Chapter 6

Energy-Efficient Technologies in Cement Grinding

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Additional information is available at the end of the chapter

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Abstract

In this chapter an introduction of widely applied energy-efficient grinding technologies in cement grinding and description of the operating principles of the related equipments and comparisons over each other in terms of grinding efficiency, specific energy consumption, production capacity and cement quality are given. A case study performed on a typical energy-efficient Horomill® grinding technology, is explained. In this context, grinding circuit is introduced and explanations related to grinding and classification performance evaluation methodology are given. Finally, performance data related to Horomill® and high-efficiency TSV™ air classifier are presented.

Keywords: Barmac Vertical Shaft Impact Crusher (VSI), High-pressure grinding rolls, Vertical roller mills, CKP pre-grinder, Cemex® mill, Horomill®, TSV™ separator, Grinding, Classification, Energy, Cement

1. Introduction

Cement is an energy-intensive industry in which the grinding circuits use more than 60 % of the total electrical energy consumed and account for most of the manufacturing cost [1]. The requirements for the cement industry in the future are to reduce the use of energy in grinding and the emission of CO_2 from the kilns. In recent years, the production of composite cements has been increasing for reasons concerned with process economics, energy reduction, ecology (mostly reduction of CO_2 emission), conservation of resources and product quality/diversity. The most important properties of cement, such as strength and workability, are affected by its specific surface and by the fineness and width of the particle-size distribution. These can be modified to some extent by the equipment used in the grinding circuit, including its configuration and control.

Performance of grinding circuits has been improved in recent years by the development of machinery such as high-pressure grinding rolls (HPGR) (roller presses), Horomills, high-efficiency classifiers and vertical roller mills (VRM) for clinker grinding which are more energy efficient than machinery which has been in common use for many years such as tube mills. Energy-efficient equipments such as high-pressure grinding rolls, vertical roller mills, CKP pre-grinders, Cemex® mills and Horomills® are used at both finish grinding of cement and raw material-grinding stages due to higher energy consumption of conventional multi-compartment ball milling circuits. Multi-compartment ball mills can be classified as:

- Single-compartment ball mills
- Two- or three-compartment ball mills

Multi-compartment ball mills and air separators have been the main process equipments in clinker grinding circuits in the last 100 years. They are used in grinding of cement raw materials (raw meal) (i.e. limestone, clay, iron ore), cement clinker and cement additive materials (i.e. limestone, slag, pozzolan) and coal. Multi-compartment ball mills are relatively inefficient at size reduction and have high specific energy consumption (kWh/t). Typical specific energy consumption is 30 kWh/t in grinding of cement. Barmac-type crushers found application as a pre-grinder in cement grinding circuits operating with ball mills to reduce the specific energy consumption of ball mill-grinding stage [2]. An overview of technical innovations to reduce the power consumption in cement plants was given by Fujimoto [1].

In this chapter, operating principles of high-pressure grinding rolls, Horomill®, vertical roller mills, CKP pre-grinders and Cemex® mills which are widely applied in finish grinding of cement are briefly explained in addition to the advantages and disadvantages over each other.

2. Energy-efficient grinding systems

2.1. Barmac VSI crusher

The Barmac rock-on-rock crusher has a rotor that acts as a high-velocity, dry stone pump, hurling a continuous rock stream into a stone-lined crushing chamber. Broken rock about 30–50 mm in diameter enters the top of the machine from a feeder set and is accelerated in the rotor to be discharged into the crushing chamber at velocities of up to 85 m/s. Collision of high-speed rocks, with rocks falling in a separate stream or with a rock-lined wall, causes shattering. The product is typically gravel and sand-sized particles. Barmac crushers are available from 75 to 600 kW. The product-size distribution can be controlled by the rotor speed [3]. A schematic of a Barmac-type VSI crusher is given in **Figure 1** [4].

2.2. High-pressure grinding rolls (HPGR)

High-pressure grinding rolls (roller presses) are used in both raw material and cement grinding. The principle of the HPGR is shown in **Figure 2**.

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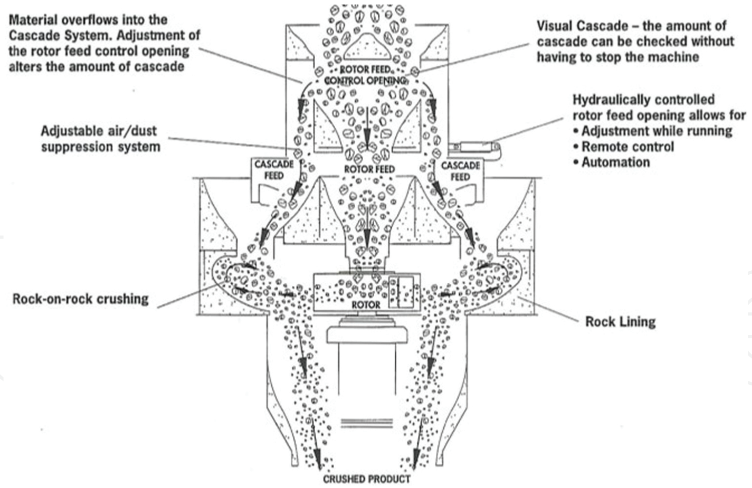

Figure 1. Barmac VSI crusher.

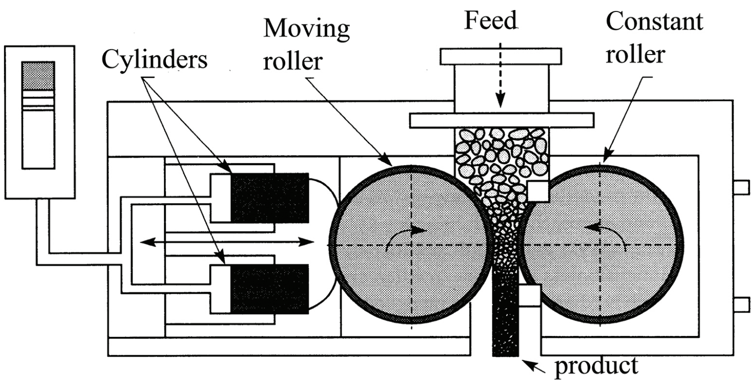

Figure 2. Principle of compressive size reduction.

The material between the rolls is submitted to a very high pressure ranging from 100 to 200 MPa. Special hard materials are used as protection against wear, for example, Ni-hard linings to protect the rollers. During the process, cracks are formed in the particle, and fine particles are generated. Material is fed into the gap between the rolls, and the crushed material leaves as a compacted cake. The energy consumption is 2.5–3.5 kWh/t and about 10 kWh/t when recycling of the material is used. The comminution efficiency of a HPGR is better than ball mills such that it consumes 30–50 % of the specific energy as compared to a ball mill. Four circuit configurations of HPGR can be used in grinding of raw materials, clinker and slag such as [5]:

1. Pre-grinding unit upstream of a ball mill
2. Hybrid grinding
3. Semifinish grinding
4. Finish grinding in closed-circuit operation

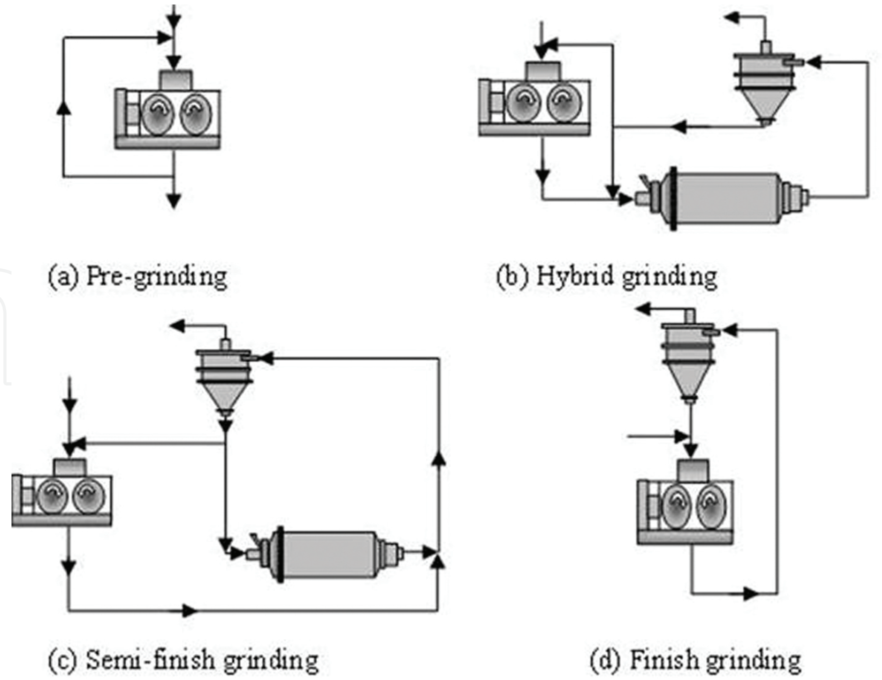

Figure 3. HPGR arrangements.

