ENERGY SAVINGS IN CEMENT INDUSTRIES

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Abstract

Energy savings utilizing chemicals in cement production processes was the main objective in this paper. By using three mixtures; grinding aids mixture, fuel additives mixture, and pigments mixture, this objective was verified.

Grinding aids mixture which was locally manufactured was applied in three factories, allowed higher fineness, higher degree of hydration, increased the compressive strength of cement by (5% in factory"A",10% in factory"B",1% in factory"C"),and reduced the initial setting time by(34%in factory"A",17% in factory"C"), also increased the output in TPH(Ton per hour) by(22% in factory"A",7% in factory"B",20% in factory"C"). It reduced Blaine value by(19% in factory"A",7% in factory "B",15% in factory"C"). Fuel additives mixture can be added to heavy fuel oil to save fuel consumption, and pigment mixture can be used to color the cement properly in order to compete with other companies.

Key Words: Cement, Grinding Aids, Fuel Additives, Pigments, Blaine Value.

1. Introduction

Even though from a technical point of view the Portland cement production process is well defined worldwide, there is still an increased demand for high quality and high performances cements. This is mainly due to the urgent needs of cost and energy savings, both for economical and environmental reasons. In order to comply with the most advanced standard, during the last years the use of grinding aids has been spreading in several countries.

1.1 Grinding aids in cement production

The grinding process of cement absorbs 60-70% of the total energy employed. Finish grinding accounts for about 38% of specific electric power consumption. The quantity of energy required by the process to obtain the correct fineness is only partially employed for the creation of new surface: in fact most of the total energy is lost as heat. Grinding efficiency rapidly decreases as fineness increases, mainly due to the agglomeration between the finest particles (Heren, 1996).

Grinding aids are organic substances that are strongly adsorbed on the surface of ground particles, so that preventing agglomeration and coating on ball and mill lining. Thanks to their dispersing effect, grinding aids also increase the efficiency of air separators because the finest particles are not carried along with the largest. The result is a reduction of circulating load and an improvement of particle size distribution (Sottili, 2001.The advantages obtained by the use of grinding aids are the followings:

- Significant mill output increase at the same fineness. The increase in production can be used to reduce production costs or to cover market demand.- Fineness increase at equal output, or both effects. In some cases very high fineness may only be obtained by using grinding aids.

- Improved particle size distribution at equal fineness. It is well known that the particle size fraction between 3 and 30 μm is directly related to the strengths development and the fractions below 3 μm contributes to the early strengths. The use of grinding aids allows higher mechanical strengths to be obtained thanks to a positive influence on particle size distribution.
- Higher separator efficiency.
- Improved flow characteristics of the cement during transport, silo storage and during loading/unloading operations (Cella, 2001).

The improvement in cement performance and quality can be determined by two types of tests:

- Process tests: like mill output in (TPH).
- Quality tests: like strength, Blaine and Initial setting time tests.

By choosing an Ordinary Portland clinker as reference substrate, whose specific gravity is 3,11 g/cm3 and chemical composition, expressed in element oxides, is shown in Table **(**1.1)

Table (1.1): Chemical Composition of the Reference Portland Clinker

SiO2	Al2O3	Fe2O3	CaO	MgO	SO3	Na2O	K2O
25.21	5.13	3.97	59.99	1.29	1.32	0.25	0.64

Water is a decent GA, as it is known since a long time, but other components such as ethylene- and propylene-glycols or ethanol- and isopropyl-amines give a much larger contribute. Also PolyCarboxylic Acid Esters (PCAE), largely utilized as super plasticizers in concrete prove themselves as good GA. This lead to hypothesize that also the further contribution by small organic molecules such as alkanolamines and glycols does not come necessarly and only from a further electrostatic screening, but also from steric or chemical interactions with cement particles .

In summary, conventional grinding aids are used to increase the production rate in the cement mill. If such additions give beneficial chemical effects during hydration of the final cement (e.g. increased strength, improved workability etc.) the grinding aid is regarded as quality improver or performance enhancer. It is emphasized that several conventional grinding aids today are also claimed to give beneficial chemical effects to a certain extent.

