

# SOIL HEALTH IS HUMAN HEALTH - AN INDIAN EARTHWORM'S EYEVIEW

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**Key words:** soil health, earthworms, vermicompost, vermiwash, organic foliar

## Abstract

*Vermicompost is an excellent organic fertiliser in which bacteria are the major colonizers, which include high population of nitrogen fixers, phosphate solubilizers, and sulphur bacteria. Fungi are established to be active degraders of organic matter in soils. Many substrates are first colonized by what are known as sugar fungi such as the Mucorales. Blue green algae (BGA) have been recorded by us in vermicompost and are the Anabaena sp, Oscillatoria, Tolypothrix, Chlorella and Westiellopsis. All these when incorporated into the soil through vermicompost contribute to soil health and provide nutritious food contributing to human health. Several simple organic foliar sprays have several components similar to plant growth promoter substances in them. Vermiwash is one such excellent liquid fertiliser. Studies by our team have revealed the presence of growth promoting substances which invariably are associated with plant growth. There are about 3 isomers of indole compounds separated in Vermiwash; the 2-(4-methylphenyl) indolizine is an alkaloid which has a significant role in plant growth promotion, Maleic acid is a well established plant growth promoter, and Methyl 2-(4-tert-butylphenoxy) acetate belongs to the ring-substituted phenoxy aliphatic acids generally exhibiting a strong retarding effect on abscission and in turn promotes plant growth. Vermiwash by its instinctive quality might probably promote humification, increase microbial activity to produce plant growth promoting compounds and enzyme production. All the compounds present in vermiwash may not individually help in plant growth but perhaps act synergistically along with the beneficial soil microbes found in vermiwash. These products influence soil health and in combination with other products such as Panchagavya, Gunapasela and likewise can provide wholesome nutrition to the plant through the soil. In organic farming practice we do not nurse the plant, we nurse the soil which in turn promotes its group of biotic elements to churn the nutrients as desired by the plant.*

## INTRODUCTION:

Soil is defined as "a collection of natural bodies synthesised into a profile." The dynamic nature of a soil is due to the tremendous activity of micro and macro organisms supported by availability of organic matter. It is this life in the soil that lends its name to soil as living soil. A vast number of organisms including the bacteria, fungi, actinomycetes, mites, snails, beetles, millipedes, wood lice, springtails, nematodes, slugs, insects, and earthworms engineer a myriad of biochemical changes as decay of organic matter takes place. Among the organisms, which contribute to soil health, the most important are the earthworms. The term "fertility" refers to the inherent capacity of a soil to supply nutrients to plants in adequate amounts and in suitable proportions. In modern days in conventional agriculture this concept of "fertility" has erroneously got related to chemical fertilisers. To distinguish the inherent capability of the soil through non-chemical inputs we use the term soil health. However productivity is related to the ability of a soil to yield crops.

Soil is a holistic entity and a living dynamic system whose functions are mediated by diverse living organisms which in man-based agro-ecosystems require management and

conservation. Soil health is the capacity of the soil to function as a vital living system to sustain plant and animal productivity. Soil microorganisms, their abundance, diversity and community stability are the main hallmarks of appropriate technology and one of the useful indicators of soil health, which directs soil fertility. Unfortunately in modern agriculture importance and attendance is showered on soil fertility and not soil health which provides an innate mechanism to the soil to sustain its “living” nature.

## **SOIL BIOTA:**

### **Earthworms:**

Earthworms are one of the chief components of the soil biota in terms of soil formation and maintenance of soil structure and fertility. They are extremely important in soil formation, principally through activities in consuming organic matter, fragmenting it and mixing it intimately with mineral particles to form water stable aggregates [1]. During feeding, earthworms promote microbial activity by several orders of magnitude, which in turn also accelerate the rates of break down and stabilization of humic fractions or organic matter. Microorganisms are the ultimate decomposers and mineralisers in the detritus food chain and in organic matter decomposition. Earthworms are the facilitators for the dormant microorganisms in soils providing them with organic carbon, optimum temperature, moisture and pH in their gut for their multiplication. Microorganisms are excreted in their casts and also harbored in the drilospheres [2,3]. Fresh casts, urine, mucus and coelomic fluid which are rich in the worm-worked soil and burrows act as stimulant for the multiplication of dormant microorganisms in the soil and are responsible for constant release of nutrients into it, which then facilitates root growth and a healthy appropriate sustainable rhizosphere.

### **Microorganisms:**

Microorganisms such as bacteria, fungi and actinomycetes play a major role in organic matter decomposition. During composting as the microorganisms begin their enzymatic degradation, the most available substrate such as sugars and starch are attacked. This results in the decrease in pH and increase in temperature due to their metabolic activity. The pH then increases during the next level of substrate, the protein and nitrogen. This increase continues till the thermophase, thereafter pH decreases and reaches the neutral phase. The event of sequential appearance of microorganisms on the substrate with respect to time is called succession. In the finished product, the vermicompost (*exsitu* or *insitu*), bacteria are the major colonizers, which include high population of nitrogen fixers, phosphate solubilizers, and the sulphur bacteria [4,5]. Actinomycetes being the next higher population of earthworm compost contribute to organic matter decomposition and are responsible for the binding property of the soil through hyphal threads. The compound geosmin produced by many of the actinomycetes indicates its high presence and in turn soil health [5].

Fungi are known to be the active degraders of organic matter in soils. Many substrates are first colonized by what are known as sugar fungi such as the Mucorales. These are capable of growing or sporulating rapidly on simple soluble sugars and nitrogen sources. *Aspergillus* sp, *Penicillium* sp, *Fusarium* sp, *Rhizopus* sp, *Trichoderma* sp, *Humicola* sp show cellulolytic, lipolytic, proteolytic and lignolytic activity.

Algae are the oxygenic phototrophs and they account for 40% of the total C fixed annually. Blue green algae (BGA) have been recorded in vermicompost and are the *Anabaena* sp, *Oscillatoria*, *Tolypothrix*, *Chlorella* and *Westiellopsis* [4,5]. All these when incorporated into

the soil contributes to soil health and through soil health provides nutritious food contributing to human health.

Most foliar sprays can be incorporated as appropriate technologies as these can be prepared from local resources; especially the organic ones, have several components similar to plant growth promoter substances in them. Vermiwash is one such excellent liquid fertiliser [1] derived as the most relevant and appropriate technology. Studies on vermiwash [6] have revealed the presence of substances (Table 1) which invariably are associated with plant growth.

Table 1: Components of Vermiwash

No	Compound	GC Retention Time (min)	Chemical Formula	CAS registry Number	Molecular Weight (g/mol)
1	2-(4-methyl phenyl) indolizine	19.33	C <sub>15</sub> H <sub>13</sub> N	7496-81-3	207.27
2	Decanoic acid, ethyl ester	19.70	C <sub>12</sub> H <sub>24</sub> O <sub>2</sub>	110-38-3	200.318
3	1-methyl-2-phenyl-indole	27.10	C <sub>15</sub> H <sub>13</sub> N	3558-24-5	207.27
4	2-methyl-7-phenyl-1H-indole	29.83	C <sub>15</sub> H <sub>13</sub> N	1140-08-5	207.27
5	Pentadioic acid, dihydrazide N <sub>2</sub> ,N <sub>2</sub> '-bis(2-furfurylideno)*	31.16	C <sub>15</sub> H <sub>16</sub> N <sub>4</sub> O <sub>4</sub>	324012-36-4	316.312
6	Methyl 2-(4-tert-butyl phenoxy) acetate*	33.44	C <sub>13</sub> H <sub>18</sub> O <sub>3</sub>	88530-52-3	222.28

\*(presumed)

There are about 3 isomers of indole compounds separated in Vermiwash, 2-(4-methylphenyl) indolizine is an alkaloid which has a significant role in plant growth promotion. At retention time of 19.70 min capric acid was separated, which is a fatty acid, obtained from the castings of earthworms which is also reported to have a significant role in plant growth promotion in lower concentrations [7]. Maleic acid which was identified is a well established plant growth promoter[8]. Methyl 2-4(-tert-butylphenoxy) acetate belongs to the ring-substituted phenoxy aliphatic acids generally exhibiting a strong retarding effect on abscission in turn promote plant growth. Vermiwash by its instinctive quality might probably promote humification, increased microbial activity to produce the plant growth promoting compounds and enzyme production [9]. All the compounds present in vermiwash may not individually help in plant growth but perhaps act synergistically along with the beneficial soil microbes found in vermiwash. These products influence soil health and in combination with other products such as Panchagavya, Gunapasela or fish-amino and likewise can provide wholesome nutrition to the plant through the soil. In organic farming practice we do not nurse the plant, we nurse the soil. The soil in turn promotes its group of biotic elements who churn the nutrients as desired by the plant.

Phytonutrients, such as polyphenols and antioxidants, protect both people and plants. Chemical based Pesticides are reported to block a plant's ability to manufacture these important plant compounds. NCBT01 (*Jeysai*), a concoction with ginger garlic asafoetida and cow's urine has proved extremely effective in the control of root grubs at 25% of the cost of using chemicals [10].

## **VERMICOMPOSTING**

### **1. Vermicomposting using local varieties of earthworms**

Of the species of earthworms that have been identified in the world, five hundred and nine species of earthworms have so far been identified in India alone and it is indeed easy to collect the epigeics and anecics from garden soils after monsoon spells. These earthworms can be cultured or used in composting applying simple procedures either in pits, crates, tanks, concrete rings or any containers [11,1]. Local species of earthworms that are generally used in vermitech (vermes= earthworms; tech= technology) in India are *Perionyx excavatus* and *Lampito mauritii*.

### **2. Vermicomposting using exotic species of earthworms**

Exotic species of earthworms have also been used in India for vermicomposting. Internationally three species of earthworms have received acclaim for vermicomposting, they being *Eisenia fetida*, *Eudrilus eugeniae* and *Lumbricus rubellus*.

## **Succession of microorganisms in the process of composting and the quality of microorganisms in vermicompost**

The process of composting, although shows the occurrence of different microorganisms such as bacteria, fungi, actinomycetes, phosphate solubilizers and the microorganisms involved in the Nitrogen cycle; succession is shown in the quantity of microbes depending upon the nature of the substrate, the age of the compost, the ambience created by the existing microbes to its successors and also the physical and chemical characteristics. The majority of the microorganisms in the initial stages of composting are the heterotrophic bacteria, which rely on the oxidation of the large amount of organic Carbon. It reduces during the thermophilic phase till the formation of the biodegradable compost. This then increases in vermicompost due to the passage of the material through the earthworm and the presence of the assimilable C, in the gut and the cast of the earthworms [12,13].

The role of microorganisms in the Nitrogen cycle is very prominent. There is increased presence of ammonifiers in the initial stage of composting, which correlates with the high amount of protein degradation and the microbial contribution to reduce C:N. Nitrifiers however increase from the initial to the final stages. The products of the ammonifiers create an environment for the multiplication of nitrifiers which utilize ammonia and convert it to nitrite and nitrate. To substantiate this extra-cellular ammonia nitrogen decreases steadily from the initial higher values during the entire composting process. The ammonification process is reported to increase due to high temperature [14].

Nitrification potential as indicated by  $\text{NO}_2^-$ -N decreases with composting time. The  $\text{NO}_2^-$  production drops and stabilizes to low levels during the later stages of composting till no further decomposition can take place, as the C:N ratio gets stabilized [15]. The  $\text{NO}_3^-$  production increases till about the 14<sup>th</sup> day of composting thereafter declining till the 35<sup>th</sup> day. This drop could be due to high temperature, as nitrification is inhibited by high temperature and could also indicate microbial immobilization. The dominance of the extra-cellular production of  $\text{NO}_3^-$  on the worm worked vermicompost could be the result of the enhanced nitrifier activity. Amount of phosphate in compost samples throughout the process and vermicompost records a steady increase from the initial phase of composting till vermicompost. This is due to the increased phosphatase activity in vermicompost as earthworm casts and feces exhibit higher phosphatase activity [16]. It is also observed that  $\text{PO}_4$  production shows a decline at about the 21<sup>st</sup> day of composting which correlates that

high  $\text{NH}_4^+$  concentration retards P fixation [17]. Phosphate solubilizers also steadily increase throughout the process. So in terms of succession ammonifiers which are the major organic N decomposers are succeeded by the nitrifiers and phosphate solubilizers. Oxidation of sulfur and sulfate compounds is elaborated by aerobic obligate autotrophs. *Thiobacillus thiooxidans* and *Thiobacillus thioparus*, recorded in vermicompost attribute to the reason for vermicompost being capable of ameliorating sodic soils. The population density of the actinomycetes increases from the initial phase of composting till the maturation phase except for a period of decline in the thermophilic phase.

