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A Review of the Utilisation of Hydrated Lime (CL-90) in Engineering Applications and it's Sustainability Implications

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Abstract

Lime is one of the widely used materials in several industries, with an estimated production of 430 million tons worldwide, with the iron, steel and metal industries as the leader, using 250 million tons, followed by the construction industry using around 75 million tons and the chemical industry with 55 million tons usage per annum worldwide. The broadly used types of lime are quick lime CaO (CL90 Q), hydrated lime $Ca(OH)_2$ (CL90 S), hydraulic lime and lime putty. The primary purpose of hydrated lime is to induce alkalinity and use it as filler material to control porosity. Hydrated lime, unlike hydraulic lime, does not exhibit much-cementing properties on mixing with water. Therefore, it requires blending with suitable binders like cement, pozzolans, and bitumen to acquire better binding characteristics. Hydrated lime is widely used in the iron and steel industry as a cheap, sustainable material for converting iron into pig iron and steel and improving the durability of refractories in the blast furnace. The agriculture and food industry also relies heavily on hydrated lime to be used as a purifying flocculating coagulating agent, especially in the sugar industry. The hydrated lime acts as an alkali activator, deodorising and anti-bacterial chemical in treating wastewater/sludge, agricultural fields and environmental protection. The hydrated lime is used to treat wet, marine and cohesive expansive clayey soils as it absorbs moisture and improves engineering properties like compressibility, strength, plasticity, bearing capacity, consistency, sheer strength and shrinkage etc. One of the main usages of hydrated lime in civil engineering applications is in cement-based mortars as a plasticiser. Therefore, the hydrated lime can be recommended for use in diverse industries and multi-purpose roles.

Keywords: Hydrated lime, CL-90, worldwide usage, applications, chemical reaction, benefits.

Introduction

There are different types of lime products including hydrated lime, quick lime, hydraulic lime and lime putty. Most of these products originate from limestone and have differing mechanical & chemical properties and hence applications. In this paper, the emphasis will be on hydrated lime. It is well known that hydrated lime is produced by carefully mixing quick lime CaO with water to make $Ca(OH)_2$ containing 25% water and 75% lime (Graymont, (n.d.)). Quick and hydrated lime are among the topmost used lime types in different industries, including construction, manufacturing, agriculture and food industries. Worldwide use of lime is estimated to be 430 million tons per year (USGS, (n.d.)). The construction industry had been a significant lime user in ancient times. Still, with the advancement of chemical and manufacturing industries after the industrial revolutions in the 1900s, these industries have become prominent users of lime (USGS, (n.d.); Carmeuse. (n.d.) Carmeuse. (n.d.)). Fig 1 shows iron and steel industry has now become the leading user of 51% lime, followed by the construction industry, chemical industry and environmental protection/ waste disposal and treatment (USGS, (n.d.); Piringer, (2017)).

