Enhancing Environmental Efficiency through use of Cleaner Production Technology in the Fertilizer Production Industry: A Case Study of FertCo in Zimbabwe

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Abstract: ***This research study investigates processes involved in the production of fertilizers and seeks to highlight the opportunities available to use Cleaner Production technology to improve on input resource efficiency, reduction of waste generation and minimize resultant pollution in a fertilizer manufacturing plant. Effort has also been made to ensure that such plants are safe for workers and complies with regulatory effluent discharge requirement. The findings can be adapted for any sizeable plant and can be found to be of value to entities seeking to attain world class fertilizer manufacturing standards.***

Key words: fertilizer, manufacturing, cleaner production, pollution, waste, resource efficiency

1. Introduction

In the past five years, there has been a sharp increase in the number of new fertilizer companies starting production. The chemical nature of fertilizer manufacturing inputs and outputs makes it mandatory to operate and progressively reduce environmental impacts due to such operations. According to L.M.Maan (International Fertilizer Industry Association 2009), the documented detrimental effect of fertilizers on flora and fauna, demands that close monitoring is done for the entire process of manufacturing, application and disposal to safeguard the environment. There is the need to investigate this area and recommend possible areas of improvement to comply with emerging and demanding regulatory requirements. Although considerable research has been devoted to impact of fertilizer usage, a rather less attention has been paid to pollution resulting from fertilizer manufacturing waste disposal [1]. This study looks at influencing the development of a Cleaner Production Management program for the fertilizer industry as a practical approach that fertilizer companies can adopt to set and achieve their environmental performance objectives.

2 . Justification

Fertilizer manufacturing involves handling of inputs like phosphates, ammonium nitrates, gypsum and limes. While end products are mainly granulated compounds and blended fertilizers ready for use by farmers [2]. Local annual fertilizer production capacity is currently estimated at around one million tons of various forms of fertilizers and blends. Waste disposal involves taking and dumping garbage at localized landfills including waste generated by fertilizer manufacturers of such as FertiCo Ltd resulting in soil degradation and water contamination in the process. It is in this regard that other than concentrating on the final disposal of fertilizer on application, a lot can be done to reduce fertilizer waste by looking at the product life cycle from raw material handling, manufacturing, distribution and application.

FertCo operations have occupational health and environmental challenges that include employee exposure to inorganic dust, ammonia fumes at the Granulation Plant and high energy use within the production process. The organization is in red category for stack emissions and pays over USD 50 000 annually for stack emissions licenses. The company loses lots of materials as particulate material through stack emission [4]. On the international scene green pressure groups are encouraging consumers to shun products from companies that are not socially and environmentally responsible.

3. Cleaner Production overview

Cleaner production is a practical method for protecting human and environmental health, and for supporting the goal of sustainable development. Poor or no regard for environmental impacts creates water and air pollution, soil degradation, and large-scale global impacts such as acid rain, global warming and ozone depletion [6]. Cleaner production activities include measures such as pollution prevention, source reduction, waste minimization and eco-efficiency. They involve better management and housekeeping, substitution of toxic and hazardous materials, process modifications, and reuse of waste products. At its heart, the concept is about the prevention, rather than the control, of pollution. The benefits of cleaner production include decreased waste, the recovery of valuable by-products, improved environmental performance, increased resource productivity, increased efficiency, lower energy consumption, and an overall reduction in costs [7].

The more sophisticated options may include switching to renewable energy sources, increasing material efficiency, and re-using and recycling by-products. Cleaner production requires a new way of thinking about processes and products, and about how they can be made less harmful to humans and the environment .Cleaner production can reduce environmental risks and liabilities and lead to greater competitiveness. By demonstrating a commitment to cleaner production, companies can also improve their public image and gain the confidence of consumers.

In fertiliser production processes, cleaner production entails saving of raw materials and energy, elimination of toxic raw materials and reduction in the quantities and toxicity of wastes and emissions [5]. The bottom line is to make companies more resource efficient and less polluting.

The Figure 1 below shows the procedure that is followed when implementing a cleaner production.

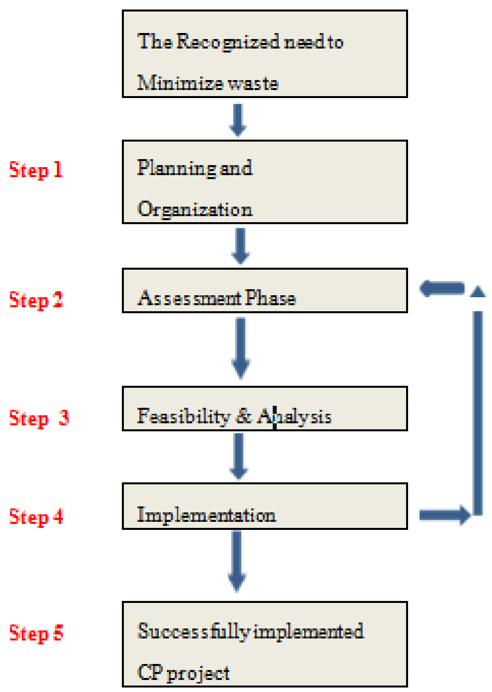

Figure 1. Cleaner production procedures [6]

Flow chart as indicated in Figure 2 focusing on areas where products, wastes and emission are generated.

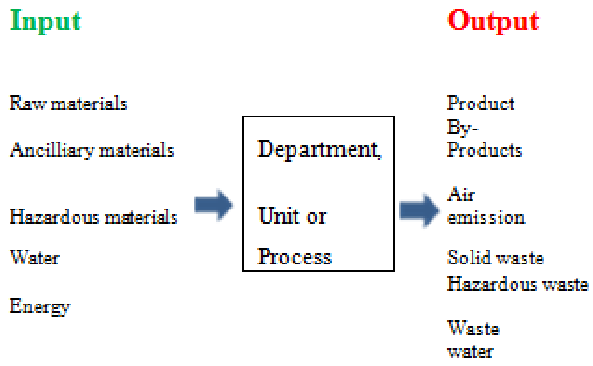

Figure 2. Sample process input/output worksheet [7]

It is important to concentrate on processes that generate large quantities of waste and emission and/ use or produce hazardous materials in the system. Options generated during assessment can then be reviewed for applicability and cost effectiveness in the next section [9].

4. Background: Fertilizer production

Fertilizer is an organic or inorganic material that is added to the soil to provide additional nutrients for plants. Fertilizers are used for soils that are nutrient-deficient naturally, or for soils that have been depleted of nutrients by harvesting and or grazing [4].

Fertilizers are widely used in agriculture to maintain soil fertility and to increase crop yields. Their application has grown immensely since the early 1900s, and continues to grow at a steady rate in developing countries. Fertilizers enable high yields on less crop area than would be required without the use of fertilizers; therefore, they are an important element in worldwide food production. As the population continues to grow, more and more agricultural output will be required, and fertilizers will play a vital role. In spite of their benefits, fertilizers are associated with high energy consumption [2]. Energy constraints and high fuel costs necessitate the implementation of energy efficiency measures in the production and use of fertilizers.

4.1 Fertilization for crop productivity

Plants require at least 16 essential elements for healthy growth. Air and water provide three of these elements (carbon, hydrogen, and oxygen), while the others are extracted from the soil. Table 1 lists essential plant nutrients obtained from the soil. These nutrients are separated into two main categories: macro-nutrients and micro-nutrients. Macro-nutrients are further categorized as primary or secondary. The table also lists nutrients that are required to a lesser degree by some plants. The predominant nutrients required by plants are nitrogen (N), phosphorus (P), and potassium (K). These are also the main nutrients in chemical fertilizers [5].

Table 1. List of essential plant nutrients obtained from soil

Macro-nutrients	*Micro-nutrients*	*Additional nutrients important for some plants*
Primary-macronutrients		
Nitrogen	Chlorine	Silicon
Phosphorous	Copper	Cobalt
Potassium	Iron	Aluminium
Secondary nutrients	Molybdenum	Sodium
Calcium	Zinc	
Magnesium	Boron	
Sulphur	Iron	

As plants are grown and harvested, they deplete the soil of its nutrients. Whatever nutrients are depleted from the soil must then be replaced to maintain soil fertility through use of inorganic fertilizers [5].