Actinomycetes occur after readily available substrate disappears in the early stages and colonize in the humification stage as the compost reaches maturity. It is also found that the optimum temperature of actinomycetes is 40-50° C, which is also the temperature for lignin degradation in compost [18].

Fungal density decreases as the composting process progresses. Mucoraceous group of fungi commonly referred to as sugar fungi are observed in the initial and early phases of composting in agreement with nutritional hypothesis. Species of *Aspergillus* dominate and are responsible for major degradation of initial organic carbon as they are known to elaborate cellulases and hemicellulases. A lignolytic fungi *Coprinus* sps is predominantly found to colonise the compost only towards the end when complex organic matter is biodegraded.

The thermophilic fungi records an increase in density and diversity during the thermophilic phase and these are known to bring about degradation of cellulose, lignin and pectin at a faster rate in conjunction with high temperature. The presence *Trichoderma viridae* and *Trichoderma harzianum*, both potential biocontrol agents, during the composting process and to a larger magnitude in the vermicompost is noteworthy. The density and diversity of algae increases progressively and maximum recorded in the vermicompost. Of special significance are the presences of algae such as *Oscillatoria* sp, *Anabaena* sp, and *Nostoc* sp which are known to enhance soil fertility.

#### **CONCLUSION:**

Healthy soils support healthy produce. Thus the application of appropriate technology in specific agroclimatic zones can rejuvenate agri practices especially in Asian and African countries, where there is wide biodiversity. Identification of botanical sources for pest repellents and resources for composting can contribute to support local farmers and promote soil health, through appropriate technologies. Personal observations and research have indicated that not just addition of organic inputs but the presence of soil biota in the soil, in fact, enhances the produce in its quantity and quality, which should influence policy decisions. Thus it is very much confirmed that “*earthworms are the pulse of the soil, healthier the pulse, healthier the soil*”.

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# Determinants of Adoption of Agricultural Innovation by Maize Farmers in Oriire Local Government Area, Oyo State Nigeria

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**Key word:** innovation, adoption, determinants

## **Abstract**

*This study investigated the determinants of adoption of agricultural innovation by maize for farmers in Oriire Local Government Area Oyo State of Nigeria. Data for the study was obtained from 110 respondents. Multistage random sampling techniques were used with the aid of a structured questionnaire. Data analysis was by the use of frequency, percentage, and mean score. The results of analysis revealed that most of the respondents were within their active age and married with household size between 5 and 8 children. The adoption score revealed that almost half of the respondents had moderate had adoption score. Significant relationship was found with some selected socio economic characteristics and level of adoption. It was recommended that introduction of technologies to farmers should be timely.*

## **INTRODUCTION**

In Nigeria, maize is one of the main staple crops and featured among the five food crops production is to be promoted for attainment of food self- sufficiency as revealed by the minister of Agriculture and water resources [1]. Although, Nigeria heavily depends on oil revenue, the role of agriculture on economics growth in Nigeria cannot be over emphasized. It contributes about 42% to the natural GDP and this value is the highest among all the other sectors Central Bank of Nigeria CBN [2]. However, the global food crisis is increasing with alarming speed and force, necessitating nations and international organization all over the globe to respond with a strategic and long-term approaches aimed at curbing the food crises. The current agriculture, energy, climate change, trade and new market demands from emerging markets [3].

According to [4] maize production in Nigeria has not been sufficient enough to meet the needs of people and livestock. Supply has not been able to meet demand despite the introduction of improved packages. A survey concluded in Nigeria reveals that maize account for about 43 percent of calorie intake, with income elasticity of demand of 0.74, 0.65 and 0.71 for low income, high income and all sample households respectively and contributes to 7.7 percent of total cash income of farm households [5].

It is against this background that this study assessed determinants of adoption of Agricultural innovation by maize farmers in Oriire Local Government area by examining the socio economics characteristics of maize farmers and level of adoption of innovation. However the study provided answers to the following research questions.

- i. What are the farmers socioeconomic characteristics
- ii. What are the maize innovations adopted by the farmers in the study area.

It was hypothesized that there is no significant relationship between selected socio economics characteristics of respondents and level of adopting innovation.

**METHODOLOGY;** The study was carried out in Oriire Local Government Area of Oyo State. The Local Government Area comprises of ten (10) wards, five out of ten wards (50%) namely Ikoyi Ile, Ikosi, Tewure, Iluju and Olose, were selected. Twenty two maize farmers were selected from each ward, using simple random method, making a total of one hundred and ten (110) respondents.

Simple statistical tools like frequency and percentage were used to describe the data. Inferential statistics like Person Product Moment Correlation was used. Data were collected with the use of structure questionnaire and data collected includes socio economics characteristics of the respondent's, levels of adoption of technologies.

## **RESULTS AND DISCUSSION**

### **Personal characteristics of the respondents**

**Age:** the result of analysis on shows that majority (85.4%) of the respondents was between the ages of 31-60. The mean age of the sampled respondents was 46 years. This shows that most of the respondents are still in their active and economic age.

**Sex:** About 82.7% of the respondents were male while 17.3% were female. This means that male were more involved in maize production in the study area.

**Marital status:** Majority (84.5%) of the respondents were married, 2.7% were widowed, and about 10.9% were single. This implies that most of the respondents were married hence they were saddle with additional responsibility which may influence their adoption of technologies in order to improve their production.

**Educational level:** The study reveals that only 29.1% of the respondents had no formal education. In essence, majority (70.9%) had one form of education or the other. The high level of literacy might help the farmers in adoption of technologies.

**Household size:** The data also reveals that 23.6% had between 1 and 4 children, 65.4% had between 5 and 8. The mean family size of the respondents is 7. Large family size may serve as source of family labour and this will reduce cost on labour in adoption of improved innovation.

**Farming experience:** The study further reveals that 29.1% of the respondents had spent between 1-10 years in farming, half (50.9%) of the respondents spent between 11-20years and only 20% had spent above 30 years in farming. The mean farming experience was 18 years. The years of farming experience could assert an influence on the farmers' readiness to adopt innovation different from what they have been practicing over the years.

**Contact with extension agent:** This study reveals that majority (74.5%) of the respondents had contact with extension agent. This shows that respondents have more tendency of adopting new technology which leads to increase in their productivity.

**Farm size:** The data also reveals that (36.4%) of the respondents cultivate farm size of about 1-5 ha while 52.7% of the respondents cultivated between 6 and 10 hectares of land. The mean farm size cultivated was 7.40 hectares. This shows that respondents in the study area are between small scale to medium scale farmers.

**Technology adopted;** Table 1 shows that 96.4% of the respondents adopted fertilizer application, 79.1% adopted planting of improved varieties, also 77.3% adopted chemical control of pest in store and 72.7% adopted mechanical threshing and 41.8% adopted thinning. This implies that the respondents adopted one technology or the other in orders to improve their productivity.

**Adoption score:** This was use to categorize the level of adoption of technology in the study area from Table 3, 13.6% of the respondents had adoption score of between 1-3 which can be categorized as low adopters. Also 55.5% of the respondents have adoption score between 4 and 7 which can be categorized as moderate adopters and only 30.9% of the respondents had adoption scores between 8 and 11 and this was categorized as high adopters of innovation. This implies that respondents in the study area adopt different maize technologies in other to improve their maize productivities.

### **Test of hypothesis**

The results of inferential analysis shows that some personal characteristics of the respondents were significantly related to level of adoption Age ( $r=0.156$ ,  $P \geq 0.05$ ) was significantly related to level of adoption of technology. This implies that as individual advance in age there is tendency to increase their level of adoption. Educational level ( $r=0.075$   $P \geq 0.05$ ) was also significantly correlated to the level of adoption. This implies that as respondents advance in level of education there will be increase in level of adopting of technologies. This is in line with [6] who stated that education plays a vital role in adoption of new technologies and enhance production efficiency. Farm experience ( $r=0.213$   $P \geq 0.05$ ) was significantly correlated to the level of adoption. This implies that the years of experience increases the level of adoption of technology increases.

### **Conclusion and Recommendation**

Results of the study have shown that socio-economic characteristic of the respondents is part of determinants factors in adopting innovation. The study revealed that majority of the respondents is within their active age, married with 5-8 children and had one form of education or the other. They have farming experience of about 17 years. Respondents in the study area adopted one form of technologies or the other. The respondents in the study area have moderate level of adoption. Extension agent contact was major widespread of information.

### **Recommendations**

The following recommendations were made based on the conclusion of the study; Cost of fertilizer should be subsidized by government and nongovernmental organization.

Effort should be made to make credit accessible to farmers since lack of credit was on obstacle to the adoption of innovation.

Introduction of technologies should be timely to farmers.

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**Table1: Distribution of respondents by Technologies adopted**

<b>Technologies adopted</b>	<b>Frequency*</b>	<b>Percentage</b>
<b>Planting of improved varieties</b>	<b>87</b>	<b>79.1</b>
<b>Herbicide</b>	<b>61</b>	<b>55.1</b>
<b>Appropriate</b>	<b>76</b>	<b>69.1</b>
<b>Fertilizer application</b>	<b>106</b>	<b>96.4</b>
<b>Weed management</b>	<b>47</b>	<b>42.7</b>
<b>Seed dressing</b>	<b>62</b>	<b>56.4</b>
<b>Chemical control of pest in store</b>	<b>49</b>	<b>44.5</b>
<b>Planting diseases resistant</b>	<b>85</b>	<b>77.3</b>
<b>Technical threshing</b>	<b>80</b>	<b>72.7</b>
<b>Thinning</b>	<b>51</b>	<b>46.4</b>
<b>Seed dressing</b>	<b>46</b>	<b>41.8</b>

Source: Field survey 2011

\*multiple responses recorded

**Table 2 Distribution of respondents according to adoption scores**

<b>Level of adoption</b>	<b>Frequency</b>	<b>Percentage</b>
<b>1-3</b>	<b>15</b>	<b>13.6</b>
<b>4-7</b>	<b>61</b>	<b>55.5</b>
<b>8-11</b>	<b>34</b>	<b>30.9</b>
<b>Total</b>	<b>110</b>	<b>100</b>

Source: Field survey, 2011

**Table 3: Relationship between socioeconomic characteristics and level of adoption**

<b>Variable</b>	<b>Correlation</b>	<b>P- value</b>	<b>Remark</b>
<b>Age</b>	<b>0.160**</b>	<b>0.032</b>	<b>Sig at 0.05</b>
<b>Educational level</b>	<b>0.750**</b>	<b>0.030</b>	<b>Sig at 0.05</b>
<b>Household size</b>	<b>-0.160*</b>	<b>0.096</b>	<b>Not Sig</b>
<b>Farming experiences</b>	<b>0.213**</b>	<b>0.025</b>	<b>Sig at 0.05</b>

**R<sup>2</sup> = 0.619**

**P-value at 0.05%**

# EVALUATING THE ADSORPTION CAPACITY OF SUBCRITICAL CO<sub>2</sub> ON SOUTH AFRICAN COALS USING A SIMULATED FLUE GAS

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**Key words:** Coal; Pure CO<sub>2</sub>; Flue gas; Sub-critical and Supercritical conditions; Adsorption isotherms

## Abstract

*There are currently many research projects focusing on the reduction of anthropogenic carbon dioxide (CO<sub>2</sub>) emissions. Sequestration of CO<sub>2</sub> in deep and unmineable coal seams is one of the attractive alternatives to reduce its atmospheric concentration. The aim is to apply underground storage techniques such as CO<sub>2</sub> and flue gas injection in unmineable coal seams under feeds of subcritical and supercritical conditions. This provides experimental data from which a predictive assessment of pure CO<sub>2</sub> and flue gas sequestration can be conducted on South African coal. The CO<sub>2</sub> adsorption capacity of five different coals found in South Africa was investigated using pure CO<sub>2</sub> and a flue gas as adsorbates.*

*The effects of coal rank, coal composition, and pressure on the CO<sub>2</sub> adsorption capacity of the samples have been evaluated. Adsorption isotherms of pure CO<sub>2</sub> and flue gas were measured at 35 °C and up to a maximum pressure of 50 bar using the volumetric method. Adsorption measurements were performed on 5 g samples with a grain size of -5+4.75 mm. The flue gas used was a simulated industrial flue gas of a coal fired plant with 96.2% CO<sub>2</sub>, 1.5% O<sub>2</sub>, and 2.3% N<sub>2</sub>. High Pressure CO<sub>2</sub> Volumetric Adsorption System (HPCVAS) was specifically designed and constructed for this research work. The laboratory data obtained from all test works was fitted in different adsorption isotherm models so as to determine their suitability in representing the adsorption of CO<sub>2</sub> onto coal.*

*Adsorption tests with flue gas were conducted to study the degree of preferential sorption of the individual components. The adsorption of CO<sub>2</sub> onto coal is not significantly hindered by the addition of other gases, other than dilution effect of the pressure. The highest ranked coal, anthracite, has the highest adsorption capacity while the low ranked coal, bituminous, has the lowest adsorption capacity.*

## 1. INTRODUCTION

The climate of the Earth is constantly undergoing changes due to a variety of factors. These factors include, among others, changes in the Earth's orbit, changes in the Sun's intensity, changes in the ocean currents, volcanic emissions and changes in greenhouse-gas concentrations. Global warming during the last decades has been a “hot” phenomenon concerning the scientific, and not only, community [1].