1.2 Fuel additives in cement production

Fuel additives**:** are chemical substances or compounds added to gasoline, diesel, kerosene, and other fuels, it can be used in many applications to improve certain properties, enhance quality and efficiency of fuels used in the motors.

Fuel additives are formed by:

1. Aqueous solution of one metallic component.

2. Organic metallic and inorganic metallic in solution.

3. Extracting some of colloidal metallic component from aqueous solution using suitable hydrocarbon medium under controlled pH, temperature and time. For example**:** Gasoline additives increase gasoline's octane rating or act as corrosion inhibitors or lubricants, thus allowing the use of higher compression ratios for greater efficiency and power, however some carry heavy environmental risks. Types of additives include metal deactivators, corrosion inhibitors, oxygenates and antioxidants (Jerknavorian, 1998).Nitrous oxide, or simply nitrous, is an oxidizer used in auto racing.

1.3 Pigments in cement production

Pigments are materials used for coloring paint, ink, plastic, fabric, cosmetics, food and other materials. Most pigments used in manufacturing and the visual arts are dry colourants, usually ground into a fine powder. This powder is added to a vehicle (or binder), a relatively neutral or colorless material that suspends the pigment and gives the paint its adhesion **.**

Many materials selectively absorb certain wavelengths of light. Materials that humans have chosen and developed for use as pigments usually have special properties that make them ideal for coloring other materials. A pigment must have a high tinting strength relative to the materials it colors. It must be stable in solid form at ambient temperatures.

Pigments appear the colors they are because they selectively reflect and absorb certain wavelengths of light. White light is a roughly equal mixture of the entire visible spectrum of light. When this light encounters a pigment, some wavelengths are absorbed by the chemical bonds and substituents of the pigment and others are reflected. This new reflected light spectrum creates the appearance of a color. Pigments, unlike fluorescent or phosphorescent substances, can only subtract wavelengths from the source light, never add new ones .

The earliest known pigments were natural minerals. Natural iron oxides give a range of colors. Two examples include Red Ochre, anhydrous Fe_2O_3, and the hydrated Yellow Ochre ($Fe_2O_3 \cdot H_2O$) . Charcoal, or carbon black, has also been used as a black pigment since prehistoric times. Two of the first synthetic pigments were white lead (basic lead carbonate, $(PbCO_3)_2 \cdot Pb(OH)_2$) and blue frit (Egyptian Blue). White lead is made by combining lead with vinegar (acetic acid, CH_3COOH) in the presence of CO_2. Blue frit is calcium copper silicate and was made from glass colored with a copper ore, such as malachite .

Selection of a pigment for a particular application is determined by cost, and by the physical properties and attributes of the pigment itself. For example, a pigment that is used to color glass must have very high heat stability in order to survive the manufacturing process; but, suspended in the glass vehicle, its resistance to alkali or acidic materials is not an issue. In artistic paint, heat stability is less important, while light fastness and toxicity are greater concerns.

2. Theory

Most of the recent works on cement additives focused the attention on their effectiveness on cement performances in terms of mechanical and rheological properties. The ambition has been to watch deeply in the interface between the components of cement additive and the cement grain surface, in presence of small (cement grinding) and large (cement hydration) amount of water. So could assembly data concerning mill output (as a process parameter), (Strength, Blaine, Initial setting time of cement) as a quality parameters.

So the additives that were used in cement production, divided in two types:

1- Cement additives (like: grinding aids (GA) and pigments).

2- Fuel additives (like: jojoba oil, biodiesel, and alcohol….etc).

2-1 Grinding aids:

The introduction of GA, started more than 50 years ago, has as ultimate task the prevention of cement particle re-agglomeration during and after milling process. What make GA application even more desirable is their significant effects on mechanical properties of cement, whose particle size distribution results narrower and shifted towards shorter diameters. Their influence on cement chemico-physical behavior has been attributed to the reduction of surface energy forces generated on cement grains during comminution. GA are constituted of polar organic compounds such as alkanolamines, which arrange their dipoles so that they saturate the charges on the newly formed particle surface, reducing re-agglomeration.