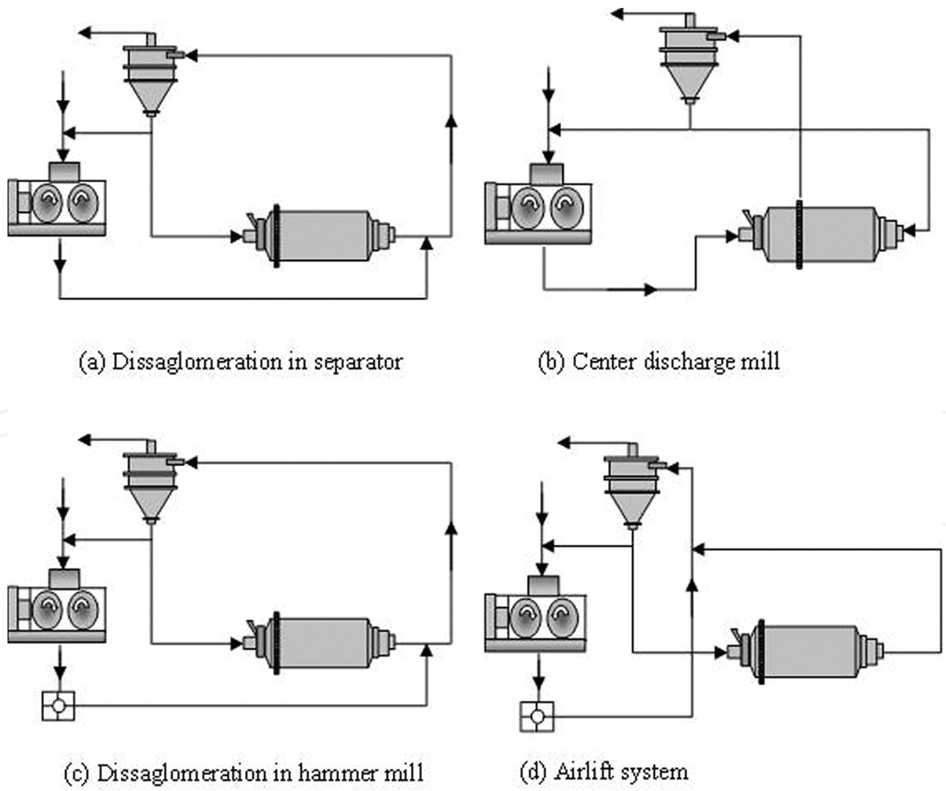

Figure 4. Semifinish-grinding options.

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Application of HPGR in cement grinding circuits and the effects of operational and design characteristics of HPGR on grinding performance were discussed by Aydoğan [6]. HPGR arrangements and semifinish-grinding options are given in **Figures 3** and **4**.

2.3. Vertical roller mills (VRM)

Vertical roller mills have a lower specific energy consumption than tumbling mills and require less space per unit and capacity at lower investment costs. Vertical roller mills are developed to work as air-swept grinding mills. Roller mills are operated with throughput capacities of more than 300 t/h of cement raw mix (Loesche mill, Polysius® double roller mill, Pfeiffer® MPS mill). Loesche roller mill and Polysius® roller mills are widely applied in cement raw material grinding. Schematical view of a Pfeiffer MPS mill is given in **Figure 5** [7], and a view from inside of a vertical roller mill is given in **Figure 6**.

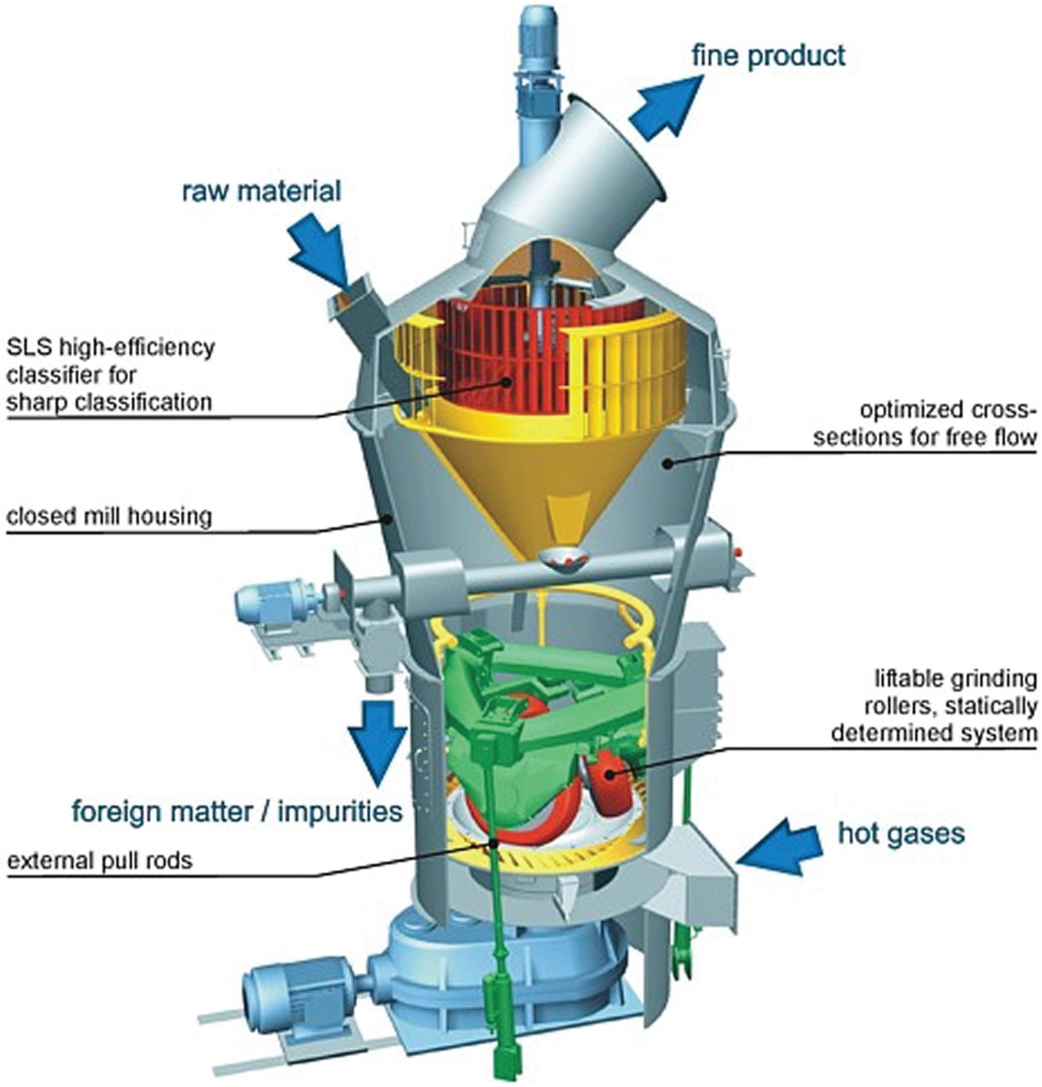

Figure 5. Schematical view of a Pfeiffer MPS mill [7].

