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OPERATIONAL PERFORMANCE OF A CONVENTIONAL TWO-COMPARTMENT BALL MILL GRINDING CIRCUIT AT DIFFERENT CEMENT PRODUCTIONS

KONVANSİYONEL İKİ KAMARALI BİLYALI DEĞİRMEN ÖĞÜTME DEVRESİNİN FARKLI ÇİMENTO ÜRETİMLERİNDE İŞLETME PERFORMANSI

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ABSTRACT

The purpose of the study is to assess the grinding and classification performance of a conventional Polysius® two-compartment ball mill and a Sepol® dynamic air classifier closed circuit process at Portland CEMI/42.5R and Portland composite CEMII/32.5R cement production types. For this purpose, industrial scale sampling surveys were performed around the circuit. JKSimMet Steady State Mineral Processing Software was used to perform mass balance around the circuits. Size reduction performance of the ball mill was determined for the sampling cases. Classification performance of the dynamic air classifier was evaluated based on the efficiency curve approach. It was determined that, approximately 12% circuit capacity increase could be achieved in composite cement production when ball mill, ball mill filter and air classifier power consumptions were considered. This figure corresponded to overall energy savings of 7% in ball mill grinding.

Anahtar Sözcükler:
Öğütme,
Bilyalı değirmen,
Havalı sınıflandırıcı,
Çimento,
Enerji.

ÖZ

Bu çalışmanın amacı, konvansiyonel Polysius® iki kamaralı bilyalı değirmen ve Sepol® dinamik havalı sınıflandırıcı kapalı devre işleminin Portland CEMI/42.5R ve Portland kompoze CEMII/32.5R çimento üretimlerinde öğütme ve sınıflandırma performanslarının değerlendirilmesidir. Bu amaçla, devre etrafında endüstriyel örnekleme çalışmaları yürütülmüştür. JKSimMet Cevher Hazırlama Yazılımı ile devre etrafında madde denkliği yapılmıştır. Bilyalı değirmenin boyut küçültme performansı örnekleme dönemleri için belirlenmiştir. Dinamik havalı sınıflandırıcının sınıflandırma performansı verimlilik eğrisi yaklaşımına göre değerlendirilmiştir. Bilyalı değirmen, bilyalı değirmen filtresi ve havalı sınıflandırıcı enerji tüketimleri düşünüldüğünde, kompoze çimento üretiminde devre kapasitesinde yaklaşık olarak %12'lik bir artış sağlanabilmektedir. Bu değer, bilyalı değirmen öğütmesinde %7'lik bir enerji tasarrufuna karşılık gelmektedir.

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INTRODUCTION

World's cement production was recorded to be 4200000 million ton/year and Turkey has a share of 77000 ton/year. Turkey is ranking in the 4th row within the countries producing cement in the world (United States Geological Survey, 2016). The cement industry is energy intensive which consumes approximately 12-15% of total industrial energy use (Madlool et.al., 2011). Finish grinding of cement requires approximately 40% of the total electrical energy consumed in a cement plant (Norholm, 1995). In this respect, energy efficiency of finish grinding stage will save significant amount of energy. Thus, ways to improve cement grinding efficiency should be searched out. Useful insights could be obtained from industrial scale applications and production efficiencies for energy saving or more energy efficient production rates (Benzer, et.al., 2001; Genç et.al., 2006; 2008; Aydoğan and Benzer, 2011; Dundar et.al., 2011; Genç and Benzer, 2012; 2016).

In this study, production performance and energy consumptions of industrial cement grinding circuit were analysed when CEMI/42.5R type Portland and CEMII/32.5R type Portland composite cements were produced in the circuits. It was demonstrated that, CEM II type Portland composite cement production provided overall energy savings of 7% with the applied circuit flow configuration.