2.2 Fuel additives:

Fuel additives that control deposits in the fuel system (fuel injectors, intake valves, combustion chamber) of internal combustion engines are produced from ethyleneamines as an example. Dispersant-detergent additives useful in gasoline are prepared with chlorinated polybutenes. Ethylenediamine (EDA), Diethylenetriamine (DETA) and Aminoethylethanolamine (AEEA) have found significant commercial application as dispersant detergent additives for gasoline when made by this route (Dow, 1995-2012)

2.3 Pigments:

A pigment is a material that changes the color of reflected or transmitted light as the result of wavelength-selective absorption. This physical process differs from fluorescence, phosphorescence, and other forms of luminescence, in which a material emits light.Many materials selectively absorb certain wavelengths of light. Materials that humans have chosen and developed for use as pigments usually have special properties that make them ideal for coloring other materials. A pigment must have a high tinting strength relative to the materials it colors. It must be stable in solid form at ambient temperatures (Herbst, 2004).

For industrial applications, as well as in the arts, permanence and stability are desirable properties. Pigments that are not permanent are called fugitive. Fugitive pigments fade over time, or with exposure to light, while some eventually blacken.Pigments are used for coloring paint, ink, plastic, fabric, cosmetics, food and other materials. Most pigments used in manufacturing and the visual arts are dry colorants, usually ground into a fine powder. This powder is added to a vehicle (or binder), a relatively neutral or colorless material that suspends the pigment and gives the paint its adhesion .

A distinction is usually made between a pigment, which is insoluble in the vehicle (resulting in a suspension), and a dye, which either is itself a liquid or is soluble in its vehicle (resulting in a solution). The term biological pigment is used for all colored substances independent of their solubility. A colorant can be both a pigment and a dye depending on the vehicle it is used in. In some cases, a pigment can be manufactured from a dye by precipitating a soluble dye with a metallic salt. The resulting pigment is called a lake pigment.
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3. Procedure

3-1 Grinding aids:

1- The grinding aid was prepared at the industrial scale, the total produced grinding aids was 21 tons.
2- A special mixer the capacity of which 3 tons/hr was used in preparations.
3- The produced grinding aid was filled in barrels, the capacity of each barrels was 200 kg.
4- The barrels were transferred to the factories by certain vehicle.
5- The ball mill was operated for hours until it was stable.
6- The grinding aid was introduced to the mill using a dosing system for 24 hours as in the grinding protocol.
7- Samples were taken and analyzed.

8-Experiments were carried in the laboratories of factory B to enhance the color of cement.

9-The flow rate for the grinding aids was based upon (105 TPH) mill feeding rate.

Table **(**3-1) Dosing rate:

Dosage (ml/t cement)	Dosage (l/min)	Duration (hrs)
35 0	0.613	4
500	0.875	12
600	1.050	6

The test started at (10:00 am) as per the above dosing rates but with some deviation especially for the 350 ml/t dosage since the mill operating conditions were not stable , so this dose took around six hours before adjusting the pump to have the new dose.

10- As stated below the trial started at 10:00 am with the lowest dosage rate. The dosing pump was calibrated directly at the injection point (mill feed end chute) to get better accuracy for the dose.

Table **(**3-2**):** The actual dosing rate during the trial.

Dosage (ml/t cement)	Dosage (l/min)	Duration (hrs)
350	0.613	6
500	0.875	13
600	1.050	3

4. Methodology

- The grinding aids were introduced in the ball mill at a flow rate of 500 ml/hr for 24 hours, and samples were taken properly, and the analysis were
- carried out in the laboratories of the cement factories.
- The prepared log sheets for process parameters monitoring were filled under process team supervision.
- The prepared log sheets for both clinker and gypsum consumption were filled under process team supervision.