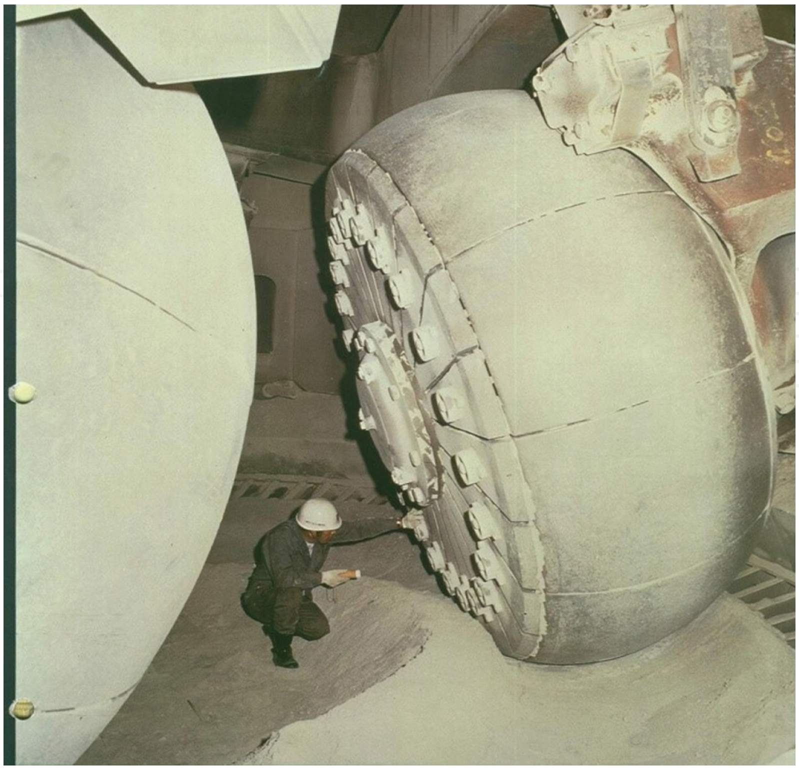

Figure 6. A view from the interior of a vertical roller mill.

2.3.1. Loesche vertical roller mill

A cross section of a Loesche mill with a conical rotor-type classifier is shown in **Figure 7**. The pressure arrangement of the grinding rolls is hydraulic. The mill feed is introduced into the mill from above, falling centrally upon the grinding plate; then it is thrown by centrifugal force underneath the grinding rollers. A retention ring on the periphery of the grinding table forms the mill feed into a layer called the grinding bed. The ground material spills over the rim of the retention ring. Here an uprising airstream lifts the material to the rotor-type classifier located at the top of the mill casing where the coarse particles are separated from the fines. The coarse particles drop back into the centre of the grinding compartment for further size reduction, whereas the fines together with the mill air leave the mill and the separator. The separator controls the product sizes from 400 to 40 μm. The moisture of the mill feed (cement raw material) can amount to 15–18 %. The fineness of the mill product can be adjusted in the range between 94 and 70 % passing 170 mesh. Capacities up to 400 t/h of cement raw mix are recorded [8].

2.3.1.1. Cement quality

Better product quality can be achieved as compared to the ball mill product due to the better options for separate grinding. For example, in additive cement production, the blast furnace slag has to be ground to Blaine values of 5,000 cm^2/g. Water demand and setting times are similar to that of a ball mill cement under comparable conditions [9].

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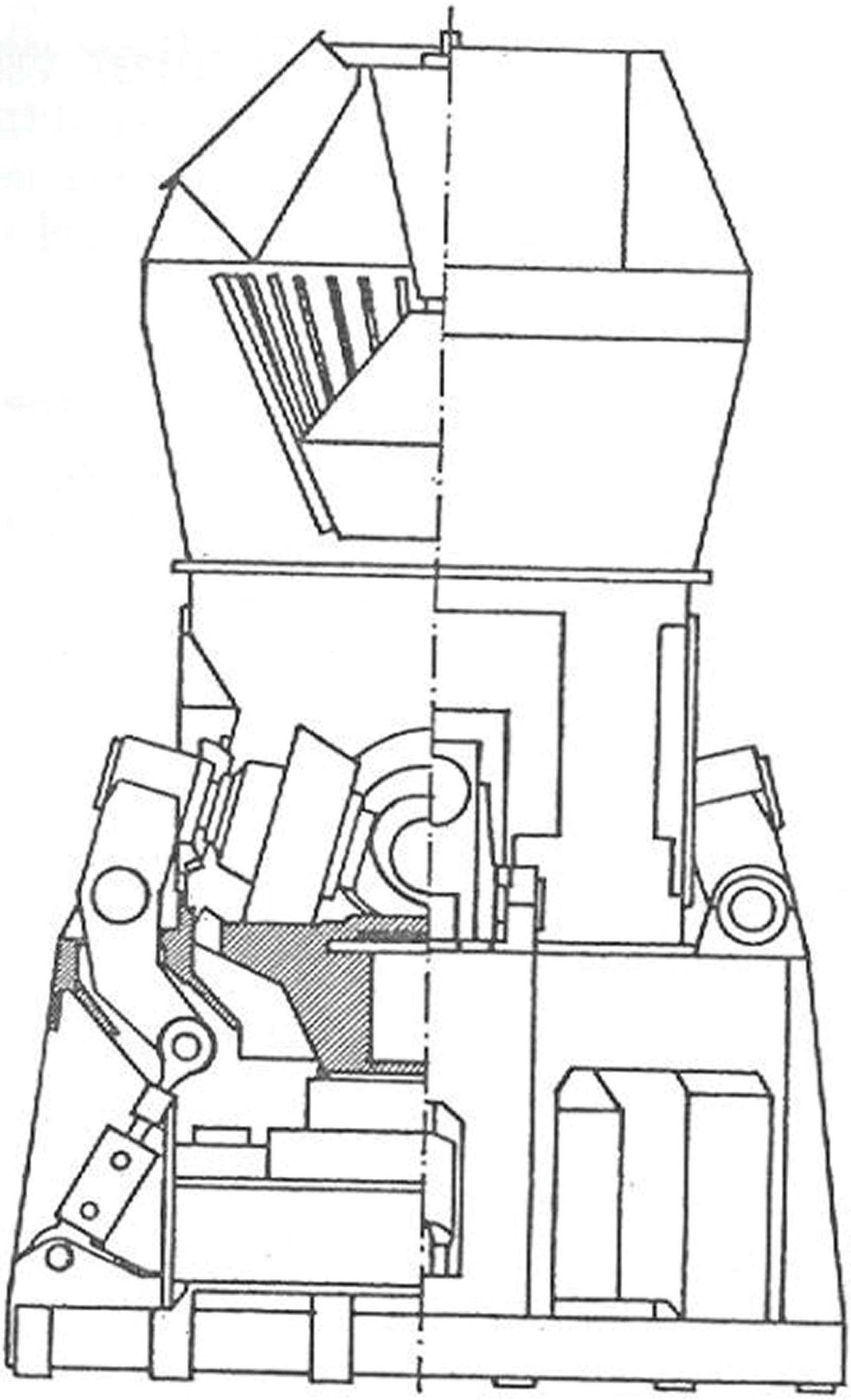

Figure 7. Loesche vertical roller mill [8].

2.3.2. Polysius® vertical roller mill (drying grinding roller mill)

A mill feed arrangement conveys the raw material to the grinding bowl. Two double rollers (representing four grinding rollers) are put in motion by the revolving grinding bowl. The double rollers are independently mounted on a common shaft; they move and adjust themselves to the velocity of the grinding bowl as well as to the thickness of the grinding bed. Thus, rollers are in permanent contact with the grinding bed. A hydropneumatic arrangement transfers the grinding pressure to the rollers. The disintegrated mill feed is shifted to the grinding bowl rim from where a gas stream emerging from the nozzle ring surrounding the grinding bowl carries the material upwards to the separator. The coarses precipitated in the separator gravitate centrally back to the grinding bowl, whereas the fines are collected in the electric precipitator. A raw material moisture of up to 8 % can be dried when utilizing the preheater exit gases only. If hot air from an air heater is also supplied, then a raw material moisture of up to 18 % can be handled [8]. The power requirement is 10–20 % lower than a ball mill, depending upon the grindability and moisture content of the raw material [10]. Other types of roller mills such as ball race mill (Fuller-Peters mill) and Raymond bowl-type ring mill are used in coal grinding.

