Environmental Sustainability: Abatement of Co₂ Emissions from a Calcination Plant in Zimbabwe

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Abstract

A small calcination company is starting up in Zimbabwe. The main challenge at the company is the abatement of Carbon Dioxide (CO₂) emissions. There are 2x3 tonne kilns that have just started operating and are releasing flue gases directly into the air. Data was collected through visits to the calcination plant and interviews of key personnel. Research into how CO₂ can be removed from the flue gas before it can be released into the air was carried out with specific reference to the plant. The results showed that environmental sustainability is achievable by minimising the emissions of CO₂ into the environment and reducing energy and material inputs. Addition of chimneys to the kilns will increase draught column and preheating of limestone hence raw materials utilisation will improve. Addition of an exhaust will make collection of CO₂ more convenient. As the flue gas is collected it is made to pass through an amine system that then captures CO₂. The collected CO₂ will be sold to companies that use it as a raw material. Addition of vermiculite insulating material between the brick layers will improve insulation and energy is utilised. Steel reinforcements to the kilns will extend their life span as well.

Key words:
Calcination, Carbon Dioxide, Vermiculite, Greenhouse gases

1. Introduction

1.1 Calcination
Calcination is essentially the process of converting (by burning) limestone into lime. It results in quicklime, Calcium Oxide. Hydrated lime or Calcium Hydroxide is produced by reacting quicklime with sufficient water to form a dry white powder. The residue is called quicklime or caustic lime. Pure quicklime is white and amorphous or crystalline. The specific gravity is 3.2 and melting point 2578°C (Brady G. S., et al, 2002). Lime is employed by a wide range of industries for innumerable uses. It is used widely used in the following industries: steel industry, waste water, cleaning of industrial gases before they are released into the air, paper, paint, ink and plastic industry, cement manufacturing, sugar refineries and gold refineries.

1.2 Background – JMK Trading Company
In Zimbabwe many companies in the industry are slowing down even shutting down due to a number of challenges and mainly the economic challenges facing the country. However a new company, JMK Trading (JKMT), has just started up in Gweru. The main line of production is the Calcination of Limestone producing limestone. The company employs 20 people at full capacity and all reporting to 1 manager and owner of the company. The main challenge at JKMT is the emissions of Greenhouse gases. There are 2 x 3 tonne kilns, shown in Figure 1. As seen in the picture these gases are being released into the air directly. There are no measures in place yet to mitigate the greenhouse gases that are being emitted directly into the air. (Mashavakure, 2016)
Figure 1: The two kilns at JMKT, each at 3000kg capacity

Figure 2 shows the construction process for the kilns. Figure 2b is showing the draw hole to collect the quicklime from and allow the air for combustion through. On top of the draw hole it is showing that the kilns are made up with 2 walls. The inner wall is made from refractory bricks and the outer wall is made of a stronger quality brick. In between the two walls is an insulation to control the amount of heat that is lost from the kilns. Figure 2c shows one side wall that is complete. These are access points that allow inspection of the process progress. The biggest supplier of Lime used to be a parastatal company located in Kwekwe but has since not been functioning for a number of years now. JMKT saw this opportunity created by this gap to start the Calcination of Limestone. Their target consumers are the over 50 Gold mines in the country, City council (for water purification process), Sugar manufacturers and eventually export too. Currently their main consumers are the Gold miners in Shurugwi (283km from Gweru), Gwanda (297km from Gweru) and Kadoma (137km from Gweru). (Mashavakure, 2016).

There is still a lot of work that needs to be done for the company to grow and meet the demand i.e. so that JMKT can supply lime to all its targeted consumers. All the work is still be done manually. Figure 3a shows quicklime being collected using a shovel by an employee and figure 3b shows a ladder that is used to assist with the feeding of the kiln. A network of ropes is used to pull buckets of limestone up.
After the collection of the quicklime, water is added to form hydrated lime powder. This will make the transportation of the lime easier as hydrated lime will no longer react with water in cases of accidental hydration. Figure 4 shows the reaction of quicklime with water to form hydrated lime. The water is collected from a nearby stream. (Mashavakure, 2016).