Inorganic fertilizers are commercially manufactured, and are formulated to contain a vast array of nutrient compositions and concentrations. Some contain one main nutrient source, while others contain multiple sources. The main nutrients in mixed inorganic fertilizers are nitrogen, phosphorus, and potassium as well as micronutrients.

Different nutrient compositions suit different crops and soil types. The level of nitrogen in a fertilizer is expressed as a percentage of total elemental nitrogen, and is often obtained by combining more than one source of nitrogen to achieve a total nitrogen percentage. Some important nitrogen sources are ammonium nitrate, urea, and ammonium phosphate, among others. The level of phosphorus is expressed as the quantity of available phosphate (P_2O_5), where 44% of P_2O_5 is phosphorus. The level of potassium is expressed as the quantity of soluble potash (K_2O), where 83% of K_2O is potassium. Fertilizers are commonly differentiated by their nitrogen–phosphate–potash levels. For example, a 5–10–5 fertilizer contains 5% total nitrogen, 10% available phosphoric acid, and 5% soluble potash; the remaining 80% could be any combination of secondary macronutrients, micronutrients (usually a small percentage), and inactive ingredients. The same ratio of primary ingredients is found in a 15–30–15 fertilizer, but the concentrations are three times as high [1].

Therefore, the 15–30–15 fertilizer is more nutritious per unit weight than the 5–10–5 fertilizer. Without some sort of fertilization, much more land would be required to achieve the same yields as found with fertilized crops. Fertilization greatly increases crop productivity.

4.3 Energy use in fertilizer production

Inorganic fertilizers are major consumers of energy in the agricultural sector. Unlike tractors, irrigation pumps, and other types of equipment, fertilizers are indirect energy consumers. That is, the bulk of energy use associated with fertilizers is not consumed directly at the agricultural site, but indirectly during its production, packaging, and transportation to the site. Additional energy is then used on-site during fertilizer application [4].

Natural gas is the principal energy resource for creating anhydrous ammonia, a key nitrogen fertilizer. The natural gas provides a source of hydrogen in the synthesis of ammonia by the Haber process.

Since natural gas is such a critical resource in fertilizer production, natural gas price fluctuations have a dramatic effect on fertilizer costs. As energy costs continue to rise, and the demand for fertilizers increases, this effect is becoming more pronounced. The implementation of energy-efficiency measures in the production and use of fertilizers will help curb the effects of rising gas costs, as well as the effects of energy costs in general. Thus it is important to effect the following in fertilizer production to save energy:

- Replace process equipment with high-efficiency models.
- Improve process controls to optimize chemical reactions.
- Recover process heat.
- Maximize the recovery of waste materials.

4.4 Measures to increase the efficiency of fertilizer use[4]

4.4.1 Soil tests

It is critical to test the soil to determine the level of soil nutrients. Soil testing also provides information about the soil's pH and organic matter content. Knowledge of the soil characteristics will help optimize the use of fertilizers. Once the nutrient level of the soil is known, only use the amount of soil additives necessary to amend the soil to the required level.

4.4.2 High-analysis fertilizers

It is less energy-intensive to use high-analysis fertilizers. These fertilizers contain a larger fraction of nutrients per volume, resulting in lower transportation, storage, and handling requirements than for fertilizers that are not as nutrient rich. This applies both to individual chemical compounds and to formulated fertilizers.

4.4.3 Apply fertilizers efficiently

One of the most important methods for increasing fertilization efficiency is to apply the appropriate amount of nutrients in the required location. Efficient fertilizer application is accomplished by distributing the fertilizer uniformly in the needed area. Too much fertilizer in a given area results in waste. If feasible, consider band application of fertilizer in place of broadcasting. This will lower fertilizer requirements. In addition, if possible, combine the application of fertilizer with other tillage tasks to reduce the number of passes on the field and ensure fertilizers are applied so that they are incorporated in the rooting zone.

4.4.4 Timing

Plants will utilize nutrients more efficiently if the nutrients are applied at the correct point in the plants' growing cycle. In particular, phosphorus should be applied early on as a nutrient for seedling development, and nitrogen application should be timed so that the nitrogen enters the rooting zone at the optimum time for the specific crop. Proper timing will increase yields and reduce fertilizer energy use. Another benefit of proper timing is that the plants will more likely be able to assimilate the nutrients before nutrient leaching and volatilization occurs.

4.4.5 Mulch to prevent nutrient loss

If cost-effective, the use of mulch provides many benefits to crops. In addition to keeping the ground temperature cooler and reducing evaporation, it can lessen nutrient volatilization. The application of plastic, or similar, mulch will also reduce nutrient leaching in times of heavy rainfall.

4.4.6 Crop rotating with legumes

Legume crops are capable of nitrogen fixation, and therefore they can restore the nitrogen level in the soil if their waste products are tilled back into the ground. It is very effective to rotate non-legume crops (which depend heavily on nitrogen) with legume crops to reduce the requirement for nitrogen fertilizer amendment.

5. Fertilizer Manufacturing Process

This study describes compound fertilizer production based on a nitro phosphoric acid plant with a capacity of 200t.d-1 of P_2O_5 (equivalent to about 700t.d-1 of phosphate rock depending on the rock). This production capacity makes it possible to produce 1,300t.d-1 of NPK 15+15+15 and also 2,000t.d-1 of calcium ammonium nitrate fertilizer (CAN, 27% N), or 1,000t.d-1 of calcium nitrate ($Ca(NO_3)_2$, 15.5% N). The principles for production, pollution prevention and control are defined for improved and achievable levels for waste and emissions to air and water for new and existing nitro phosphate based NPK plants.

5.1 Basic process concept

Phosphate rock sources must be converted into a form which can be taken up by plants ("available"). This can be achieved by using the integrated "Nitro phosphate" process which produces compound fertilizers containing ammonium nitrate, phosphate and potassium salts. This process aims to produce nitrate containing straight and compound fertilizers starting from rock phosphate and using all the nutrient components in an integrated process without solid wastes and with minimal gaseous and liquid emissions.

The integrated process starts with the dissolution of the rock phosphate in nitric acid following the reaction [5]:

$$Ca_5F(PO_4)_3 + 10HNO_3 = 3H_3PO_4 + 5Ca(NO_3)_2 + HF$$

Varying amounts of volatile compounds such as carbon dioxide (CO_2), nitrous gases (NO_X) and hydrogen fluoride (HF) may be liberated, depending on the rock phosphate. The mother liquor obtained contains too many calcium ions to guarantee the production of plant available P_2O_5. The solution is therefore cooled so that calcium nitrate tetra hydrate (CNTH) crystallizes out following the reaction:

$$H_3PO_4 + HNO_3 + Ca(NO_3)_2 + 4H_2O = H_3PO_4 + HNO_3 + Ca(NO_3)_2.4H_2O \,¯$$

The solution of phosphoric acid, remaining calcium nitrate and nitric acid, called nitro phosphoric acid can be separated from the CNTH crystals by filtration. The nitro phosphoric acid is then neutralized with ammonia, mixed with potassium/magnesium salts, sulphate and/or micro-nutrients and converted in a rotary granulation drum, fluidized bed, prilling tower or pug-mill to obtain solid compound fertilizers containing nitrate. The separated calcium nitrate crystals are dissolved in ammonium nitrate solution and treated with ammonium carbonate solution following the reaction:

$$Ca(NO_3)_2 + (NH_4)2CO_3 = CaCO_3 \,¯ + 2NH_4NO_3$$

This solution is filtered and the calcium carbonate crystals are removed and used for the production of granular calcium ammonium nitrate fertilizer[8]. The resulting dilute ammonium nitrate solution is concentrated and also used to produce calcium ammonium nitrate fertilizer or NPK. The calcium nitrate solution may also be neutralized and evaporated to obtain a solid fertilizer.