2.4. CKP vertical pre-grinder

The CKP pre-grinder has been under development by Chichibu Cement and Kawasaki Heavy Industries since 1987. It has been commissioned by Technip under licence since 1993. The system is applied widely for clinker grinding and has also been used on raw material grinding. In operation, material is fed through the inlet chute onto the grinding table centre, spread out to the grinding path by the centrifugal force arising from the table rotation, before being compressed and ground by the rollers. The preground material drops down out of the periphery of the table to the bottom of the casing and is discharged by the scrapers through the discharge chute. Grinding principle of the CKP system is shown in **Figure 8**. Typical CKP application is given in **Figure 9** [11].

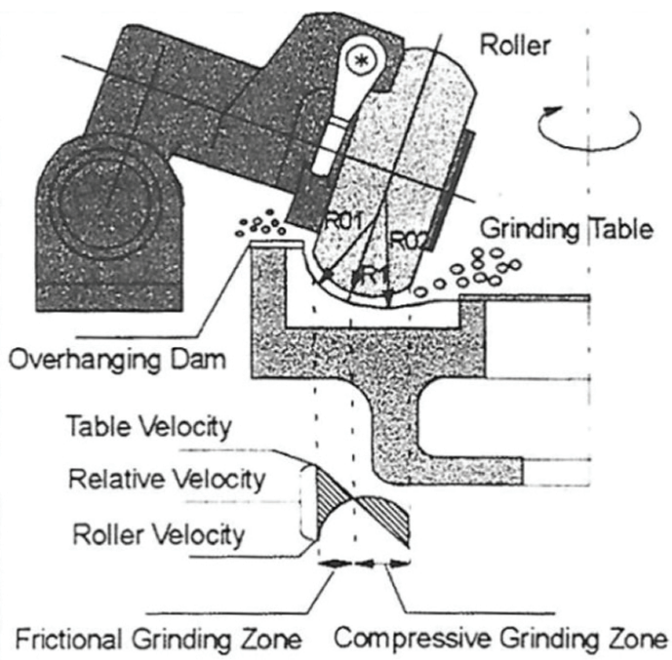

Figure 8. The grinding principle of the CKP [11].

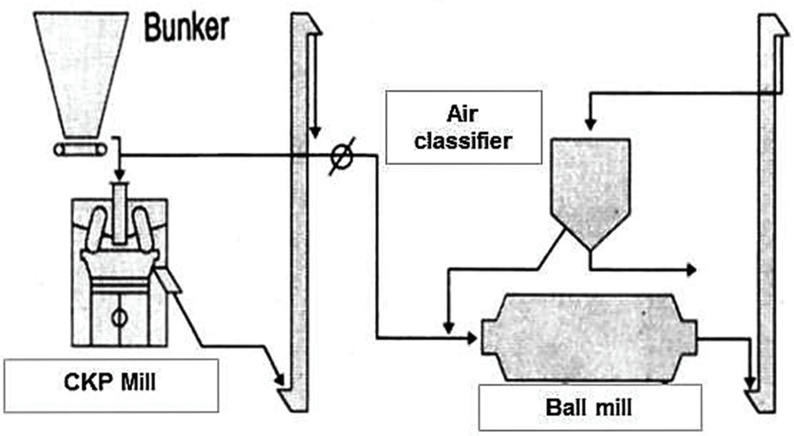

Figure 9. Typical CKP pre-grinding circuit.

Main advantages of the CKP pre-grinders are stated by Dupuis and Rhin [11] as follows:

- The grinding capacity can be increased up to 120 % for some raw materials.
- Installation is very easy due to the compact design as well as the possibility of installing the CKP outdoors.
- The energy consumption of the total grinding plant can be reduced by 20–30 % for cement clinker and 30–40 % for other raw materials.
- The overall grinding circuit efficiency and stability are improved.
- The maintenance cost of the ball mill is reduced as the lifetime of grinding media and partition grates is extended.

2.5. Cemex® ring roller mill

F.L.Smidth has developed this cement grinding system which is a fully air-swept ring roller mill with internal conveying and grit separation. This mill is a major improvement of the cement grinding systems known today which are ball mill, roller press (HPGR)/ball mill, vertical roller mill and closed-circuit roller press for finish grinding. Views of mill interior are given in **Figures 10** and **11**. Cemex® grinds the material by compressing it between a ring and a roller. The roller rotates between dam rings fitted on the sides of the grinding ring, ensuring uniform compaction and grinding. The mill rotates at a subcritical speed, and scooping devices at both ends of the ring ensure effective internal conveying of the material being ground. The material leaves the scooping devices at various points, which ensures good distribution of the material in the airstream between the air inlets and outlets. The process air enters through two inlets at either end of the mill and leaves through an outlet at either end of the mill. The air passes the falling material and carries the finer particles to Sepax® separator, in which the final classification of the product takes place. The oversize particles are returned from Sepax® to Cemex® for further grinding. Due to this unique combination of internal grit separation and air-swept material conveying to Sepax®, no external mechanical conveyor is needed, which makes the installation very compact and simple. The airflow rate through the mill is relatively low, the only lower limitation being the need for sufficient internal grit separation and conveying of the preseparated material to the final classification in Sepax® separator [12].

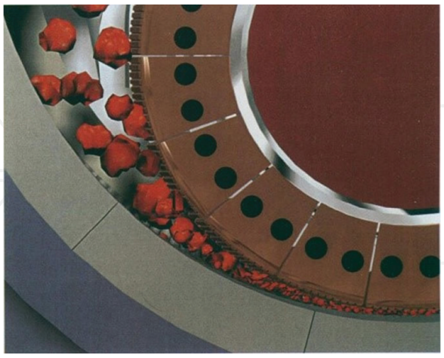

Figure 10. F.L.Smidth Cemex® mill grinding [12].

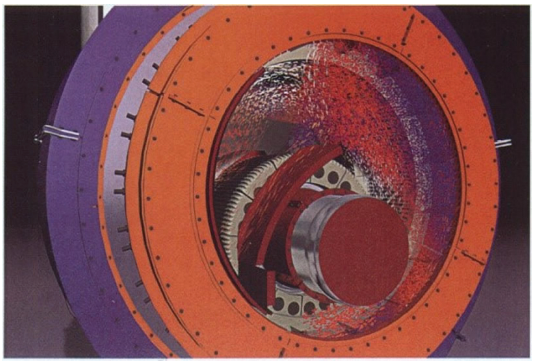

Figure 11. F.L.Smidth Cemex® mill [12].

Main purposes in designing of the ring roller mill (Cemex®) can be summarized as follows:

- To reduce the specific energy consumption of grinding
- To reduce the wear on the mill elements by applying pressures on the grinding bed
- To reduce the energy consumption of the mill fan by reducing the air consumption in the grinding process
- Simple mechanical design
- Simple and compact design to reduce the external mill load recirculation
- Simple and easy control of product quality and mill operation
- Simple and easy change of product type

Grinding tests by the F.L.Smidth company have shown that Cemex® produces cement which meets the requirements of the standard specifications while enabling substantial savings in

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grinding energy consumption compared to the traditional ball mill systems. Due to the more energy-efficient grinding process, Cemex® ground cement will usually have a steeper particle-size distribution curve than corresponding ball mill cements. Consequently, when ground to the same specific surface (Blaine), Cemex® cement will have lower residues on a 32 or 45 μm sieve and tend to have a faster strength development. Grinding of cement to a lower Blaine value will reduce the specific power consumption [12]. A comparison of typical specific energy consumption of Cemex® mill with conventional multi-compartment ball mill grinding and HPGR pre-grinding closed-circuit operations is given in **Table 1**.

Operating equipments	Specific energy consumption (kWh/t)		
	Ball mill closed circuit	Ball mill + HPGR pre-grinding closed circuit	Cemex®
Ball mill	30	20.9	–
HPGR	–	4.5	–
Cemex®	–	–	18
Air classifier	0.40	0.40	0.60
Air classifier fan	2.10	2.10	3.90
Ball mill fan	0.70	0.50	0.20
Auxiliary equipment	1.00	1.30	2.00
Total (kWh/t)	34.20	29.70	24.70
Energy savings %	–	13	28.00

Table 1. Comparison of typical specific energy consumption of Cemex® mill with conventional multi-compartment ball mill grinding and HPGR pre-grinding closed-circuit operations.

Some of the advantages of Cemex® mill can be summarized as follows:

- Up to 40 % lower energy costs compared with conventional grinding installations.
- Low-maintenance cost.
- Fully air-swept mill installation.
- Internal conveying and grit separation.
- No external mechanical conveyor.
- Low noise level.
- Well-proven mill components.
- A third of the grinding pressure of the roller press and moderate grinding pressures.
- Long life of wear segments.
- Drying and cooling ability.
- Compact and simple design.