Once this is done the hydrated lime is then taken to the grinder where it is ground to form powder form of the hydrated lime that will be ready for collection. Figure 5 shows the grinding mill that is powered by an electric motor.
Coal is used as the source of energy here. It is bought from a company in Hwange at $1300.00 per 25tons including transportation charges. 25 tons of coal produce 100Mt of lime.

Possibilities of reducing energy cost are:

- use of insulating material such as vermiculite between the inner brick skin and outer and
- addition of a chimney to each kiln could increase draught column hence preheating of limestone

Material costs can be reduced by constructing kilns close to limestone and coal mines, but on condition there is a ready water source nearby. As has been illustrated by all the pictures this calcination and furnace design was done with 'limited resources'. However the urgent issue that needs to be addressed is the issue of greenhouse gas emissions.

2. LITERATURE REVIEW

2.1 Calcination process

Calcination is an endothermic process where limestone (calcium carbonate) $\text{CaCO}_3$ is converted by thermal decomposition into lime (calcium oxide) $\text{CaO}$ and (Carbon Dioxide) $\text{CO}_2$. The process of calcination (thermal decomposition of a limestone particle) can be divided into three stages (Figueroa J D, et al, 2008): (a) heat energy transported by calciner gases (i.e. combustion products and exhaust gases from the rotary kiln) supplied to the limestone particle by convection and radiation, pre-heats the particle from the ambient temperature to the decomposition temperature. The decomposition temperature is in the temperature range from 600 °C to 900 °C (Freund P, 1997) depending on the type of limestone; (b) at the decomposition temperature, when the pressure of $\text{CO}_2$ produced by the decomposition of limestone at the particle surface is greater than the partial pressure of $\text{CO}_2$ in the surrounding gas, the process of calcination begins, making a lime shell around the limestone core; (c) by conduction the heat passes through the porous layer increasing the internal temperature, which causes continued calcination. The released $\text{CO}_2$ diffuses through the porous layer to the surface and by convection is released into the calciner. As long as the particle temperature increases and the partial pressure of $\text{CO}_2$ is below the decomposition pressure, the process of calcination will continue until all the limestone is converted into lime (Mikulc’ic’ H., et al, 2012).

The following equation presents the calcination process:

$$\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \quad \Delta H = +182 kJ \ mol^{-1}$$

This means that the forward reaction is favoured by higher temperatures, as the reaction is endothermic. The reaction will proceed only if the partial pressure of $\text{CO}_2$ in the gas above the solid surface is less than the decomposition pressure of the $\text{CaCO}_3$. The latter pressure is determined by equilibrium thermodynamic considerations (Stanmore B.R., et al, 2005).

Figures 6, 7 and 8 show the vertical kiln and the rotary kiln that may be used in the Calcination process. Kilns may have steel shells lined with refracting bricks. The design of the vertical kiln in figure 2 makes it easier to collect the produced $\text{CO}_2$. 
2.2 Furnace Construction

The principal objective of a furnace is to achieve controlled heating of the product at higher temperature and lower fuel consumption than could be achieved in the open air (Mullinger P., et al, 2008). Use of less fuel is becoming increasingly important as fossil fuel reserves are diminishing and permissible carbon emission limits are increasing. Furnaces in the early days were built of brick and stone. As demand grew furnaces became larger and the brick and stone structure became susceptible to failure and steel reinforcing bands were often added externally to strengthen the structure. With that the steel reinforcing became part of the initial design in addition to the basic brick structure. The rotary kiln was invented in the late nineteenth century and it required that an outer steel tube with a brick lining be used, thus a new form of construction was established and in time spread to most other
furnaces. These days most furnaces consist of a steel outer structure with a heat resistant lining. Some of these types of furnaces are shown in figures 9 and 10.