1. MATERIALS AND METHODS

1.1. Materials

CEMI/42.5R Portland cement was obtained by grinding Portland cement clinker and mineral additive material gypsum ($CaSO_4{:}2H_2O$). Portland cement clinker is a black nodular hydraulic material, made by burning in a rotary kiln (pyroprocessing), at least to sintering a precisely specified mixture of raw materials containing CaO, SiO_2, Al_2O_3 and Fe_2O_3 at temperatures of about 1400^{o}C (Hewlett ,2010). Portland composite cement (CEMII/32.5R) was obtained by grinding clinker, gypsum and natural puzzolanic material which is called trass. Pozzolana is a siliceous and aluminous material that contains volcanic material such as pumice or volcanic ash. Trass effects several properties of cement mortar and cement clinker significantly such as strength, setting time, the amount of C_3S ($3CaO.SiO_2$) (alite mineral) and durability, depending on the their substitution ratio and fineness. In the investigated circuit, fly ash was added to air classifier feed stream directly due to its fineness in Portland composite cement (CEMII/32.5R) production case. Fly ash is a puzzolanic material and it is a by-product of burning pulverized coal in an electrical generating power station. It is collected from the exhaust gases by mechanical and electrostatic precipitators. It improves the long-term strength and reduces the permeability of the concrete (Thomas, 2007).

1.2. Plant-site Studies

Figure 1 shows the circuit flowsheet with the sampling points for the (CEMI/42.5R) Portland cement production case. Polysius® two-compartment ball mill and a Polysius® Sepol® dynamic high efficiency air classifier were operated in closed circuit to obtain the required cement types.

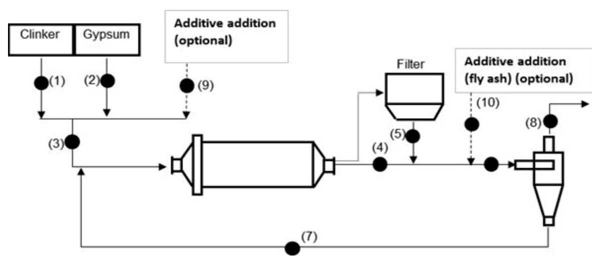

Figure 1. Simplified flowsheet of the industrial scale cement production circuit

Sampling points correspond to the following streams in Figure 1:

(1) Clinker feed
(2) Gypsum feed
(3) Total fresh feed
(4) Mill overflow
(5) Filter return
(6) Air classifier (separator) feed
(7) Air classifier reject
(8) Air classifier fine
(9) Trass (in composite cement production)
(10) Fly ash (in composite cement production)

Sampling surveys at the cement plant were performed to characterize particle size distributions around the circuits and inside the mills at the steady state conditions at Portland cement (CEMI/42.5R) and Portland composite cement (CEMII/32.5R) production types.

Design specifications for the ball mill and air classifier are tabulated in Tables 1 and 2. An electrofilter at the discharge of the mill collects fine particles (100% -212µm in CEMI production and 100% -850µm in CEMII production) from the mill by air sweeping. The circuit was operated without grinding aid in survey-1. However, grinding aid was added to the mill when trass and ash were added to the process in survey-2. Fly ash was added to the air classifier feed stream in survey-2. Samples were collected from the streams shown in Figure 1 at the steady state condition of the circuits at both cement production types.

Table 1. Polysius® two-compartment ball mill specifications

Parameter	Value
Diameter (m)	4.8
Compartment-1 length (m)	4.25
Compartment-2 length (m)	10
Mill motor (kW)	5200
Mill revolution (rpm)	14.87
Critical speed (%)	77.02
Volumetric air flowrate (m^3/h) at 100% fan opening	65000
Ball load (%) (compartment-1)	32.3
Ball load (%) (compartment-2)	31.2

Table 2. Air classifier design and operational specifications

Air classifier brand	Sepol® NSV310/4
Diameter (mm)	3100
Revolution of motor (rpm)	251.13
Revolution of rotor (rpm)	31
Number of cyclones	4
Pressure increase (mbar)	38.1
*Air flowrate, Q (Bm^3/h)	254107

*Bm^3 /h: Cubic meter at operating pressure

1.3. Mill Inside Sampling Survey

Ball mill was crashed-stopped for inside mill sampling in survey-1 after completing of the circuit sampling. Both compartments of the ball mill were sampled by approximately 1meter along the long axis of the mill from an approximate depth of 40cm below the mill ball charge level. Mill inside sampling locations are tabulated in Table 3.

Table 3. Measured mill inside sampling locations in grinding compartments 1 and 2 in survey-1 (CEMI/42.5R Portland cement production)

Compartment-1 axial length (m)	Compartment-2 axial length (m)
0 (compartment inlet)	0 (compartment inlet)
1.2	1
2.4	2
3.6	3
4.8	4
	5
	6
	7
	8
	9
	10

1.4. Material Characterization

1.4.1. Particle Size Distribution

Particle size distributions of the samples were determined by dry sieving from the top size which was 50mm down to 150µm. Sub-sieve sample of -150µm material was dry sized down to 1.8µm by using a Sympathec® laser diffractometer. Ro-tap screening and laser sizing results were mathematically combined to obtain the full size distribution from the top size down to 1.8µm.

