Portland cement

Portland cement (often referred to as **OPC**, from *Ordinary Portland Cement*) is the most common type of cement in general use around the world because it is a basic ingredient of concrete, mortar, stucco and most non-specialty grout. It is a fine powder produced by grinding Portland cement clinker (more than 90%), a limited amount of calcium sulfate (which controls the set time) and up to 5% minor constituents as allowed by various standards such as the European Standard EN197.1:

> Portland cement clinker is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates ($3CaO.SiO_2$ and $2CaO.SiO_2$), the remainder consisting of aluminium- and iron-containing clinker phases and other compounds. The ratio of CaO to SiO_2 shall not be less than 2.0. The magnesium oxide content (MgO) shall not exceed 5.0% by mass.

(The last two requirements were already set out in the German Standard, issued in 1909).


A pallet with Portland cement


Blue Circle Southern Cement works near Berrima, New South Wales, Australia.

ASTM C 150 defines portland cement as "hydraulic cement (cement that not only hardens by reacting with water but also forms a water-resistant product) produced by pulverizing clinkers consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulfate as an inter ground addition." Clinkers are nodules (diameters, 0.2-1.0 inch [5–25 mm]) of a sintered material that is produced when a raw mixture of predetermined composition is heated to high temperature. The low cost and widespread availability of the limestone, shales, and other naturally occurring materials make portland cement one of the lowest-cost materials widely used over the last century throughout the world. Concrete becomes one of the most versatile construction materials available in the world.

Portland cement clinker is made by heating, in a kiln, a homogeneous mixture of raw materials to a sintering temperature, which is about 1450 °C for modern cements. The aluminium oxide and iron oxide are present as a flux and contribute little to the strength. For special cements, such as Low Heat (LH) and Sulfate Resistant (SR) types, it is necessary to limit the amount of tricalcium aluminate ($3CaO.Al_2O_3$) formed. The major raw material for the clinker-making is usually limestone ($CaCO_3$) mixed with a second material containing clay as source of alumino-silicate. Normally, an impure limestone which contains clay or SiO_2 is used. The $CaCO_3$ content of these limestones can be as low as 80%. Second raw materials (materials in the rawmix other than limestone) depend on the purity of the limestone. Some of the second raw materials used are: clay, shale, sand, iron ore, bauxite, fly ash and slag. When a cement kiln is fired by coal, the ash of the coal acts as a secondary raw material.

History

Portland cement was developed from natural cements made in Britain in the early part of the nineteenth century, and its name is derived from its similarity to Portland stone, a type of building stone that was quarried on the Isle of Portland in Dorset, England.[1]

The Portland cement is considered to originate from Joseph Aspdin, a British bricklayer from Leeds. It was one of his employees (Isaac Johnson), however, who developed the production technique, which resulted in a more fast-hardening cement with a higher compressive strength. This process was patented in 1824.[1] His cement was an artificial cement similar in properties to the material known as "Roman cement" (patented in 1796 by James Parker) and his process was similar to that patented in 1822 and used since 1811 by James Frost who called his cement "British Cement". The name "Portland cement" is also recorded in a directory published in 1823 being associated with a William Lockwood, Dave Stewart, and possibly others.

Aspdin's son William, in 1843, made an improved version of this cement and he initially called it "Patent Portland cement" although he had no patent. In 1848 William Aspdin further improved his cement and in 1853 he moved to Germany where he was involved in cement making.[2] Many people have claimed to have made the first Portland cement in the modern sense, but it is generally accepted that it was first manufactured by William Aspdin at Northfleet, England in about 1842.[3] The German Government issued a standard on Portland cement in 1878.

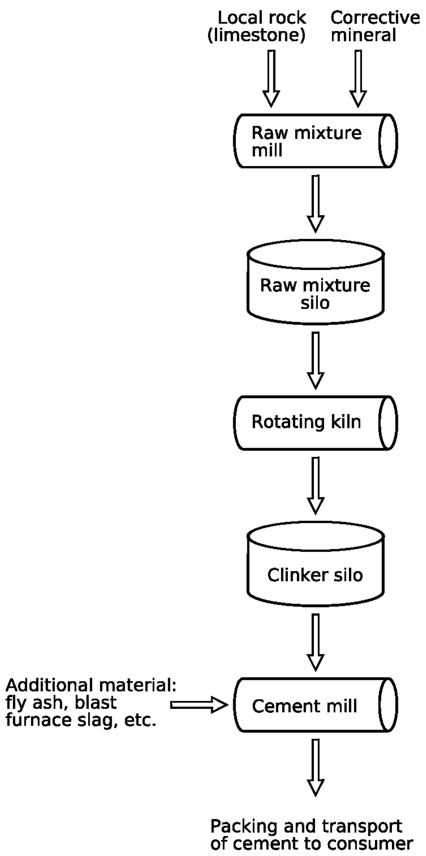
Production

Panorama of TXI cement plant, Midlothian, Texas

There are three fundamental stages in the production of Portland cement:

1. Preparation of the raw mixture
2. Production of the clinker
3. Preparation of the cement

To simplify the complex chemical formulae which describe the compounds present in cement, a cement chemist notation was invented. This notation reflects the fact that most of the elements are present in their highest oxidation state, and chemical analyses of cement are expressed as mass percent of these notional oxides.



Schematic explanation of Portland cement production

Rawmix preparation

A limestone prehomogenization pile being built by a boom stacker

The raw materials for Portland cement production are a mixture of minerals containing calcium oxide, silicon oxide, aluminium oxide, ferric oxide, and magnesium oxide, as fine powder in the 'Dry process' or in the form of a slurry in the 'Wet process'. The raw materials are usually quarried from local rock, which in some places is already practically the desired composition and in other places requires the addition of clay and limestone, as well as iron ore, bauxite or recycled materials. The individual raw materials are first crushed, typically to below 50 mm. In many plants, some or all of the raw materials are then roughly blended in a "prehomogenization pile." The raw materials are next ground together in a rawmill. Silos of individual raw materials are arranged over the feed conveyor belt. Accurately controlled proportions of each material are delivered onto the belt by weigh-feeders. Passing into

A completed limestone prehomogenization pile

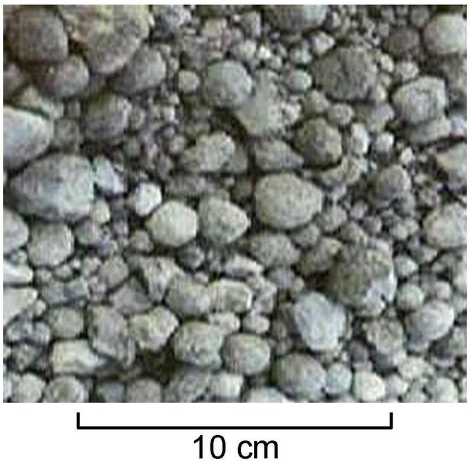
the rawmill, the mixture is ground to rawmix. The fineness of rawmix is specified in terms of the size of the largest particles, and is usually controlled so that there are less than 5%-15% by mass of particles exceeding 90 μm in diameter. It is important that the rawmix contain no large particles in order to complete the chemical reactions in the kiln, and to ensure the mix is chemically homogeneous. In the case of a dry process, the rawmill also dries the raw materials, usually by passing hot exhaust gases from the kiln through the mill, so that the rawmix emerges as a fine powder. This is conveyed to the blending system by conveyor belt or by a powder pump. In the case of wet process, water is added to the rawmill feed, and the mill product is a slurry with moisture content usually in the range 25-45% by mass. This slurry is conveyed to the blending system by conventional liquid pumps.

Rawmix blending

The rawmix is formulated to a very tight chemical specification. Typically, the content of individual components in the rawmix must be controlled within 0.1% or better. Calcium and silicon are present in order to form the strength-producing calcium silicates. Aluminium and iron are used in order to produce liquid ("flux") in the kiln burning zone. The liquid acts as a solvent for the silicate-forming reactions, and allows these to occur at an economically low temperature. Insufficient aluminium and iron lead to difficult burning of the clinker, while excessive amounts lead to low strength due to dilution of the silicates by aluminates and ferrites. Very small changes in calcium content lead to large changes in the ratio of alite to belite in the clinker, and to corresponding changes in the cement's strength-growth characteristics. The relative amounts of each oxide are therefore kept constant in order to maintain steady conditions in the kiln, and to maintain constant product properties. In practice, the rawmix is controlled by frequent chemical analysis (hourly by X-Ray fluorescence analysis, or every three minutes by prompt gamma neutron activation analysis). The analysis data is used to make automatic adjustments to raw material feed rates. Remaining chemical variation is minimized by passing the raw mix through a blending system that homogenizes up to a day's supply of rawmix (15,000 tonnes in the case of a large kiln).

