

AustStab Technical Note

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What is Lime?

The word “lime” is a generic term used to describe many calcium based chemicals.

To clarify some of the confusion arising, a summary has been compiled of the different forms of “lime” and gypsum.

Calcium Chemicals and Minerals

Limestone is a sedimentary rock composed largely of the mineral calcite (calcium carbonate CaCO_3). Limestone is usually composed of grains made up of skeletal remains of marine organisms or created by chemical precipitation.

Quicklime is the chemical *calcium oxide* [chemical formula CaO], produced from limestone (chemical formula CaCO_3) by calcining (burning) at high temperatures to decompose the limestone to *quicklime*. Because of this calcining process, the product is sometimes called *burnt lime* or the name is abbreviated to *lime*. It is an alkaline (basic) product with pH >12 and is usually a powder or granule with a density greater than 1000 kg/m^3 .

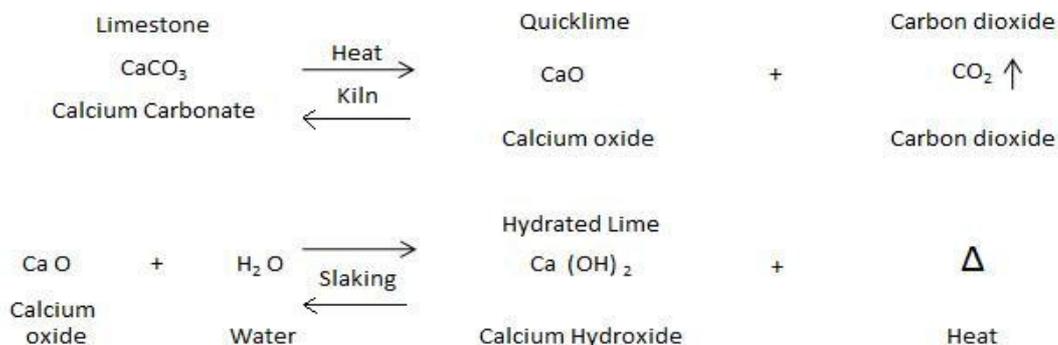
Hydrated Lime is the chemical *calcium hydroxide* [chemical formula Ca(OH)_2]. Produced from *quicklime* (chemical formula CaO) by mixing in water so that the *quicklime* hydrates (also called slaking) with heat given off (exothermic). The name is sometimes abbreviated to *lime*. It is an alkaline (basic) product with pH >12 and is a fine powder with a variable density from 450 to 780 kg/m^3 .

Gypsum is the mineral *calcium sulphate* [chemical formula $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$]. Produced from mining deposits of the mineral (*natural gypsum*) or as a by product of the chemical industry (*chemical gypsum*) – usually from fertilizer manufacture. Maybe used to change the chemical structure of clays by ion exchange between the calcium (Ca^{2+}) ions in the gypsum and the sodium (Na^+) ions in the clay to produce a non-clay like soil that easily dewater and compacts. Considered pH neutral and therefore is not as reactive as *lime* in soil stabilisation processes. Gypsum is often added to clay in dams to prevent or reduce severe cracking and subsequent piping leading to water loss.

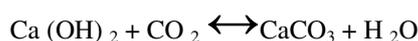
Agricultural Limestone is the mineral *calcium carbonate* [chemical formula (pure) CaCO_3]. Produced from mining deposits of limestone and crushing to a powder or granule that’s mostly < 1mm in sizing. The name is sometimes abbreviated to *Aglime* but should never be called lime as this is the abbreviation for either *quicklime* or *hydrated lime*. Pure *aglime* is 100% calcium carbonate but is rarely found at this level in mined deposits. The *aglime* is slightly basic (pH 8) and is mainly used in agricultural applications to neutralise acidic (pH<7) and acid sulphate soils as well as to adjust Ca^{2+} to Mg^{2+} ion ratios in the soil.

Chemical Process

The process of the progressive change of limestone to lime is shown in the diagram below:- both reactions are reversible



If hydrated lime is exposed to carbon dioxide, it may revert back to calcium carbonate



Use of Lime in Stabilisation

Quicklime and hydrated lime are often used in soil stabilisation. It is necessary to slake quicklime to hydrated lime in the field. Slaking is the process of converting quicklime to hydrated lime by reacting it with water. The reaction is an exothermic chemical reaction, and produces steam which is sometimes mistaken for dust. Hydrated lime is always used in the laboratory and sometimes in the field.

How does lime work

The lime's reaction with clay is two-fold.

Firstly, it modifies the structure of the clay/soil. This is achieved due to cation exchange, where the calcium cation replaces other cations as documented by the Lyotropic series, leading to flocculation/agglomeration of clay particles. The net result is:

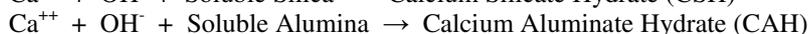
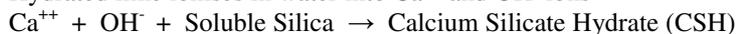
1. Substantial reduction in the adsorbed water layer effectively lowering the water holding capacity of the soil.
2. Increased internal friction among agglomerates and greater aggregate shear strength.
3. Much greater workability due to the textural change from a plastic clay to a friable, sand-like material.

Secondly, the lime raises the pH to above 12.4, which encourages chemical reactions that lead to the formation of calcium silicates and aluminates.