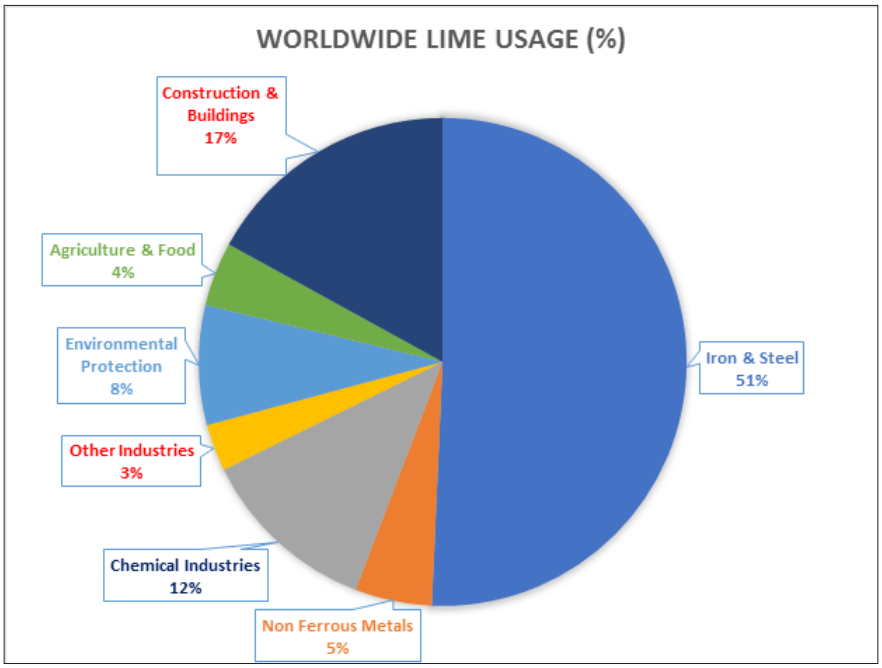

Figure 1: Worldwide lime use by different sectors (USGS, (n.d.); Piringer, (2017)).

Applications of Hydrated Lime

Iron, Steel and other Metals Industry

Lime is a significant component used in the iron and steel industry to convert iron ore into pig iron which is then used to produce steel. Lime is used as a fluxing agent to remove impurities like sulphur, silica and phosphorus in electric arc or oxygen furnaces to form a slag as a waste product, which is used as Ground Granulated Blast furnace Slag (GGBS) as a supplementary cementitious material (SCM) in concrete. Dolomite (lime with MgO) enhances the refractory life furnace as it prevents slag from depleting furnaces by absorbing MgO from the refractory walls (Graymont, (n.d.)). Lime is a floatation agent for purification in sulphur, nickel, gold, silver, lead, copper and zinc ore mining and concentrated extraction of desired metals (Blitzitzco, (n.d.)). High calcium hydrated lime has exhibited the best flocculation, absorption, neutralising and stabilising capabilities in the purification of metals from ores, making it the top used material in the mineralogy and manufacturing of pure metals and steel worldwide (Graymont, (n.d.); Graymont, 2020).

Construction Industry

The construction industry had been the primary user of lime since ancient times as all masterpieces of construction by Romans, Egyptians, Chinese and Babylonians etc., used lime as the essential material for rendering, masonry, plastering, cementing and facade work. It has been mainly used in the construction sector for buildings, soil stabilisation, road construction and all cementing works till the 1860s, when Portland cement was manufactured and replaced lime as a large-scale construction material. The researchers have used hydrated lime and natural/ industrial/ agricultural pozzolanic materials to make composites of SCMs as environmentally friendly, economical, sustainable concrete replacements. The hydrated lime (CL90) conforms to BS EN 197-1 and is considered a suitable building material (Nadir & Ahmad, 2020; Britannica, (n.d.); Rehan & Nehdi, 2005; Worrell et al., 2001; *If the cement industry were a country, it would be the third-largest emitter in the world.* (13 September 2018); Rajkumar et al., 2019; Nadir & Ahmad, 2021; Akça, et al., 2015; Yildirim, et al., 2015; Ash et al., 2020). Lime is still the essential ingredient in cement manufacturing as it constitutes around 62% of lime, 27% of silica and up to 11% of gypsum, magnesia, sulphur and soda etc. (Brehm, 2009; EPA, (n.d.); The History of Concrete, (n.d.)). The use of hydrated lime in the construction industry is further elaborated later in this paper.

Chemical Industry

As shown in fig 1, the chemical industry is the third leading sector which uses around 12% of the world's lime production (USGS, (n.d.); Piringer, 2017). Hydrated lime is primarily used as an alkali activator and a purifier/ fluxing agent in the chemical industry (Piringer, 2017). It is also a low-cost protective material against chemical hazards and the emission of dangerous gases to the environment (Blitzitzco, (n.d.)). It is a commonly used purifier in the sugar industry, sulphide manufacturing, soda ash, paper and pulp, water-based emulsions, and mining industry as an anti-leaching and protective agent against the release of cyanide into the environment. It is used in the paper and pulp industry to reform caustic soda reactions with Na_2CO_3 and $Ca(OH)_2$ (Graymont, (n.d.)).