Formation of clinker

Precalciner kiln

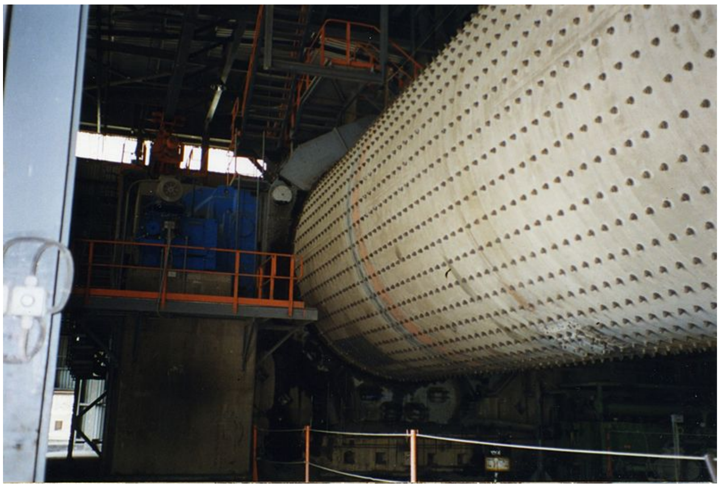


Typical clinker nodules

The raw mixture is heated in a cement kiln, a slowly rotating and sloped cylinder, with temperatures increasing over the length of the cylinder up to a peak temperature of 1400-1450 °C. A complex succession of chemical reactions takes place (see cement kiln) as the temperature rises. The peak temperature is regulated so that the product contains sintered but not fused lumps. Sintering consists of the melting of 25-30% of the mass of the material. The resulting liquid draws the remaining solid particles together by surface tension and acts as a solvent for the final chemical reaction in which alite is formed. Too low a temperature causes insufficient sintering and incomplete reaction, but too high a temperature results in a molten mass or glass, destruction of the kiln lining, and waste of fuel. When all goes according to plan, the resulting material is clinker. On cooling, it is conveyed to storage. Some effort is usually made to blend the clinker because, although the chemistry of the rawmix may have been tightly controlled, the kiln process potentially introduces new sources of chemical variability. The clinker can be stored for a number of years before use. Prolonged exposure to water decreases the reactivity of cement produced from weathered clinker.

The enthalpy of formation of clinker from calcium carbonate and clay minerals is about 1500 to 1700 kJ/kg. However, because of heat loss during production, actual values can be much higher. The high energy requirements and the release of significant amounts of carbon dioxide makes cement production a concern for global warming. See "Environmental effects" below.

Cement grinding



A 10 MW cement mill, producing cement at 270 tonnes per hour

In order to achieve the desired setting qualities in the finished product, a quantity (2-8%, but typically 5%) of calcium sulfate (usually gypsum or anhydrite) is added to the clinker and the mixture is finely ground to form the finished cement powder. This is achieved in a cement mill. The grinding process is controlled to obtain a powder with a broad particle size range, in which typically 15% by mass consists of particles below 5 μm diameter, and 5% of particles above 45 μm. The measure of fineness usually used is the "specific surface area", which is the total particle surface area of a unit mass of cement. The rate of initial reaction (up to 24 hours) of the cement on addition of water is directly proportional to the specific surface area. Typical values are 320–380 $m^2 \cdot kg^{-1}$ for general purpose cements, and 450–650 $m^2 \cdot kg^{-1}$ for "rapid hardening" cements. The cement is conveyed by belt or powder pump to a silo for storage. Cement plants normally have sufficient silo space for 1–20 weeks production, depending upon local demand cycles. The cement is delivered to end-users either in bags or as bulk powder blown from a pressure vehicle into the customer's silo. In industrial countries, 80% or more of cement is delivered in bulk.

Typical constituents of Portland clinker plus Gypsum

Cement chemists notation under CCN.

Clinker	CCN	Mass %
Tricalcium silicate $(CaO)_3 \cdot SiO_2$	C_3S	45-75%
Dicalcium silicate $(CaO)_2 \cdot SiO_2$	C_2S	7-32%
Tricalcium aluminate $(CaO)_3 \cdot Al_2O_3$	C_3A	0-13%
Tetracalcium aluminoferrite $(CaO)_4 \cdot Al_2O_3 \cdot Fe_2O_3$	C_4AF	0-18%
Gypsum $CaSO_4 \cdot 2\ H_2O$		2-10%

Typical constituents of Portland cement

Cement chemists notation under CCN.