It is widely believed that increasing atmospheric greenhouse gas levels are influencing the global climate system through global warming with important implications for environmental

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stewardship [2]. The anthropogenic CO<sub>2</sub> is supposed to be responsible for the warming of the earth's atmosphere by the so-called greenhouse effect [3]. In recent years the emission of CO<sub>2</sub> from flue gases and other sources has accelerated rapidly due to technological and industrial development [4]. Between 1800 and 2010, the atmospheric concentration of CO<sub>2</sub> increased from 280 to 379 ppm [5]. A doubling of atmospheric CO<sub>2</sub> is estimated to produce 1.5–4.5 °C surface warming based on pale climate data and models with uncertainties mainly from cloud–climate feedback. Unabated fossil fuel burning could lead to between two and three times this warming [6]. While the amount of CO<sub>2</sub> emissions from human activities is modest compared to the large natural cycles that exchange CO<sub>2</sub> between the atmosphere, oceans, and terrestrial biosphere, there is no doubt that the current emissions exceed the capacity of the natural systems to absorb them [7]. With increasing environmental concerns, sequestration and separation of CO<sub>2</sub> now looks mandatory [4].

CO<sub>2</sub> sequestration in deep unmineable coal seam is a potential management option for greenhouse gas emissions, reducing the risk of CO<sub>2</sub> migration to the surface and meanwhile enhancing coalbed methane recovery (ECBM) [8]. According to a geological survey conducted by Viljoen et al. [9] a total estimated CO<sub>2</sub> storage capacity in the South African coal fields is 1, 271.9 Mt, however, this is based on techno-economics and the future of mining these coalbeds must also be taken into consideration.

South Africa has acceded to the Kyoto Protocol as a non-Annex I country, which e.g. means that South Africa currently has no obligations regarding the reduction of greenhouse gas emissions. However the current protocol will expire in 2013 and there is significant pressure from developed countries on non-Annex I countries to also develop policies to reduce greenhouse gas emissions as part of a follow-up Kyoto protocol [10]. Before embarking on an ambitious carbon capture and storage campaign in South Africa, it was important to ascertain its in-country potential. To that end, The Department of Minerals and Energy commissioned an investigation from the CSIR, the results of which were released during the year 2004 and indicated that such potential did exist [11].

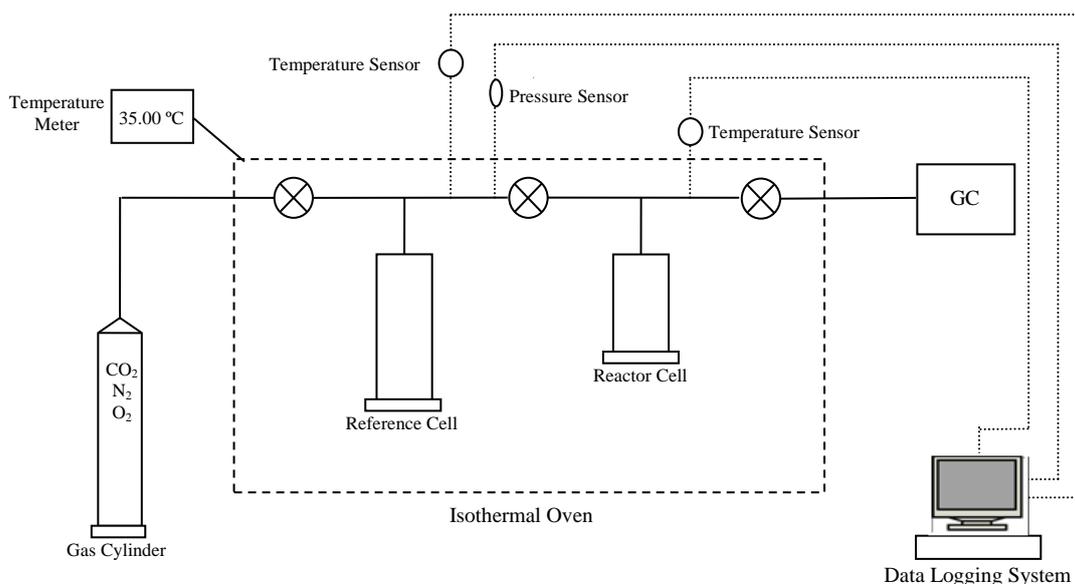
In the context of the geological storage of CO<sub>2</sub> a few projects consider the direct injection of flue gases from power plants or other flue gas emitting industries [12]. Therefore, the aim of this research is to investigate how the addition of impurities in a CO<sub>2</sub> stream influences the CO<sub>2</sub> adsorption capacity; hence the use of an industrial flue gas instead of pure CO<sub>2</sub>.

## **2. EXPERIMENTAL**

### *2.1. Experimental Setup*

A volumetric sorption apparatus was designed in order to perform experiments to evaluate and estimate the sorption capacities of the coal samples that were studied. A schematic diagram of High Pressure CO<sub>2</sub> Volumetric Adsorption System (HPCVAS) is shown in Figure 1.

The setup consists of a reservoir cell, a sorption cell, a sample drying vessel and a digital control system for temperature and pressure control.



**Figure 1 Schematic Diagram of the Adsorption Apparatus**

An SRI instruments Gas Chromatograph (GC – Model 8610C) supplied by Chromspec was attached to the HPCVAS setup and it was used to measure the gas composition before and after the multicomponent adsorption tests. The data logging system was used to collect the temperature and pressure data every 0.3 seconds.

## 2.2. Sample description and preparation

Five different coal samples were collected from different locations (basins) around South Africa and used for this research. These basins include the Witbank (Greenside No.5 and Inyanda), Highveld (Syferfontein), Ermelo, and KwaZulu-Natal (Anthracite) basins. Each sample was identified by location and was characterized by coal rank (vitrinite reflectance), maceral composition, and chemical composition (proximate analysis). The proximate and petrographic properties of all the five coals are presented in Table 1.

**Table 1 Proximate and Petrographic Analysis of the Coals Used**

Sample ID	Proximate Analysis (%)				Petrographic Analysis (%)			
	Fixed C	Moisture	Vol. Matter	Ash	Vitrinite	Inertinite	Liptinite	Mineral Matter
Ermelo	27.8	4.5	59.8	17.9	9.6	71.6	8.6	2.4
Greenside No.5	50.2	4.2	32.7	12.9	45.6	39	4.2	11.2
Inspec. Anthracite	84.6	1.4	5.2	8.8	32	63.4	0	4.6
Inyanda	54.7	2.1	25	18.2	45	42.4	2.2	10.2
Syferfontein	44.1	5.6	22	28.3	18.2	67.2	2.2	12.4

## 2.3. Experimental procedure

Each run involved three sequential procedures: degassing the sample being studied; filling the reactor cell with the coal, placing the reactor cell under vacuum prior to gas injection; determining the void volume ( $V_{void}$ ) of the reactor cell filled with a coal sample, and; running the adsorption tests.

A size fraction of -5 mm + 4.75 mm was prepared for each sample prior to the experimental test work. Each coal sample was dried before the adsorption measurements could take place. Each sample was subjected to vacuum at a pressure of -0.7 bar and at a temperature of 130 °C for 2 hours so as to degas the sample. The void (gas) volume,  $V_{void}$ , in the equilibrium cell was determined by injecting a known quantity of helium. Since helium is not adsorbed, the void volume can be determined from measured values of the temperature, pressure and amount of helium injected into the cell as described by Sudibandriyo [13].

After the void volume determination, the helium was evacuated from the system and was replaced by an appropriate adsorbate (CO<sub>2</sub> or flue gas). The adsorbate was charged into the system at seven pressure steps, from atmospheric pressure to 50 bar. In the initial tests of up to 20 hrs, it was found that 90 min was sufficient for the adsorption of CO<sub>2</sub> to reach equilibrium. The captured data of temperature and pressure was used determine the amount of gas adsorbed.

### 2.3.1. Adsorption of pure component gas (CO<sub>2</sub>)

The most fundamental operational procedure to quantify gas adsorption is the Gibbs approach. Here the amount of adsorbed gas ( $n_{sorbed}$ ) is defined as the difference between the total amount of gas ( $n_{total}$ ) present in the system and the amount occupying the void volume ( $V_{void}$ ), i.e. the volume not occupied by the solid sample. The Gibbs excess sorption method assumes a constant ratio of condensed phase volume and void volume throughout the experiment and requires no further assumptions [14]. The excess amount of CO<sub>2</sub> adsorbed was calculated from the mass balance between the reference and sample cells at each gas expansion step using the Gibbs approach as expressed in the following expressions:

$$n_{sorbed}^{excess} = \frac{n_{total} - \rho_{eq} V_{void}}{m_s} \quad (1)$$

where  $n_{sorbed}^{excess}$  is the excess amount adsorbed (mmol/g),  $n_{total}$  is the total amount injected into the system (mmol),  $\rho_{eq}$  is the density of the gas (mmol/cm<sup>3</sup>) (in this case CO<sub>2</sub>),  $V_{void}$  is the void volume of the sample cell, and  $m_s$  is the sample mass as expressed in equation.

The CO<sub>2</sub> densities ( $\rho_{eq}$  and  $\rho_{gas}$ ) at a given  $T$  and  $P$  in the gas phase were obtained from the NIST website which uses an equation of state (EOS) correlation by Span and Wagner [15]. Furthermore, the amount of gas adsorbed was expressed in the absolute form. The adsorbed phase density is usually assumed to be constant across the experimental range [16]. Some authors have previously applied it successfully in their work [16-18]. The adsorbed-phase density estimates do, however, affect the calculated absolute adsorption isotherm [17]. In this study the value of 22.6 mmol/cm<sup>3</sup> for CO<sub>2</sub> was applied to the model.

### 2.3.2. Adsorption of multi-component gases

Adsorption isotherms were measured using a flue gas mixture on coal at 35 °C and pressures up to 50 bar. The measurements were conducted at one feed composition of the gas mixture. Initially, the gas mixture was sampled from its cylinder using a 5 ml syringe and analyzed using the Gas Chromatograph (GC) so as to verify a good homogeneity of the gas composition in the cylinder. After equilibrium pressure was reached for each pressure step, the gas remaining in the sample cell was sampled *via* sampling valve connected between the

sample cell and the GC. This was done so as to determine the unadsorbed amounts of individual gas components.

#### 2.4. Isotherm regression analysis

The Langmuir isotherm model is the most commonly used for the prediction of gas adsorption on coal. The Langmuir model assumes that adsorption occurs on a flat surface. At equilibrium, a continual process of bombardment of molecules onto the surface and a corresponding evaporation of molecules from the surface maintain a net zero rate of accumulation at the surface. The Langmuir model further assumes that the surface is homogeneous, that is, the adsorption energy is constant over all sites [19].

$$V = \frac{V_L BP}{1 + BP} \quad (2)$$

where  $V$  is adsorption volume,  $V_L$  is Langmuir volume,  $B$  is Langmuir constant,  $P$  is pressure.

Some other equations have been based on pore filling theory, such as Dubinin-Astakhov equation. However, due to the simplicity and well accordance with lots of experimental data, the Langmuir adsorption isotherm is more widely used in scientific research than others. The above cases are based on the single gas system and not available for binary or multi-component systems, so the extended Langmuir model is developed to meet the requirement, especially for CO<sub>2</sub> replacing methane case [8]. When extended to mixed-gas adsorption assuming no interaction among the adsorbed molecules, the Langmuir model becomes:

$$V_i = \frac{V_{L,i} B_i y_i}{1 + \sum_{j=1}^N B_j P y_j} \quad (3)$$

where  $V_i$  is the amount of component  $i$  adsorbed,  $V_{L,i}$  and  $B_i$  are Langmuir constants for  $i$ ,  $P$  is pressure, and  $y_i$  is the mole fraction of  $i$  in the gas face.

