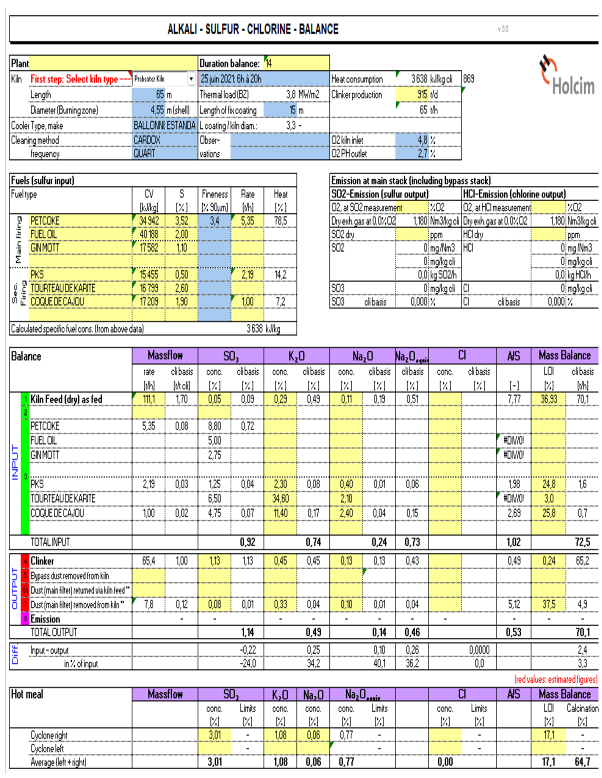

Fig. 3. Process simulation model.

B. Methods

Study of alternative fuel dosing systems. In order to study the alternative fuel dosing systems, we carried out the following tasks in the following order.

— Carry out the countermeasures

— Give a flow set point to the dosing unit;

— Recover during 5 minutes the quantity of fuel at the exit of the dosing unit and weigh it;

— Calculate the flow rate;

— Calculate the absolute error on the dosing unit

— Assess *the results*

Study of the impact of alternative fuels on the finished product

— Presentation of the finished product simulation model

To do this work, we used a simulation model (property of SCB-LAFARGE) which aims at predicting in a first time, the chemical and mineralogical composition and the cement moduli of the raw meal according to the input data such as: the chemical and mineralogical composition of the limestone and the clay, and the proportion of each of these elements in the heap formed in the pre-homogenization hall. In a second time to predict the chemical and mineralogical composition and the cement moduli of the clinker according to the input data such as: the chemical, mineralogical, energetic and flow characteristics of the flour, dust and all the fuels used. It should be noted that our work will only take into account the simulation part of the clinker quality according to the flour and fuels.

Verification. At this stage, we performed several simulations on specific dates and compared the results of the simulation with the results given by the laboratory after analyzing the clinker of the day. The target dates for the analysis are days when: kiln operation is as stable as possible, variations in flour and fuel flow are negligible and flour quality is good.

The verification of the product simulation model consists of checking the following assumptions in order:

— the actual results (chemical composition of the clinker given by the laboratory) are within the expected range for a Portland clinker;

— the simulation results are within the expected range for a Portland clinker;

— for each chemical element, the difference between the actual result and the simulation result is less than or equal to 1/3 of the range expected for a Portland clinker.

— Run several simulations and compare the results.

Study of the impact of alternative fuels on the process

— *Indicate the elements* at the basis *of the impact on the process*

— *Give the permissible limits of these elements in a preheater furnace*

— *Assess the behavior of these elements in the SCB-LAFARGE process*

Modeling. This part is dedicated to the identification of mathematical models related to the study of alternative fuel metering systems and the evaluation of the production cost with the use of alternative fuels.

Alternative fuel metering systems

Calculation of the flow rate of the dosing system.

Its expression is :

$$\text{Flowrate} = \frac{\text{Mass}}{\text{time}} \quad (1)$$

With the flow rate in t/h, the mass in tons and the time in hours.

Calculation of the absolute error on the dosing system. Its expression is as follows:

$$Ea = flowrate_{con} - flowrate_{cal} \quad (2)$$

With Ea the absolute error on the doser in t/h, $flowrate_{con}$ the set flow rate in t/h and $flowrate_{cal}$ the cal flow rate in t/h.