5.2 Technologies of the Nitro phosphate Process

All the nutrients are totally used in the production of nitrate-containing fertilizers. This can only be realized through corresponding investment, together with a high integration of the different plants. The process is restrictive in the sense that only nitrate-containing fertilizers can be produced [2]. A modern compound fertilizer plant, based on the nitro phosphate route, requires an integrated production complex of different units. The links between the different units are shown in Figure 3 below:

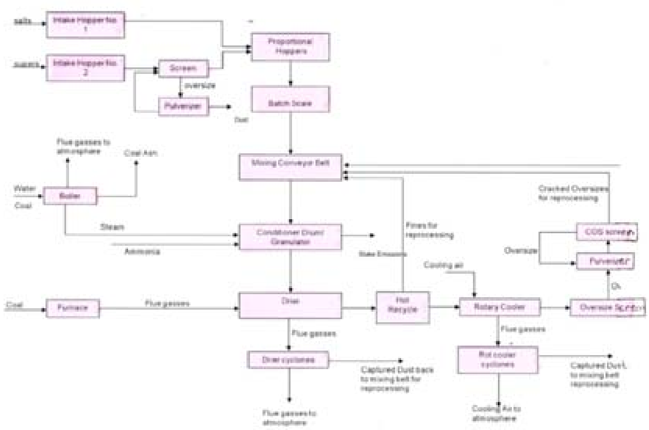

Figure 3: Fertilizer manufacturing process flow chart at FertCo

Local fertilizer industry is lagging behind in assessing and implementing Cleaner Production projects, this could be due to the poor prevailing economic situation.

6. Implementation of Cleaner Production at FertCo

The concept of Cleaner Production was new to FertCo management and the rest of the staff, so the benefits of Cleaner Production were highlighted to them and encouraged to be involved. The possible benefits included the following:

- Improved environmental efficiency.
- More efficient use of raw materials, water and energy.
- Recovery of valuable by-products.
- Less pollution.
- Lower costs for waste disposal and waste water treatment.
- Improved company image.
- Improved occupational health and safety.
- Reduced environmental liability

6.1 Pre-assessment

The walk through was done of the plant to get an overview of manufacturing process. The objective of the pre-assessment was to get a feel of the status of production plant, waste treatment, and disposal facilities. Production processes are best represented by a flow chart showing inputs, outputs and environmental problem areas in Figure 4 below:

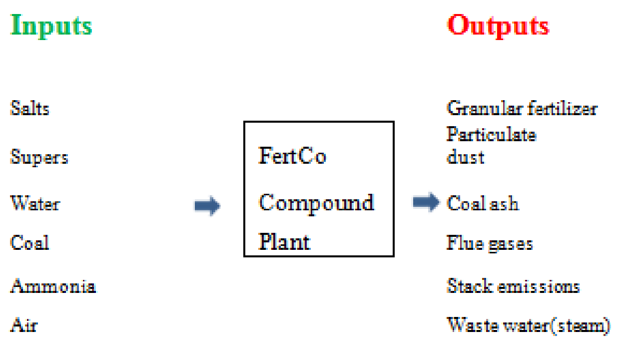

Figure 4. Fertilizer process input / output flow chart [3]

The flow charts paid particular attention to activities which are often neglected such as:

- Cleaning:
- Materials storage and handling:
- Ancillary operations (cooling, steam and compressed air production):
- Equipment maintenance and repair:
- Materials that are not easily recognisable in output streams (catalysts, lubricants etc.):
- By-products released to the environment as fugitive emissions.

Areas of concern picked by the in-plant survey and noted of immediate rectification at FertCo are:

- Waste emissions from processes such as particulate dust
- Strange odours and eyes irritations
- Signs of poor housekeeping
- Uncovered drains
- Spillages of raw materials and finished product along conveyor belts
- Levels of water and energy consumption

Focus areas of Cleaner Production were selected after the pre-assessment and these included the level of

environmental emissions, cost of raw materials and non-compliance with the present regulatory requirements.

6.2 Cleaner Production (CP) Assessment

The process flow charts provided an overview of each department and is accompanied by individual input/output sheets for each unit department. The CP methodology identifies areas of inefficient use of resources and poor management of wastes, by focusing on the environmental aspects and impacts of industrial processes. This stage involved the collection of data that enabled the evaluation of the environmental performance and waste generated. Water meter recordings of each month were documented . Effluent samples were sent to the laboratory. This data was consolidated into key figures that were then be used as benchmarks against which to track improvement. Data on the quantities of resources consumed and wastes and emissions generated was collected.

6.2.1 Measuring procedure

International procedure requires that samples be taken for efflux or discharge stack emission velocity, gaseous emissions such as SO2, NOx CO, CO2 and particulate matter in the stack. Emission velocity is such an important parameter in that the emissions are propelled downstream from the point of discharge and hence the polluter may not be affected directly. In terms of the 'Polluter Pays Principle' the polluter has to pay for his pollution. The emission velocity is used as a parameter to estimate the fall-out zone of the emissions hence the requirement that it be assessed. In more advanced social systems, environmental liability can be leveled against a polluter on the basis of emission velocity, wind direction and expected pollution impact.

In determining emission velocity, there are parameters upon which the velocity is dependent upon such as flue gas temperature and barometric pressure at the sampling point which are supposed to be measured. The higher the internal stack temperature, the more the molecular activity / energy and hence the emission velocity. The barometric pressure is inversely proportional to the emission velocity [3].

6.2.2 Test Method

The measurement of gaseous emissions such as (CO2, CO, NO2, NO, O2 and SO2) was carried out using Testo 340. Testo 340 is a handheld analyzer for industrial flue gas analysis and it is fitted with an O2 sensor as a standard. This guarantees highest flexibility when adapting to change in application and measurement jobs. The sensor can be changed or upgraded in an additional gas parameter by the user directly on site. The main advantage of this is that its adjustment data is saved in the gas sensors. In this way, time consuming test gas adjustment when changing sensors is dispensed with.

6.2.3 Gaseous Emissions [3]

- The Flue Gas analyzer specific for these gases as well as the horiba portable gas analyser were used to measure:
- Nitrous Fumes
- Sulphur Dioxide and
- Carbon dioxide

6.2.4 Particulate Concentration

A BNF stack sampler was used to measure particulate concentration in the stack [3].

A Pitot tube was used to measure gas pressures and the same used to calculate the emission velocity. The following standard method was used to determine particulate concentration:

- A filter membrane is weighed using a four or five decimal place sensitive digital scale
- This filter is then mounted on a cassette, which is also connected to the sampling train of heat resistant metal probe.
- The stack sampling pump is then started with the probe in the discharging stack and the run time measured.

6.2.5 Stack Velocities Calculation

Velocity of Stack gases Vs = 23.69 x $[Hw]^{0.5}$ x $[T_s/P_a]^{0.5}$
Where T_s = Stack temperature (measured inside the discharge duct expressed in degrees Kelvin)

H_w = pressure differentials (as measured inside the stack)
P_a = Ambient pressure and, 23.69 is a constant

The basis of this formula is that Emission Velocity is a factor of molecular activity, such activity which depends on temperature and pressure

Main Stack emission velocity:

$V_s = 23.69 \times 0.96^{0.5} \times (344/946.00^{0.5})$
= 13.997m/s

Rot cooler emission velocity:

$V_s = 23.69 \times 0.96^{0.5} \times (327/946.00^{0.5})$
= 13.65m/s

Conditioner emission velocity:

$V_s = 23.69 \times 0.96^{0.5} \times (294/946.00^{0.5})$
= 12.94m/s

The basis of this formula is that Emission Velocity is a factor of molecular activity, such activity which depends on temperature and pressure

6.2.6 The importance of the emission velocity

Using the emission_velocity FertCo can estimate the fall-out distance of its emissions from any of its stacks.
As required by AQ1 form from S.I 72 of 2009, the emission velocity can be used to estimate the volume of the emissions i.e.
Volume = emission velocity (V) x cross sectional area (A) of the discharging stack
= V (m/s) x A (m^2)
= VA (m^3/s)
= 13.997m/s × π R^2 (Where R is the radius and π is 3.14)
= **V** m^3/s

6.2.7 Wooden Tray Method

This method involved taking wooden trays and placing them on selected sites within the employee's workstations. Each of the ten trays was placed on top of a stand and each tray measured 1metre by 1metre and left there for 24hours whilst the plant was running. After 24hours the contents of each tray were emptied and weighed. The surface area of the plant affected was measured and multiplied by the average weight of the tray contents, and the result was the amount of material lost to the environment per day.

Some identified workstations which were thought to emit dust to the environment were also subjected to measurement to ascertain how much dust is lost to the environment and how this dust which in essence is part of the material charged into the production process, and how it affects the material balance. Operators at those stations were advised of the research proceedings in their areas and in the results

6.3 Cleaner Production implementation

FertCo is ISO 140001: 2008 certified and seeks to have environmental management programs in place.