### 3. RESULTS AND DISCUSSION

#### 3.1. Adsorption of Pure Component Gas (CO<sub>2</sub>)

Looking at Figure 2(a) below, the high ranked Anthracite coal has a consistently higher CO<sub>2</sub> sorption capacity than any other coals at all measured pressures, with Ermelo giving significantly the lowest sorption capacity. The Highveld coal, Syferfontein, has an intermediate sorption capacity. One of the Witbank coals, Greenside No.5, has significantly high sorption capacity which happens to be closest to the Anthracite coal. The other Witbank coal, Inyanda, has a lower sorption capacity which is close to being as low as the Ermelo coal. Despite the fact that both Inyanda and Greenside No.5 coals are from Witbank, the Greenside No.5 coal has shown a stronger CO<sub>2</sub> sorption capacity than Inyanda by slightly more than 34%.

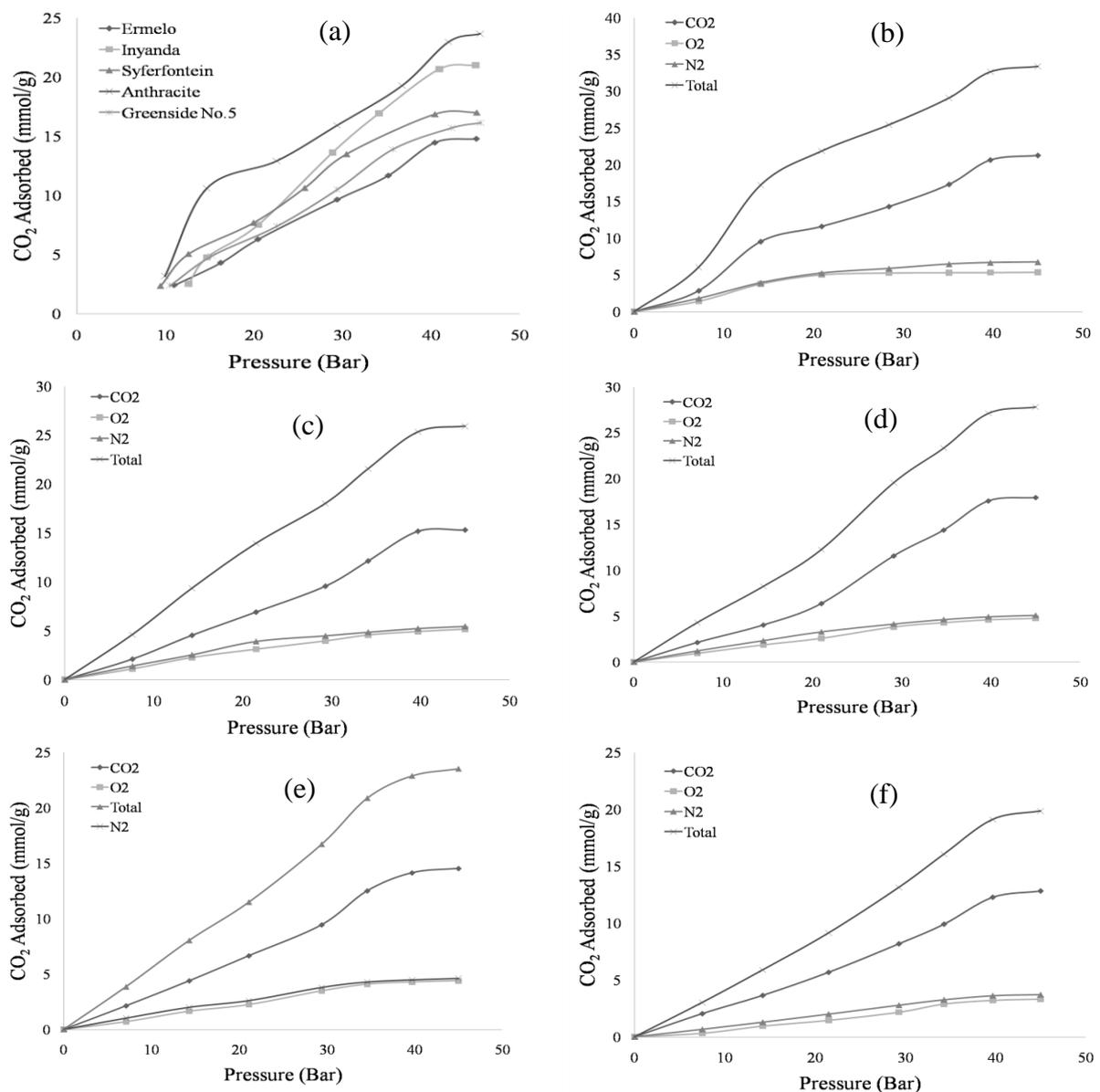
#### 3.2. Adsorption of Multicomponent Gas

Adsorption tests on five selected coals described above were performed at 35 °C and pressures up to 50 bar with a multicomponent gas mixture containing 96.2% CO<sub>2</sub>, 2.3% N<sub>2</sub>,

and 1.5% O<sub>2</sub>, making it a ternary mixture. The sorption isotherms for multicomponent gas for all coals studied are shown in Figure 2(b-f).

The adsorption of multicomponent gas mixtures on coals is typically a competitive adsorption with a strong interaction between the components. A high preferential adsorption of CO<sub>2</sub> was observed for high rank coals, while low rank coals showed a lower preferential adsorption of CO<sub>2</sub> over the whole pressure range.

All five coals that were studied in this research showed a significantly very low preferential adsorption of N<sub>2</sub> and O<sub>2</sub> gases. It was also observed that the CO<sub>2</sub> sorption capacity was reduced when N<sub>2</sub> and O<sub>2</sub> were added as impurities compared to pure CO<sub>2</sub> sorption capacity for all coals. However, on average, all CO<sub>2</sub> sorption capacities reduced by 12%. The O<sub>2</sub> adsorption preferential was lower compared to N<sub>2</sub> for all coal over the whole pressure range (Figure 2).



**Figure 2 (a) Adsorption Isotherms of Pure Component Gas (CO<sub>2</sub>). Multicomponent Gas Adsorption Isotherms: (b) Anthracite; (c) Syferfontein; (d) Inyanda; (e) Greenside No.5; (f) Ermelo**

The predicted adsorption capacities of the multicomponent mixture using the Extended Langmuir equation did not conventionally model the experimental data. Therefore, the discussion of this research only focuses on data interpretation associated with the competitive adsorption experiments and adsorption capacities of CO<sub>2</sub>, N<sub>2</sub>, and O<sub>2</sub> as a mixture.

#### **4. CONCLUSIONS**

The effect of coal rank, coal composition and multicomponent mixtures was investigated using five of South African coals. From the results obtained, the following conclusions can be drawn from this study:

- 1) Coal rank is a significant controlling factor for CO<sub>2</sub> adsorption capacity. The high rank coal, anthracite, has the highest CO<sub>2</sub> adsorption capacity while the low rank coal, bituminous, has the lowest CO<sub>2</sub> adsorption capacity.
- 2) Adsorption capacity on coal is highly affected by the coal composition. Vitrinite rich coals have a positive correlation to CO<sub>2</sub> sorption capacity, and inertinite rich coals show a negative correlation to CO<sub>2</sub> sorption capacity.
- 3) Coal has got a high preferential of CO<sub>2</sub> compared to other gases (in this case N<sub>2</sub> and O<sub>2</sub>), this behaviour applies to all five coals that were put under investigation.

#### **Acknowledgements**

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# Comparing CO<sub>2</sub> uptake capacity for different South African coal types for low-high pressure adsorption

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**Key words:** Coal; Pure CO<sub>2</sub>; Sub-critical conditions; Adsorption isotherms

## Abstract

*Due to the energy- and carbon-intensive economic structure of South Africa, the country has become one of the biggest contributors to greenhouse gas emissions, emitting more CO<sub>2</sub> than any other African country. Increasing global greenhouse gas levels have led to “global climate change” resulting in more severe weather events than previously recorded. Burning of fossil fuels results in excess CO<sub>2</sub> emissions; this is believed to be the main cause of climate change. It is therefore strongly advised to stabilize greenhouse gas emissions within the next five years, and then to rapidly reduce CO<sub>2</sub> emissions by a third by 2020, with continued reduction up to 2050.*

*There are many international projects investigating reduction of anthropogenic carbon dioxide (CO<sub>2</sub>) emissions by sequestration in deep, unmineable coal seams. Fundamental experimental data needs to be generated from which a predictive assessment of pure CO<sub>2</sub> sequestration can be conducted on South African coals. The objective and nature of this research was to investigate the adsorption capacity of six different South African coals using pure CO<sub>2</sub> to evaluate best adsorption capability.*

*The effects of coal rank, coal composition, i.e. mineral and maceral matter, and pressure on the CO<sub>2</sub> adsorption capacity of the samples have been evaluated. Adsorption isotherms of pure CO<sub>2</sub> were measured at 35 °C and up to a maximum pressure of 50 bar using the volumetric method using 5 g samples with a grain size of -5+4.75 mm. High Pressure CO<sub>2</sub> Adsorption System (HPCAS: volumetric system) was specifically designed and constructed for this research work. The raw data obtained from all experiments were used to calculate the total amount of CO<sub>2</sub> adsorbed per coal type using gas density as suitable CO<sub>2</sub> property indicator*

*The highest ranked coal, anthracite, has the highest adsorption capacity while the low ranked coal, Ermelo, has the lowest adsorption capacity.*

## 5. Introduction

Increasing global greenhouse gas levels have led to “global climate change”. Many research studies indicate that a continued rise in average global temperatures will adversely affect the Earth’s climate [1]. In South Africa, coal is the predominant form of energy, which emits large amounts of CO<sub>2</sub> gas. South Africa is currently ranked at number 12 in the world emitting over 400-million tons of CO<sub>2</sub> a year, representing 1% of total CO<sub>2</sub> global emissions [2]. Carbon storage is defined as the placement of CO<sub>2</sub> into a repository in such a way that it will remain stored (or sequestered) permanently [3]. Coal seams exists potential for enhancing coalbed methane recovery (ECBM). A recent geological survey conducted by

Viljoen *et al.* [4] at the Council for Geoscience estimated 1, 271.9 Gt CO<sub>2</sub> storage capacity in the SA coal fields.

Since March 2002 SA signed the KYOTO PROTOCOL (legally binding agreement: GHG emissions worldwide), requiring reduction of CO<sub>2</sub> emissions by 5.2% before 2012. In November 2011, COP 17 was held in Durban, South Africa. SA signed a second commitment KYOTO PROTOCOL starting January 2012 to 2017 or 2020 to working towards emission reduction globally. There is a lack of CO<sub>2</sub> adsorption data on SA coals; most of the adsorption data currently available pertain to CO<sub>2</sub> adsorption studies for Northern Hemisphere and Australian coals. To develop the potential for CCS in SA coal seams, in-situ trials and injection studies on the CO<sub>2</sub> uptake behavior of South African coals are needed.