- High grinding capacity.
- Cement quality meets prevailing standards.
- Same or better strengths than cement from ball mill.

2.5.1. Cement quality

As it was stated in the literature, grinding tests have shown that Cemex® produces cement which meets the requirements of standard specifications while enabling substantial savings in grinding energy consumption compared to the traditional ball mill systems. Due to the more energy-efficient grinding process, Cemex® ground cement will usually have a steeper particle-size distribution curve than corresponding ball mill cements. Consequently, when ground to the same specific surface (Blaine), Cemex® cement will have lower residues on a 32 or 45 μm sieve and tend to have a faster strength development. When grinding to a 28-day-strength target, Cemex® cement can be ground to a lower Blaine value, which further reduces specific power consumption [12].

2.6. Horomill®

Horomill® is a ring roller mill which is a joint development by the French plant manufacturer FCB Ciment and the Italian cement producer Buzzi Unicem Group [13]. Horomill® can be used in grinding of:

- Cement raw materials (i.e. limestone, clay, iron ore, etc.)
- Cement clinker and cement additive materials (i.e. limestone, slag, pozzolan, etc.)
- Minerals and coal

2.6.1. Horomill® design and operational principle

The Horomill® (horizontal roller mill) consists of a horizontal shell equipped with a grinding track in which a roller exerts grinding force. The shell rotates faster than the critical speed which leads to centrifuging of the material. The main feature is the roller inside the shell which is rotated by the material freely on its shaft without a drive. Operating principle is schematically shown in **Figure 12**. Material is fed to the mill by gravity. There are scrapers located in the upper part of the shell. Scrapers cover the entire length of the mill and scrape off the material which falls onto the adjustable panel of the material advance system. Position of the material advance system which is sloping towards the discharge end could be changed in such a way that material could advance slower or faster, and thus it determines the number of passage of material under the roller which means the adjustment of circulating load. Grinding pressures change within a range of 500–800 bars. Concave and convex geometries of the grinding surfaces lead to angles of nip two or three times higher than in roller presses resulted in a thicker layer of ground material [14].

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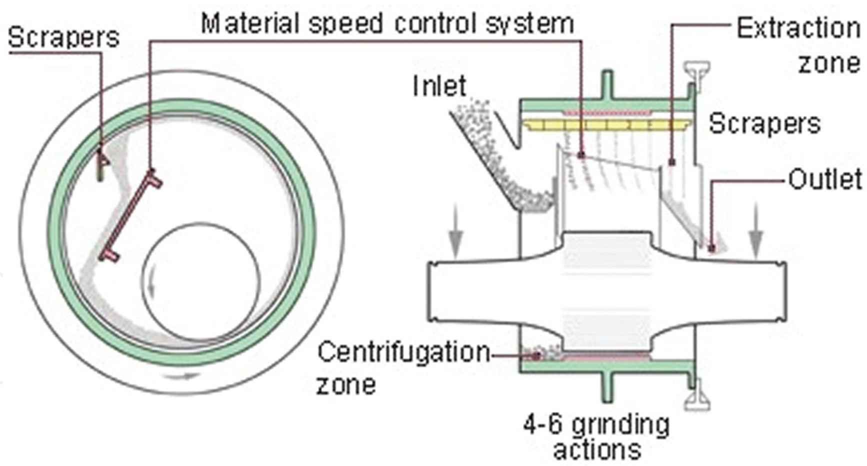

Figure 12. Operating principle of FCB Horomill®.

Horomill® mainly consists of three zones:

- Feeding
- Grinding
- Discharging

In the grinding zone, the cylindrical roller transfers the grinding power onto the material. Material bed in the mill is generated by the centrifugal effect.

As compared to hybrid systems, Horomilling resulted in lower energy consumptions with energy savings of 30–50 % for the same product quality. Noise generated is lower than conventional ball mill. They are smaller and compact units. Frictional forces in the Horomill grinding are kept at its minimum, and hence wear is due to the lack of differential speed between the material and the grinding ring. Horomill® is designed for closed-circuit finish grinding when compared with an HPGR. Bed thickness is two or three times the roll press (HPGR) [15].

It also has the flexibility of a vertical roller mill in grinding of different materials. A larger angle of nip draws the material bed into the grinding gap and reduces wear as compared to vertical roller mills. The recirculation of material within a vertical roller mill is very high. The recycle ratios are 15 or more, but it is practically impossible to measure the recycle ratios in a mill operating on the airflow principle. Material bed passes many times through the stressing gap, and it is possible to adjust the number of stressing during operation in a Horomill®. Also an internal bypass can be implemented if some of the ground material is returned from the mill outlet to the inlet. The external recycle ratio of a Horomill® connected in a closed circuit lies between four and eight and is therefore lower than with a roller press (HPGR) and vertical roller mill [14]. A comparison of the angles of nip of material is given in **Figure 13** [15]. A photograph of an industrial scale Horomill® [13] is shown in **Figure 14**.

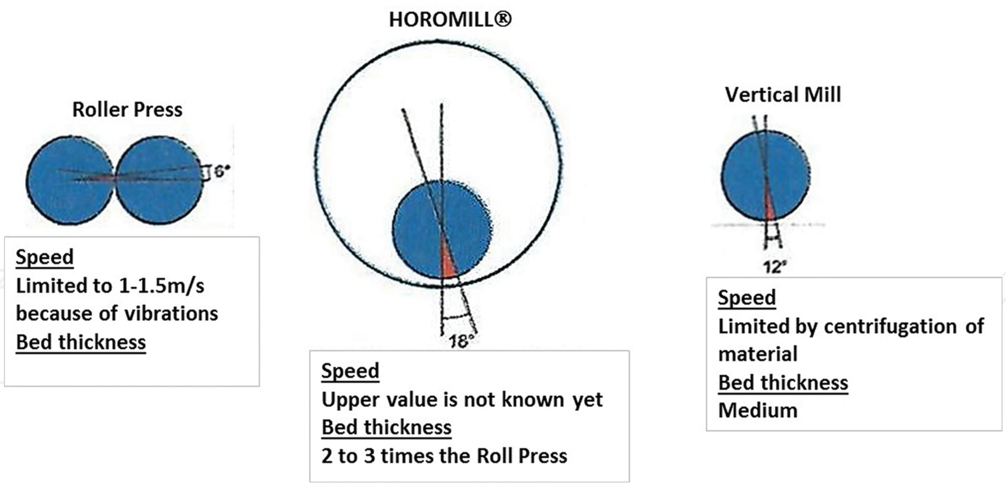

Figure 13. Comparison of the angles of nip [15].

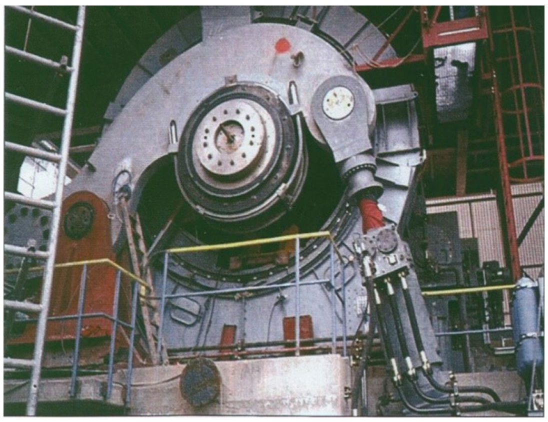

Figure 14. An industrial scale Horomill® [13].