Raw materials such as single super phosphates and ammonium nitrate are procured locally in the country while other raw materials such as Potassium Chloride, Potassium Sulphate, Di-ammonium nitrate, mono-ammonium nitrate, Borate, Granular sulphur and other ingredients are imported from Bolivia, Israel, and France. Liquid ammonia is imported from Sasol in South Africa.

When raw materials rail wagons arrive at FertCo plant they are first analyzed in laboratory and satisfied to be true in terms of concentration and moisture content before they are offloaded. The storage bins are asbestos sheet roofed and the walls are concrete cast to ensure no ingress of water. A single bin capacity ranges from 1500mt to 2500mt of raw materials. Ammonia is stored in steel vessels which are 15mm thick and their carrying capacity is 20mt of anhydrous ammonia which is quarantined area where access is by permission. Every raw material is accompanied by a Material Safety Data Sheet(MSDS) which provides important information for handling, storage and other dangers associated with that particular chemical or raw material

6.3.1 Granulation plant

The fertilizer production method used at FertCo plant is a dry granulation process in Figure 5. Raw materials are mixed, screened, formed into granular particles, dried, cooled and then stacked for bagging. The main raw materials used for the production processes are Single Super Phosphates (SSP), Sulphate of Potash (SOP), Muriate of Potash (MOP), Mono Ammonium Phosphates (MAP) and Ammonium Nitrate. These materials are subjected to Ammonia vapour and wet steam in a rotary drum called a granulator. These materials are usually in bulk powder form, which is inherently dusty. As a result, the entire production process produces a lot of dust. Some of the dust produced was accounted for in the design of the plant. However, there is still some that escapes into the atmosphere.

The nature of the raw materials as stated above (powdery) makes conveyance a big challenge, especially conveyance through bucket elevators and conveyor belts. The fertilizer is subjected to a temperature of around 450C in the rotary drier which is fired by a coal furnace. The fertilizer is cooled in a rotary cooler which, together with the rotary drier are connected to stacks. The Granulator is the Reactor where material from the batch scale is subjected to steam and ammonia vapour to become moist material before it is discharged into the rotary drier where the fertilizer is dried. The top outlet of the Granulator is connected to a stack. Steam and ammonia vapours escape through this stack to the environment.

The drier and the rotary cooler are connected to individual fans and stacks and both emit particulate dust to the environment. The elevators and conveyors are a source of dust emission and spillages. The plant showed high signs of poor housekeeping evidenced by lots of material on the ground and on structures. The granulation plant is the major consumer of electricity due to numerous electric drives that are involved in the production of fertilizer, such as ID fans, FD fans, elevators, conveyor belts, rotary drums etc. The system is an old stand alone system and each time there is a breakdown or plant stoppage, the drives are kept running.

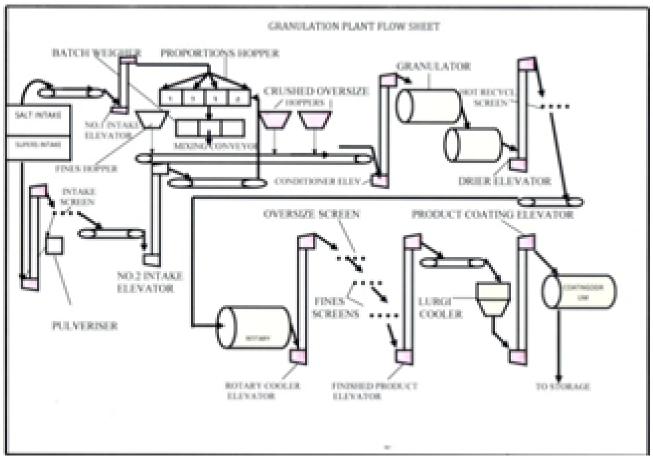

Figure 5: FertCo granulation plant

6.3.2 Bagging and loading plant

The bagging and loading plant is composed of an intake hopper, a small conveyor, two bucket elevators, a double deck screen, a bagging machine and a packaging unit. The bagging and loading plant receives product from the product bin by a front end loader which feeds the intake hopper. Under a hopper is a short conveyor which feeds the bucket elevator which in turn discharges the product onto the double deck screen. The screened fertilizer is discharged into another bucket elevator which in turn deposits the good sized fertilizer into a bagging hopper sitting on top of a bagging machine. The bagging machine is operated by an operator who packs the bags mostly in 50kg bags. The bags are stitched and taken by a conveyor to a waiting vehicle as per customer demand.

The bagging and loading plant operations pollute the environment through elevator doors which are not properly secured. The material (fertilizer) received from finished product bins is free flowing and emits dust when passing through the screening process. There is also evidence of material lost as spillages before it is bagged.

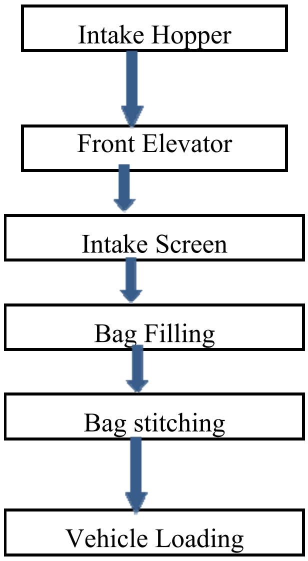

Figure 6. Bagging and loading process

6.3.3 Blending plant

The blending plant has a blending section before the bagging machine. The blending plant starts with a pre-screening unit which is composed of a hopper, an elevator, a double deck screen and a rubber conveyor belt. The on size material becomes the raw material for the blending plant, whilst the fines are taken back into the plant by a front end loader. The process at this plant is dusty due to the nature of the materials used which has dust.

The screened material such as granular is batched automatically as per product formulation and discharged into a screw mixer which in turn after a complete cycle discharges the mixed batch (which is equivalent to 1 tone) into a hopper sitting on top of a bagging machine. The bagging machine is operated by an operator who packs the bags mostly in 50kg bags. The bags are stitched and taken by a conveyor to a waiting vehicle as per customer demand. The raw materials are pre-screened before formulated into a required product. Due to the nature of the raw materials which is powdery, the screen emits dust to the environment. The conveyor has no scrapers and a substantial amount of material is lost as spillages and if it is raining some find its way to the drains.

6.3.4 Boiler House

The boiler house has two boilers, one running at a time, whilst the other one is on stand-by. The boilers are coal fired and the steam requirements of the Granulation plant which is the major customer of the boiler in the granulating process is up to 12bars. The boiler is very important in that its activities constitute part of the production cost, so its inefficiencies increase the product unit cost and have an effect on the environment. The coal is fed into a hopper sitting on top of a conveyor belt which feeds the boiler. The boiler is connected to two fans, the ID fan and the FD fan. The water into the boiler is softened before it is charged into the boiler for conversion into steam. The coal rubble from the boiler is not completely burnt a sign of incomplete combustion. The boiler uses municipal water despite the plant having five boreholes operating. Coal fed into the boiler is washed by an operator before it is charged into the boiler and the water is left flowing to the drains before treating it. The amount of the water is not measured and there is no care or awareness that the water should be preserved. The flue gases contain products of combustion like CO2, SO2, CO, moisture, suspended solids and other products of combustion.

These emissions pollute the quality of air and are responsible for formation of acid rain. The suspended particles finally settle down on the ground and cover vegetation hence pollute it. Gardens for nearby residential areas are affected by these emissions.

Boiler blow down that contain chemicals from the boiler are discharged directly into the municipal sewer line. Blow down emanates from the chemical reaction of chemicals used to remove suspended particles and salts from the boiler. This ends up at the sewer dams and is responsible for eutrophication if discharged into the rivers it has an effect of killing flora and fauna. The same applies for disposal of regenerated water used for treatment of boiler water that is discharged into the municipality sewer. This water contains sodium chloride and suspended solids generated when washing the resin in the water softeners.