- Close monitoring for mill process parameters in cooperation with operation team from both CCR (Central Control Room) and onsite.
- Maintain stable operating conditions for the mill especially for the product fineness and see the possibility for feed rate increasing.
- Cooperate with quality team to collect and analyze product samples for each hour, and to inform process team in case of having any deviations.
- Calibration for the dosing pump after finishing each dose interval.
- After finishing the whole trial both process and quality data were collected and analyzed to end up with a trial report showing all trial features, results & recommendations.
- For Fuel additives; lab scale sample was prepared and tested in lab scale, then 2 tons of fuels were prepared and tested in the rotary kiln in cement industry.
- For Pigments; lab scale samples were prepared by mixing in lab scale then a sample of 2 tons was prepared to be tested in the factory.

5. Results

Part one: Grinding aids results.

Industrial Test :

- Factory "A":

Table **(5.1)** Process and Quality tests for cement without grinding aids.

Dose (ml)	Blaine	Strength(MPa/m^2)			TPH	Initial Setting time(min)
		2 DAYS	7 DAYS	28 DAYS		
0	4456	31.2	44.2	56.1	48	145
0	4400	32.2	45	57	50	120
0	4176	30	-	55.1	52	130
0	4420	31.6	-	56.6	48	130
0	4346	30.8	-	54.9	52	130
0	4325	31.8	-	55	52	155
0	4400	31.3	-	56.2	50	130
0	4780	31.7	-	56.5	45	135
0	4658	33.5	-	57.1	48	130
0	4700	31.7	-	57.5	45	120
0	4620	31.7	-	57.4	46	135
0	4750	32.3	-	56.5	45	130
0	4423	31.5	-	55	48	120

0	4488	31.61	44.6	56.16	48.64	131.1

Table (5.2) Process and Quality tests for cement with grinding aids. .

Hour	Dose **(ml)**	BLAINE	Strength (MPa/m^2)				TPH	Initial Setting time(min)
			1DAY	2 DAYS	7 DAYS	28 DAYS		
04:00	500	3747	24.7	32.7	45.6	60	60	85
09:00	600	4032	25.8	36.4	48.4	57.1	60	85
12:00	600	4702	28.5	38.20	49.50	58.40	60	95
23:00	600	4660	27.1	35.10	49.80	58.40	60	80
01:00	600	4446	25.1	34.20	48.20	57.80	60	90

Table (5.3) Process and Quality tests for cement with certain doses of grinding aids..

Dose (ml)	Blaine	Strength(MPa/m^2)			TPH	Initial Setting Time(min)
		2 DAYS	7 DAYS	28 DAYS		
0	4488	31.99	44.6	57	49	129
500	3747	32.7	45.6	60	60	85
600	4460	35.98	48.98	58	60	87.5