### 5.1. Previous Studies

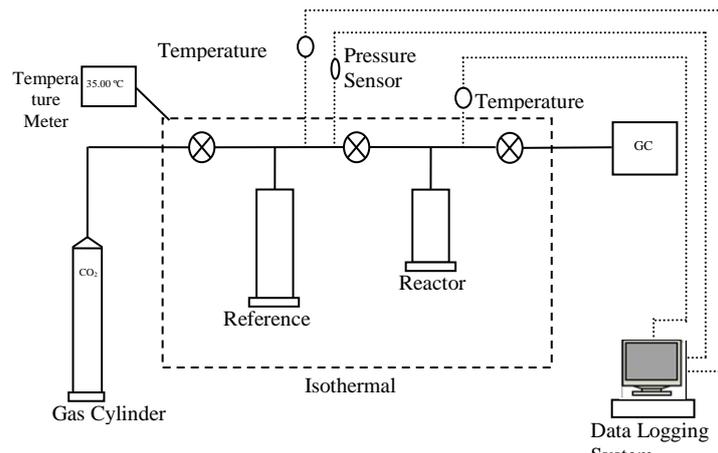
The successful storage of CO<sub>2</sub> in geological formations has been demonstrated over a period of 20 years, with or without economic benefit. Currently 70 000 tons of CO<sub>2</sub> per year are injected in a deep coal seam in the United States, and, a similar project, at a smaller scale has been developed in Alberta Canada [5]. The European RECOPOL project has demonstrated the technical feasibility of CO<sub>2</sub> injection into typical European carboniferous coal seams, which in conjunction with a follow up project by Delft University of Technology (The Netherlands) and RWTH Aachen University (Germany) within RECOPOL and the national CO<sub>2</sub>TRAP project, have provided fundamental information on the interaction of coals with CO<sub>2</sub> and CH<sub>4</sub> under in-situ conditions [6], [7]. Coal is able to store a significant amount of gas due to its highly porous nature, having micro and meso pores, as well as fractures and cleats. From international research, it is shown that coal can absorb more CO<sub>2</sub> than CH<sub>4</sub>, with preferential absorption onto the coal structure over CH<sub>4</sub>, at least two to three molecules of CO<sub>2</sub> are sequestered for each molecule of CH<sub>4</sub> extracted [8]. Saghafi *et al.* [9] concluded that the CO<sub>2</sub> storage capacity for the Australian coals tested is about twice that of CH<sub>4</sub> and six times that of N<sub>2</sub>, and the diffusivity of CO<sub>2</sub> in coal is about twice that of CH<sub>4</sub>. The maximum quantity of gas that can be stored in a given coal is mainly a function of its absorption capacity, although pressure can significantly increase the amount of gas absorbed, as was shown by Mazumder *et al.* [10].

Studies conducted by Gurdal and Yalcin [11] determined a correlation between the ash content and adsorption capacity for Turkish coals, but could not conclude which of the other controlling parameters (such as maceral composition, coal rank and carbon content) dominated due to scattered results. Research carried out by Crosdale *et al.* [12] concluded that maceral composition significantly affects both adsorption and desorption properties of coals. They also concluded that micro pore structure also plays a significant role, and this related to type and rank of coal. While Walker *et al.* [13] determined that CO<sub>2</sub> uptake occurs in open and closed micro-pores, Ceglarska-Stefańska and Zarębska [14] observed that the capillary structure of hard coals is heterogeneous, and differences between pores lie in their shape and size. The macro and mesopore contribution to the sorption capacity of coals is a minor factor, although they play a role in the processes of diffusion and gas migration. Hence, hard coals are regarded as heterogeneous sorbents as a result of changes to the original organic matter during coalification. This is closely associated with the chemical content and properties of the coal deposit, due to the presence of reactive oxygen groups and the differences in the elemental compositions of macerals of vitrinite, liptinite, and fusinite. Thus, the structural parameters of coal are closely related to its maceral content. Micropores tend to predominate in vitrinite, while meso-pores and macro-pores predominate in inertinite [14].

## 6. Experimental

### 6.1. Experimental Setup

A volumetric sorption apparatus was designed to execute experiments to determine the sorption capacities of the coal samples. Schematic diagram of CO<sub>2</sub> Adsorption System (HPCVAS) is shown in figure 1.1. The setup consists of stainless steel reservoir cell (467.2 cm<sup>3</sup>) and sorption cell (64.89 cm<sup>3</sup>). Pressure was controlled using digital control system via accurate pressure sensors. A data logging system was used to collect the temperature and pressure data.



**Figure: 3.1 Schematic Diagram of the Adsorption Apparatus**

### 6.2. Sample description and preparation

Six different coals listed in Table 1 were collected from different basins around SA and characterized petrographically to determine coal rank (vitrinite reflectance), maceral composition, and chemical composition (proximate analysis). A jaw crusher was used to obtain fraction range of -5 mm + 4.75 mm.

**Table 2 Proximate data and Petrographic Analysis of the Coals Used**

Sample ID	Proximate Analysis (%)				Petrographic Analysis (%)			
	Fixed C	Moisture	Vol. Mat	Ash	Vitrinite	Inertinite	Liptinite	Mineral Mat
<b>Ermelo</b>	27.8	4.5	59.8	17.9	29.6	51.6	8.6	2.4
<b>Waterberg</b>	32.6	1.1	25.2	39.4	2.8	51.2	2.4	43.6
<b>Greenside No.5</b>	50.2	4.2	32.7	12.9	45.6	39	4.2	11.2
<b>Anthracite</b>	84.6	1.4	5.2	8.8	32	63.4	0	4.6
<b>Inyanga</b>	54.7	2.1	25	18.2	45	42.4	2.2	10.2
<b>Syferfontein</b>	44.1	5.6	22	28.3	18.2	67.2	2.2	12.4

### 6.3. Experimental procedure

Experimental test runs involved the following sequential steps:

1. Degassing (heating at temperature of 130 °C for 2 hours and vacuuming at a pressure of -0.7 bar) to ensure that the adsorption capacity by the presence of inherent moisture of the coal sample [16].
2. Filling the reactor cell with coal in the reactor, then under vacuum prior to gas injection;
3. Determining the void volume ( $V_{void}$ ) of the reactor cell filled with a coal sample by injecting a known quantity of helium. Since helium is not adsorbed, the void volume can

- be determined from measured values of the temperature, pressure and amount of helium injected into the cell as described by Sudibandriyo [17]. Evacuating
4. Helium the system and adsorbate (CO<sub>2</sub>) injected into the system, seven pressure steps chosen which were increased evenly from atmospheric pressure to 50 bar. The captured data of temperature and pressure was used determine the amount of gas adsorbed.

#### *Adsorption of pure component gas (CO<sub>2</sub>)*

The most fundamental operational procedure to quantify gas adsorption is the Gibbs approach. Here the amount of adsorbed gas ( $n_{sorbed}$ ) is defined as the difference between the total amount of gas ( $n_{total}$ ) present in the system and the amount occupying the void volume ( $V_{void}$ ), i.e. the volume not occupied by the solid sample. The Gibbs excess sorption method assumes a constant ratio of condensed phase volume and void volume throughout the experiment and requires no further assumptions. The excess amount of CO<sub>2</sub> adsorbed was calculated from the mass balance between the reference and sample cells at each gas expansion step using the Gibbs approach as expressed in the following expressions:

$$n_{sorbed}^{excess} = \frac{n_{total} - \rho_{eq} V_{void}}{m_s} \quad (4)$$

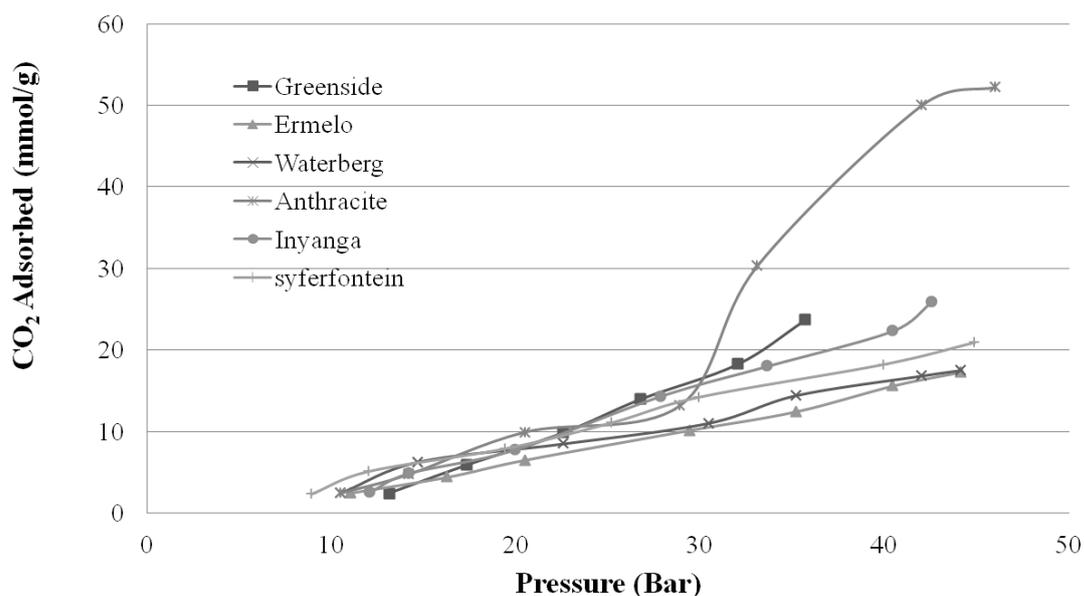
where  $n_{sorbed}^{excess}$  : excess amount adsorbed (mmol/g),  $n_{total}$  : total amount injected into the system (mmol),  $\rho_{eq}$  : density of CO<sub>2</sub> gas (mmol/cm<sup>3</sup>),  $V_{void}$  : void volume of the sample cell, and  $m_s$  : sample mass. CO<sub>2</sub> densities ( $\rho_{eq}$  and  $\rho_{gas}$ ) at a given ( $T$ ;  $P$ ) in gas phase were obtained using equation of state (EOS) correlation by Span and Wagner [18]. Furthermore, the amount of gas adsorbed was expressed in the absolute form. The adsorbed phase density is usually assumed to be constant across the experimental range [19]. 22.6 mmol/cm<sup>3</sup> will be used for CO<sub>2</sub> in this study.

## **7. Results and Discussion**

### *7.1. Adsorption of Pure Component Gas (CO<sub>2</sub>)*

The main aim was to determine the adsorption capacities of different South African coal types. Six SA coals as outlined in Table 1 were tested to evaluate their ability to adsorb CO<sub>2</sub> according to their respective properties of rank, maceral, and mineral matter, etc. All coals tested essentially show comparable adsorption profiles at lower pressures, with the lines beginning to diverge after around 25 bar. At 30 bar, the anthracite sample suddenly showed a sharp uptake of CO<sub>2</sub>. The Inyanga sample also showed the beginning of a sharp intake at around 44 bar, and the Greenside sample at around 37 bar as can be seen in Figure 3.1. The high ranked Anthracite coal has a consistently higher CO<sub>2</sub> sorption capacity than any of the other low ranking coals that were at measured at the same pressures and test parameters. The Ermelo coal has a significantly lower sorption capacity compared to all other coals that were studied in this research. The Highveld coal, Syferfontein, has an intermediate sorption capacity. The results indicate that adsorption is lower at lower pressures, and at higher pressures more CO<sub>2</sub> is adsorbed, as expected. What is possibly not expected are the changes in the slopes of the lines, showing that adsorption is not linear.

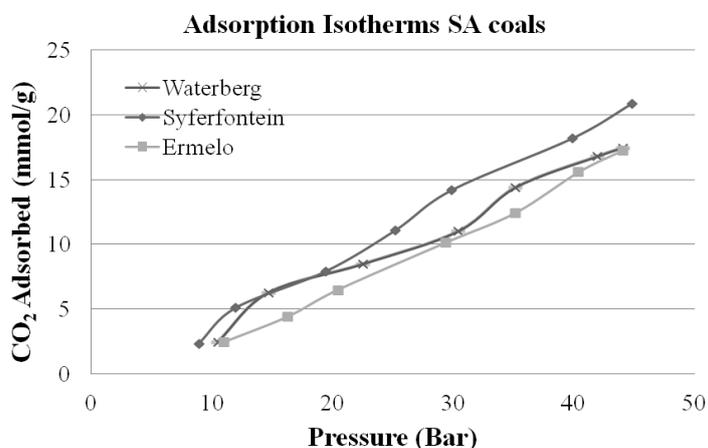
## Adsorption Isotherms for SA Coals



**Figure 3.1 Adsorption Isotherms of SA Coals Tested**

The anthracite coal reported the highest adsorption of 52.22 mmol/g at a pressure of 46 bar. The Waterberg and Ermelo samples showed the lowest adsorption potential; the Waterberg sample has a very high ash content (39.4%) and mineral matter (43.6), which may explain this result.

According to Gurdal *et al.* [20] the micropore volume of coal decreases with an increase of  $R_{\text{omax}}$  (maximum vitrinite reflectance), up to a value of 1.0 – 1.1%. However, with an increasing  $R_{\text{omax}}$ , the micropore volume is seen to increase again. Hence, the anthracite sample is capable of adsorbing more  $\text{CO}_2$  than the bituminous samples. Compared to the other bituminous coals, the anthracite has the lowest mineral matter of 4.6% and highest carbon content, however in terms of maceral comparison it has a higher inertinite value of 63.4% and a lower vitrinite value of 32% i.e. a ratio of vitrinite to inertinite of 1:2. Hence, rank is more significant than coal type for  $\text{CO}_2$  adsorption.