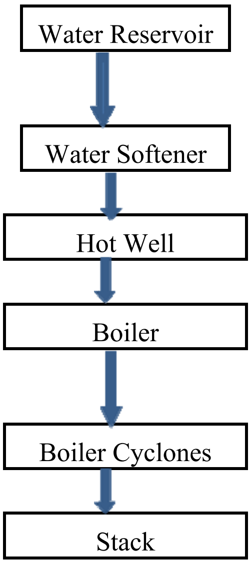

Figure 7. Boiler House Flow Chart

7. Cleaner production Data Collection

This section consists of the in-depth evaluation of the selected assessment focus in order to develop a comprehensive set of alternate Cleaner Production options. This requires a quantification of the volume and composition of the various waste streams and emissions as well as a detailed understanding of the causes of these waste streams and emissions. The collection of data that enables to evaluate the environmental performance, production efficiency and wastes generated by the FertCo.

7.1 Raw Material Consumption (January-April, 2012)

The raw material consumption of the company for four months is given in Table 2 below. The cost per unit price is also represented and these figures are used for the evaluation of the material balance for the fertilizer processes.

Table 2. Raw material consumption

Raw material	*Jan (tons)*	*Feb (tons)*	*Mar (tons)*	*Apr (tons)*	*Cost/ton USD*
High Furnace Oil	16	19	17	20	90
Bentonite	54	61	60	65	80
Single super phosphate	3680	4800	3560	3968	200
Potassium chloride	915	1230	923	940	400
Potassium sulphate	400	320	300	480	450
Ammonium nitrate	800	1200	940	540	500
Ammonia gas	43	48	55	46	400
Borate	15	12	10	23	360
Steam	23000	28900	14000	6100	0.70
Coal	87.66	131.99	48.44	42.71	360

Raw materials and energy charges (coal and electricity) are the main factors driving cost of fertilizer production at FertCo plant.

Table 3. Electricity tariffs for industrial consumers

	11Kv Supply	*33Kv Supply*
Fixed Monthly Charge	$99.14	$99.14
Monthly MD charge per unit of demand	$4.88	$3.58
On- Peak Energy charge per kWh	$0.12	$0.12
Standard Energy charge per kWh	$0.07	$0.07
Off-Peak Energy charge per kWh	$0.05	$0.05

Performance indicators were developed using above rates to get the following parameters:

1. Specific material consumption for each material input, or at least for important input materials (tons of input material/ton of product).
2. Specific energy consumption for electricity and fuels (kWh per ton of product, kg or litre of fuel per ton of product).
3. Production cost (per ton of product).
4. Electricity, fuel, water, chemicals, transport, manpower as a percentage of production cost.

The performance indicators need to be compared with world class benchmarks to assess improvement potential.

7.2 Toxicity of raw materials `

The table 4 shows chemical raw material toxicity levels according Material Safety Data Sheets (MSDS) that were drawn up in accordance to ISO11014-1:1994. Less harmful products only pose potential health effects after prolonged or repeated contact, while those put under more toxic are hazardous to humans and the aquatic environment when inhaled or when reacting with acids releasing toxic gases.

Table 4: Toxicity of chemicals

More Toxic	*Toxic*	*Less Harmful*
Borate	Potassium chloride	Superfine
Granular sulphur	Di-ammonium phosphate	Talc
Single super phosphate	Ammonium nitrate	Bentonite
Ammonia gas	High furnace oil	Fertilizer
Potassium sulphate	Calcium sulphate	

7.3 Pollutants from the Granulation Plant

Table 5: Sources of Pollution

Source	*Type of polluting material*
Coal	SO_x, NO_x ,CO
SSP	Dust; Sulphuric acid
SOP	Dust , SO_4
Fertilizer	Dust, spillages
Main fan	SO_X, NO_X, Ammonia
Ammonia	Obnoxious odour
Heavy furnace oil	Oil

7.4 Granulation Section

Figure 6 below shows the inputs and outputs for the granulation plant or the material balance of the fertilizer production process, from batch scale section to product storage of compound D (7-14-7) produced in four months.

Table 6: Granulation Material Balance

INPUTS		*OUTPUTS*	
Single super phosphate	3 680 ton	Compound D	5 200 ton
Potassium chloride	915 ton	Waste ammonia gas	12 ton
Ammonium nitrate	800 ton	Waste steam	8 000 ton
Steam	23 000 ton	Stack particulate	22 ton
Bentonite	54 ton	Spillage	219 ton
Ammonia gas	43 ton	Fugitive dust	22 ton
Coal	88 ton	Coal rubble	95 ton
Energy	784 801 kWh	Oversize material	10 ton
		Process fines	23 ton

The material balance shows that a lot of material is lost between the batch scale and finished product storage due to conveyor belts and bucket elevators spilling. It is also seen that the three stacks i.e. drier stack, rotary cooler stack and the granulator stack are a major source of emissions of particulate dust. After a production run of 10 hours, the batch scale recorded 150 drops which is equivalent to 150 tons, whilst the finished product scale recorded 127 tons of finished product translating to a negative variance of 23 tons lost between the batch scale and the finished product scale. The stack emissions of individual stacks were sampled and were found to be overloaded with particulate dust.

Dust exposure: Dust levels in the 'granulation' plant is very high. This applied to the two types of dust fractions i.e.'total' & 'respirable'. The crusher had the highest concentration levels.

Education of the exposed population so that they are aware of the risks that they are exposed to. Strict adherence to the usage of all types of controls which are cost effective. Ensuring that personal protective clothing (PPE) order levels for PPE are within the levels that ensure that the workers will always have access to adequate PPE. Fugitive or diffuse dust emission is the source of environmental pollution at FertCo plant.

Table 7: Emissions from Drier Stack

Parameter	**Measured value**	**Licence Category**
O_2	19.85%	**N/A**
CO	48.07 mg/m^3	**Green**
NO	16.11 mg/m^3	**Blue**
CO_2	0.65%	**N/A**
NOx	17.17 mg/m^3	**Blue**
SO_2	179.82 mg/m^3	**Non-Permissible**
T°C (ambient)	**26.1**°C	

Emissions from the rotary cooler indicate that emissions are all within the blue license category. This is because the rotary cooler stack does not channel any products of combustion out of the process but only provides exit to air that has been used to cool the product out of the process. The concentrations of pollutants from the Rotary cooler are shown in Table 8

Table 8: Emissions from the Rotary Cooler

Parameter	**Measured value**	**Licence Category (SI 72 OF 2009, ZIM)**
O_2	20.60%	**N/A**
CO	3.42 mg/m^3	**Blue**
NO	1.24 mg/m^3	**Blue**
CO_2	-	
NOx	1.24 mg/m^3	**Blue**
SO_2	13.03 mg/m^3	**Blue**
T°C (ambient)	**26.9**°C	

Table 9 indicates that the results of emissions (flue gases) sampled from the granulation stack are within the blue licence category according to S.I 72 of 2009. The granulation stack provides an exit column for fumes such as ammonia and other gaseous chemical products from the granulation process. In this regard products of fuel combustion (CO, CO_2, SO_2) are not expected to come out of the process. This explains the absence of NO_X, CO, CO_2 and SO_2 from the granulation stack column.

Table 9: Emissions from the Granulator Stack

Parameter	*Measured value*	*Licence Category (SI 72 OF 2009, ZIM)*
O_2	20.32%	**N/A**
CO	0	**Blue**
NO	0	**Blue**
CO_2	-	**N/A**
NO_X	0	**Blue**
SO_2	0	**Blue**
T°C (ambient)	**26.1°C**	

7.5 Stack Emissions

The emission concentration of Sulphur dioxide from all the three stacks including background levels were above the controlled limit as outlined in S.I 72 of 2009. The concentration of all other gaseous emissions such as nitrous compounds, particulates were within the controlled limit. The levels of exceedances for sulphur dioxide were between 153ppm to 456ppm against a limit of 15ppm or 40mg/m3. This therefore means that FertCo have to put in place a programme for the management of the emissions including a more rigorous social responsibility program.