2. RESULTS AND DISCUSSION

2.1. Mill Inside Granulometry

Measured mill inside particle size distributions are plotted in Figures 2 and 3 which shows the size reduction progress inside the mill. As the particle size distributions become finer towards the end of the compartment length, grinding performance increases. When the particle size distributions become coarser, grinding performance decreases within that segment of the mill due to operational conditions.

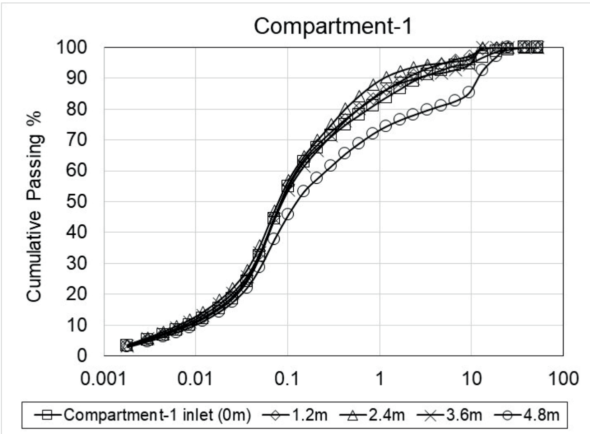

Figure 2. Mill inside particle size distributions in compartment-1

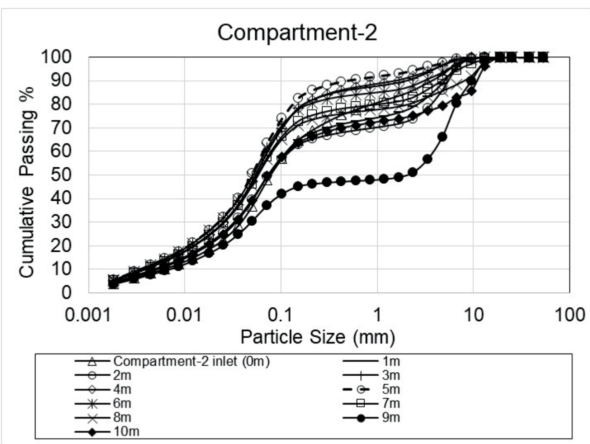

Figure 3. Mill inside particle size distributions in compartment-2

2.2. Mass Balance Calculations Using JKSimMet Software

Mass balance of the circuits were performed to estimate statistically adjusted tonnage flowrates and particle size distributions by using the mass balance module of the JKSimMet Mineral Processing Simulator. Calculated (mass balanced) tonnage flowrates and fineness values are given in Figures 4 and 5. Agreement between the experimental and calculated particle size distributions are shown in Figures 6 to 8. A comparison for ball mill feed and discharge particle size distributions is given in Figure 9. A very good agreement was obtained which indicated a successful sampling operation in each survey. Hence, mass balanced values could be used in performance evaluation study.

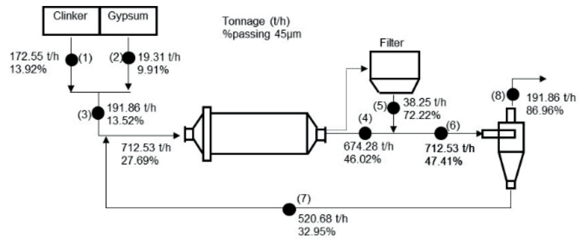

Figure 4. Mass balanced flowsheet of the sampled circuit in CEMI/42.5R Portland cement production (survey-1)

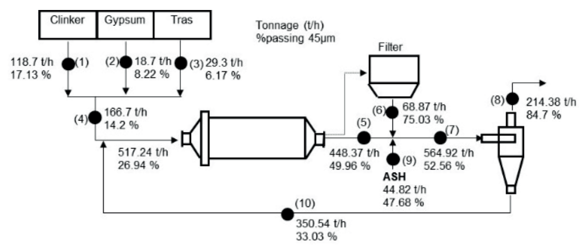

Figure 5. Mass balanced flowsheet of the sampled circuit in CEMII/32.5R Portland composite cement production (survey-2)