**Figure 3.2 Adsorption Isotherms of three different SA Coals Tested**

From figure 3.2 above, the Ermelo and Waterberg coals exhibit the poorest adsorption of CO<sub>2</sub> for all test runs, with capacities of 17.3 mmol/g at 44 bar and 17.5 mmol/g at 44 bar, respectively. It is well known that porosity is related to maceral composition, i.e. vitrinite predominantly contains microporous, whereas inertinite contains mesoporous and macroporous. Although a higher adsorption rate for higher rank coals has been observed as with previous studies, it must be noted that previous studies have also concluded that best sorption was noted mostly for vitrain-rich facies in high rank coals that contain low amounts of minerals [21], [22]. However, in contrast, an investigation by Faiz *et al.* [23] showed no systematic differences between gas sorption capacities of vitrinite- and inertinite-rich coals, as noted from the current results. Chalmers and Bustin [24] showed that medium volatile bituminous rank dull coals with lower non-reactive inertinite contents showed a greater gas sorption capacity, because of higher micropore volumes. It was suggested that reactive inertinite should be considered when assessing dull coals as an adsorption media for CBM resource. In this study, all coals show comparable reactive inertinite contents (with Greenside being the highest at 7 vol% mmf (mineral matter free)); in terms of total reactive maceral content, the Greenside sample is the highest at 63.1 vol% mmf, followed by the Inyanga sample. The difference in the maceral component may explain the slight difference in adsorption behaviour, with the more reactive sample reporting a slightly higher level of CO<sub>2</sub> adsorption.

The effect of ash content regarding CO<sub>2</sub> adsorption is discussed as follows:

**Table: 3.1 Ash and vitrinite content and CO<sub>2</sub> adsorbed for select high ash coals.**

Coal sample	Ash content (wt%)	Vitrinite content (vol%, mmf)	CO <sub>2</sub> adsorbed (mmol/g)	Pressure (bar)
<b>Ermelo</b>	17.9	10.7	17.3	44.0
<b>Syferfontein</b>	28.3	20.8	20.89	44.1
<b>Waterberg</b>	39.4	5.0	17.46	44.8

The coal samples listed in Table 3.1 show similar adsorption capacity as depicted in figure 3.2 and variable ash content, with differences in their vitrinite contents, although all samples can be considered to be low to very low in vitrinite and moderate to very high in terms of their ash content. The samples come from 3 different coalfields in South Africa. Although the Waterberg coal has a greater ash content than the Ermelo coal (almost double), very little difference in adsorbed amount can be noted from this study. From a petrographic perspective, the Syferfontein and Ermelo samples have similar mineral matter values compared to the Waterberg sample, which has mineral matter content of 43.6%. But again, the adsorptive behaviour does not appear to be affected by the high mineral matter content, or the very low vitrinite content of the Waterberg sample, in comparison to the other two samples. These three samples reported the lowest CO<sub>2</sub> adsorptive capacity as per Figure 3.1.

## 8. Conclusions

The effect of coal rank, coal composition and adsorption pressure was investigated and the following conclusions can be drawn from this study:

- 4) Coal rank is a significant controlling factor for CO<sub>2</sub> adsorption capacity. The high rank coal, anthracite (inertinite-rich), has the highest CO<sub>2</sub> adsorption capacity while the low ranking coal bituminous, has the lowest CO<sub>2</sub> adsorption capacity.
- 5) Highveld sample adsorbed less than Witbank samples, which report comparable vitrinite and ash contents. The difference in ash and maceral composition, most likely account for differences in adsorption behaviour between the Highveld and Witbank coals.
- 6) Mineral matter is also a contributing factor to poor CO<sub>2</sub> adsorption. Coal with low inertinite, but high mineral matter gave very poor adsorption rates as compared to a coal

with much lower mineral matter content. From samples tested the Ermelo (10.2% ash) and Witbank Inyanga (10.4% ash) samples had almost the same mineral matter content, but adsorption was notably much greater for the Witbank coal compared to the Ermelo. Hence, other properties in varying ratios need further consideration. The mineral composition in coal does have an impact on the CO<sub>2</sub> adsorption capacity of the coal to some extent.

Coal properties, including coal composition (e.g. rank, permeability, mineral matter, macerals, lithotypes, etc.), pore structure, grain size, and moisture content of the coal are very pertinent properties that need further research.

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# ENERGY PERFORMANCE OF ECO-FRIENDLY R432A AND R433A AS ALTERNATIVE TO R22 IN SUB-COOLING HEAT EXCHANGER REFRIGERATION SYSTEM

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**Key words:** Energy, performance, eco-friendly, alternative refrigerants, R432A, R433A

## Abstract

*This study investigates the energy performance of eco-friendly R432A and R433A as alternatives to R22 in a vapour compression refrigeration system with sub-cooling heat exchanger. The effects of sub-cooling on the various refrigeration cycle performance parameters were evaluated. The results obtained showed that the saturated vapour pressure and temperature characteristic profiles for R432A and R433A are similar to those of R22 without any significant deviation between the curves. This indicates that R432A and R433A exhibited similar properties and could be used as substitute for R22. The two alternative refrigerants exhibited higher coefficient of performance (COP) and higher relative capacity index (RCI) than R22. The average COPs obtained for R432A and R433A were 12.9 and 16.7% higher than that of R22. They also exhibited lower power per ton of refrigeration (PPTR) than that of R22, but R433A emerged as the most energy efficient refrigerant among all the investigated refrigerants with average PPTR of 13.3% lower than that of R22. Generally, incorporation of sub-cooling heat exchanger in the system, greatly improved the performance of the system; it increases the COP, reduces the compressor energy input and the specific power consumption of the system. The two alternative refrigerants, consistently exhibited better performance than R22 in sub-cooling heat exchanger refrigeration system. R433A performed better than both R22 and R432A in that the highest RCI, COP, reduction in energy input and lowest PPTR were obtained using R433A in the system.*

## INTRODUCTION

The continuous depletion of the ozone layer, which shields the earth's surface from the biologically damaging ultraviolet sunlight called UV-B radiation, has resulted in a series of international treaties demanding a gradual phase out of chlorofluorocarbons (CFC) and hydro-chlorofluorocarbons (HCFC) refrigerants. The CFCs have been phased out in developed countries since 1996, and 2010 in developing countries [1]. Initial alternative to CFCs included some HCFCs, but they will also be phased out internationally by year 2020 and 2030 in developed and developing nations respectively [2].

Since R22 came into common use as a refrigerant in 1936, it has been applied in systems ranging from smallest window air-conditioners to the largest chillers and heat pumps because of its inherent efficiency and high refrigeration capacity and it has the largest sales volume among all refrigerants. Individual equipment using this versatile refrigerant ranges from 2 kW to 33 MW in cooling capacity. No other refrigerant has achieved such a wide range of applications [3]. However, R22 is one of a class of chemicals, HCFCs, being phased out due to the environmental hazard of ozone depletion [4].

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Ozone depletion and global warming are two major environmental concerns with serious implications for the future development of the refrigeration-based industries. Ozone is a variant of oxygen, the ozone molecule having three atoms of oxygen. Ozone layer surrounds the earth's stratosphere which is about 11 kilometres above the earth surface. It acts as shield to protect the earth against the harmful ultraviolet radiation from the sun. The efficacy of ozone destruction is often measured by a comparative unit termed Ozone depletion potential (ODP), which is based upon the ODP of R11 being assigned a value of unity [5].

The second major environmental concern is climatic changes or global warming. In a green house, glass allows sunlight in but prevents some infrared radiation from escaping. The gasses in the earth's atmosphere, which exert a similar effect, are called "greenhouse gasses". The concern is that man's activities are increasing the concentration of greenhouse gases in the atmosphere, causing the amount of absorbed infrared radiation to increase, and leading to increased atmospheric temperatures and consequent long-term climate changes. The amount of radiant energy that the refrigerants absorb is measured by an index called Global Warming Potential (GWP). GWP is the amount of infrared radiation that the gas can absorb, relative to carbon dioxide (with an assigned GWP of 1), integrated over a period of 100 years [5].

These days, greenhouse warming has become one of the most important global issues and Kyoto protocol was proposed to resolve this issue, which classified Hydro-fluorocarbons (HFCs) as part of the greenhouse warming gases [6]. HFC refrigerants are the leading replacement for CFC and HCFC refrigerants, in refrigeration and air-conditioning systems. Although the ODP of HFC refrigerants is zero, their GWPs are relatively high. Therefore, application of HFC refrigerants as ultimate refrigerants in refrigeration air-conditioning systems may not be adequate any more. For this reason, environmentally benign, 'natural' refrigerants have attracted a considerable attention.

R432A and R433A in the group of natural refrigerants have both zero ODP and very low GWP (Table 1). They are compatible with common materials found in refrigeration systems and are soluble in conventional mineral oils [7]. The most important concern regarding the adoption of R432A and R433A as refrigerant is their flammability. It should be remembered that millions of tonnes of hydrocarbons are used safely every year throughout the world for cooking, heating, powering vehicles and as aerosol propellants. In these industries, procedures and standards have been developed and adopted to ensure the safe use of the product. The same approach is also been followed by the refrigeration industry. Various applications have been developed in handling the flammability and safety problems such as using enhanced compact heat exchangers, optimizing system designs, reducing the charge of systems and establishing rules and regulations for the safety precautions [8].

Sub-cooling heat exchanger is commonly installed in refrigeration systems with the intent of ensuring proper system operation and increasing system performance. It has been used by some researchers [11-14] to evaluate the performance of some alternative refrigerants to R22 and R12. Therefore, in this paper, the performance of hydrocarbon mixtures (R432A and R433A) with zero ODP and negligible GWP (Table 1) as alternatives to R22 in vapour compression refrigeration system was investigated theoretically employing a sub-cooling heat exchanger refrigeration system. R432A is a near azeotropic mixture composed of 80% propylene (R1270) and 20% dimethylether (RE170) by weight. R433A is also a near azeotropic mixture composed of 30% propylene (R1270) and 70% propane (R290) by weight. The effects of sub-cooling and performance parameters of the system working with alternative refrigerants were evaluated and compared with those of R22.

Table 1: Environmental and thermophysical properties of investigated refrigerants [9, 10]

Environmental and thermophysical properties	Refrigerants				
	R22	R432A	R433A	R407C	R410A
Critical Temperature (°C)	96.2	97.3	94.4	86.0	71.4
Boiling point, BP (°C)	-40.8	-46.6	-44.6	-44.0	-51.0
Temperature glide (°C)	-	1.0	0.4	5	0.2
Composition	-	R1270 (80%) RE170 (20%)	R1270 (30%) R290 (70%)	R32 (23%) R125 (25%) R134a (52%)	R32 (50%) R125 (50%)
Molar mass (kg/kmol)	86.5	42.8	43.5	86.2	72.6
Ozone Depleting Potential (ODP)	0.05	0	0	0	0
Global warming potential (GWP)	1500	4	4	1525	1725

## MATERIALS AND METHODS

### Refrigeration system with sub-cooling

Sub-cooling in refrigeration implies cooling the refrigerant in liquid state, at uniform pressure, to a temperature that is less than the saturation temperature, which corresponds to condenser pressure. Schematic diagram of vapour compression refrigeration system with a sub-cooling heat exchanger is shown in Fig. 1.

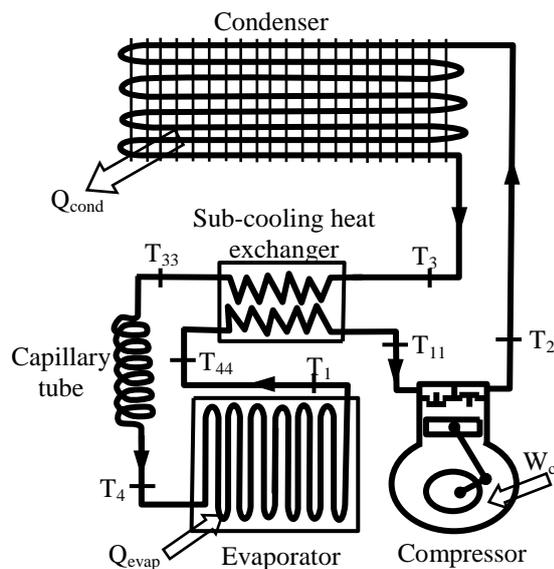


Fig. 1: Refrigeration system with a sub-cooling heat exchanger.