Cement	CCN	Mass %
Calcium oxide, CaO	C	61-67%
Silicon oxide, SiO_2	S	19-23%
Aluminum oxide, Al_2O_3	A	2.5-6%
Ferric oxide, Fe_2O_3	F	0-6%
Sulfate	$\bar{S}$	1.5-4.5%

An alternative fabrication technique EMC (Energetically modified cement) uses very finely ground cements that are made from mixtures of cement with sand or with slag or other pozzolan type minerals which are extremely finely ground together. Such cements can have the same physical characteristics as normal cement but with 50% less cement particularly due to their increased surface area for the chemical reaction. Even with intensive grinding they can use up to 50% less energy to fabricate than ordinary Portland cements.[4]

Chemical composition of EMC (50/50 OPC/FA - Fly Ash)

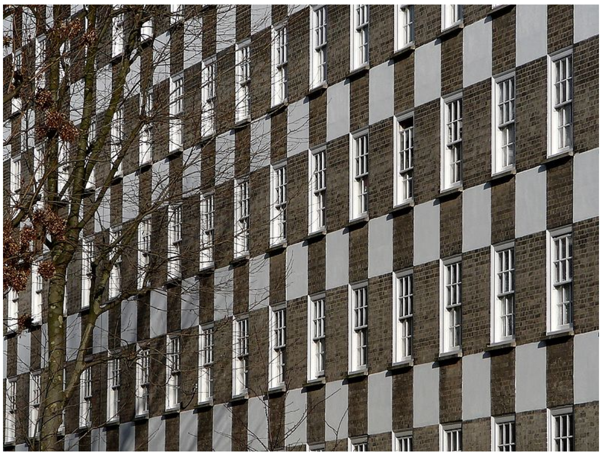
Compound	OPC %	FA %	EMC %
CaO	62.4	15.0	40.9
SiO_2	17.8	49.4	33.2
Al_2O_3	4.0	19.6	6.3
Fe_2O_3	3.9	5.2	4.1
SO_3	3.2	0.8	1.6
Na_2O	<0.1	0.3	0.1
K_2O	0.3	1.2	1.2
Insolubles	0.5	51.3	21.6

Setting and hardening

Cement sets when mixed with water by way of a complex series of chemical reactions still only partly understood. The different constituents slowly crystallise and the interlocking of their crystals gives cement its strength. Carbon dioxide is slowly absorbed to convert the portlandite ($Ca(OH)_2$) into insoluble calcium carbonate. After the initial setting, immersion in warm water will speed up setting. In Portland cement, gypsum is added as a compound preventing cement flash setting.

Use

The most common use for Portland cement is in the production of concrete. Concrete is a composite material consisting of aggregate (gravel and sand), cement, and water. As a construction material, concrete can be cast in almost any shape desired, and once hardened, can become a structural (load bearing) element. Users may be involved in the factory production of pre-cast units, such as panels, beams, road furniture, or may make cast-*in-situ* concrete such as building superstructures, roads, dams. These may be supplied with concrete mixed on site, or may be provided with "ready-mixed" concrete made at permanent mixing sites. Portland cement is also used in mortars (with sand and water only) for plasters and screeds, and in grouts (cement/water mixes squeezed into gaps to consolidate foundations, road-beds, etc.).



Decorative use of Portland cement panels on London's Grosvenor estate[5]

When water is mixed with Portland Cement, the product sets in a few hours and hardens over a period of weeks. These processes can vary widely depending upon the mix used and the conditions of curing of the product, but a typical concrete sets in about 6 hours and develops a compressive strength of 8 MPa in 24 hours. The strength rises to 15 MPa at 3 days, 23 MPa at 1 week, 35 MPa at 4 weeks and 41 MPa at 3 months. In principle, the strength continues to rise slowly as long as water is available for continued hydration, but concrete is usually allowed to dry out after a few weeks and this causes strength growth to stop.

Types

General

There are different standards for classification of Portland cement. The two major standards are the ASTM C150 used primarily in the U.S. and European EN-197. EN 197 cement types CEM I, II, III, IV, and V do not correspond to the similarly-named cement types in ASTM C 150.