Assessment of the results

Accept if error <|0.2| t/h (3)

Evaluation of the cost of production with the use of alternative fuels

Determination of the amount of useful heat to prepare one ton of clinker in the cement kiln

Cost per megacalorie of fuels (fossil and alternative) :

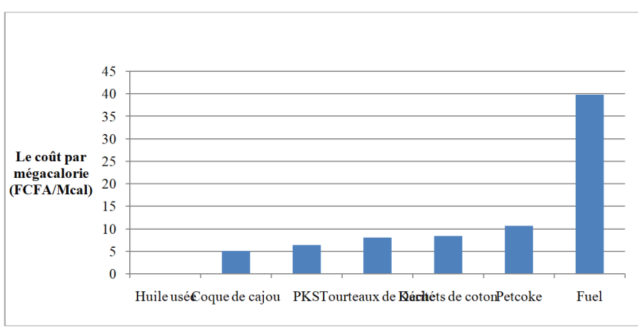

Fig. 4: Cost per megacalorie.

Its expression is :

$$C_{Mcal} = \frac{Price of a ton}{PCI} \quad (4)$$

With C_{Mcal} the cost per megacalorie in FCFA/Mcal, PCI the lower calorific value in Mcal/ton.

Evaluation of the current cost of production

$$\text{CUC} = C_{Mcal} \times CUtkk \quad (5)$$

With CUC the cost per unit of clinker in FCFA/ton and CUtkk the heat consumption per ton of clinker in Mcal/ton.

Evaluation of the cost of production by 2023 (50% alternative fuels)

$$\text{CUC} = \mathrm{C_{Mcal}} \times \mathrm{CUtkk} \quad (6)$$

III. RESULTS AND ANALYSIS

Results

All the results of the study of the alternative fuel dosing systems, the study of the impact of alternative fuels on the finished product and on the process and the evaluation of the cost of production with the use of alternative fuels are recorded in Tables 1 to 25 and on the graph in Fig. 5.

Table 1*:* Results of countermeasures on volumetric dosing systems.

Results of countermeasures on alternative fuel volumetric feeders			
Number of counter measures	Absolute error on dosing unit	**Acceptable** error (<|0,2| t/h)	**Unacceptable** Error
16	**0,1 à 1,2 t/h**	**12, 5%**	**87,5%**

Table 2: **Validation element for product simulation.**

Clinker composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O
Limite values (%)	62-70	20-25	2-9	1-5	0-5	0-3	0-0,6	0-0,7
1/3 of the range of the limit values	2,6	**1,66**	**2,33**	**1,33**	**1,66**	**1**	**0,2**	**0,23**

Table 3: Chemical and mineralogical composition of clinker (laboratory and simulation results).

		SIMULATION AND LABORATORY RESULTS ON CLINKER							
		SiO_2	**Al_2O_3**	**Fe_2O_3**	**MgO**	**SO_3**	**K_2O**	**Na_2O**	**CaO**
Limit values (%)		20-25	2-9	1-5	0-5	0-3	0-0,6	0-0,7	62-70
1/3 of the range of the limit values		1,66	2,33	1,33	1,66	1	0,2	0,23	2,6
23/07/2021	**Labo (%)**	21,6	4,47	3,32	2,57	0,59	0,42	0,1	67,71
	Simu (%)	**20,51**	**4,61**	**3,44**	**2,30**	**0,26**	**0,42**	**0,12**	**65,6**
	|labo - Simu|	**0,9**	**0,19**	**0,15**	**0,26**	**0,33**	**0**	**0,03**	**1,91**
02/08/2021	**Labo (%)**	22,1	4,25	3,27	2,8	0,68	0,39	0,1	67,7
	Simu (%)	**21**	**4,98**	**3,34**	**2,44**	**0,21**	**0,36**	**0,08**	**65,2**
	|Labo - Simu|	**1,1**	**0,73**	**0,07**	**0,44**	**0,47**	**0,03**	**0,02**	**2,51**