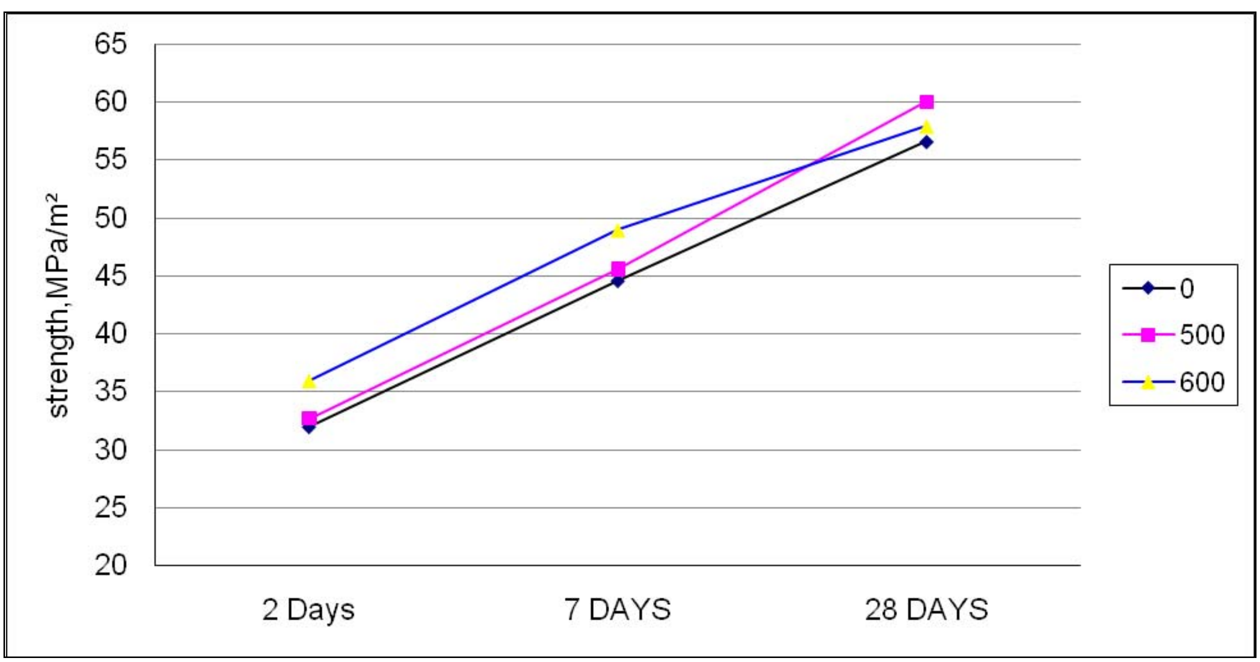

Fig. (5.1)The relationship between the strength of cement and the time of rigidity at different doses of grinding aids.

At (500) ml :

- Blaine reduced by19%
- 28 days strength increased by 5%
- TPH increased by 22%
- Initial setting time decreased by34%

➢ Factory "B":

Table (5.4) Quality tests before and after grinding aids addition.

Date	Time	Dose ml/t cement	Residue 45 µm (%)	Blaine cm^2/g
1/6/2010	10:00	0	7.04	3300
1/6/2010	11:00	350	5.08	3400
1/6/2010	12:00	350	6.96	3206
1/6/2010	14:00	350	4.48	3503
1/6/2010	16:00	500	3.2	3560
1/6/2010	21:00	500	3.3	3577
1/6/2010	22:00	500	3.5	3524
1/6/2010	23:00	500	3.7	3668
1/6/2010	00:00	500	3.1	3587
1/7/2010	01:00	500	3.3	3418
1/7/2010	02:00	500	3.5	3607
1/7/2010	03:00	500	3.9	3587
1/7/2010	04:00	500	3.3	3566
1/7/2010	05:00	500	3.8	3628
1/7/2010	06:00	500	3.8	3545
1/7/2010	07:00	500	3.8	3545
1/7/2010	09:00	500	3.5	3352
1/7/2010	10:00	600	3.1	3566
1/7/2010	11:00	600	3.9	3640
1/7/2010	13:00	600	3.1	3493
Average			3.97	3514

Table (5.5) 2 and 7 days compressive strength results.

Dosage rate (ml/t cm)	2 day strength (Mpa/m^2)	7 days strength (Mpa/m^2)
0	23.5	37.1
350	25.4	39.2
500	25.4	40.2
600	25.8	41.3

Table (5.6) Process tests without grinding aids addition.

Date	Mill feed rate t/h	Main drive power kW	Sonic level %	Product bucket A	Separator speed rpm	Blaine cm²/g
9/11/2009	107	4.50	30	100	1160	3450
10/11/2009	104	4.50	31	102	1150	3540
11/11/2009	103	4.40	30	92	1150	3500
12/11/2009	105	4.50	30	85	1155	3500
13/11/2009	105	4.45	30	90	1150	3550

Table (5.7) Process tests during 350 ml/t dose.