ASTM C150

There are five types of Portland cements with variations of the first three according to ASTM C150.

Type I Portland cement is known as common or general purpose cement. It is generally assumed unless another type is specified. It is commonly used for general construction especially when making precast and precast-prestressed concrete that is not to be in contact with soils or ground water. The typical compound compositions of this type are:

55% (C_3S), 19% (C_2S), 10% (C_3A), 7% (C_4AF), 2.8% MgO, 2.9% (SO_3), 1.0% Ignition loss, and 1.0% free CaO.

A limitation on the composition is that the (C_3A) shall not exceed fifteen percent.

Type II is intended to have moderate sulfate resistance with or without moderate heat of hydration. This type of cement costs about the same as Type I. Its typical compound composition is:

51% (C_3S), 24% (C_2S), 6% (C_3A), 11% (C_4AF), 2.9% MgO, 2.5% (SO_3), 0.8% Ignition loss, and 1.0% free CaO.

A limitation on the composition is that the (C_3A) shall not exceed eight percent which reduces its vulnerability to sulfates. This type is for general construction that is exposed to moderate sulfate attack and is meant for use when concrete is in contact with soils and ground water especially in the western United States due to the high sulfur content of the soil. Because of similar price to that of Type I, Type II is much used as a general purpose cement, and the majority of Portland cement sold in North America meets this specification.

Note: Cement meeting (among others) the specifications for Type I and II has become commonly available on the world market.

Type III is has relatively high early strength. Its typical compound composition is:

57% (C_3S), 19% (C_2S), 10% (C_3A), 7% (C_4AF), 3.0% MgO, 3.1% (SO_3), 0.9% Ignition loss, and 1.3% free CaO.

This cement is similar to Type I, but ground finer. Some manufacturers make a separate clinker with higher C_3S and/or C_3A content, but this is increasingly rare, and the general purpose clinker is usually used, ground to a specific surface typically 50-80% higher. The gypsum level may also be increased a small amount. This gives the concrete using this type of cement a three day compressive strength equal to the seven day compressive strength of types I and II. Its seven day compressive strength is almost equal to types I and II 28 day compressive strengths. The only downside is that the six month strength of type III is the same or slightly less than that of types I and II. Therefore the long-term strength is sacrificed a little. It is usually used for precast concrete manufacture, where high 1-day strength allows fast turnover of molds. It may also be used in emergency construction and repairs and construction of machine bases and gate installations.

Type IV Portland cement is generally known for its low heat of hydration. Its typical compound composition is:

28% (C_3S), 49% (C_2S), 4% (C_3A), 12% (C_4AF), 1.8% MgO, 1.9% (SO_3), 0.9% Ignition loss, and 0.8% free CaO.

The percentages of (C_2S) and (C_4AF) are relatively high and (C_3S) and (C_3A) are relatively low. A limitation on this type is that the maximum percentage of (C_3A) is seven, and the maximum percentage of (C_3S) is thirty-five. This causes the heat given off by the hydration reaction to develop at a slower rate. However, as a consequence the strength of the concrete develops slowly. After one or two years the strength is higher than the other types after full curing. This cement is used for very large concrete structures, such as dams, which have a low surface to volume ratio. This type of cement is generally not stocked by manufacturers but some might consider a large special order. This type of cement has not been made for many years, because Portland-pozzolan cements and ground granulated blast furnace slag addition offer a cheaper and more reliable alternative.

Type V is used where sulfate resistance is important. Its typical compound composition is:

38% (C_3S), 43% (C_2S), 4% (C_3A), 9% (C_4AF), 1.9% MgO, 1.8% (SO_3), 0.9% Ignition loss, and 0.8% free CaO.

This cement has a very low (C_3A) composition which accounts for its high sulfate resistance. The maximum content of (C_3A) allowed is five percent for Type V Portland cement. Another limitation is that the (C_4AF) + 2(C_3A) composition cannot exceed twenty percent. This type is used in concrete that is to be exposed to alkali soil and ground water sulfates which react with (C_3A) causing disruptive expansion. It is unavailable in many places although its use is common in the western United States and Canada. As with Type IV, Type V Portland cement has mainly been supplanted by the use of ordinary cement with added ground granulated blast furnace slag or tertiary blended cements containing slag and fly ash.