Table 4: **Simulation results (kiln operating conditions on 7/23/2021).**

	FUEL SUBSTITUTION RATE (%)			
	PKS BAF	**Cashew shell BAF**	**Waste cotton nozzle**	**Petcoke nozzle**
23/07/2021	33%	2%	12%	53%
Simu 1			12%	88%
Simu 2	33%			67%
Simu 3	35%		15%	50%
Simu 4	50%			50%

	SIMULATION AND LABORATORY RESULTS ON CLINKER IN %							
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**
23/07/2021	20,51	4,61	3,44	65,6	2,30	**0,27**	0,42	0,12
Simu 1	20,51	4,61	3,44	65,6	2,30	**0,24**	0,42	0,12
Simu 2	20,51	4,61	3,44	65,6	2,30	**0,26**	0,42	0,12
Simu 3	20,51	4,61	3,44	65,6	2,30	**0,26**	0,42	0,12
Simu 4	20,51	4,61	3,44	65,6	2,30	**0,25**	0,42	0,12

Table 5: **Simulation results (oven operating conditions of 02/08/2021 and 07/07/2020).**

	FUEL SUBSTITUTION RATE (%)				
	PKS BAF	**Cashew** BAF	**Shea cakes** BAF andnozzle	**Cotton waste** nozzle	**Petcoke**nozzle
02/08/2021	38%	3%		9%	50%
Simu 6	38%	12%			50%
Simu 7	38%				62%
07/07/2020			40%	17%	43%
Simu 8				17%	83%

	SIMULATION AND LABORATORY RESULTS ON CLINKER IN %							
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**
02/08/2021	20,91	4,95	3,32	65,08	2,49	**0,19**	0,36	0,11
Simu 6	20,91	4,95	3,32	65,08	2,49	**0,21**	0,36	0,11
Simu 7	20,91	4,95	3,32	65,08	2,49	**0,18**	0,36	0,11
07/07/2020	19,91	3,94	64,34	2,81	2,81	**0,51**	0,56	0,14
Simu 8	19,91	3,94	64,34	2,81	2,81	**0,44**	0,56	0,14

Table 6: Simulation results (furnace operating conditions on 23/07/2021).

	FUEL SUBSTITUTION RATE (%)				
	PKS BAF	**Cashew shell BAF**	**Used oil** nozzle	**Waste cotton nozzle**	**Petcoke** nozzle
23/07/2021	33%				67%
Simu 9	33%		15%		53%

	SIMULATION AND LABORATORY RESULTS ON CLINKER IN %							
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**
23/07/2021	20,51	4,61	3,44	65,6	2,29	***0,26***	0,42	0,12
Simu 9	20,51	4,61	3,44	65,6	2,29	***0,27***	0,42	0,12

Table 7: Limits of the material present in the lower stage of cyclone 4 (C4) [14].

	Normal limit	**Maximum limit**
$K_2Oeq=K_2O+1,5.\ Na_2O$	3,7%	6%
Chlorine as Cl^-	0,8%	2,0%
Sulfur SO_3	2,5%	5%

Table 8: Maximum tolerated intake of volatile components (preheater furnace) [15].

	Normal limit	**Maximum limit**
$Na_2O+0,\ 65.K_2O$	1%	1,5%
Chlorine as Cl^-	0,023%	0,023%
Sulphur in the forme of SO_3	1%	1,6%

Table 9: Process simulation of 29/06/2021.

29/06/2021		**SO_3** (%)	**K_2O** (%)	**Na_2O** (%)	**Cl** (%)	Débit (kg/h)	**Substitution rate**
Entry	**FLOUR**	0,07	0,38	0,16		107 000	
	Pet coke tuyère	0,94				6 968,0	**100%**
	TOTAL	**1**	**0,38**	**0,16**	**0**		
Output	**Clinker**	1,32	0,42	0,13			
	Dust	0,01	0,03	0,01			
	TOTAL	**1,33**	**0,45**	**0,14**	**0**		
Cyclone 4 (C4)		**1,595**					

Table 10: Volatile Component Input of 06/29/2021.