In this system, high temperature liquid from the condenser is sub-cooled in the heat exchanger before entering the expansion device where it is being throttled to the evaporator pressure. The sub-cooling heat exchanger affects the performance of a refrigeration system by influencing both the high and low pressure sides of the system. Fig. 2 shows the key state points for a vapour compression cycle utilizing an idealized sub-cooling heat exchanger on a pressure-enthalpy diagram. Degree of sub-cooling is the difference between the saturation temperature of the liquid refrigerant corresponding to condenser pressure and the temperature of the liquid refrigerant before entering to the expansion device.

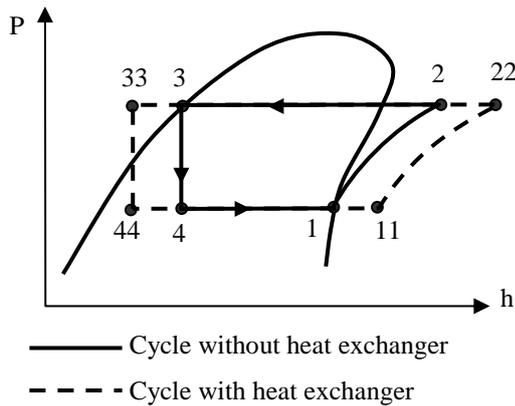


Fig. 2: Pressure-enthalpy diagram showing effect of an idealized sub-cooling

### Relative Capacity Index (*RCI*)

Without a sub-cooling heat exchanger, the refrigerating effect per unit mass flow rate of circulating refrigerant is the difference in enthalpy between states 1 and 4 in Fig. 2. When the heat exchanger is installed, the refrigeration effect per unit mass flow rate increases to the difference in enthalpy between states '1' and '44'. If there were no other effects, the addition of a sub-cooling heat exchanger would always lead to an increase in the refrigeration capacity of a system. The extent of the capacity increase is a function of the specific heat of refrigerant, the degree of sub-cooling and the system operating conditions. According to Klein and Reindl [15], the effect of a sub-cooling heat exchanger on refrigeration capacity can be quantified in terms of a relative capacity index (*RCI*) as defined in Eq. (1):

$$RCI = \left( \frac{RC_{hx} - RC_{nohx}}{RC_{nohx}} \right) \times 100\% \quad (1)$$

where,  $RC_{hx}$  = the refrigeration capacity with a sub-cooling heat exchanger; and  $RC_{nohx}$  = the refrigeration capacity for a system operating at the same condensing and evaporating temperatures without a sub-cooling heat exchanger.

### Determination of Thermodynamic Properties of Refrigerants

The most fundamental of a working fluid's thermal properties that are needed for the prediction of a refrigerant system's performance are the pressure-volume-temperature (PvT) in an equilibrium state. These equations have been used to develop the most widely used refrigerant database software known as REFPROP [10, 16]. It was developed and is

maintained by the National Institute of Standards and Technology and is currently in its ninth edition. It uses several equations-of-state to correlate 33 single component refrigerants and 29 predefined mixtures, along with the ability to construct virtually any desired mixture of up to five components [17]. This software was used in this work to compute the properties of investigated refrigerants.

### Data Reduction

After the thermodynamic properties of each state of the cycle are determined, the equations for the cycle analysis are obtained by means of mass and energy conservation. The data reduction of the theoretical results are analysed with the equations stated below. Considering the cycle on p-h diagram in Fig. 2, the heat absorbed by the refrigerant in the evaporator or refrigerating effect ( $Q_{evap}$ , kJ/kg) is calculated as:

$$Q_{evap} = (h_1 - h_4) \quad (2)$$

where,  $h_1$  = specific enthalpy of refrigerant at the outlet of evaporator (kJ/kg); and  $h_4$  = specific enthalpy of refrigerant at the inlet of evaporator (kJ/kg). The compressor work input ( $W_{comp}$ , kJ/kg) is obtained as:

$$W_{comp} = (h_2 - h_1) \quad (3)$$

where,  $h_2$  = specific enthalpy of refrigerant at the outlet of compressor (kJ/kg). The flow of refrigerant in the throttling valve from point 3 to point 4 is at constant enthalpy. Therefore,

$$h_3 = h_4 \quad (4)$$

where,  $h_3$  = specific enthalpy of refrigerant at the outlet of condenser (kJ/kg). The specific power consumption is a useful indicator of the energy performance of refrigeration system. This is obtained as Power per ton of refrigeration (*PPTR*) and is expressed as [18]:

$$PPTR = \frac{3.5W_{comp}}{Q_{evap}} \quad (5)$$

The coefficient of performance (COP) is the refrigerating effect produced per unit of work required; therefore, COP is obtained as the ratio of Eq. (2) to Eq. (3):

$$COP_{ref} = \frac{Q_{evap}}{W_{comp}} \quad (6)$$

## RESULTS AND DISCUSSION

The variation of saturated vapour pressure and temperature for R22 and its alternative refrigerants (R432A and R433A) is shown in Fig. 3. As shown in this figure, the saturated vapour pressure curves for R432A and R433A are almost the same with that of R22 without any significant deviation between the curves. This indicates that R432A and R433A can exhibit similar properties and could be used as substitute for R22.

Fig. 4 shows the influence of the degree of sub-cooling on refrigerating effects for R432A, R433A and R22 at condensing temperature of 40°C and evaporating temperature of -20°C. As shown in the figure, refrigerating effect increases with increase in degree of sub-cooling. This is due to the increase in latent heat value of the refrigerant. R432A and R433A exhibited higher refrigerating effect than R22, therefore, very low mass of refrigerant will be required

for the same capacity, and smaller compressor size will also be required due to their high latent heat values. The highest refrigerating effect was obtained using R432A in the system.

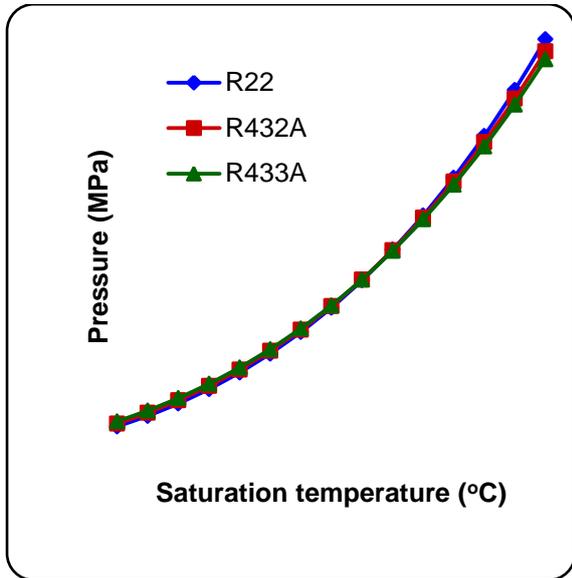


Fig. 3: Saturation vapour pressure curves

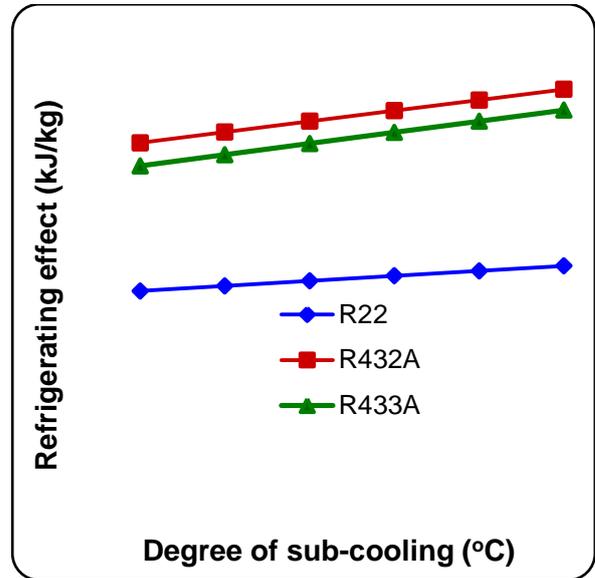


Fig. 4: Influence of the degree of sub-cooling on refrigerating effect at 40°C condensing and -20°C evaporating temperatures

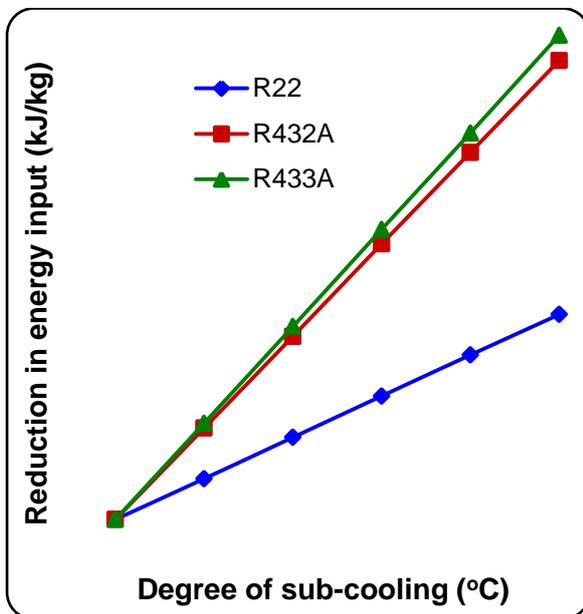


Fig. 5: Effect of the degree of sub-cooling on the reduction in compressor energy input at 40°C condensing and -20°C evaporating temperatures

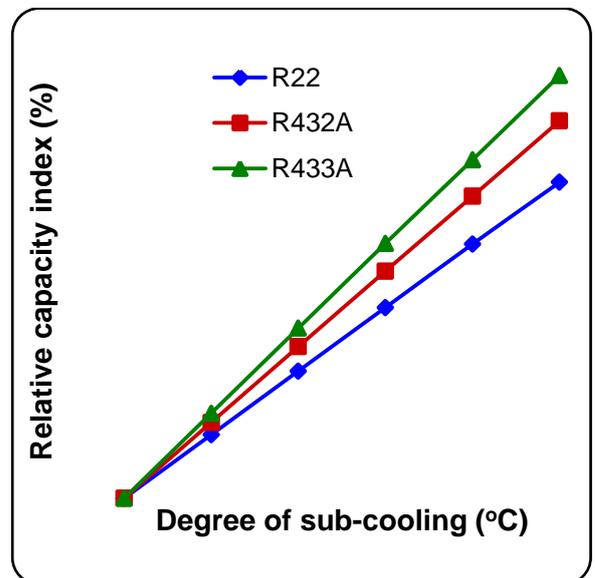


Fig. 6: Effect of the degree of sub-cooling on the relative capacity index (RCI) at 40°C condensing and -20°C evaporating temperatures

Fig. 5 shows the reduction in the compressor energy input for the investigated refrigerants at varying degree of sub-cooling for 40°C condensing and -20°C evaporating temperatures. As shown in the figure, reduction of energy input increases as the degree of sub-cooling increases. The two alternative refrigerants exhibited higher reduction in energy input than R22, but the highest reduction in energy input was obtained using R433A in the system.

Fig. 6 shows the effect of the degree of sub-cooling on the relative capacity index (RCI) for R22, R432A and R433A at 40°C condensing and -20°C evaporating temperatures. As shown in this figure, an increase in capacity is observed for all refrigerants, although there is considerable variation in the magnitude of the effect of sub-cooling on each refrigerant. The average relative capacity indices obtained within the range of 2 to 10°C sub-cooling for R432A and R433A were 19.2 and 33.6% higher than that of R22.

Fig. 7 shows the effect of degree of sub-cooling on the COP at 40°C condensing and -20°C evaporating temperatures for R22 and the two alternative refrigerants. As shown in this figure, at zero degree sub-cooling (without sub-cooling), the COP of R22 was very close to those of R432A and R433A, but the degree of sub-cooling increased the COP of the two alternative refrigerants more than that of R22. The average COPs obtained within the range of 2 to 10°C sub-cooling for R432A and R433A were 12.9 and 16.7% higher than that of R22.

Fig. 8 shows the influence of the degree of sub-cooling on the power consumption per ton of refrigeration at 40°C condensing and -20°C evaporating temperatures. As shown in the figure, the power per ton of refrigeration (PPTR) reduces as the degree of sub-cooling increases for all the investigating refrigerants. R432A and R433A exhibited lower PPTR with the average values of 10.9 and 13.3% lower than that of R22, respectively.