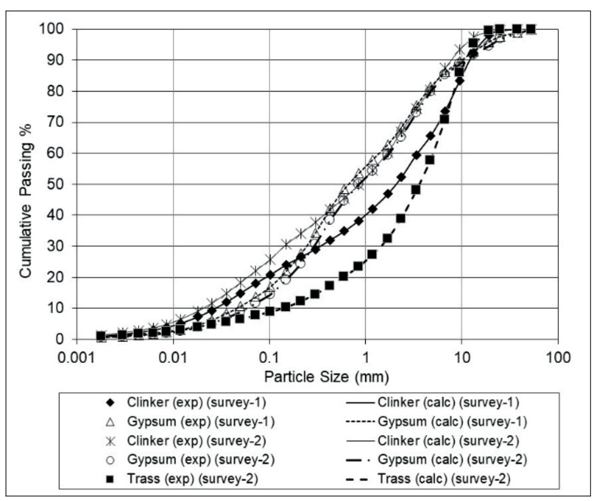

Figure 6. Experimental and calculated particle size distributions of circuit fresh feed materials in survey-1 and survey-2

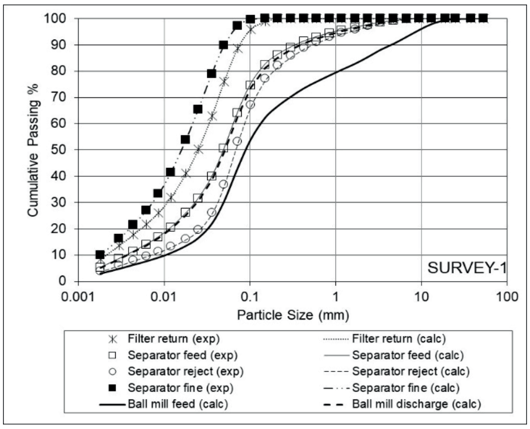

Figure 7. Experimental and mass balanced particle size distributions around the circuit in CEMI/42.5R Portland cement production (survey-1)

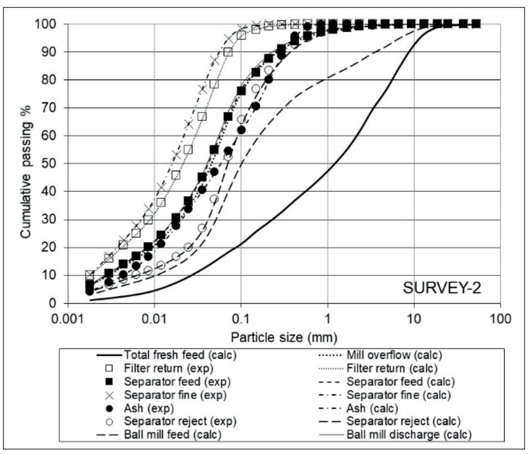

Figure 8. Experimental and mass balanced particle size distributions around the circuit in in CEMII/32.5R Portland composite cement production (survey-2)

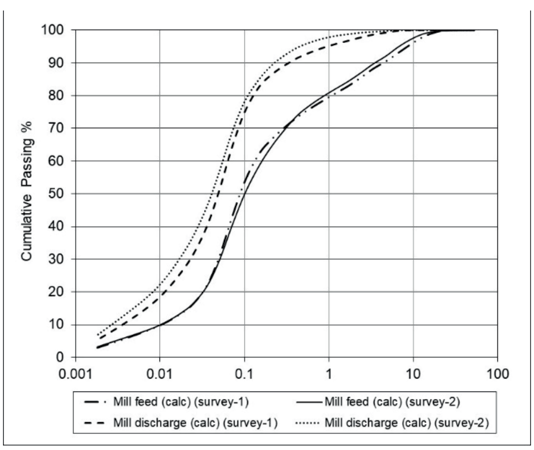

Figure 9. Ball mill feed and discharge particle size distributions in survey-1 and survey-2

2.3. Size Reduction Performance

Cumulative 90%, 80% and 50% passing sizes which are x_{90}, x_{80} and x_{50} sizes of the mill inside samples respectively are determined to evaluate the size reduction progress along the long axis of the compartments. Mill inside sampling was not performed in survey-2 due to the operational conditions. Results are tabulated in Table 4 for survey-1. Mill inside fineness variation was characterized by the variation of x80 and x50 particle sizes along the long axis of the mill. Variations are shown in Figures 10 and 11.