	Effective rate	**Maximum limit**	**Observation**
$Na_2O+0,\ 65.K_2O$	**0,41%**	1,5%	**good**
Chlorine as Cl-		0,023%	**good**
Sulfure as SO_3	**1%**	1,6%	**good**

Table 11: Volatile matter at C4 on 06/29/2021.

	Effective rate	**Maximum limit**	**Observation**
$K_2Oeq=K_2O+1,5.Na_2O$		6%	**good**
Chlorine as Cl^-		2,0%	**good**
Sulfure as SO_3	**1,60%**	5%	**good**

Table 12: Minor elements in clinker on 06/29/2021.

	Effective rate	Maximum limit	Observation
Na_2O+K_2O	**0,55%**	1,5%	**good**
Chlorine as Cl^-		0,1%	**good**
Sulfure as SO_3	**1,32%**	1,6%	**good**

Table 13: Evaporation coefficient of minor elements on 29/06/2021.

	Effective rate	**Maximum limit**	**Observation**
ε_{SO3}	$\mathbf{0,17}$	0,7	**good**

Table 14: Process simulation of 04/07/2021.

04/07/2021		**SO_3(%)**	**K_2O (%)**	**Na_2O (%)**	**Cl** (%)	**Flow rate (kg/h)**	**Substitution rate**
Entree	**Flour**	0,07	0,38	0,15		112 000	
	Petcoketuyère	0,66				4 913,3	**64%**
	PKS BAF	0,1	0,18	0,03	0,002	5 016,7	**36%**
	TOTAL	0,83	0,56	0,18	0,002		
Sortie	**Clinker**	0,8	0,34	0,13			
	Dust	0,07	0,33	0,1			
	TOTAL	0,81	0,38	0,14	0		
Cyclone 4 (C4)		**5,144**					

Table 15: Input of volatile components from 04/07/2021.

	Effective rate	Maximum limit	Observation
Na_2O+0, 65.K_2O	**0,54%**	1,5%	**good**
Chlorine as Cl-	**0,002%**	0,023%	**good**
Sulphure as SO_3	**0,83%**	1,6%	**good**

Table 16: Volatiles at C4 on 04/07/2021.

	Effective rate	Maximum limit	Observation
$K_2Oeq=K_2O+1.5.Na_2O$		6%	**good**
Chlorine as Cl^-		2,0%	**good**
Sulphur as $S0_3$	**5,14%**	5%	**bad**

Table 17: Minor elements in clinker on 04/07/2021.

	Effective rate	Maximum limit	Observation
Na_2O+K_2O	**0,47%**	1,5%	**good**
Chlorine as Cl^-		0,1%	**good**
Sulphur as $S0_3$	**0,8%**	1,6%	**good**

Table 18: Evaporation coefficient of minor elements on 04/07/2021.

	Effective rate	Maximum limit	Observation
ε_{SO3}	**0,84**	0,7	**bad**

Table 19: **Process simulation of 02/08/2021.**

	02/08/2021	SO_3(%)	K_2O (%)	Na_2O (%)	Cl (%)	Flow rate (kg/h)	Substitution rate
Entry	**flour**	0,65	0,39	0,11		107 000	
	Petcoketuyère	0,47				3 496,2	**50%**
	Waste cottontuyère	0,05	0,57	0,13	0,0006	1 223	**9%**
	PKS BAF	0,09	0,16	0,03	0,0016	4 476,2	**38%**
	Cashew shellBAF	0,02	0,05	0,01	0,0001	305,1	**3%**
	TOTAL	**1,28**	**1,17**	**0,28**	**0,0023**		
Output	**Clinker**	0,68	0,39	0,1			
	Dust	0,01	0,04	0,01			
	TOTAL	**0,69**	**0,43**	**0,11**			
Cyclone 4 (C4)		6,31					

Table 20: **Volatile Component Inputs from 02/08/2021.**

	Effective rate	Maximum limit	Observation
Na_2O+0, 65.K_2O	**1,04%**	1,5%	**good**
Chlorine as Cl-	**0,0023%**	0,023%	**good**
Sulfure as $S0_3$	**1,28%**	1,6%	**good**

Table 21: Volatile matter at C4 on 02/08/2021.