Types Ia, IIa, and IIIa have the same composition as types I, II, and III. The only difference is that in Ia, IIa, and IIIa an air-entraining agent is ground into the mix. The air-entrainment must meet the minimum and maximum optional specification found in the ASTM manual. These types are only available in the eastern United States and Canada but can only be found on a limited basis. They are a poor approach to air-entrainment which improves resistance to freezing under low temperatures.

Types II(MH) and II(MH)a have recently been added with a similar composition as types II and IIa but with a mild heat. The cements were added to ASTM C-150 in 2009 and will be in publication in 2010.

EN 197

EN 197-1 defines 5 classes of common cement that comprise Portland cement as a main constituent. These classes differ from the ASTM classes.

I	Portland cement	Comprising Portland cement and up to 5% of minor additional constituents
II	Portland-composite cement	Portland cement and up to 35% of other single constituents
III	Blastfurnace cement	Portland cement and higher percentages of blastfurnace slag
IV	Pozzolanic cement	Portland cement and up to 55% of pozzolanic constituents(volcaince ashs)
V	Composite cement	Portland cement, blastfurnace slag or fly ash and pozzolana

Constituents that are permitted in Portland-composite cements are artificial pozzolans (blastfurnace slag, silica fume, and fly ashes) or natural pozzolans (siliceous or siliceous aluminous materials such as volcanic ash glasses, calcined clays and shale).

White Portland cement

White Portland cement differs physically from the gray form only in its color, and as such can fall into many of the above categories (e.g. ASTM Type I, II and/or III). However, its manufacture is significantly different from that of the gray product, and is treated separately.

Safety issues

Bags of cement routinely have health and safety warnings printed on them because not only is cement highly alkaline, but the setting process is exothermic. As a result, wet cement is strongly caustic and can easily cause severe skin burns if not promptly washed off with water. Similarly, dry cement powder in contact with mucous membranes can cause severe eye or respiratory irritation. Cement users should wear protective clothing.[6] [7] [8]

Sampling fast set concrete made from Portland cement

When traditional Portland cement is mixed with water the dissolution of calcium, sodium and potassium hydroxides produces a highly alkaline solution (pH ~13): gloves, goggles and a filter mask should be used for protection, and hands should be washed after contact as most cement can cause acute ulcerative damage 8–12 hours after contact if skin is not washed promptly.[9] The reaction of cement dust with moisture in the sinuses and lungs can also cause a chemical burn as well as headaches, fatigue,[10] and lung cancer.[11] The development of formulations of cement that include fast-reacting pozzolans such as silica fume as well as some slow-reacting products such as fly ash have allowed for the production of comparatively low-alkalinity cements (pH<11)[12] that are much less toxic and which have become widely commercially available, largely replacing high-pH formulations in much of the United States. Once any cement sets, the hardened mass loses chemical reactivity and can be safely touched without gloves.

In Scandinavia, France and the UK, the level of chromium(VI), which is considered to be toxic and a major skin irritant, may not exceed 2 ppm (parts per million).

Environmental effects

Portland cement manufacture can cause environmental impacts at all stages of the process. These include emissions of airborne pollution in the form of dust, gases, noise and vibration when operating machinery and during blasting in quarries, consumption of large quantities of fuel during manufacture, release of CO_2 from the raw materials during manufacture, and damage to countryside from quarrying. Equipment to reduce dust emissions during quarrying and manufacture of cement is widely used, and equipment to trap and separate exhaust gases are coming into increased use. Environmental protection also includes the re-integration of quarries into the countryside after they have been closed down by returning them to nature or re-cultivating them.

> Epidemiologic Notes and Reports Sulfur Dioxide Exposure in Portland Cement Plants, from the Centers for Disease Control, states "Workers at Portland cement facilities, particularly those burning fuel containing sulfur, should be aware of the acute and chronic effects of exposure to SO_2 [sulfur dioxide], and peak and full-shift concentrations of SO_2 should be periodically measured."
>
> —[13]

"The Arizona Department of Environmental Quality was informed this week that the Arizona Portland Cement Co. failed a second round of testing for emissions of hazardous air pollutants at the company's Rillito plant near Tucson. The latest round of testing, performed in January 2003 by the company, is designed to ensure that the facility complies with federal standards governing the emissions of dioxins and furans, which are byproducts of the manufacturing process." [14] Cement Reviews' "Environmental News" web page details case after case of environmental problems with cement manufacturing.[15]

An independent research effort of AEA Technology to identify critical issues for the cement industry today concluded the most important environment, health and safety performance issues facing the cement industry are atmospheric releases (including greenhouse gas emissions, dioxin, NO_x, SO_2, and particulates), accidents and worker exposure to dust.[16]

The CO_2 associated with Portland cement manufacture falls into 3 categories:

- CO_2 derived from decarbonation of limestone,
- CO_2 from kiln fuel combustion,
- CO_2 produced by vehicles in cement plants and distribution.