	Date: 6/1/2010					
	Grinding aids dosage : 350 ml/t					
Time	Mill feed rate t/h	Main drive power kW	Sonic level %	Product bucket A	Separator speed rpm	Blaine cm²/g
10:00	110	4.58	33.9	87	1080	3300
11:00	116	4.53	30.3	101	1100	3400
12:00	110	4.48	30.5	125	1100	3200
13:00	107	4.45	32.3	118	1150	3500
14:00	106	4.45	29.9	128	1170	3500
15:00	101	4.40	31.5	102	1170	3500

Table(5.8) Mill production & power consumption during 350 ml/t dose.

Material consumption (tons) at 350 ml/t dose	
Clinker	Gypsum
605.78	38.78
Power consumption (kWh) at 350 ml/t dose	
Main drive	The whole shop
26,769	32,558

Table (5.9) Process tests during 500 ml/t dose (6/1/2010).

	Date: 6/1/2010					
	Grinding aids dosage : 500 ml/t					
Time	Mill feed rate t/h	Main drive power kW	Sonic level %	Product bucket A	Separator speed rpm	Blaine cm²/g
21:00	103	4.45	32	94	1150	3577
22:00	100	4.00	34	91	1160	3524
23:00	100	4.45	33	95	1160	3668

0:00	103	4.47	32	96	1150	3590

Table (5.10) Process tests during 500 ml/t dose (7/1/2010).

	Date: 7/1/2010 Grinding aids dosage : 500 ml/t					
Time	Mill feed rate t/h	Main drive power kW	Sonic level %	Product bucket A	Separator speed rpm	Blaine cm²/g
1:00	103	4.52	32	103	1130	3420
2:00	101	4.48	32	104	1140	3608
3:00	104	4.41	32	98	1150	3590
4:00	103	4.47	32	105	1140	3570
5:00	104	4.53	33	102	1140	3630
6:00	106	4.44	32	98	1130	3550
7:00	106	4.42	32	88	1140	3550
8:00	106	4.48	31	101	1140	3570
9:00	104	4.46	30	109	1140	3570

Table (5.11) Mill production & power consumption during 500 ml/t dose.

Material consumption (tons) at 500 ml/t dose	
Clinker	Gypsum
1244.5	80
Power consumption (kWh) at 500 ml/t dose	
Main drive	The whole shop
57,336	69,440

Table (5.12) Process tests during 600 ml/t dose.

	Date: 7/1/2010 Grinding aids dosage : 600 ml/t					
Time	Mill feed rate t/h	Main drive power KW	Sonic level %	Product bucket A	Separator speed rpm	Blaine cm²/g
10:00	104	4.43	31.1	107	1150	3560
11:00	104	4.48	30.9	110	1160	3560
12:00	104	4.43	30.4	112	1160	3640
13:00	104	4.40	30.6	112	1160	3490

Table (5.13) Mill production & power consumption during 600 ml/t dose.

Material consumption (tons) at 600 ml/t dose	
Clinker	Gypsum
323	22.5
Power consumption (kWh) at 600 ml/t dose	
Main drive	The whole shop
14,395	17,498

Table (5.14) Process parameters /final trial results

Dose (ml/t)	Running hours (hrs)	Production (T)	Production (TPH)	MD power (kWh)	MD SPC (kWh/t)	Shop power (kWh)	Shop SPC (kWh/t)
350	6	644.3	107.4	26,769	41.5	32,558	50.5
500	12.8	1324.5	103.5	57,336	43.3	69,440	52.4
600	3.3	345.5	104.7	14,395	41.7	17,498	50.6

- This experiment was repeated 8 months later, and it turned out to be that 7% improvement in the output of the mill was achieved.
- The output was 78 tons/hour without grinding aids and with grinding aids was 84 tons/hour.
- An improvement in the cement 7 days strength was around 10%. .
- An improvement in cement size distribution was noticed through the residue on 45 μm analysis that reduced by 4%.
- Blaine value reduced by 7%.

➢ Factory "C" :

- The Output of mill without grinding aid was 18 ton/hour, and with grinding aid was 21.6 ton/hour. That means the output increased by 20%.
- Strength increased by1%
- Blaine reduced by15%
- Initial setting time decreased by 17%

Part two : fuel additives cost analysis.