	Effective rate	Maximum limit	Observation
Chlorine as Cl^-		2,0%	**good**
Sulphur in the form of $S0_3$	**6,31%**	5%	**bad**

Table 22: **Minor elements in clinker (02/08/2021).**

	Effective rate	Maximum limit	Observation
Na_2O+K_2O	**0,49%**	1,5%	**good**
Chlorine as Cl^-		0,1%	**good**
Sulfur as $S0_3$	**0,68%**	1,6%	**good**

Table 23: Evaporation coefficient of minor elements on 02/08/2021.

	Effective	Maximum limit	Observation
ε_{SO3}	**0,89**	0,7	**bad**

Table 24: Current cost of clinker production according to fuels.

Substitution rate	**100% Fuel**	**100% Petcoke**	**67,5% Petcoke + 32,5 % AF**
Total cost (FCFA/t of kk)	35 774	9 637	**8 387**
Gain (FCFA/t of kk)	**1 250**		

Table 25: Cost of clinker production by 2023.

Substitution rate	**100% Fuel**	**100% Petcoke**	**50% Petcoke + 50% AF**
Total cost (FCFA/t of kk)	35 774	9 637	**7 889**
Gain (FCFA/t of kk)	**1 748**		

The graph below shows the savings from the thermal contribution of alternative fuels.

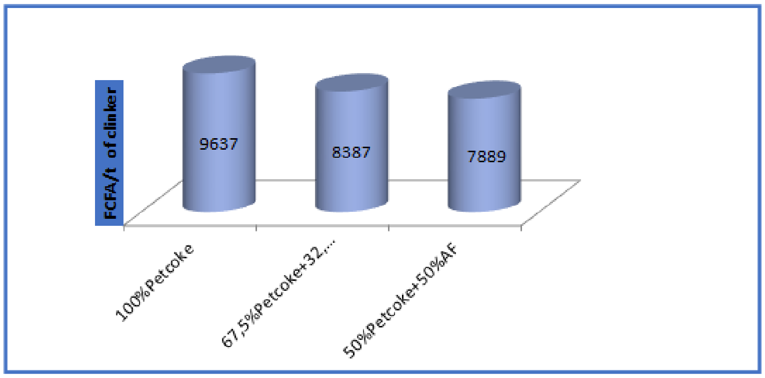

Fig. 5. Cost in CFAF/t of kk as a function of the FA substitution rate.

Analysis of the results

Study of the dosing systems for alternative fuels. From the analysis of Table 1, it should be noted that only 12.5% of the absolute errors on doser are acceptable. This justifies the instability of the clinker firing and can be explained by the cooling of the kiln or the overheating of the kiln. However, according to [13], any dosing unit with 50% of unacceptable errors must be downgraded in order to guarantee the quality of the finished product. From this statement, we propose that the volumetric fuel feeders alternative to SCB-LAFARCE should be replaced by weight feeders (weight belt feeder) because of the accuracy that this type of feeder offers.

Impacts of alternative fuels on the finished product

- Chemical and mineralogical composition of the clinker

After analyzing the results presented in Table 3, it can be seen that the three validation steps are met by the product simulation model. The discrepancy between the results of the simulation and those of the laboratory is justified by the following reasons: the discrepancy between the real phenomenon and the simulation model, the frequency of occurrence of errors on the alternative fuel dosers, the number of samples taken by the laboratory (09 per day on clinker, 02 on dust and 09 on flour) and the small variations observed on the chemical composition during the different analyses carried out during the day. This model was used to study the impact of alternative fuels on the quality of clinker by making several simulations.

- Finished product simulation

From the simulation results reported in Tables 4, 5 and 6 above, it should be noted that the replacement of 50% of the fossil fuels by alternative fuels in the raw meal to clinker process varies the SO_3 content of the clinker by 0.1%. In our work, a variation in the SO_3 content of clinker less than 5% of the amplitude of the range given for a Portland clinker (0 to 3% for SO_3) is considered negligible on the quality of clinker [14]. The results of our study (0.1% variation in SO_3 content) represent 3.33% of the amplitude of the tolerable range for Portland clinker (3%). However, 3.33% is less than 5%, so the impact on the product is considered negligible.