The advantages of having a steel casing over reinforcing a brick structure with steel are:

- Reduced gas out and air in leakages.
- Relining a furnace is cheaper than rebuilding it hence it becomes easier and less expensive to maintain.
- Safety is improved since flying debris is reduced in the event of an explosion.
- Shape, size and type of lining can be changed so there is now greater flexibility in design (Mullinger P., et al, 2008).

2.3 Basic Performance Requirements of a Furnace Structure

A basic furnace is made up of a casing with a source of heat. This source of heat maybe a flame that provides process energy. Through the use of flames the heating may be direct and/or convective. Direct heating uses radiation from the flame and convective heating transfers the heat from combustion products or indirectly through radiant heat from a heated wall. Figures 11 and 12 show a basic furnace showing direct fired and indirect fired heat source respectively.
Whatever method of heat transfer is used the furnace is required to:

- have a controlled environment for the process.
- have optimum-shaped space for the combustion process and for effective heat transfer.
- contain, and in some cases transport, the product safely.
- diminish air and gas leakage in or out.
- diminish radiation and convection losses.
- have a long working life and easy to maintain.

A furnace needs to be designed for temperatures ranging from ambient up to 2000°C in some instances. This is a challenge in the designing and maintaining of furnaces. However, critical issues that should be incorporated are:

- Tolerance for differential thermal expansion allowance.
- Tolerance for irreversible expansion caused by structural changes in the refractory during initial heating.
- Reduction of high temperature corrosion.
- Having adequate strength under load.
- Possibility of a chemical reaction occurring between the feed/product and furnace lining. (Mullinger P., et al, 2008). In order to resolve such issues it requires careful consideration of all the factors concerned, for example, choice of materials appropriate for ceramic refractories, methods of accommodating differential expansion, etc.

### 2.4 Effects on the Environment of the Production of CO₂ during Calcination

The latest manifestation of pollution is that of climate change. This has been brought about to a certain degree by human activity contributing to an increase of greenhouse gases in the atmosphere, principal among these being Methane (CH₄) and CO₂. As such there is considerable pressure on industries which rely on combustion to minimise their emissions of CO₂. An in-depth understanding of these processes is relevant for the reduction of CO₂ emission. The calcination reaction has CO₂ as its direct product. Proposals included capturing the CO₂ in the combustion gases, and then release it separately in a concentrated stream, which is able to be fixed more efficiently and economically than the dilute combustion gas (Freund P., 1997). CO₂ capture and storage (CCS) is gradually becoming an important concept in reducing greenhouse gas emissions, next to other options, such as, the use of renewable energy, the use of nuclear energy, energy efficiency improvements and switching from coal to gas firing (Feron P.H.M., et al, 2005). This option is now much better understood and can be compared with these more established measures, such as fuel switching, energy efficiency improvements and use of renewable energy (Freund P, 1997). CCS will be looked into as a possible option for the Calcination Plant in the abatement of CO₂ emissions.

### 2.5 CO₂ Capture and Storage

CCS is one way that will make way for the possible sustenance of the use of fossil fuels (coal, gas and oil), by drastically reducing the CO₂ emissions. In CCS, CO₂ is collected, prepared to be transported and kept in a suitable geological sink, where it is kept for a sufficiently long period. It is therefore crucial that CCS limits or altogether avoids the release of CO₂ into the atmosphere as a result of calcination process (Feron P.H.M., et al, 2005). In case of calcination the capture and storage of CO₂ will result in a net decrease of CO₂ in the atmosphere. The three steps followed in CCS are:

- Capture - Large amounts of CO₂ are emitted in diluted streams at atmospheric pressure. In order to be transported and stored it needs to be concentrated. In general it needs to be a near pure CO₂ product at an absolute pressure of 100 bar after being captured. Therefore a compression step is carried out to achieve the correct transport/storage state.
Transportation – It is not always that the CO₂ storage sinks are at the same place as the source of emissions. Therefore transport is needed to link the CO₂ source to the sink.