2.6.2. Typical Horomill® grinding application

Typical industrial scale Horomill® grinding and classification closed circuit are given in **Figure 15**. The circuit includes an elevator, a conveyor to the TSV™ classifier, a finished-product recovery filter at the TSV™ outlet and an exhauster. The rejects from the TSV™ classifier are returned by gravity to the mill inlet. The main features of the plant are as follows [15]:

- Horomill®-installed power: 600 kW at variable speed
- Horomill® diameter: 2,200 mm
- Circuit nominal rate in CP42.5R cement production: 25 t/h at 3,200 Blaine
- Nominal-circulating load: 140 t/h
- TSV™ classifier for classification

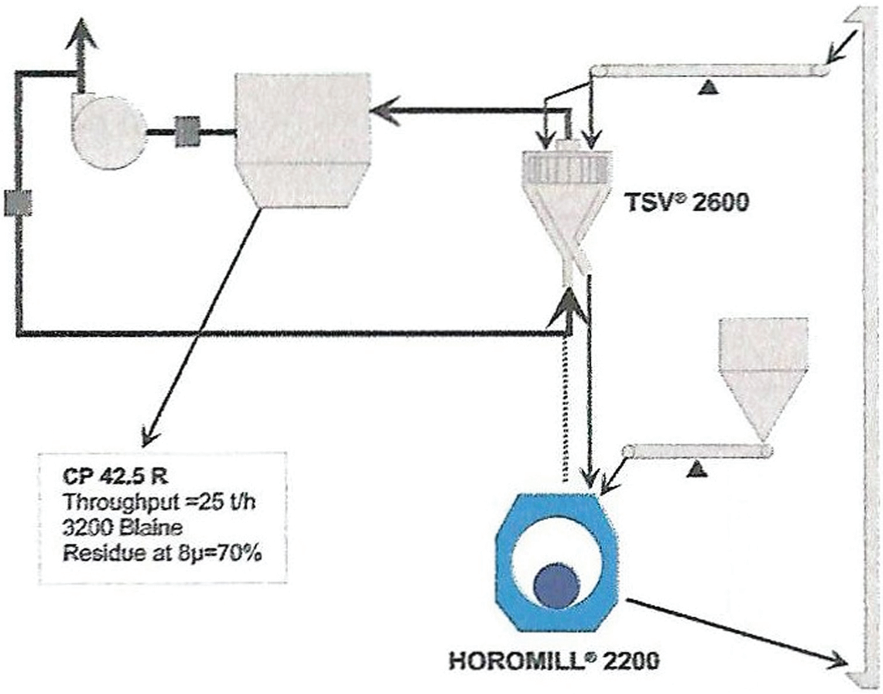

Figure 15. Flowsheet of Trino's Horomill® plant [15].

2.6.3. Typical Horomill® grinding and classification circuit (case study)

An industrial sampling survey was carried out during CPP-30R (pozzolanic portland cement) production around the Horomill® grinding and classification circuit given in **Figure 16**. Sampling points of the circuit are shown in a simplified flowsheet (**Figure 16**). Horomill® was closed circuited with a TSV™-type dynamic separator in the circuit.

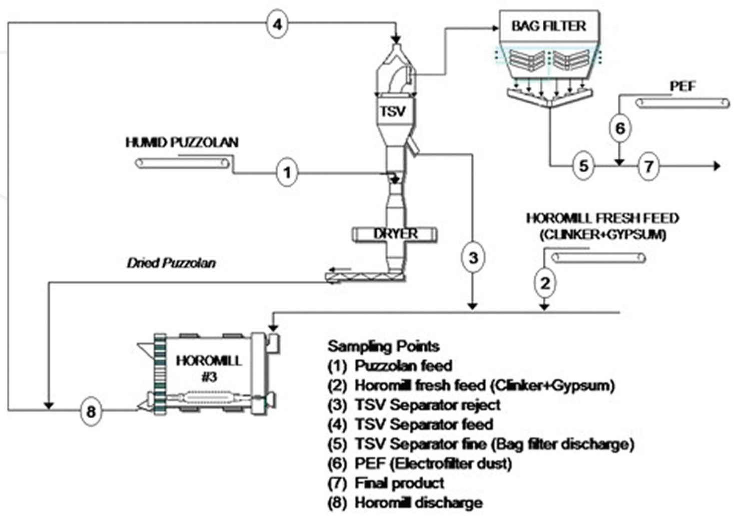

Figure 16. Simplified flowsheet of a Horomill® grinding and classification circuit.

2.6.4. Performance evaluation methodology

Prior to sampling surveys, steady-state conditions were verified by examining the variations in the values of variables in the control room. When steady-state condition was achieved in the circuit, sampling was started, and sufficient amount of samples were collected from each point as shown in **Figure 16**. Due to the physical limitations, dried pozzolan stream was not sampled. Samples collected after stopping the belt conveyors by stripping the material from a length between 3 and 5 m is shown in **Table 2**. The operation during sampling was closed to steady-state conditions. Important variables of the operation were recorded in every 5 min in the control room. Average values of the control room data were used in the mass balance calculations. Mass balance calculations were carried out using JKSimMet computer program. Design parameters of the Horomill are presented in **Table 3**.

2.6.4.1. Laboratory studies

A combination of sieving and laser-sizing techniques was used for the determination of the whole particle-size distributions for each sample. SYMPATEC® dry laser sizer was used to determine the particle-size distribution of subsieve sample of 149 μm for each sample. Size distribution of +149 μm material was determined by dry sieving using a Ro-Tap. The entire size distribution for each sample was calculated using the sieving results obtained from the top size (50.8 mm) down to 149 μm and laser results obtained for the subsieve sample of −149 μm.

Sampling points	Swept length (m)
Pozzolan feed	5.0 m
Clinker + gypsum feed	3.0 m

Table 2. Typical sample amounts taken after stopping the belt conveyors during survey.

Horomill#3®	Value
Inside diameter (m)	3.64
Roller diameter (m)	1.82
Roller/track width (m)	1.365
Nominal pressure (at cylinder) (bar)	220
Type of motor	Slip ring
Installed motor power (kW)	2500
Mill shell speed (rpm)	35.9

Table 3. Design parameters of the Horomill®.

2.6.4.2. Mass balance calculations

Some errors are inevitable in any sampling operation. These errors result from dynamic nature of the system, physical conditions at particular point, random errors, measurement errors and human errors. Mass balancing involves statistical adjustment of the raw data to obtain the best fit estimates of flow rates. In this context, by using the particle-size distributions and the control room data, an extensive mass-balancing study was performed around Horomill®#3 circuit. Tonnage flow rates (t/h) and particle sizes of the streams are calculated by JKSimMet mass balance software. The success of the mass balance was checked by plotting the experimental and calculated (mass-balanced) particle-size distributions as shown in **Figure 17**. These results plotted in a 45° line indicate the quality of both sampling operation and laboratory studies.

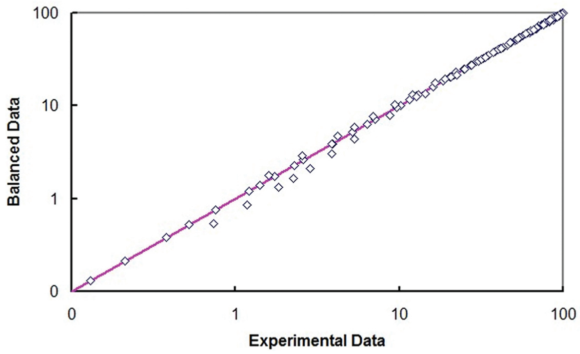

Figure 17. Comparison of mass-balanced and experimental particle-size data of each sample across the grinding circuit.

According to the result of mass balance calculations, if there had been a statistically significant difference between experimental and calculated values (scattering data), the data would have been rejected and not be used for performance evaluation studies. In this research, data obtained as a result of sampling and experimental studies were found to be in a satisfactorily good fit. Mass balance model of the circuit with the calculated tonnage flow rates (t/h) in every stream and fineness as 45 μm% residue is shown in **Figure 18**.

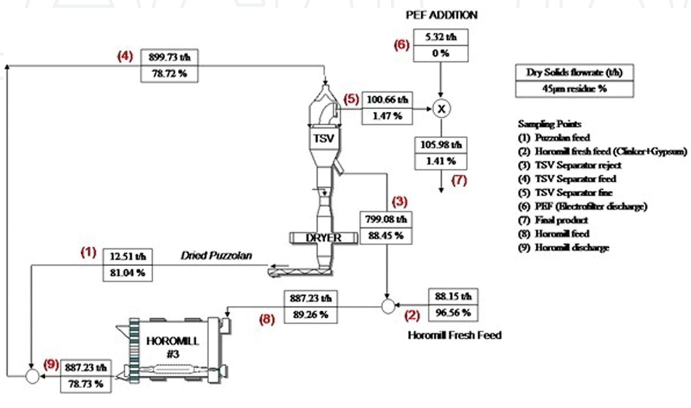

Figure 18. Calculated flow rates (t/h) and fineness after mass balancing around the circuit.