Environmental Protection and Waste Disposal/ Sewerage Treatment

Hydrated lime is used widely in treating black water/ sludge as a cost-effective and easy-to-use option. The OH- rich hydrated lime is used to induce an alkaline environment in sludge treatment to prevent further reproduction of pathogens, germs and bacteria. It acts as a coagulant and flocculant anti-bacterial agent. The hydrated lime is injected into the sludge tanks in the mixing phase, which segregates effluent and solid sludge in 24-72 hours which is then pumped out separately as liquid

and solid for further disposal, as shown in fig 2. Lime removes hazardous minerals containing phosphorus, sulphur, nitrogen, sulphide, nitrates, phosphates and CO2 etc. ((Blitzitzco, (n.d.); Gensch et al., (n.d.); Farzadkia & Bazrafshan, 2014). Production of hydrogen sulphide from sewerage disposal, landfilling sites, disposal of crops, vegetables, eatables and other organic matter is another environmental hazard which causes acid rains and deterioration of concrete structures due to external sulphate attack caused by hydration/ ingress of hydrogen sulphide. Hydrated and quick lime is used to treat sewerage disposal and landfilling/ waste disposal sites. Hwidi et al. (2018), in their study on the reduction of hydrogen sulphide emission by using hydrated lime, found that an increased percentage of hydrated lime for treatment of organic waste disposal decreases the emission of hydrogen sulphide (HS). They used 1%, 3%, 5% and 8% hydrated lime with the same samples of 40% vegetables, 30% meat and 30% rice products in Malaysia. They compared the production of hydrogen sulphide in ppm with a 0% lime-containing standard sample for 9, 12 and 15 days. Their findings showed that the sample containing 8% hydrated lime best controlled the emission of HS and can be used as an economical waste disposal agent, as shown in fig 3 (Hwidi et al., 2018). Similarly, hydrated lime is used as a deodorising agent and water purification chemical in water treatment plants. Mixing lime in water ponds prevents the uncontrolled growth of weeds and algae and reduces stagnation. Lime is also used in coal power plants and incinerators to treat their emissions containing harmful sulphur to save the environment and trees ((Blitzitzco, (n.d.); Gensch et al., (n.d.); Farzadkia & Bazrafshan, 2014; Hwidi et al., 2018; Sagastume Gutiérrez et al., 2012).

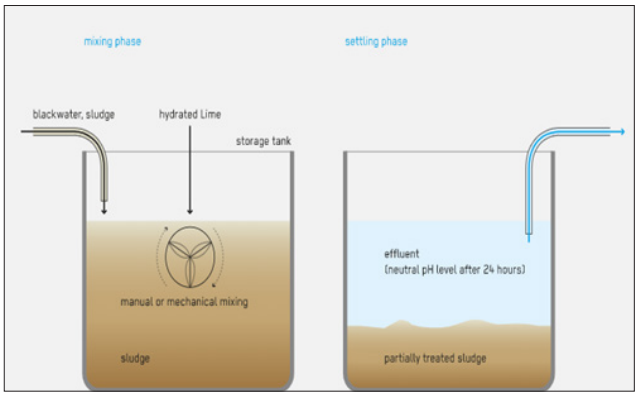

Figure 2: Use of hydrated lime for wastewater treatment [22]