Storage – When CO₂ is stored it must remain inaccessible to the atmosphere, at times, for relatively long periods of time. Possible choices are mainly underground, e.g. exhausted oil and gas fields, deep coal beds and aquifers. (Feron P.H.M., et al, 2005).

2.6 CO₂ Capture Technologies

Capture and storage of CO₂ is one of the methods used to mitigate greenhouse gas emissions into the atmosphere. Therefore it is not the amount of carbon dioxide captured per unit of production that is important, but it is the amount of carbon dioxide emission avoided (Feron P.H.M., et al, 2005). The calcining process produces diluted CO₂ due to the process being coal/air fueled. This now brings about the challenge of separating the CO₂ from the rest of the flue gases. It is particularly important to integrate technologies that allow separation of CO₂ at low cost and highly efficient capture routes. When considering how best to capture CO₂, there are three technologies that can be pursued in order to capture CO₂ from coal-derived processes. They are: post-combustion capture, pre-combustion capture, and oxy-combustion (Yang H., et al, 2008). In post-combustion capture, the CO₂ that is separated from other flue gas constituents is either originally present in the air or produced by combustion. In pre-combustion capture, carbon is removed from the fuel before combustion, and in oxy-combustion, the fuel is burned in an oxygen stream that contains little or no nitrogen (Figueroa J D, et al, 2008). Advantages and disadvantages of the different CO₂ capture technologies are as follows.

Post-combustion - Advantages

1. Applicable to the majority of existing coal-fired power plants
2. Retrofit technology option

Disadvantages

1. Flue gas is dilute in CO₂ at ambient pressure resulting in:
   - Low CO₂ partial pressure
   - Significantly higher performance or circulation volume required for high capture levels
   - CO₂ produced at low pressure compared to sequestration requirements (Leung D. Y. C., et al, 2014)

Pre-combustion - Advantages

1. Synthesis gas is concentrated in CO₂ at high pressure resulting in:
   - High CO₂ partial pressure
   - Increased driving force for separation
   - More technologies available for separation
   - Potential for reduction in compression costs/loads

Disadvantages:

1. Applicable mainly to new plants, as few gasification plants are currently in operation
2. Barriers to commercial application of gasification are common to pre-combustion capture
3. Availability
4. Cost of equipment
5. Extensive supporting systems requirements

Oxy-combustion - Advantages

1. Very high CO₂ concentration in flue gas
2. Retrofit and repowering technology option

Disadvantages

1. Large cryogenic O₂ production requirement may be cost prohibitive
2. Cooled CO₂ recycle required to maintain temperatures within limits of combustor materials
3. Decreased process efficiency

The above leads to a conclusion that post-combustion capture applies primarily to coal/air-fueled processes. Pre-combustion capture applies to gasification plants. Oxy-combustion can be applied to new plants or modified to existing plants. These process classifications are applicable to both fossil fuel and biomass based energy
conversion processes (power plants and industrial plants). The process specifics will however differ for each type of fuels, and each type of process. Also, for coal based processes the sulphur content of coal has an impact on the design, operation and costs of capturing CO₂. Power plants maybe the largest point sources of diluted CO₂ but other large single point sources of diluted CO₂ are furnaces and industrial boilers, and calcining processes (Feron P.H.M., et al, 2005). Since calcination process produces CO₂ as a by-product post-combustion capture and oxy-combustion technologies can be applied to the calcining process. This is because they allow the capture of CO₂ after processing. However one of the disadvantages of the oxy-combustion technology is that large cryogenic O₂ production requirement may be cost prohibitive and one of the challenges is that of developing a separation process that recovers CO₂ from the flue gas at acceptable costs. This then leaves post-combustion technology as a viable technology to be used at JMKT.