F_{80} and P_{80} particle-size values from the mass-balanced size distributions can be used to calculate the ratio of size reduction which can be given by Eq. (1):

$$S.R = \frac{F_{80}}{P_{80}} \tag{1}$$

where F_{80} is the 80 % passing size of the Horomill® feed determined as 1.06 mm and P_{80} is the 80 % passing size of the Horomill® discharge determined as 0.56 mm. It means that the ratio of size reduction is 1.88.

Using the F_{80} (13.21 mm) and P_{80} (0.024 mm) size values from the mass-balanced size distributions of the fresh feed and the TSV® fine, the ratio of the overall size reduction was calculated as 550.42 by Eq. (1):

$$S.R = \frac{F_{80}}{P_{80}} = \frac{13.21\ \text{mm}}{0.024\ \text{mm}} = 550.42$$

Circulating factor (CF) can be defined by Eq. (2)

$$\text{C.F} = \frac{\text{Mill feed}\ (\text{t/h})}{\text{Total fresh feed}\ (\text{t/h})} \tag{2}$$

$$\text{C.F} = \frac{887.23}{100.66} = 8.81$$

and recycling factor (RF) can be defined by Eq. (3)

$$\text{R.F} = \frac{\text{TSV reject}\ (\text{t/h})}{\text{TSV fine}\ (\text{t/h})} \tag{3}$$

$$\text{R.F} = \frac{799.08}{100.66} = 7.94$$

Circulating and recycling load percentages are determined as 881 and 794 %, respectively.

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2.6.4.3. Specific energy consumption (Ecs) calculation

Horomill® motor power (2,126 kW) is the average operating mill motor power reading from the control room during the sampling survey and used in the calculation. Total fresh feed tonnage is the dry tonnage amount used in the mass balance calculations represented by the TSV fine stream tonnage flow rate which is 100.66 t/h. Thus, the specific energy consumption (Ecs) can be calculated by Eq. (4):

$$E_{CS} = \frac{\text{Mill power (kW)}}{\text{Total fresh feed (t/h)}} \tag{4}$$

$$E_{CS} = \frac{2126}{100.66} = 21.12 \ kWh/t$$

When the final cement tonnage is considered which is 105.53 t/h, specific energy consumption (Ecs) is calculated by Eq. (5):

$$E_{cs} = \frac{\text{Mill power (kW)}}{\text{Final cement (t/h)}} \tag{5}$$

$$E_{CS} = \frac{2126}{105.53} = 20.15 \ kWh/t$$

2.6.4.4. Tromp curve of the TSV® separator

The performance of any classifier, in terms of size separation, is represented by an efficiency (TROMP) curve. An example for a classifier is shown in **Figure 19**. It describes the proportion of a given size of solids which reports to the coarse product. Mass-balanced particle-size distributions and tonnage flow rates around the separator were used to evaluate the performance of the separator. Percentage of any fraction in the feed pass to the coarse product (%) is defined as partition coefficient and expressed by Eq. (6):

$$P = \frac{Uu_i}{Ff_i} \tag{6}$$

where U is the separator coarse tonnage (t/h), F the separator feed tonnage (t/h), u_i is the % of size fraction (i) in separator coarse and f_i is the % of size fraction (i) in separator feed.

Actual TROMP curve established for TSV® is presented in **Figure 19**.

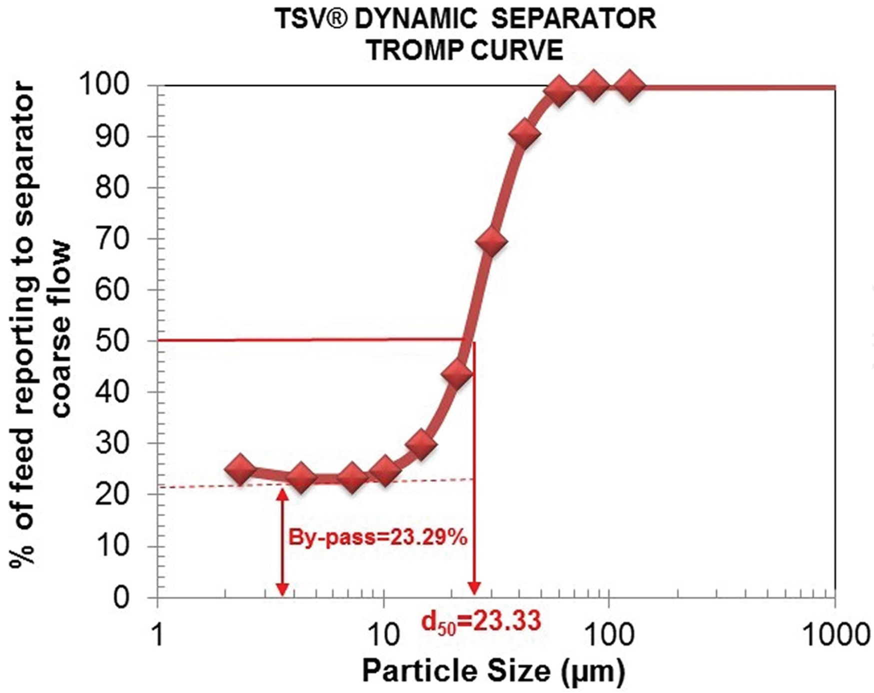

Figure 19. Actual TSV® TROMP curve.

The d_{50} size corresponds to 50 % of the feed passing to the coarse stream. It is therefore the size which has equal probability of passing to either coarse or fine streams. When this size is decreased, the fineness of the product increases. The operational parameters that affect the cut size are rotor speed and separator air velocity. Cut size for the TSV® was determined as 23.33 μm. The percentage of the lowest point on the tromp curve is referred as the bypass. It is the part of the feed which directly passes to the coarse stream (separator reject) without being classified. Bypass value is a function of the separator ventilation and separator feed tonnage. The bypass value of TSV® was 23.29 % which indicated a consistent performance for this separator. Fish-hook effect (β) is the portion of fines returning back into separator reject stream. When there is incomplete feed dispersion at the separator entry, or even within the classification zone, aggregates of fine particles may be classified as coarse particles and thus report to the coarse stream. Fish-hook amount of TSV® was 1.58 % which also indicated how effectively it is operating:

$$\text{Fish} - \text{hook} = 24.87 - 23.29 = 1.58\%$$

The sharpness of separation was defined as d_{25}/d_{75}

where d_{75} is the particle size whose 75 % is reported to the separator reject and d_{25} is the particle size whose 25 % is reported to the separator reject.

For the TSV®, parameter values determined from the TROMP curve are d_{75} as 32.36 μm and d_{25} as 10.50 μm.

The range of this parameter *k* (acuity) depends on the type of separator. This parameter can be calculated by Equation 7 as 0.32:

$$\kappa = \left[\frac{d_{25}}{d_{75}} \right] \tag{7}$$

$$\kappa = 0.32$$

Usually, for TSV®-type separator, it is between 0.55 and 0.7. When the normal range for sharpness (*k*) parameter is considered, it is found to be not in the normal range [16]. When the normal range for sharpness (*k*) parameter is considered, it was found to be not in the normal range. The imperfection of separation is defined by Equation 8, and I was calculated as 0.47:

$$I = \left[\frac{d_{75} - d_{25}}{2d_{50}} \right] \tag{8}$$

$$I = 0.47$$

The value of I indicated that separation performance is sufficiently good.

Operational parameters	Horomill® circuit	Polysius® two-compartment ball mill circuit
Production type	CPP-30R pozzolanic	CPP-30R pozzolanic
Pre-crushing stage	–	HPGR
Fresh feed (t/h)	87.95	134.88
Fresh feed (clinker + gypsum) t/h	83.18	83.48
Pozzolan %	11.80	16.52
Electrofilter dust %	5.02	–
Separator type	TSV™	SEPOL®
Recirculated load %	881	257
Specific energy consumption (kWh/t)	21.12	38.25
Specific energy consumption HPGR	–	3.1
Critical speed %	161.92	77.69
Fresh feed fineness (f80) mm	13.21	5.62
Separator fine (p80) mm	0.024	0.033
Final product + 45 μm%	1.44	10.66
Reduction ratio = f80/p80 f80 fresh feed/p80 separator fine	550.42	169.28

Table 4. Operational characteristics of Horomill® and Polysius® HPGR/Polysius® two-compartment ball mill and classification closed-circuit operations at the same cement production type.