Impact of alternative fuels on the process

- *Minor components*

The minor components introduced into the process by the flour and fuels (fossil and alternative) can disrupt the operation of the process by an internal shrinkage in the kiln called ring and in the pre-chaser called concretion if their concentration is excessive. These minor components are usually potassium, sulfur, sodium and chlorine [15].

- *Permissible limits*

For a preheater cement kiln to operate without being disturbed by the concentration of minor components, it must meet the conditions presented in Tables 7 and 8.

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Process simulation

- *Process simulation of 29/06/2021*

The SO_3 content present at cyclone 4 is far below the maximum recommended threshold. The lower cyclone chutes and the smoke box are clean. The sulfur and alkali content in the clinker is well below the limit. The results of the simulation of 29/06/2021 show us that despite the excess of SO_3 (excess above the maximum limit) in the raw fuel mixture, the evaporation coefficient of SO_3 is below the minimum limit. The simulation results show us that despite the excess of SO_3 (excess above the maximum limit) in the raw fuel mixture, the SO_3 evaporation coefficient is lower than the minimum limit.

- ***Process simulation of 04/07/2021***

The SO_3 content in cyclone 4 is above the maximum recommended limit. Therefore, frequent blockages will occur if actions are not taken to regularly clean the lower cyclone chutes and the smoke box. The sulfur and alkali content in the clinker is well below the limit. The SO_3 evaporation coefficient (0.84) associated with the SO_3 content of C4 material tells us that there are major combustion problems in the smoke box.

- ***Process simulation of 02/08/2021***

The quantities of volatile materials brought into the furnace by the raw meal and the fuels are below the threshold. The SO_3 content in cyclone 4 is higher than the maximum recommended threshold. Frequent blockages will occur if action is not taken to regularly clean the lower cyclone chutes and the smoke box. The sulfur and alkali content in the clinker is well below the limit. The SO_3 evaporation coefficient (0.89) associated with the SO3 content of C4 material tells us that there are major problems of incomplete combustion at the smoke box.

Even with 36% alternative fuel (PKS only), we still have major combustion problems (evaporation coefficient equal to 0.84). The sulfur content of hot meal also exceeds the maximum limit.

From the 03 simulations performed above, we can see that the impact of alternative fuels on the process comes from the incomplete combustion of alternative fuels, which is the basis for the increase of the sulfur evaporation coefficient. The high sulfur evaporation coefficient is in turn responsible for the high SO_3 content in the hot meal that gives rise to the concretions.

Evaluation of the cost of production with the use of alternative fuels. The results presented in Table 24 show that the cost savings of substituting petcoke with alternative fuels at the ONIGBOLO plant are

1,250 FCFA per ton of clinker produced. The results presented in Table 25 show that in 2023, the savings that the ONIGBOLO plant could achieve by substituting 50% of fossil fuel represent 1,748 FCFA per ton of clinker produced, compared to 1,250 FCFA under the current operating conditions.

The partial substitution of alternative fuels in the cement industry presents a certain advantage in terms of energy savings. This is one of the main reasons for using waste as fuel in cement kilns. Thus, by 2023, (50% alternative fuel) the ONIGBOLO plant would save 498 FCFA per ton of clinker produced, taking as a reference the current situation where substitution is already 32.5%.

IV. CONCLUSION

This work was devoted to the study of the impacts of alternative fuels on the finished product and the process. After analyzing the results of the countermeasures carried out on the volumetric dosing systems of the alternative fuels, we finally opted for the weighted dosing systems. We also studied the impact of alternative fuels on the finished product and the process. This study showed that the alternative fuels used at SCB-LAFARGE have no impact on the quality of the finished product. On the other hand, the impact on the process revealed that they cause concretions in the preheater. We have focused on: monitoring the quality of the AF; regularly inspecting the smoke box and lower cyclone spouts and, if necessary, cleaning them; searching for alternative fuels; and modifying the AF tuyere. These points will make it possible to reduce the process impact and achieve the 2023 objective. We also evaluated the interest of increasing the substitution rate to 50%, i.e. 498 FCFA per ton of clinker produced, and proposed to encourage the collection of waste oils to reach a gain of 115 781 444 FCFA compared to the year 2020.

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