2.7 Post-combustion CO₂ capture
This process removes CO₂ from the flue gas after combustion (or calcination in this case) has taken place. Its ability to be retrofitted into existing power plants makes it the preferred option for CO₂ capture. Post-combustion decarbonisation in Calcination comprises of two main steps: calcining during which lime is produced, followed by a CO₂ separation process in which a concentrated stream of CO₂ is produced. This process has the greatest near-term potential for reducing GHG emissions, because it can be retrofitted to existing calcining plants (Figueroa J D, et al, 2008). The leading option is an absorption process using amine based solvents such as Monoethanolamine (H₂NCH₂CH₂OH) (MEA) absorption. (Mikulcíc H., et al, 2012).

2.8 Amine-Based Systems
Amines are chemicals derivatives of ammonia (NH₃) in which one or more of the hydrogen atoms are replaced by an organic radical. Generally the formula for amines is R—NH₂. They are available in three forms (primary, secondary, and tertiary), each with its advantages and disadvantages as a CO₂ solvent. The classification of amines is based on the number of organic groups attached to the nitrogen atom as shown in Figure 13.

![Figure 13: Classification of amines.](image)

Methylamine, CH₃NH₂, is a primary amine. It has one ammonia hydrogen substituted. It is a gas and, like ammonia, is soluble in water and handled in water solution. It is flammable, a 40% solution having a flash point of 20°F (–7°C), and the vapours are explosive in air. Dimethylamine, (CH₃)₂NH, is a secondary amine. It forms a hydrate in water solution, (CH₃)₂NH·7H₂O, that has a low freezing point, 1.76°F (–16.8°C). Trimethylamine, (CH₃)₃N, a tertiary amine, is a gas liquefying at 37.2°F (2.87°C). Methylamines are extensively used as a source of nitrogen. Isopropylamine, (CH₃)₂CNNH₂, may be used as a replacement for ammonia in many chemical processes or as a solvent for oils, fats, and rubber. It is a clear liquid of specific gravity 0.686, boiling point 89°F (31.9°C), freezing point –150°F (–101°C). Sipenols are a group of amines used as textile lubricants and softeners. They are clear to light yellow liquids and are dimethyl ethanol amines or dibutyl ethanol amines (Brady G. S., et al, 2002). Most of the amines have a strong decaying fish odour. (Ballinger J. T., et al, 2011). Amines react with CO₂ to form water soluble compounds. Thus amines are able to capture CO₂ from streams with a low CO₂ partial pressure. Therefore amine-based systems are able to recover CO₂ from the flue gas of conventional pulverized coal fired plants. An advantage of this technique is that it produces a relatively pure CO₂ stream (Yang H., et al, 2008). Design modifications are possible to decrease capital costs and improve energy integration. These modifications include modified tower packing that reduces pressure drop and increases contacting, increased heat integration to reduce energy requirements, additives to reduce corrosion and allow higher amine concentrations, and improved regeneration procedures (Figueroa J D, et al, 2008).