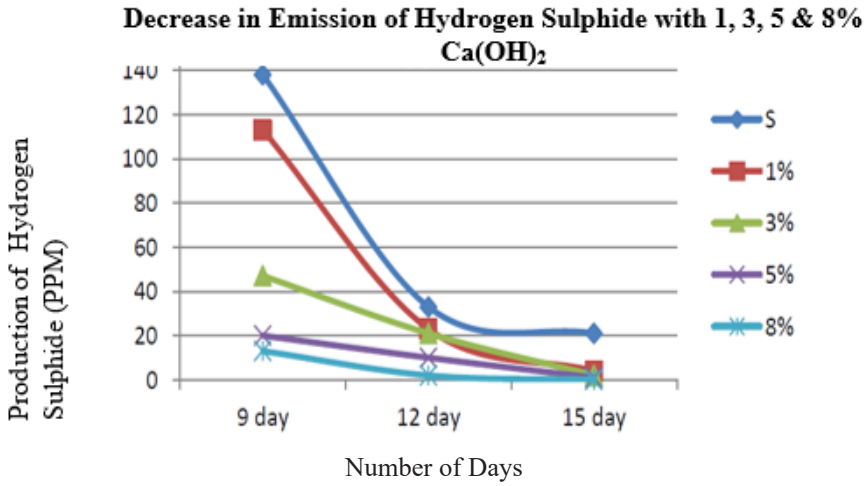

Figure 3: Reduction of Hydrogen Sulphide emission with use of 1,3,5 and 8% hydrated lime on 9, 12 & 15 days [24].

Agriculture and Food

The use of fertilisers and manure by the farmers in the agriculture fields causes the reduction in the ph value of soil, resulting in acidic behaviour, which is hazardous for crop production. The hydrated lime is used to mix with soil to improve (increase) the ph value to induce alkalinity, aeration, better soil structure and fertility, as shown in fig 4 (Anderson, & Bell, 2019; Goulding, 2016; Anderson et al., 2013). The exchange of cations and anions of hydrated lime with acidic soil transforms the soil into the hydrated and calcium-rich matter by reducing H+ ions attached to the soil particles, as shown in fig 5. The use of CaCO3 instead of Ca(OH)2 increases the alkalinity in the same way but also increases the CO2 emissions (fig 6) (Anderson et al., 2013).

Figure 4: Lime application in agriculture fields [28]

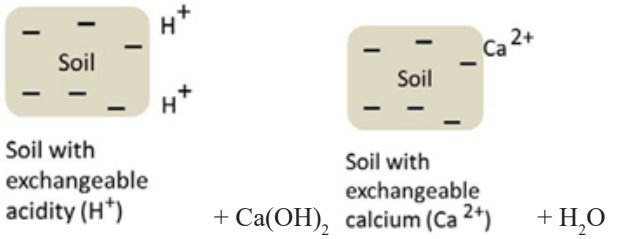

Figure 5: Chemical reaction of hydrated lime with acidic soil (Anderson et al., 2013)

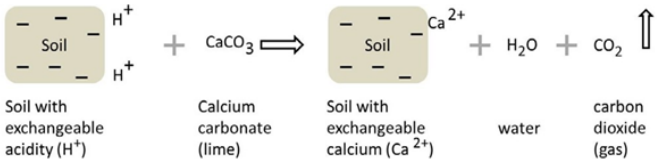

Figure 6: Chemical reaction of $CaCO_3$ lime with acidic soil, causing the emission of CO2 (Anderson et al., 2013)

Review of Hydrated Lime Applications in the Construction Industry

Use of Lime in Cement and Concrete

The use of lime (from limestone) is an essential part of cement manufacturing as cement contains around 62% of lime with other ingredients (Brehm, 2009). The hydrated lime has minimal cementing capability in comparison to hydraulic lime, which becomes a cementitious material when mixed with water. Therefore, adding hydrated lime directly to cement concrete reduces the strength of cement-lime composite (Sotiriadis et al., 2012). However, hydrated and quick lime mixed with aluminium powder and concrete are used to produce autoclave aerated concrete blocks which are lightweight and honeycombed and gives excellent thermal and sound insulation (Lesueur et al., 2011). The hydrated lime can partially replace cement with different pozzolans to produce SCMs, as discussed later.