Table 4. x_{90}, x_{80} and x_{50} sizes for mill inside samples in compartment-1 and 2 in survey-1

Sampling location	x_{90} (mm)	x_{80} (mm)	x_{50} (mm)
0m (compartment-1 inlet)	2.75	0.74	0.086
1.2m	1.90	0.57	0.085
2.4m	1.10	0.42	0.080
3.6m	2.40	0.57	0.086
4.8m	11.80	3.50	0.125
0m (compartment-2 inlet)	3.70	0.85	0.077
1m	5.00	2.60	0.074
2m	5.50	3.60	0.073
3m	2.00	0.17	0.054
4m	1.50	0.17	0.055
5m	0.45	0.13	0.049
6m	3.00	0.19	0.050
7m	4.50	0.90	0.056
8m	8.00	2.10	0.057
9m	9.50	6.50	2.000
10m	10.70	5.00	0.073

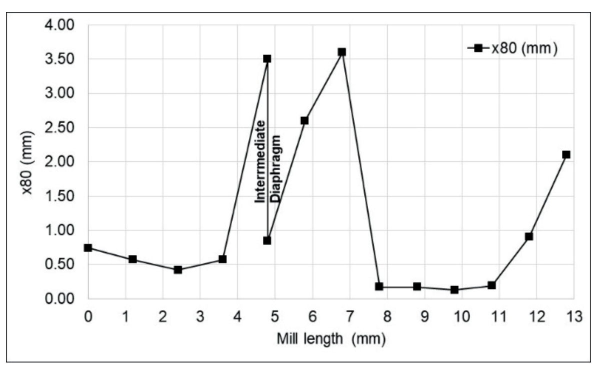

Figure 10. x_{80} size variation along the mill length (survey-1/CEM I production)

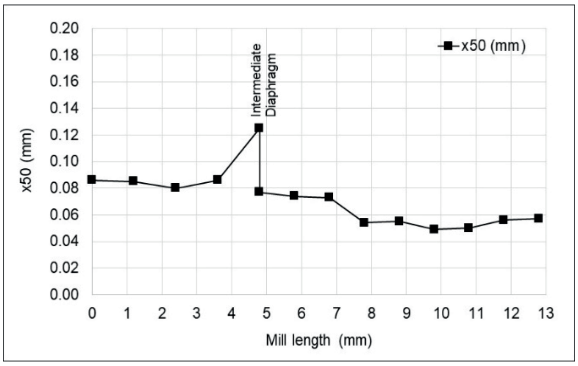

Figure 11. x_{50} size variation along the mill length (survey-1/CEM I production)

A consistent size reduction was observed in the first 2.4meters of the compartment length when x_{80} size of the mill inside particle size distributions were considered (Figure 10). Accumulation of coarse particles were increased at the rest of the compartment-1 length due to the screening effect. At coarse size ranges which is indicated by the x_{80} particle size, coarse particle accumulation was observed in the first 2meters and in the last 2meters of the compartment-2 length. Inefficient grinding conditions in the first 2 meters of the compartment-2 length could be attributed to the ball size classification inside the mill. Balls in the second compartment should be classified from coarser to finer due to the classifying liner effect. That's why, ball size classification and liner conditions (i.e. abrasion, damage etc.) should be checked systematically during production and necessary maintenance should be performed. A rapid size reduction was observed at the 7.8meters of the mill length. However after this point, a considerable size reduction could not have been observed. It could be concluded that, size reduction performance in the second compartment was very low at coarse size ranges.

A consistent size reduction was determined in the first 2.5meters of the first compartment on the basis of the x_{50} particle size (Figure 11). However, x_{50} size started to increase after the 2.4meters of the compartment length due the screening effect of the intermediate diaphragm. As the material was screened on the intermediate diaphragm, coarser particles were rejected back into the compartment-1. That's why particle size distributions became coarser at the end of the first compartment. Consistent size reduction was observed in the second compartment up to the 11th meters of the mill length. However, size reduction performance was decreased at the rest of the mill length. As similar to the case in compartment-1 due to the screening effect of the discharge diaphragm, particle size distributions became very coarse towards the end of the second compartment which corresponded to the length of last 1meter of the second compartment. Size reduction performance was determined to be very low at fine size ranges which was assummed to be represented by the median size (x_{50}) of the mill inside size distributions.