2.9 AEP (1-(2-Aminoethyl) Piperazine) Solution Compared to Primary, Secondary and Tertiary Amines
Various aspects of CO₂ absorption such as absorption capacity, absorption rate, reaction heat, degradation of absorbent, and corrosion have been studied. Monoethanolamine (MEA), which is commonly used in commercial processes, exhibits a faster reaction rate with CO₂ than other alkanolamine absorbents, such as diethanolamine (DEA), methylidethanolamine (MDEA), and 2-amino-2-methyl-1-propanol (AMP). Nevertheless, the manufacturing and operating costs of MEA processes maybe increased due to high absorbent makeup rate through thermal and oxidative degradation and vaporization, high corrosion of equipment, low absorption capacity, and high regeneration energy required for absorbent regeneration at the desorber. In recent times, an aqueous 1-(2-
Aminoethyl) piperazine (AEP) solution emerged as a new absorbent (Choi J.H., et al, 2016). AEP is a cyclic amine that includes a primary, a secondary, and a tertiary amino group in a molecule. The AEP molecule exhibits desirable physical properties, such as a high boiling point (218-222°C), low vapor pressure (0.05 hPa at 22°C) and good solubility in water (fully miscible). It has been proposed that an innovative blend of piperazine (PZ) with AEP exhibited superior absorbency for CO₂ capture (Du Y., et al, 2013). Aqueous PZ/AEP showed high CO₂ loading and stable degradation resistance without the precipitation problem of highly concentrated PZ. The CO₂ absorption characteristics of an aqueous AEP solution, which features primary, secondary, and tertiary amino groups, were studied by comparing the solution to the representative commercial amine, MEA. The results at 60°C showed that AEP exhibits 2.2-fold greater CO₂ loading than MEA. AEP exhibits all the characteristics of primary, secondary, and tertiary amines. Three different amino groups in the AEP reacted with CO₂ in the following order: primary greater than and secondary greater than tertiary. The AEP exhibited excellent CO₂ absorption characteristics, including CO₂ loading and the absorption rate. Additionally, AEP also exhibited high stability for thermal degradation compared with MEA. Therefore, AEP could be expected to replace MEA as an absorbent. Nonetheless, additional research is still needed to replace the absorbent as physical properties, oxidative degradation, nitrosamine formation, foaming potential, mass transfer under absorber conditions and CO₂ cyclic capacity (Choi J.H., et al, 2016).

2.10 Compression of the CO₂
After capture, the high CO₂ content stream need to be transported for geological storage or for CO₂ utilization (Leung D. Y. C., et al, 2014). In all cases CO₂ is required at high pressure in order to be transported. Ship transport requires liquefaction. The CO₂ is only at moderate pressure, e.g. 0.6 MPa (although it has to be compressed as part of being liquefied) (Feron P.H.M., et al, 2005). The purpose of CO₂ capture is to produce a concentrated stream of CO₂ at high pressure that can readily be transported. In principle, the entire gas stream containing low concentrations of CO₂ could be transported and injected underground (geological storage), energy and other associated costs generally make this approach impractical. It is, therefore, necessary to produce a nearly pure CO₂ stream for transport and storage (Manovic V., et al, 2009).

3. Conclusion: Proposed Solutions to JMK Trading Company
3.1 Energy & Material Utilisation and CO₂ Capture
The most urgent requirement at JMK trading company is taking care of the environmental concerns. These will be achieved by minimising the emissions of greenhouse gases into the environment and aiming at reducing energy and material inputs.

1. Addition of chimneys to the kilns. This will increase draught column hence preheating of limestone as shown in Figure 14. The energy and material utilised will then reduce while achieving the same output. Figure 16 is also showing the exhaust, when this is added to the kilns the capture of the flue gases, hence CO₂ becomes much more convenient. As the flue gas is collected it is made to pass through an amine system. Amines will react with the CO₂ to form water soluble compounds. Thus CO₂ is captured from the stream with a low CO₂ partial pressure. This technique will produce a relatively pure CO₂ stream. AEP solution is giving hope of better CO₂ absorption properties, but more work is still being done on its physical properties. At this time Amines systems would work the best.

Figure 14: Addition of the chimneys and exhausts to the kilns.
2. Heat loss reduction will be achieved through use of insulating material such as vermiculite between the inner brick skin and outer brick layer. Energy utilisation is optimised this way.
3. Steel reinforcements to the kilns as shown in Figure 4 will assist in the sustainability of the kilns.