Lime in Soil Stabilization

Hydrated lime improves ph value and soil particles microstructure as discussed in section 2.5 for agriculture purposes. Hydrated lime is equally recommended for treating expansive clayey soils, especially marine soils and hydraulic structures like rivers and canal banks (Ash et al., 2020). Recent studies have focussed on using hydrated lime and natural fibres like coconut coir to improve the mechanical properties of swelling marine soils. It was observed that up to 5% lime and 1-2% coir can improve the soils' shrinkage, grain size, bearing capacity, plasticity and compressive strength. Anggraini et al. (2014), in their study on the use of lime for expansive soil stabilisation, found out that lime improves the strength and engineering properties. Using coconut coir fibres augments soil's flexural strength and torsional behaviour. However, more than 1% use of fibres leads to reduced density and strength due to a reduction in intra-particles bonding (Ash et al., 2020; Agopyan, 1998; Rosenbalm & Zapata, 2017; Inkoom et al., 2019; Thirumalai et al., 2017; Rao et al., 2009; Anggraini et al., 2014; UKEssays, 2015).

Lime in Stabilization of Hydraulic Structures

The destabilisation of hydraulic structures and embankments made of expansive soils is a common problem faced in civil engineering structures along water streams, rivers and channels. Current research has been exploring using hydrated lime with soil for its long-term stability and improvement of soil properties. Akula et al. (2020), in their study on the long-term effects of lime on hydraulic structures, explored the case study of the Friant kern canal in California, where lime was used for channel stabilisation in the 1980s. They discovered that mixed lime soil remained stable even after 40 years with a ten times improvement of strength and a four times reduction in plasticity index. Therefore, using quick or hydrated lime in soil for improvement of soil structure and stability along with other mechanical properties like plastic limit, liquid limit, moisture contents, moisture containing capability, prevention against expansion on moisture absorption etc., is a recommended and feasible option (Akula et al., 2020).

Application of Hydrated Lime in Road Construction and Hot Mixed Asphalt

The hydrated lime is a primary additive used with subgrade soil and hot mixed asphalt as an anti-slipping neutralising agent to prevent the ingress of moisture loaded with hazardous chemicals from underground or overground sources (UKEssays, 2015). Mixing hydrated lime with clayey soils for subgrade preparation is an economical option compared to cement-treated soil to transform it into friable soil. Mixing quick lime with wet soils results in moisture absorption and converts it into a stable, impervious, better load-bearing soil (Blitzitzco, (n.d.)). The hot mixed asphalt uses stone dust, cement, or hydrated lime as binder/ filler with fine aggregate for a smooth and flexible binding layer of asphalt carpeting in road construction [38]. The use of hydrated lime for improvement of unconfined compressive strength of the subgrade soil was studied by Abdullah and Salih (2020) by using 0%, 2.5%, 5%, 7.5%, and 10% hydrated lime with the soil samples, and they found that an increased quantity of hydrated lime increased the unconfined compressive strength subgrade soil as shown in fig 7 (Abdullah & Salih, 2020).

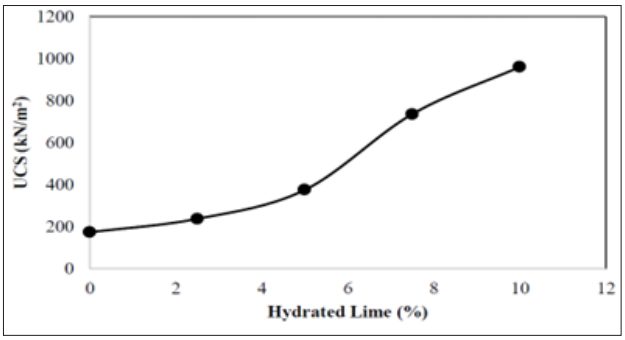

Figure 7: Use of hydrated lime to improve the unconfined compressive strength (UCS) of soil [40]