Table 10: Detailed Results

Values in mg/m^3 unless specified & limits in brackets						Comments in view of the emissions characterization
Readings / Stack identity	Stack temperature in degrees Kelvin & Ambient pressure in Mb (millibars)[1]	NO_x ppm 150 as NO_2	SO_x 40 mg/m^3	Particulate 120mg/m^3	CO_2 % 0.03%	Particulate concentration exceeds the controlled limit of 120mg/m^3 with the main stack exceeding this limit by 61%. The concentration of sulphur dioxide in the factory especially near the emitting appliances / points was very high. This means that there is a lot of Sulphur dioxide escaping and if there is no means and ways to capture this analyte, then there is need for a long term plan to mitigate the impact arising from this emission. All the other emissions were within the controlled limit in terms of S.I 72 of 2009. Background emission were within limits save sulphur dioxide. Particulate background emission needed the fall-out dust monitoring hence no further comments are made.
Main stack	71^{O}C 946.0	27	182.00ppm	193.343	16.83	
Background concentration	25.6 ^{O}C		1096ppm		0.89	
Rot cooler stack	54^{O}C	1.0	153.0ppm	122.098	8.06	
Background concentration	25.6 ^{O}C		113.00		0.57	
Conditioner stack	21^{O}C 946.0	0.3	456.0ppm	83.404	8.25	

7.6 Boiler House Material Balance

Table 11: FertCo boiler material balance

INPUT		*OUTPUTS*	
Coal	88 ton	Coal ash	30 ton
Water	2 800 ton	Steam	25 000 ton
Energy	208 538 ton	Emissions (Sox, NOx, CO)	5 ton

The material balance Table 11 above shows that there is incomplete combustion of coal as the amount of coal rubble signifies the amount of unburnt coal. The steam generated is less than the water fed into the boiler. This is as a result of steam pipes leaking and boiler operators continuously firing the boiler even if the granulation plant which is the only consumer of steam is on breakdown or when maintaining steam pressure all the time.

7.7 Water use

Making steam requires a lot of water which is softened so as to reduce scaling in boiler pipes. All the boiler water comes from the municipal supply. Borehole water can be used to make steam instead in order to reduce costs of paying for municipal water. Operators also use the water to clean coal before it is charged into the boiler and that water is not measured and at times the valve is left open spilling water to the drains. This black soot water is not treated and finds its way to the municipal drains further contaminating water sources.

Table 12: Water checklist

Water use	*Jan*	*Feb*	*Mar*	*Apr*	*Cost /m3*	*Value $*
Water used m^3	28 000	34 000	17 000	10 000	0.6	52 600

The water used is more than the steam generated because some water is used for washing coal in the coal hopper before it is charged into the boiler. That water is not recovered because it flows straight into municipal sewer before it is processed.

Good combustion is the ability to mix air and fuel, with as little excess air as possible, at high enough temperature to sustain the process and completely burn the fuel (complete carbon conversion) with minimum environmental emissions. It is therefore necessary to find out the current level of efficiency for performance evaluation, which is fundamental for energy conservation action and environmental protection. This section provides the stack sampling results as well as an analysis of the results.

Table 13: Emissions from the boiler

Parameter	*Measured value*	*Licenec category (S.I 72 of 2009)*
O_2	15.15%	**N/A**
CO	112.6mg/m³	**Non-Permissible**
NO	81.6 mg/m³	**Green**
CO_2	5.12%	**N/A**
NO_X (NO + NO_2)	85.2 mg/m³	**Green**
SO_2	1271.12 mg/m³	**Non-Permissible**
Boiler Efficiency	86%	**N/A**
T°C (T gas)	213°C	**N/A**
T°C (ambient)	**21.8**°C	-

Emission test results from the boiler shown in Table 14 indicate that SO_2 and CO recorded concentrations of 1271.12 mg/m3 and 112.6 mg/m3 respectively. These levels fall within the non-permissible category according to the legislative limits indicated in the third schedule of S.I 72 of 2009. However NO_x concentrations recorded fall within the green license category (low hazard category).

From the gas stream sampled, it has been observed that NO contributes more than 95% of the NO_x gas. This phenomenon usually reflects poor mixing of O_2 and the fuel (coal) to support complete combustion despite the high percentage of oxygen (15.15%) being drawn into the process. The incomplete combustion is also reflected in the high concentration of CO levels even though the boiler indicates fair operational performance.

Table 14: Energy checklist

Fuel Used	*Jan*	*Feb*	*Mar*	*Apr*	*Cost/ kWh/t on*	*Value/ USD*
Electricity /kWh	208538	148588	214 342	213 433		$99 907
Coal/ ton	87.66	131.99	48.44	42.71	$360	111 888

7.8. Loss identification and cause diagnosis

Having identified, quantified and characterized various streams, the researcher carried out a cause diagnosis to find out why waste was being generated. The common problem is emission of dust. The fishbone diagram of Figure 15 highlights factors that are likely to cause dust emissions in granulation operations [3]. The factors are grouped into four main areas of man, method, equipment, and material.

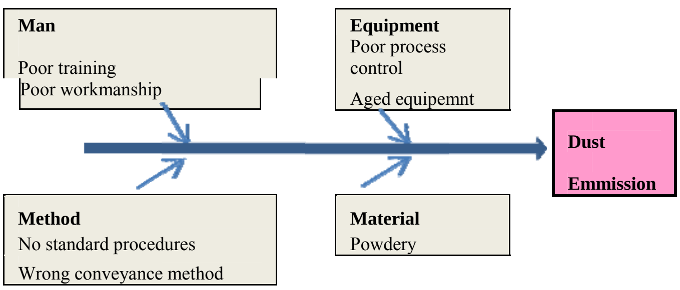

Figure 8: Fishbone diagram for dust emissions

8. Cleaner Production Options Generation

In this study, options were generated for the processes described in the preceding sections. CP options may fall in one of the following categories:

Housekeeping:
- improvements to work practices and methods
- proper maintenance of equipment, etc., come into this category
- Minimize water use by closing off taps when not in use

Proper operation and maintenance of all equipment and machinery:
- Preventing the build- up of oils, dirt and material build up.
- Standardizing the use of coolants and lubricants.
- Lag steam pipes and mend any steam leaks.
- Seal off all elevator doors with sealant or properly folded plastic papers to suppress dust emission.
- Put used conveyor belts as scrappers at tipping points of running conveyor belts to avoid spillages.

Management and personnel practices:
- Effective supervision
- Employee training & enhancing operator skills
- Provision of incentives and bonuses to encourage employees to strive conscientiously to reduce material and energy wastes and emissions.

New technology and machinery modifications:
- Putting steam relief valves on steam pipes
- Collecting the condensate as laboratory de-ionized water for lab use.
- Spraying water on powdery potassium sulphate before it is transported by elevator eliminates dust and loss.
- Taking used 50kg empty bags and properly folding them to seal off elevator doors will act as gaskets and avoid dust emissions.
- Steam and Ammonia flow meters can be installed in order to measure the amount of these raw materials in the granulator to avoid overuse and polluting the environment.
- Putting a canvass spout on conveyor tipper chute will suppress dust when off loading powdery raw materials .
- Connect all stack chimneys to a scrub house in order to recover particulate material and eliminate air pollution

Raw material substituting:
- Use graphite blocks as lubrication for rotary drums instead of grease
- Use bentonite instead of High Furnace Oil as fertilizer coating agent.
- Negotiate with suppliers to bring in cleaner raw materials, e.g. good sized washed coal peas ready for charging into the boiler or furnace.
- Replace steel gratings in rust prone areas with asbestos gratings.
- Use biodegradable 50kg empty bags for packing fertilizer.

- Rubberize all conveyor belt rollers in order to lengthen the life of conveyor belts and also in order to keep conveyor belts on track thereby eliminating spillages.

New product design:

- Use of granulated raw materials such as potassium chloride, potassium sulphate and borate will increase productivity and reduce stack emissions.
- Production of high formulated fertilizers will reduce overall consumption of fertilizer by the farmer per hactre.
- Use of liquid fertilizer will reduce or eliminate environmental pollution due to wet working which suppresses dust and spillages and is not energy intensive.

Recovery of useful by-products, materials and energy:

- Water used to wash coal before it is charged into the boiler can be recycled/ recovered by putting a settling pond where fine coal can be recovered and sold to brick making companies.
- A scrub house can be installed in order to recover particulate materials lost through the stack emissions which will be fed back into the production line.
- Operators to stop all the drives when there is a breakdown in order to save energy.
- The boiler should not be fired during the period the granulation plant is on breakdown in order to save on coal.