6. Discussions

- The efficiency of grinding process is directly affected by grinding aid percentage, so that this effect was studied as shown in the previous table and figures.
- All the industrial tests of grinding aid were carried out and analyzed in Jordanian cement factories.
- The process and quality tests for cement were analyzed and both results were represented in table (2)without grinding aid , table (3) with grinding aid that were included the results of output in TPH as a process test ,then the results of quality tests such as (strength ,Blaine and initial setting time tests).

- By comparison between these results of table(2) and table(3),the table (4) results were listed ,it can be observed that the results with certain doses of grinding aid were good, especially at (500)ml of grinding aid additive per ton, the output in TPH increased by (22%),then the maximum strength of cement with grinding aid after 28 days was obtained, it was (60) MPa/m^2 so that mean the strength of cement increased by (5%),and it was better than (600)ml/ton dose because it caused a reducing in 28 days strength , for this reason (500)ml/ton was considered as an optimal dose for addition as shown in figure (5.1).

- The same experiment was repeated in factory B and factory C and it gave good results in all industrial tests, (7%) improvement in output of mill and (10%) improvement in 7 days strength of cement were achieved in factory B, as shown in table (5-9). Then it could be clearly noticed from table(5-10) that the improvement was on the cement size distribution (reducing residue on 45μm) since it was around 7% before the trial and reached to 3.9% during the trial. This resulted from the fact that the grinding aids reduce the cement agglomeration before entering to the separator which shall also slightly improve the cement early strength (1, 2 days).
- At 350 ml/ton, it was noticed that the mill feed rate at(11:00) was(116 ton/hr) and at (15:00) after noon it was(110 ton/hr) this means that the mill was over filled with almost(16 ton) more. The Chinese made new calibration for the weigh feeders and didn't operate the mill to set the reference point, and they started with high rate(110-116ton/hr), while the capacity of the mill was (100ton/hr), this mean that the mill was over filled and the feed rotated with the mill.
- At 500 ml/ton, it was noticed that the mill feed rate at(1:00) was(103 ton/hr) and at (2:00) after noon it was(101 ton/hr) this means that the mill was over filled with almost(2 ton) more. The Chinese made new calibration for the weigh feeders and didn't operate the mill to set the reference point, and they started with high rat(101-103ton/hr), while the capacity of the mill was (100ton/hr), this mean that the mill was over filled and the feed rotated with the mill.
- In factory C the improvement in output was (20%) ,and improvement in strength was (1%).
- The economics of fuel additives mixture production have taken big attention with the increase of crude oil price in the world, in this project the total cost of fuel additives was calculated and equal (1.46)JD/L. Then as a result of using fuel additives, it can reduce burning temperature in chamber, improve internal combustion in engine,

6. Conclusions and Recommendations

6.1 Conclusions

1. The grinding aids addition trials took place to improve cement mill productivity and product quality.
2. There was a significant impact on the mill production rate even during the optimal grinding aid dosing rate (500ml/ton) , taken into consideration all cement mill feeders were well calibrated before the trial, then the output in TPH was increased by (22% in factory"A",7% in factory"B",20% in factory"C").
3. The compressive strength of cement was increased after grinding aid addition by (5% in factory"A",10% in factory"B",1% in factory"C").
4. The Blaine value of cement was reduced after grinding aid addition by (19% in factory"A", 15% in factory"C").

5. The initial setting time was reduced after grinding aid addition by (34%in factory"A", 17% in factory"C").
6. The grinding aid addition reduced the power consumption by almost (10-15) %.
7. The aim of grinding clinker with grinding aid was to increase the efficiency of grinding by avoiding the accumulation of cement or clinker around ball mills.

1- Applying the grinding aids after the chinese hand over the factory B, since many obstacles were created by them in the course of experimenting the grinding aids.
2- For the factory C, it is recommended to use a strength enhancer to increase the strength of white cement.

6.2 Recommendations

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