Source 1 is fairly constant: minimum around 0.47 kg CO_2 per kg of cement, maximum 0.54, typical value around 0.50 worldwide. Source 2 varies with plant efficiency: efficient precalciner plant 0.24 kg CO_2 per kg cement, low-efficiency wet process as high as 0.65, typical modern practices (e.g. UK) averaging around 0.30. Source 3 is almost insignificant at 0.002-0.005. So typical total CO_2 is around 0.80 kg CO_2 per kg finished cement. This leaves aside the CO_2 associated with electric power consumption, since this varies according to the local generation type and efficiency. Typical electrical energy consumption is of the order of 90-150 kWh per tonne cement, equivalent to 0.09-0.15 kg CO_2 per kg finished cement if the electricity is coal-generated.

Overall, with nuclear- or hydroelectric power and efficient manufacturing, CO_2 generation can be as little as 0.7 kg per kg cement, but can be as high as twice this amount. The thrust of innovation for the future is to reduce sources 1 and 2 by modification of the chemistry of cement, by the use of wastes, and by adopting more efficient processes. Although cement manufacturing is clearly a very large CO_2 emitter, concrete (of which cement makes up about 15%) compares quite favorably with other building systems in this regard.

Cement plants used for waste disposal or processing

Due to the high temperatures inside cement kilns, combined with the oxidizing (oxygen-rich) atmosphere and long residence times, cement kilns are used as a processing option for various types of waste streams: indeed, they efficiently destroy many hazardous organic compounds. The waste streams also often contain combustible materials which allow the substitution of part of the fossil fuel normally used in the process.

Used tires being fed to a pair of cement kilns

Waste materials used in cement kilns as a fuel supplement:[17]

- Car and truck tires – steel belts are easily tolerated in the kilns
- Paint sludge from automobile industries
- Waste solvents and lubricants
- Meat and bone meal - slaughterhouse waste due to bovine spongiform encephalopathy contamination concerns
- Waste plastics
- Sewage sludge

- Rice hulls
- Sugarcane waste
- Used wooden railroad ties (railway sleepers)
- Spent Cell Liner (SCL) from the aluminium smelting industry (also called Spent Pot Liner or SPL)

Portland cement manufacture also has the potential to remove industrial by-products from the waste-stream, effectively sequestering some environmentally damaging wastes.[18] These include:

- Slag
- Fly ash (from power plants)
- Silica fume (from steel mills)
- Synthetic gypsum (from desulfurisation)

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[18] *Design and Control of Concrete Mixtures*. Skokie, Illinois: Portland Cement Association. 1988. pp. 15. ISBN 0-89312-087-1. "As a generalization, probably 50% of all industrial byproducts have potential as raw materials for the manufacture of Portland cement."

External links

- World Production of Hydraulic Cement, by Country (http://www.indexmundi.com/en/commodities/minerals/cement/cement_t22.html)
- PCA - The Portland Cement Association (http://www.cement.org)
- Alpha The Guaranteed Portland Cement Company: 1917 Trade Literature from Smithsonian Institution Libraries (http://www.sil.si.edu/exhibitions/doodles/cf/doodles_enlarge.cfm?id_image=68)
- Cement Sustainability Initiative (http://www.wbcsdcement.org/)
- A cracking alternative to cement (http://technology.guardian.co.uk/weekly/story/0,,1771589,00.html)
- What is the Difference Between Cement, Portland Cement & Concrete? (http://www.the-artistic-garden.com/concrete-vs-cement.html)

- Aerial views of the world's largest concentration of cement manufacturing capacity, Saraburi Province, Thailand, at 14°37′57″N 101°04′38″E
- Fountain, Henry (March 30, 2009). "Concrete Is Remixed With Environment in Mind" (http://www.nytimes.com/2009/03/31/science/earth/31conc.html). The New York Times. Retrieved 2009-03-30.

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