9. Cleaner Production Option Evaluation

9.1 Technical evaluation

Technical evaluation should cover the following aspects [8]:

- Consumption of materials and energy
- Product/by-product quality
- Right First Time (RFT): estimate must be made of the possible improvement in RFT that would result from implementation of the option.
- Risks in implementing the option
- Ease of implementation
- Time required for implementation
- Cross-linkages with other

9.2 Environmental evaluation

The environmental evaluation should include estimates of the following benefits that each option may bring about:

- Likely reduction in the quantity of waste or emissions generated.
- Likely reduction in GHG emissions.
- Likely reduction in the release of hazardous, toxic, or non-biodegradable wastes or emissions.
- Likely reduction in consumption of non-renewable natural resources.
- Likely reduction in noise levels.
- Likely reduction in odour nuisance.
- Likely reduction in on-site risk levels.
- Likely reduction in release of globally important pollutants.

9.3 Economic evaluation

Criteria such as payback period, Net Present Value (NPV) or Internal Rate of Return (IRR) are used [9].

Payback Period:

A simple payback period is evaluated from comparison of the annual savings resulting from implementation and initial investment. This simply indicates the time needed to recoup the initial investment. It is calculated as:

Payback period (in years) = (Capital Investment/ Annual Net Savings)

NPV and IRR:

The simple payback period is generally considered as an approximate, as it ignores depreciation of the investment made and the time value of money. Investment decisions are usually made solely on the basis of payback period when the investment required is low and /or the returns are high enough for the payback period to be less than two years. If these conditions are not met, it is advisable to consider NPV or IRR. These take account of the time value of cash inflows and outflows during the useful life of the investment made. This kind of economic evaluation requires information on:
The capital costs associated with any investments required.
Net revenue, calculated as the difference between total revenue and operating costs.

Rates of interest and depreciation, to allow calculation of the present value. NPV can be calculated using the following equation:

$$NPV = (CFO)\ 1\sum_{I=o}^{i=n} \text{net cash flow}/(1+r)^{i}$$

Where,
CFO = cash outflow in the first year (capital investment)
r= opportunity cost of capital (for a rate of 10%, ‘r’ would be 0.1)
n= useful life of the investment in years

For an investment to be financially viable, NVP must be greater than zero. Another indicator commonly used along with NVP is the Profitability Index (PI). PI is the ratio of the present value of the total cash inflows to the present value of the total cash outflows. For an investment to be financially viable, PI must be greater than 1.

An evaluation of the economic feasibility of using a Scrub House to avoid loss of particulate material to the environment, polluting the environment and avoiding paying of license fees to Environmental Management Agency and the municipal authority was done. The Scrub House would save % of fertilizer lost as particulate material which is 61% above the legal limit as shown in table 9 above constituting 48tons of fertilizer in four months amounting to $86 400/annum plus other license fees amounting to $52 000/annum plus energy saved when the operators switch off the drives in the plant when there is a breakdown which amounts to 20% of energy cost in four months totaling $59

944.20/annum and coal saved when there is a breakdown totaling $67 132.80/annum.
Total amount to be saved per annum=$265 477.00.

The evaluations are as follows:

Initial Investment =$135 342,74
Savings per annum =$265 477.00
Pay Back Period = 6 months
The initial investment constitutes purchase of the following shown in the table:

Table 15: Scrub house economic evaluation

A. INFRASTRUCTURE			
Description	*Quantity*	*Per Unit Cost*	*Total Cost*
Scrubber House Civil Construction	1	102,038.86	102,038.86
Total Infrastructure			102,038.86
B. CONSULTING			
Description	*Quantity*	*Per Unit Cost*	*Total Cost*
Civil and Structural Engineering (Order of magnitude estimate	1	10,000.00	10,000.00
Total Consulting			10,000.00
D. TEMPORARY STAFF			
Description	*Quantity*	*Per Unit Cost*	*Total Cost*
Construction Contractors	1	10,000.00	10.000.00
Total Temporary Staff			10,000.00
E. OTHER PROJECT COSTS			
Description	*Quantity*	*Per Unit Cost*	*Total Cost*
Documentation and processing	1	1,000.00	1,000.00
Total Other Project Costs			1,000.00
Total Project Estimated Cost Less Contingency			123,038.86
Contingency (10%)			12,303.88
TOTAL PROJECT ESTIMATED COST INCLUDING CONTINGENCY			**135,342.74**

10. Cleaner Production Option Selection

The preceding evaluation of options helps to eliminate those that are not feasible. The remaining options can then be prioritized and implementation done on those that obtain top priority. Prioritizing CP options can be done using a weighted sum method and weights vary depending on technical competency, financial conditions, and environmental sensitivity.

FertCo puts emphasis on protecting the environment as they are a member of the International Fertilizer Association will abide by all the rules and regulations in doing business friendly with the environment. The second priority is Financial issues and lastly Technical feasibility issues which are most of the time outsourced to contractors. In light of the above the study proposed the following weights:

Environmental feasibility (60%)
Economic feasibility (25%)
Technical feasibility (15%)

Simple indicators such as scores can then be assigned to assess the relative performance of each option. The weighted sum of the scores gives an index for each option and this can be used as a basis to rank options in terms of their level of priority. The options can be grouped into categories such as 'top', 'medium' and 'low' priority. Prioritizing options in this way provides a basis for preparation of the implementation plan.

In this report, thirteen options weighted and ranked as shown in Table 16. From the results of Table 17, the options can be implemented according to their rankings that is starting with the options with a rank of 1 and ending with the one with a rank of 11.

Table 16: Weighted option evaluation

Option No	*Option*	*Technical feasibility*	*Environment al Impact*	*Economic Feasi bility*	*Total*	*Rank*
Weght		15%	60%	25%	11	
1	Preventing the build- up of oils, dirt and material build up.	5	6	7	6.1	11
2	Standardizing the use of coolant and lubricants.	7	7	6	6.8	8
3	Minimize water use by closing off taps when not in use and lag steam pipes and mend any steam leaks.	6	9	9	8.6	2
4	Seal all elevator doors with sealant or properly folded plastic papers to suppress dust	7	9	8	8.5	3
5	Put used conveyor belts as scrappers at tipping points of running conveyor belts to avoid spillages.	8	10	6	8.7	1
6	Put steam relief valves on steam pipes and collect the condensate as laboratory de-ionized water for lab use.	6	9	5	7.6	5
7	Spraying water on powdery potassium sulphate before it is transported by elevator eliminates dust and material loss.	6	9	7	8.1	4
8	Taking used 50kg empty bags and properly folding them to seal off elevator doors will act as gaskets to avoid dust emissions.	7	8	6	7.4	7
9	Putting a canvas spout on conveyor tipper chute will suppress dust when off-loading powdery raw materials.	6	8	7	7.5	6
10	Negotiate with suppliers to bring in cleaner raw materials e.g. good sized coal ready for charging into boiler and furnace	6	7	5	6.4	10
11	Use of granulated raw material such as potassium sulphate, potassium chloride and borate will	6	7	6	6.6	9

	increase productivity and reduce stack emissions.					
12	Operators to switch off all the drives in the plant when there is a breakdown in order to save energy (electricity).	8	6	5	6.1	11
13	The boiler should not be fired when the Granulation Plant is on breakdown in order to save on coal.	8	7	8	7.4	7

10.1 Low or No Cost Options

The options that follow can be implemented at low or no cost

- Preventing the build- up of oils, dirt and material build up.
- Standardizing the use of coolant and lubricants
- Minimize water use by closing of taps when not in use and lag steam pipes and mend any steam leaks.
- Seal all elevator doors with sealant or properly folded plastics to suppress dust.
- Put used conveyor belts as scrappers at tipping points of running conveyor belts to avoid spillages.
- Put steam relief valves on steam pipes and collect the condensate as laboratory de-ionized water for lab use.
- Spraying water on powdery potassium sulphate before it is transported by elevator eliminates dust and material loss.
- Taking used 50kg empty bags and properly folding them to seal off elevator doors will act as gaskets to avoid dust emissions.
- Putting a canvas spout on conveyor tipper chute will suppress dust when off-loading powdery raw materials.
- Negotiate with suppliers to bring in cleaner raw materials e.g good sized coal ready for charging into the boiler or furnace.
- Use of granulated raw materials such as potassium sulphate, potassium chloride and borate will increase productivity and reduce particulate stack emissions.
- Operators to switch off all the drives in the plant when there is a breakdown in order to save on energy (electricity).
- The boiler should not be fired when there is a breakdown at the Granulation Plant in order to save on coal.
- Water used to wash coal before it is charged into boiler or furnace can be recycled /recovered by putting a settling pond where fine coal will be recovered and sold hence not polluting municipal water.
- Three hoppers are sitting directly on top of screw feeders or conveyor belts. The effect of this is that you would need bigger motors to convey the material in the hopper due to the load exerted by the material in the hopper over the screw feeder or conveyor belt. Redesigning the hoppers in order to make the screw feeder or conveyor belt only to move out the material in the hopper would require small motors and gear boxes resulting in energy savings of at least 10%.