Reactive silica and alumina become soluble or available in a high pH environment. When the lime demand of a particular soil is met then the hydrated lime in the presence of water sets up an alkaline environment (pH>12.4) in which the calcium ions will react with Pozzolans (materials containing reactive silica and alumina) that are present in the pavement material or subgrade. This chemical process is at work in road stabilisation projects where clays provide the silica and alumina components required for the reaction.

As long as enough residual calcium remains in the soil-lime-water system to combine with the pozzolans and as long as the pH remains high enough to maintain solubility, the pozzolanic reaction will continue. The reactions are illustrated by the following equations:

Hydrated lime ionises in water into Ca^{++} and OH^- ions



These calcium complexes initially form as a gel which coats and binds soil particles as the chemical processes move toward the crystallisation (cementitious) stage as they form hydrates. The rate of crystallisation is temperature dependent and may take many months to reach completion. This in turn correlates to a steady strength gain that can be tracked and measured using the CBR test.

The hydrated complexes are cementitious products, similar in composition to those found in cement paste, and are the end results of physio-chemical reactions with clayey soil minerals (or other Pozzolans such as fly ash) that dramatically reduce the plasticity of the soil, increase its workability and improve its compaction characteristics. The result is a durable product which is not usually affected by time or water and develops compressive and tensile strength which is utilised in pavement design.

Lime reactivity

Understanding the reactive nature of quicklime leads to a better use of lime in pavement stabilisation work.

Hydrated lime and quicklime are used directly in pavement stabilisation works with hydrated lime also being used as the activator for manufactured blended products that use blast furnace slags or fly ash. Quicklime is used extensively for subgrade stabilisation in heavy clays.

Quicklime is converted to hydrated lime either at the manufacturing plant or by the addition of water at site. This process of "slaking" by adding water to the quicklime causes an exothermic reaction generating heat and steam. In the field this can sometimes be confused with dust generation.

There are factors which can effect the hydration of quicklime and these include:

- The inherent reactivity of the quicklime
- Its mean apparent density and the distribution of its particle density
- Its particle size distribution
- Impurities, which if they were to form a surface layer on the quicklime particles, would inhibit the hydration process.

Loss of reactivity of lime is caused by over burning, or by holding lime in the kiln at too high a temperature for too long. When lime is calcined, the release of carbon dioxide leaves pores in the lime, creating extra surface area on which the reaction can occur. Over burning results in the collapse of these pores, reducing the ability of lime to react with water. Over burning will also result in the impurities in the lime (mainly silica, alumina and iron) forming cement clinker minerals, further reducing the calcium content available for reaction with water.

General properties of lime stabilised soils.

Property	Description
Plasticity	The plasticity index decreases, as much as four times in some circumstances. This is due to the liquid limit decreasing and the plastic limit increasing.
Moisture density relationship	The result of immediate reactions between lime and the clay soil is a substantial change in the moisture density relationship. The moisture density changes reflect the new nature of the soil and are evidence of the physical property changes occurring in the soil upon lime treatment.
Swell potential	Soil swell potential and swelling pressures are normally significantly reduced by lime treatment.
Drying	Lime (particularly quicklime) aids the immediate drying of wet clay soils. This allows compaction to proceed more quickly.
Strength properties	Both the Unconfined Compressive Strength (UCS) and CBR increase considerably with the addition of lime. These values can be further increased by a follow up treatment of cement after the initial lime treatment. Experience has shown increases of CBR's from 3 up to 20 with lime only treatment and as high as CBR 50 with a follow up cement treatment. This gain in strength is often used in the design of pavements in order to reduce the depth of pavement material required.
Water resistance	The lime stabilised layer forms a water resistant barrier by impeding penetration of moisture from above and below. Thus, the layer becomes a working platform shedding water and allowing construction to proceed unaffected by weather. Experience in Victoria is that a second treatment with cement is required to achieve long-term waterproofing of the clay-stabilised layer unless the stabilised layer is covered by another pavement layer as quickly as possible.

Product	Use	Advantages	Comments
Quicklime	Changes structure of plastic soils leading to increased strength and reduced permeability. Drying out wet soils.	Most efficient lime by mass therefore cheaper per M ² . Minimal problem with dust. Most efficient drier of wet soils.	Requires more water on site due to the slaking process. Generates steam cloud during slaking process. Often mistaken for dust (refer to AustStab Construction Tips The steam cloud emanating from slaking of quicklime).
Hydrated Lime	To strengthen and reduce permeability of plastic soils. Drying out wet soils. Laboratory testing (eg. CBR).	Able to be mixed immediately into the stabilisation process, therefore saving time. Requires less water on site.	Is light and fluffy. Can become airborne more easily. More expensive per M ² than hydrated lime.
Lime Slurry	To strengthen and reduce permeability of plastic soils.	Eliminates dust problems.	Expensive and not common. Can set in the equipment causing high maintenance. Environmental problems
Agricultural Lime	Altering the pH of soils	Mildly alkaline for agriculture Rectifying acid sulphate soils exposed and stockpiled during construction process.	Not used in traditional pavement stabilising activities.
Gypsum	Altering soil properties and treatment of water retaining structures	Cheap	Not used in traditional pavement stabilising activities.
Limestone	Aggregate Manufacture of hydrated and quicklime.	Treatment of acid sulphate soils	Negligible binding action. Long time to react usually more efficient to use Aglime.

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