Size reduction (F_n/P_n) determined according to x_{90}, x_{80} and x_{50} particle sizes for compartments 1 and 2 in survey-1 (n=90, 80, 50) are given in Table 5. x_{90}, x_{80} and x_{50} particle sizes of mass balanced mill feed and discharge size distributions are given in Table 6 for the determination of the overall size reduction performance of the ball mills. Size reduction ratios are tabulated in Table 7. Size reduction performance in compartment-2 was determined to be higher than that of the compartment-1. Mass balance calculations showed that, mill throughput rate was 712.53t/h in survey-1 (when grinding aid was not added).

Table 5. Size reduction (F_n/P_n) determined according to x_{90}, x_{80} and x_{50} particle sizes for compartments 1 and 2 in survey-1 (n=90, 80, 50) (C-1: Compartment-1, C-2: Compartment-2, MD: Mill Discharge)

	Mill feed	C-2 inlet (0m)	Mill feed	C-2 inlet (0m)	Mill feed	C-2 inlet (0m)
	F_{90} (mm)	P_{90} (mm)	F_{80} (mm)	P_{80} (mm)	F_{50} (mm)	P_{50} (mm)
C-1	4.2	3.7	1.05	0.85	0.086	0.077
F_n/P_n	1.1		1.2		1.1	
	C-2 inlet (0m)	MD	C-2 inlet (0m)	MD	C-2 inlet (0m)	MD
C-2	3.7	0.34	0.85	0.126	0.077	0.048
F_n/P_n	10.9		6.7		1.6	

Table 6. x_{90}, x_{80} and x_{50} particle sizes of mass balanced mill feed and discharge size distributions

Characteristic size	Survey-1	Survey-2
Feed F_{90} (mm)	4.200	3.500
Discharge P_{90} (mm)	0.340	0.230
Feed F_{80} (mm)	1.050	0.800
Discharge P_{80} (mm)	0.126	0.110
Feed F_{50} (mm)	0.086	0.097
Discharge P_{50} (mm)	0.048	0.040

Table 7. Overall size reduction (F_n/P_n) determined according to x_{90}, x_{80} and x_{50} particle sizes (n=90, 80, 50)

Sampling Surveys	F_{90}/P_{90}	F_{80}/P_{80}	F_{50}/P_{50}
Survey-1	12.4	8.3	1.8
Survey-2	15.2	7.3	2.4

However, it was calculated as 564.92t/h when grinding aid was added. Circulating load ratio of the mill was decreased from 271% to 164% in survey-2. Size reduction ratio (SRR) based on x_{90} and x_{50} sizes were increased. SRR of x_{80} size was decreased slightly which is not significant. Consequently, we could say that, SRR was increased in grinding aid addition case. Overall size reduction performance of the mill was improved at CEMII type Portland cement production. This achievement lead to the increase in circuit throughput rate. By this way, circuit capacity was increased. The same circuit could be operated at a 12% higher capacity value by using grinding aid at CEMII type Portland cement production. Grinding aid should be applied to ease the grinding of trass in the mill which increases the production capacity. Energy consumptions of the ball mill are compared for the sampling surveys in Table 8. According to these figures 7% energy saving was attained in survey-2.

Table 8. Energy consumptions of the ball mill during sampling surveys

Operational parameters	Survey-1	Survey-2
Circuit capacity (t/h)	191.86	214.38
Operational ball mill motor power (kW)	4580.00	4785.51
Energy consumption (kWh/t)	23.87	22.32

1.4. Classification Performance of the Sepol® Dynamic Air Classifier

The Sepol® high efficiency separator (air classifier) has a high availability, high selectivity, low specific energy consumption, short amortization period and relatively capital cost. Sepol®SV (Standard Version) is equipped with cyclones which collect fine material. There is filter which dedusts the separator. The central material feed provides uniform material distribution and achieves effective utilization of the separation area. The separating air stream is produced by an external fan and fed to the separating chamber through a spiral-shaped duct. The material is separated into fine and coarse fractions in the separating chamber due to the action of gravitational and airflow forces. Guide vanes at the outlet of the spiral maintain the swirl of the air stream. Rotor blades prevent coarse material from entering the interior of the rotor. The coarse material falls into the grit cone and is returned to the grinding process. The fines are carried by the separating air into the interior of the rotor and are sucked downwards and then carried to the fines collectors (cyclones). Utilization of the gravitational force significantly reduces the energy requirement of the machine. The dedusted separating air stream is returned to the fan. The fineness and granulometric composition of the finished material (product) can be varied over a large range, primarily by altering the rotor speed and secondarily by controlling the separating air flowrate (Polysius Co., 2018) Efficiency or partition (Tromp) curves were plotted to determine the classification performance of the Sepol® dynamic air classifier in the sampling surveys. The tromp curve indicates the probability of a particle in the air classifier feed that will be returned to the mill (Genç and Benzer, 2017). Partition coefficients were calculated from Equation 2.1 to plot the efficiency curves.