10.2 Scrubber house option

From the amounts in Figure 17 the cost of putting up a scrubber might seem not feasible but it is the best option for addressing the perennial problem of stack emissions for the fertilizer industry considering that emissions are eminent due to the nature of the raw materials used in the manufacture of compound fertilizers at FertCo plant. The pay-back period of 6 months makes the project feasible and worth investing in. The table below illustrates the benefits.

Table: 17: Benefits of scrubber option

	How the Objective Benefits the Company:			
Project Objective	*Customers*	*Staff*	*Residents in surrounding areas*	*The Company*
1.Reduce dust emission into the atmosphere to accepted sustainable levels	Dust captured will be recycled into the production process resulting in lower cost per bag	Cleaner, healthier working environment	Reduced exposure to pollution	Reduction in the fines that have to be paid to regulatory bodies. Higher employee morale and lower production costs

10.3 Flue Gas Diffusers

Gas diffusers incorporated into the boiler or furnace should redirect the flue gas back into the furnace or boiler and keep it for much longer before allowing it to suck induced draught into the chimney. It is important to continuously monitor air emissions to establish information required to respond rapidly to adverse operating conditions during combustion so as to ensure efficient and environmentally acceptable performance. When monitoring boiler emissions it is also critical to assess its efficiency to determine how far the boiler drifts away from best efficiency. Any observed abnormal deviations could therefore be investigated to identify the problem areas for corrective and preventive action

10.4 Air Blowers Orientation

The air blowers into the chimney must be spread evenly along the length of the boiler or combustion chamber. The blowers act as supply of oxygen and also as soot blowers, which can improve heating efficiency very considerably by almost 10-to-15%.

10.5 Digital Automation

Digital automation is highly recommended as it will come with the added benefit of a higher than expected plant yield in the Granulation Plant. Savings will be realized on electricity whenever there is a breakdown because of easy of operating the plant. Currently the drives are left running even if there is a breakdown and that constitutes 20% of electricity charges instead of saving that amount by switching off the drives instantly.

10.6 Improvement of raw material conveyance

The raw materials used in fertilizer manufacture are by nature powdery and cannot be treated lightly. Raw materials like SOP or MOP need to be moistened in order not to emit dust unnecessarily or to change the nature of these raw materials altogether preferably to get a supply of granulated raw material which do not emit dust after all. The raw materials are discharged from a height of 10 metres and thus the discharge chute should be put a canvas chute to suppress dust evolution. The elevators also contribute to dust emission by their nature and the doors need to be sealed with used 50kg empty bags properly folded in order to suppress emission of dust. Conveyor belts also contribute towards spillages, hence the need to rubberize all the rollers which don't turn causing the belts to off-track resulting in spillages which affect the G/Plant material balance and the wearing away of conveyor belts which are supposed to last for 2years but currently last for 4months costing a lot of money thereby affecting price of fertilizer produced by FertCo.

10.7 Scrubbing SO_2 and nitrogen compounds from flue gas

Recover sulphur dioxide SO_2 and some nitrogen compounds such as N_2O from the furnace or boiler flue gases by incorporating necessary scrubbing mechanisms to carry out the de-sulphonation process and de-nitrification process. Sulphur dioxide causes acid rain that kills flora and fauna. Nitrogen compounds have a great potential to cause global warming.

10.8 Scrubbing Particulate Emissions

A scrub house connected to all the stacks i.e. Granulator stack, Rotary cooler stack and Conditioner stack so that all the particulate dust can be recovered and recycled back into the production process resulting in lower cost per bag, cleaner, healthier working environment, reduced exposure to pollution, reduction in fines that have to be paid to regulatory bodies, higher employee morale and lower production costs.

10.9 Raw Material state

Coal should be transported to site in good pea size in order not to be washed before charging into the respective furnaces where water is lost and discharged into municipal sewer where it fetches disposal fines unnecessarily. The coal should be dust free in order to minimize amount of dust produced and this lowers the amount of energy consumed as well as ease of storage before use.

10.10 Waste Generation

The researcher noted that almost all of the respondents were aware of the types of wastes their organization produced. The sector is so familiar with some types of wastes that they no longer recognize them as wastes. An example is the spillage in the granulation plant and used oil by the rotary drums and scrap metal are so common that they no longer recognize them as wastes. The company should therefore do the following:

- Keep a register of wastes generated by the facility and their sources.
- Composition of wastes (identify the contaminants found in wastes).
- Identify options for treating and disposing wastes.
- Evaluate the costs of waste disposal.

10.11 Changing Electric Motors

The electric motors driving smoothing hopper material need to be changed after redesigning of the hoppers themselves so that the material in the hopper does not add load onto the motor but only to drive out the material from the hopper, using relatively smaller motor that do not consume much power. The amount of drawn power by these smaller motors will save on energy consumption.

10.12 Resource Consumption

The main resources consumed by the industry include raw materials (mainly single super phosphates, potashes and ammonium nitrate, electricity, coal, water, ammonia gas and steam. The sector is currently slack about matching material and utility resources to finished products. The problem is lack of an Energy Management programme which should do an analysis of the major drives of energy consumption and come up with a solution to what can be done to reduce energy consumption by the company. Resources such as electricity, ammonia gas and steam are difficult to apportion to products that have been produced. In view of this, the framework suggests the following activities to help optimize resource consumption:

- Standardise products and material requirements.
- Resources and utilities need to be apportioned to finished products through reasonable estimates.
- Benchmarks must be put in place to control the consumption of resources.
- An Energy Management Programme should be put in place in order to identify the mechanisms to reduce electricity consumption in order to match new technology.
- Put in place an effective planned maintenance system for utility supplies to prevent losses through leaks and poor equipment performance.

11. Research Recommendations

The level of pollution is so high that if residents in the surrounding suburbs were to take the company to court for pollution the company would pay hefty fines so before that happens the company should consider the issue of investing in building a scrubber house whose cost won't match the damage caused by litigation. The company will realize profits by saving on wastes, getting income from recycling, income from waste being used as inputs in other areas, energy savings, water re-use and less legal suits.

Waste handling procedures: Coal ash can be sold to those companies which manufacture cement for a small fee to recover costs of transport. By so doing the company eliminates waste by re-use. The coal ash can still be used for construction purposes.

Trade effluent: From the boiler and the plant can be filtered to remove solid particles and settle the water which can be sent to the trial garden, whilst condensate can be used as laboratory water.

Coal rubble can be sold to the construction industries or individuals building houses.

12 Conclusion

The study analysed the flow of materials and energy in the fertilizer industrial operations. The Cleaner Production assessment carried out established that fertilizer companies generate waste and pollute the environment. Other than wasting raw materials, energy (coal and electricity) and water, the main pollutants are generated by boiler emissions, boiler blow down and trade effluent, stack emissions, fugitive dust and spillages mostly from mainly the granulation plant. The company can cut on disposal and emission fees if it recycles some of its waste. Implementation of CP options will conserve water by 30%, electricity can be saved by 25% and coal can also be saved by 25% and this will result in lower cost per bag of fertilizer and results in competitive advantage and responsible fertilizer manufacture without polluting the environment. The environmental factors such as heat, noise and light exposure levels are below the recommended limits. Controlling and further minimizing these stress factors results in an improved work environment for the workers.

13 Further Research

Cleaner Production options that have been put forward for implementation in this report are no or low cost options but further research is needed to find out the economic feasibility of those options that require financial investment. This can be made possible through rigorous costing of the cost savings made by employing these options. Environmental accounting techniques can help in this regard [8]. Also effectiveness of scrubbers used for gaseous fertilizer emissions can be a possible area for further research work to ensure well minimized environmental impact at FertCo plant.

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