Use of Hydrated Lime with Cement Replacement / Pozzolans as Supplementary Cementitious Materials SCMs

The focus of contemporary research for the last few decades has remained on the development of environmentally friendly,

greener materials, especially to substitute the use of cement. Pozzolans and lime have historically been recognised as excellent supplementary cementitious materials. Several partial cement replacements from industrial (pulverised fly ash, ground granulated blast furnace slag, silica fume), agricultural (rice husk ash, palm ash) and natural (metakaolin, zeolite) sources have been explored to mix with hydrated lime as better SCMs (Sotiriadis et al., 2012; Ahmed & Kamau, 2017; Divya et al., 2015; Kamau, et al., 2016; Kavitha et al., 2016). The pozzolans provide silicates, and hydrated lime provides portlandite (Ca(OH)2) to create calcium silicate hydrate (C-S-H) gel which provides the strength in concrete, as shown in the equation below (Nadir & Ahmed, 2021). Moreover, using hydrated lime and pozzolans with cement concrete acts as a good filler material to reduce porosity and permeability and prevent external attacks by chemicals like sulphates, thus increasing the sustainability of structures.

$$2SiO_2 + 3Ca(OH)_2 \rightarrow 3CaO.2SiO_2.3H_2O$$

Utilisation of Hydrated Lime in Cement-Based Mortars

One of the most prominent applications of lime is its use as a mortar for brick/stone masonry since ancient times. Most lime mortars are either based on lime putty or hydraulic lime (Ahmed et al., 2022). Cement-based mortars have taken over the use of lime mortars due to their swift setting time. However, the emission of CO_2 from manufacturing/use of cement is reverting the industry back to the use of lime mortars again due to their economic/ environmental benefits. The aforementioned lime products can be used as a partial or full cement replacement after mixing with pozzolans or cement replacement materials. Ahmed et al. (2022), in their experimental studies on pozzolan-based lime putty mortar, elucidated that 2% -20% GGBS-lime mortar exhibited at par or better strength than the typically designated i-iv lime-cement-based mortars (Ahmed et al., 2022). The main disadvantage of pure lime mortars is the slow setting time; however, the above study is one of several research findings showing that by adding SCMs to lime can overcome this issue. Although, hydrated lime (CL-90) is not the base material in mortars, it is used extensively as a plasticiser in cement-based mortars. The typical cement-based mortar ratios containing hydrated lime with their designated classification and range of compressive strengths are shown in Table 1 as per BS EN 5628 (Civilnode, (n.d)). Currently, these mortars are extensively used for many construction projects.

Mortar Designation	Cement: Lime Ratio	Sand Ratio	Known as	Mortar Class	Typical Compressive Strength Range (MPa)
(i)	1:0 to 0.25[1/4]	3	1:3	M12	9 - 12
(ii)	1:0.5	4	1:1/2:4	M6	5 - 8
(iii)	1:1	6	1:1:6	M4	3-5
(iv)	1:2	8/9	1:2:9	M2	1.5 - 2.5

Table 1: Classification of cement-based mortars and comparison to GGBS-based mortars Ahmed et al. (2022)

Conclusion

The hydrated lime (CL90) conforms to BS EN 197-1 as a good building material. It can broadly be used as a basic mortaring, rendering, plastering and lime washing material in civil engineering applications. It is used as water stripping, anti-slipping, flocculating, and coagulating filler binding material in soil stabilisation, subgrade preparation, channel stabilisation, pozzolans-based SCMs, and water. Additionally, it's used in wastewater treatment, waste disposal and filler in hot mixed asphalt carpeting of road surfacing. It reduces porosity/ permeability, shrinkage/ expansion of soils, increases moisture absorption in wet soils, and improves mechanical properties of soil, concrete and SCMs. It helps prevent external sulphate attacks, cracking, rutting and leaching of blended materials. One of the main construction/civil engineering applications is in cement-based mortars as a plasticiser.

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