$$\text{Partition coefficient} = \frac{Uu}{Ff} \times 100 \quad (2.1)$$

U :Air classifier reject flowrate (t/h)
F :Air classifier feed flowrate (t/h)
u :Percentage of particle size i in an air classifier reject stream (%)
f :Percentage of particle size i in an air classifier feed stream (%)

Sepol® air classifier feed size distributions are compared in Figure 12 for the sampling surveys. It was determined that, feed size distribution of the air classifier became slightly finer in survey-2. Efficiency curves for the air classifier are given in Figure 13. Performance parameters of the efficiency curves are tabulated in Table 9. Cut size or separation size (d_{50}) defines the size for which 50% of the particles in the feed report to the underflow stream (Svarovsky, 1984). By-pass represents the percentage of feed material reporting to air classifier reject without classification. Fish-hook parameter represents the difference between the maximum percentage of fine material amount that appears in underflow of the air classifier and the by-pass percentage. As the fish-hook and by-pass amount decrease, separation performance increases. Perfect separation can be achieved with zero fish-hook and by-pass amount.

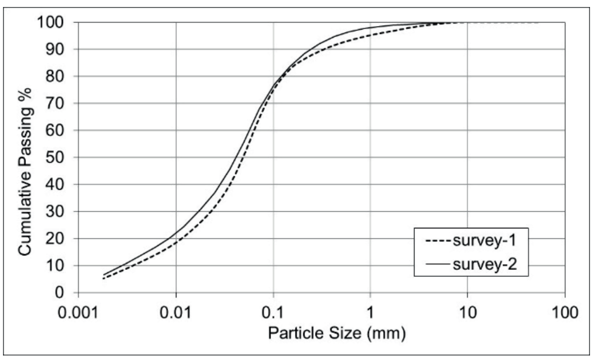

Figure 12. Sepol® air classifier feed size distributions in sampling surveys

Air classifier performance was determined to be higher in CEMII Portland cement production case with lower by-pass and fish-hook per cent values. Grinding aid addition lowered the air classifier feed rate and more finer material was fed to the air classifier. This condition improved the classification performance. Since by-pass amount decreased in the new operational case, less amount of fine material was rejected to the ball mill which could be one of factors affecting the size reduction performance of the ball mill. Consequently, circulating load was recorded to decrease in survey-2. Recirculation of less fine material to the ball mill will prevent coating and cushioning effects in the mill. It could be concluded

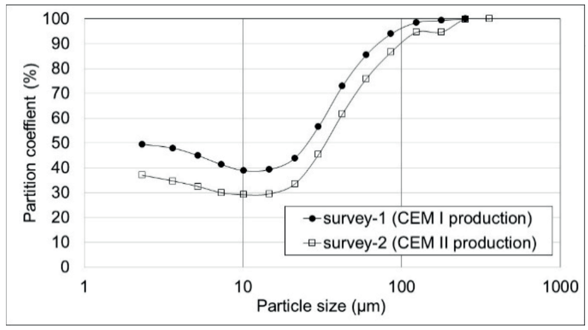

Figure 13. Efficiency curves of the air classifier in survey-1 and survey-2

Table 9. Air classifier performance parameters

Parameters	Survey-1	Survey-2
d_{50} (µm)	25.30	33.20
By-pass (%)	38.85	29.18
Fish-hook (%)	10.65	7.84

CONCLUSIONS

Grinding performance of the two-compartment ball mill was improved in CEMII type Portland cement production in which grinding aid was applied as the mill feed size distribution became coarser. Air classifier separation performance was also improved in CEMII type Portland cement production case. Addition of fly ash to the air classifier feed stream also affected the circuit capacity. Consequently, approximately 12% circuit capacity increase was achieved in CEM II Portland cement production case which lead to decrease the overall energy consumption by 7% in ball mill grinding.

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