2.6.5. Operational results from an industrial scale Horomill® grinding and HPGR/two-compartment ball mill and classification closed circuit

Typical operating conditions for the Horomill® and two-compartment ball mill grinding with HPGR pre-crushing and classification circuits are compared in **Table 4** for the same production type. As can be seen from **Table 4**, Horomill® production configuration has resulted in energy savings of 50 % as compared to HPGR/two-compartment ball milling configuration [16].

2.6.6. Comparison of different grinding technologies

Typical specific energy consumption comparison between Horomill® product and HPGR hybrid system for pozzolanic cement with a 4,200 Blaine is as follows [13]:

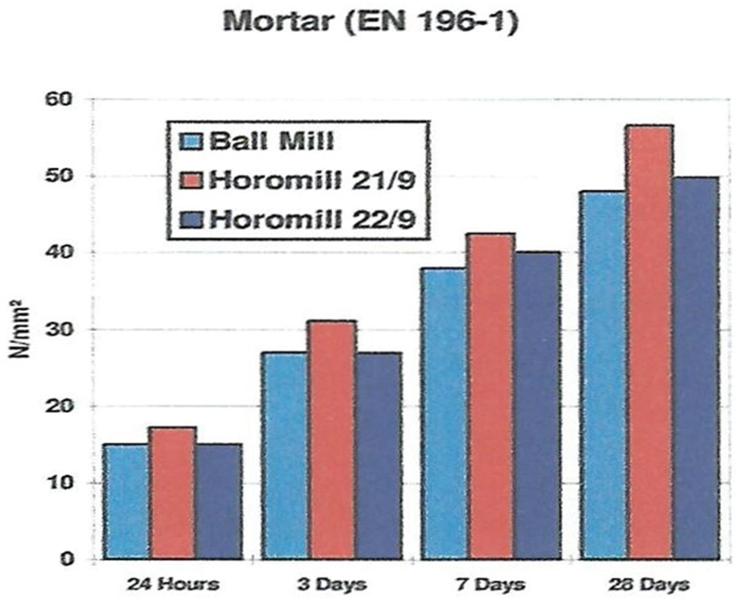

Figure 20. Compressive strength on mortar [15].

- Pozzolanic cement 4,200 Blaine:
  Horomill®, 23.1 kWh/t
  Hybrid system, 32 kWh/t
- Portland cement 3,100 Blaine:
  Horomill®, 28.3 kWh/t
  Hybrid system, 39 kWh/t

It was also reported that concrete workability from a portland cement with a 3,200 Blaine which is a Horomill® product is equal or better than an equivalent ball mill product. Mortar and concrete strengths are always higher as shown in **Figures 20** and **21**. The closed-circuit recirculation factor is noted as about six in Horomill® grinding [17]. A comparison between the grinding systems and conventional ball mills applied in cement grinding circuits is given

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in **Table 5**. Grinding efficiencies of different systems in grinding of cement to a fineness according to a Blaine of 3,000 cm^2/g were compared in **Table 6**.

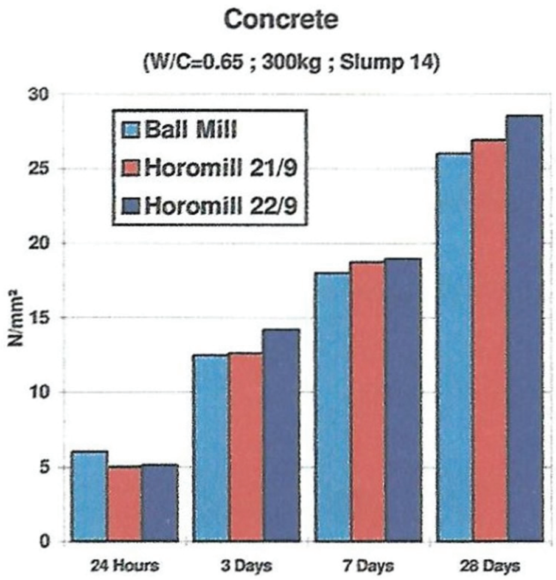

Figure 21. Compressive strength on concrete [15].

Mill type	Application	Capacity increase %	Energy savings %
Vertical roller mill	Pre-grinding	40–55	15
Vertical roller mill	Finish grinding	–	15–25
HPGR	Pre-grinding	30–40	10–15
HPGR	Finish grinding	–	35–50
Barmac VSI	Pre-grinding	30–100	20
CKP pre-grinder	Pre-grinding	60–120	25–30
Cemex®	Finish grinding	–	40
Horomill®	Finish grinding	–	30–50

Table 5. Comparison between the grinding systems and conventional ball mills applied in cement grinding circuits.

Mill type	Efficiency
Ball mill	1.00
Horizontal roller mill (Horomill®)	1.50
Roller mill	1.65
High-pressure grinding rolls (HPGR)	2.15

Table 6. Comparison of typical mill-grinding efficiencies.

The efficiency of a two-compartment ball mill is defined to be 1.0. This efficiency reflects the power consumption of the mill only and does not include any auxiliary equipment like conveyors and dust collectors nor the separator.

3. Conclusions

Comparisons between different energy-efficient grinding technologies and applications were presented for production of cement with energy savings. Industrial-scale data related to Horomill® and Polysius® HPGR/two-compartment ball mill circuit provided insights into the operational and size-reduction characteristics of Horomill® and HPGR/two-compartment ball mill-grinding process with indications that Horomill® application could produce the same type of pozzolanic portland cement at lower grinding energy requirement. The specific energy consumption figures indicated approximately 50 % grinding energy savings in Horomill® process.

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References

[1] Fujimoto S. Reducing specific power usage in cement plants, *World Cement*, 1993; 7: 25-35.

[2] Jankovic A, Valery W, Davis E. Cement grinding optimization. *Minerals Engineering*. 2004; 17: 1075-1081.

[3] Lynch AJ, *Comminution Handbook*, The Australasian Institute of Mining and Metallurgy, Spectrum 21; Australia: 2015.

[4] Barmac Thousand Series Duopactor™ Rock-on-Rock VSI Crushers, Svedala Crushing and Screening Brochure, Svedala New Zealand Ltd, New Zealand: 1995.

[5] Ghosh SN, *Cement and Concrete Science and Technology*, Volume I, Part I, ABI Books Private Ltd, First Edition, New Delhi: 1991.

[6] Aydoğan NA, *An Investigation of the Performance of High Pressure Grinding Rolls in Cement Industry*. PhD Thesis. Mining Engineering Department. University of Hacettepe; Ankara, Turkey: 2006.

[7] http://www.gebr-pfeiffer.com/en/equipment/equipment/mps-roller-mill, 2016

[8] Duda WH, *Cement-Data-Book*, Vol. 1, International Process Engineering in the Cement Industry. French & European Pubns. 3rd edition; 1985.

[9] Nobis R. Experience with grinding slag and clinker in a Loesche mill. *ZKG International*. 2001; 54 (4): 196-204.

[10] Tiggesbaumker P. Trends and developments in dry raw material and clinker grinding. *Ciments, Betons, Platres, Chaux*. 1982; No. 744-5/83: 272-284.

[11] Dupuis J, Rhin C. Increased grinding capacity at R.A.K. *World Cement.* 2003: 79-83.

[12] Cemax® ring roller mill brochure: F.L.Smidth & CO. Denmark:1-8.

[13] Brunelli G. A proven partnership. *International Cement Review*. Buzzi Unicem Group. Italy: 2001.

[14] Buzzi S, The Horomill a new mill for fine comminution. *ZKG International*. 1997; Nr.3: 127-138.

[15] Cordonnier A. A new grinding process Horomill®. 8th European Symposium on Comminution. Stockholm, Sweden: 1994.

[16] Genç Ö, Benzer AH. Horizontal Roller Mill (Horomill®) application versus Ball Milling in Finish Grinding of Cement. 6th International Comminution Symposium (Comminution 08), 2008.

[17] Buzzi S. Horomill to offer grinding advances. *International Cement Review*. 1993: 42-43.