3.2 Uses of the Captured CO₂

After the capture of the CO₂ it is crucial for the company to know how best to dispose of it and most importantly make some money out of it. Here are some proposals as to how CO₂ is used in industry hence making it easier to identify possible consumers (Gopito, 2016):

1. Multi-Industry Uses for Carbon Dioxide (CO₂) - Carbon dioxide in solid and in liquid forms is used for refrigeration and cooling. It is used as an inert gas in chemical processes, in the storage of carbon powder and in fire extinguishers.
2. Metals Industry - Carbon dioxide is used in the manufacture of casting moulds to enhance their hardness.
3. Manufacturing and Construction Uses - Carbon dioxide is used on a large scale as a shield gas in MIG/MAG welding, where the gas protects the weld puddle against oxidation by the surrounding air. A mixture of argon and carbon dioxide is commonly used today to achieve a higher welding rate and reduce the need for post weld treatment. Dry ice pellets are used to replace sandblasting when removing paint from surfaces. It aids in reducing the cost of disposal and clean-up.
4. Chemicals, Pharmaceuticals and Petroleum Industry Uses - Large quantities are used as a raw material in the chemical process industry, especially for methanol and urea production. Carbon dioxide is used in oil wells for oil extraction and to maintain pressure within a formation. When CO₂ is pumped into an oil well, it is partially dissolved into the oil, rendering it less viscous, allowing the oil to be extracted more easily from the bedrock. Considerably more oil can be extracted from through this process.
5. Rubber and Plastics Industry Uses - Flash is removed from rubber objects by tumbling them with crushed dry ice in a rotating drum.
6. Food and Beverages Uses for Carbon Dioxide - Liquid or solid carbon dioxide is used for quick freezing, surface freezing, chilling and refrigeration in the transport of foods. In cryogenic tunnel and spiral freezers, high pressure liquid CO₂ is injected through nozzles that convert it to a mixture of CO₂ gas and dry ice "snow" that covers the surface of the food product. As the dry ice sublimes (goes directly from solid to gas states) refrigeration gas is transferred to the product to freeze it. Carbon dioxide gas is used to carbonate soft drinks, beers and wine and to prevent fungal and bacterial growth. Liquid carbon dioxide is a good solvent for many organic compounds. It is used to de-caffeinate coffee. It is used as an inert “blanket”, as a product-dispensing propellant and an extraction agent. It can also be used to displace air during canning. Supercritical CO₂ extraction coupled with a fractional separation technique is used by producers of flavours and fragrances to separate and purify volatile flavour and fragrances concentrates. Cold sterilization can be carried out with a mixture of 90% carbon dioxide and 10% ethylene oxide, the carbon dioxide has a stabilizing effect on the ethylene oxide and reduces the risk of explosion.
7. Health Care Uses - Carbon dioxide is used as an additive to oxygen for medical use as a respiration stimulant.
8. Environmental Uses - Used as a propellant in aerosol cans, it replaces more environmentally troublesome alternatives. By using dry ice pellets to replace sandblasting when removing paint from surfaces, problems of residue disposal are greatly reduced. It is used to neutralize alkaline water.
9. Miscellaneous Uses for Carbon Dioxide (CO₂) - Liquid carbon dioxide's solvent potential has been employed in some dry cleaning equipment as a substitute for conventional solvents. This use is still experimental - some types of soil are more effectively removed with traditional dry cleaning equipment, and the equipment is more expensive. Yields of plant products grown in greenhouses can increase by 20% by enriching the air inside the greenhouse with carbon dioxide. The target level for enrichment is typically a carbon dioxide concentration of 1000 PPM (parts per million) - or about two and a half times the level present in the atmosphere.
4. References


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Biography

Loice Gudukeya is a PhD student at the University of Johannesburg, South Africa. She is also a lecturer in the Mechanical Engineering Department at the University of Zimbabwe. She attained her first degree in Industrial and Manufacturing Engineering at NUST (Bulawayo, Zimbabwe) in 2004 and her Masters in Renewable Energy at the University of Zimbabwe in 2012. She is a Board and Corporate member of the Zimbabwe Institution of Engineering (ZIE). As a corporate member she is part of the subcommittee National Engineering of Student Award Committee. She served on the ZIE board from April 2013 to March 2015.

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