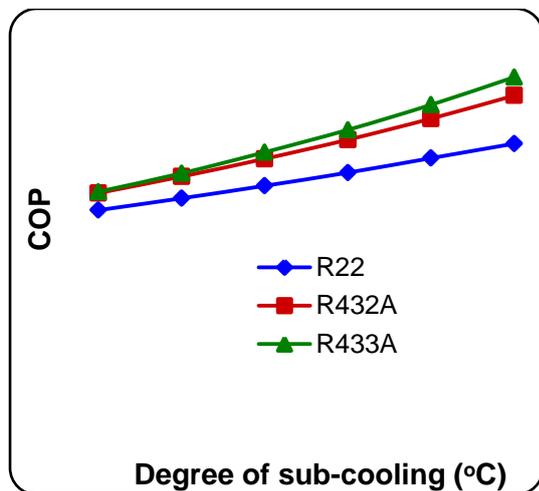


Fig. 7: Effect of the degree of sub-cooling on the coefficient of performance (COP) at 40°C condensing and -20°C evaporating temperatures.

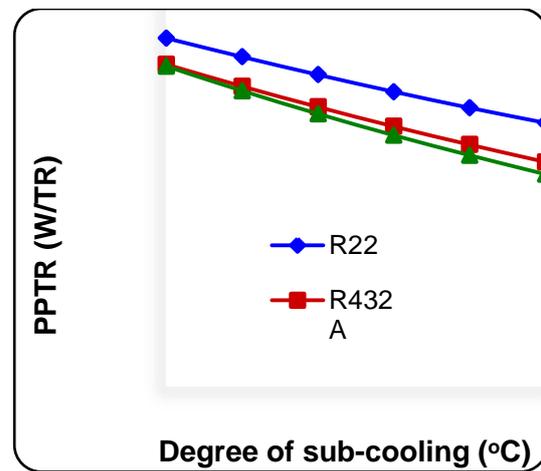


Fig. 8: Influence of the degree of sub-cooling on the power per ton of refrigeration (PPTR) at 40°C condensing and -20°C evaporating temperatures.

## CONCLUSION

In this study, the energy performance of eco-friendly R432A and R433A as alternatives to R22 in vapour compression refrigeration system was investigated theoretically employing a sub-cooling heat exchanger refrigeration system. The effects of sub-cooling on the various refrigeration cycle performance parameters were evaluated. Based on the investigation results, the following conclusions are drawn:

- (i) The saturated vapour pressure and temperature characteristic profiles for R432A and R433A are very close without any significant deviation between the curves. This indicates that they exhibited similar properties and could be used as substitute for R22
- (ii) R432A and R433A exhibited higher refrigerating effect than R22. Therefore, very low mass of refrigerant will be required for the same capacity, and smaller compressor size will also be required due to their high latent heat values.
- (iii) The reduction in the compressor energy input using the two alternative refrigerants is higher than that of R22, but the highest reduction in energy was obtained using R433A in the system.
- (iv) The effect degree of sub-cooling has on the refrigerating capacity is higher for the two alternative refrigerants than for R22. The highest relative capacity index (RCI) was obtained using R433A in the system.
- (v) The two alternative refrigerants exhibited higher coefficient of performance (COP) than R22. The average COPs obtained for R432A and R433A were 12.9 and 16.7% higher than that of R22.
- (vi) The two alternative refrigerants exhibited lower power per ton of refrigeration (PPTR) than that of R22, but R433A emerged as the most energy efficient refrigerant among all the investigated refrigerants with average PPTR of 13.3% lower than that of R22.

Generally, incorporation of sub-cooling heat exchanger in the system, greatly improved the system performance; it increases the COP, reduces the compressor energy input and the specific power consumption of the system. The two alternative refrigerants consistently exhibited better performance than R22 in sub-cooling heat exchanger refrigeration system. R433A performed better than both R22 and R432A in that the highest reduction in energy input, RCI, COP and lowest PPTR were obtained using R433A in the system.

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# VERMICOMPOSTING OF SUGARCANE BAGASSE AND RICE STRAW AND ITS EFFECT ON GROWTH OF (*PHASEOLUS VULGARIS* L.)

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**Key words:** Earthworms, Guyana, Microbial interaction, Rice straw, Sugarcane bagasse, Vermicomposting

## Abstract

*The paper discusses appropriate technology which is important towards recycling of organic waste and its usage in agricultural crops, leading to one of the objectives of low carbon strategy. The present study was carried out during the year 2006-2007 at University of Guyana, Georgetown. Experiments were aimed at production, quantitative comparison and rate of production of vermicomposts from sugar cane bagasse, rice straw, and a combination of sugar cane bagasse and rice straw. Results indicated that the combination of bagasse and rice straw showed the highest percentage of production. The vermicomposts samples were assessed for nutrient value and subjected to studies on plant growth parameters of *Phaseolus vulgaris* L. and were then compared with treatments using cow dung and chemical fertilizer. The results indicated that vermicompost is a competitive biofertilizer and showed better growth patterns in *Phaseolus vulgaris* L. than chemical fertilizers and can retain nutrients for longer period. *Phaseolus vulgaris* L. with vermicompost had better fruit quality in terms of physical dimension, biochemical constituents. There was significant improvement in the soil quality in the experimental plots treated with vermicompost produced from bagasse and rice straw {BV+RSV}. The combination treatment {BV+RSV} was the found to be better suggesting qualitative improvement in the physical and chemical properties of the soil which is substantiated by T-test and composite index in comparison to control and chemical fertilizers.*

## INTRODUCTION

Disposal of organic wastes from various sources like domestic, agriculture and industrial has been cause of concern for all of us with series of environmental hazards and economic problems. In the present day scenario, recycling of organic waste is necessitated towards production of useful organic manure for agricultural applications. Compost is becoming an important aspect in the quest to increase productivity of food in an environmentally friendly way. Various composting techniques like vermicomposting offer a solution to tonnes of organic wastes through recycling to promote our agricultural development in more efficient, economical and environmentally friendly manner.

Vermicomposting offers a solution to tonnes of organic agro-wastes that are burned by farmers, to recycle and reuse these refuse to promote our agricultural development in economical and environment friendly manner. Sugar and rice industries burn organic wastes contributing tremendously to environmental pollution. This process also releases large amounts of carbon dioxide in the atmosphere, the main contributor to global warming. Burning also destroys the soil organic matter content, kills the microbial population and affects the physical properties of the soil. Vermicompost has been widely used to grow vegetables and other crops successfully and has been found to be economical and productive [1, 2, 3].

The role of earthworms in organic solid waste management has been well established since first highlighted by Darwin (1881) and the technology has been improvised to process the waste to produce an efficient bio-product vermicompost [5, 6, 1]. Epigeic earthworms like *Perionyx excavatus*, *Eisenia fetida*, *Lumbricus rubellus* and *Eudrilus eugeniae* are used for vermicomposting but the local species like *Perionyx excavatus* has proved efficient composting earthworms in tropical or sub-tropical conditions [6, 7].

The method of vermicomposting involving a combination of local epigeic and anecic species of earthworms (*Perionyx excavatus* and *Lampito mauritii*) is called Vermitech [6, 1]. The compost prepared through the application of earthworms is called vermicompost and the technology of using local species of earthworms for culture or composting has been called Vermitech [6]. Vermicompost is usually a finely divided peat-like material with excellent structure, porosity, aeration, drainage and moisture holding capacity [8, 9]. The nutrient content of vermicompost greatly depends on the input material. It usually contains higher levels of most of the mineral elements, which are in available forms than the parent material [10]. Vermicompost improves the physical, chemical and biological properties of soil [7]. There is a good evidence that vermicompost promotes growth of plants [11] and it has been found to have a favourable influence on all yield parameters of crops like wheat, paddy and sugarcane [1]. Vermiculture is the culture of earthworms and vermicast is the fecal matter released by the earthworms [1]. Many agricultural industries use compost, cattle dung and other animal excreta to grow plants. In today's society, we are faced with the dilemma of getting rid of waste from our industries, household etc. In order for us to practice effective waste management we can utilize the technology of vermicomposting to effectively manage our waste. This process allows us to compost the degradable materials and at the same time utilize the products obtained after composting to enhance crop production and eliminate the use of chemical fertilizers. As indicated by Ansari and Ismail [12, 13], the application of chemical fertilizers over a period has resulted in poor soil health, reduction in produce, and increase in incidences of pest and disease and environmental pollution. In order to cope with these trenchant problems, the vermin-technology has become the most suitable remedial device [10, 14]. The study focused on utilization of organic waste that is subjected to appropriate simple technology and subsequently utilized for the cultivation of crops that is one step further in low carbon development strategy.

## **MATERIALS AND METHODS**

The present work was carried out during the year 2006-2007 at University of Guyana, Georgetown. Vermicomposting units were set up using vermitech pattern [1]. Plastic crates were used as the container and placed in a shaded elevated area to facilitate the effective water drainage. A basal layer of vermibed comprising broken bricks and a layer of sand to the thickness of 6 to 7.5 cm was set up to ensure proper drainage. This was then covered with a layer of loamy soil upto the height of 15 cm, after it was moistened. 50 locally collected earthworms, *Eisenia foetida*, were inoculated into the soil. Small lumps of fresh cattle dung was then scattered over the soil. The soil was then covered with 10 cm of agro waste. The entire unit was kept moist by sprinkling water biweekly and turned once in a week up to the 7<sup>th</sup> week. Three units were set up as follows: Unit 1 with 150 g sugarcane bagasse + 1 kg of cow dung {BV}, Unit 2 with 150 g rice straw + 1 kg of cow dung {RSV} and Unit 3 with 75 g rice straw + 75 g sugarcane bagasse + 1 kg cow dung {BV +RSV}.

The vermicompost was harvested after 45 days and subjected to physicochemical analysis using standard procedure for pH, EC<sub>w</sub>, organic carbon, total kjeldahl nitrogen, available phosphate, calcium, magnesium and potassium [15]. The analysis of the vermicompost

samples was carried out at Central Laboratory, Agriculture Department, GuySuCo (Guyana). The analysis of food components was done at Food and Drug Analysts Department, Guyana. Pot experiment with *Phaseolus vulagris* L. was carried out in triplicate with the different substrate based vermicomposts, cow dung, chemical fertilizers and chemical pesticide and control. Each set of plants (in triplicate) was treated at the first week, after three weeks and at flower initiation stage with the following treatments:

Treatment	Symbol	Amount added/ g
Soil	{CON}	No addition
Bagasse Vermicompost	{BV}	100
Rice Straw Vermicompost	{RV}	100
Bagasse + Rice Straw Vermicompost	{BV + RSV}	100
Cow Dung	{CD}	100
Chemical fertilizer (Urea)	{CHM}	13.6

Growth parameters (number of leaves, height of plant, circumference, number of nodes and leaf abscission) were taken every week. Upon maturity, the fruits were harvested, counted, weighed and preserved for analysis. At the end of the experiment plants were then uprooted to record physical parameters. Fruits were subjected to quantitative estimation of protein and fat. Soil samples were subjected to physicochemical analysis (pH, EC<sub>w</sub>, organic carbon, total kjeldahl nitrogen, available phosphate, potassium, calcium and magnesium [15])

## RESULTS AND DISCUSSION

The vermicompost (from different substrate) was harvested after a 50-day period for the first set. This period was reduced by 5 and 9 days, respectively for the other two harvests. There was consistent increase in the production of vermicomposts in each unit from each successive harvest (Table 1). This can be attributed to the increase in the population of the earthworms, each unit were started with 300 earthworms. However this increase was greater and even more consistent in the rice straw {RSV} and bagasse + rice straw {BV +RSV} units. Composting of bagasse {BV}, rice straw {RSV} and a combination of bagasse with rice straw {BV +RSV} were successful. However, the composting process of the combination was faster and the productivity was higher. For combination {BV +RSV}, the average productivity was 76%, followed by rice straw {RSV} with 74% and bagasse {BV} with 54%. Earthworms preferred cow dung along with plant litter and other plant debris in combination thereby converting it into the organically rich vermicompost at a faster rate [1, 16].

**Table 1** Productivity of vermicomposts from the different materials

Organic material	Amount (kg)	Cow dung (kg)	Average harvests (kg)	Average Productivity (%)
Bagasse {BV}	0.4	0.6	0.54 ± 0.14	54
Rice straw {RSV}	0.4	0.6	0.74 ± 0.02	74
Bagasse + Rice straw {BV +RSV}	0.2 + 0.2	0.6	0.76 ± 0.02	76

The pH remains slightly alkaline for all the samples but the most alkaline vermicompost was harvested from the combination of bagasse and rice straw {BV +RSV} (Table 2). Carbon was higher in {CON} as it was not decomposed appropriately. C:N ratio was observed to be 5.46, 6.91, 7.09 and 9.43 for {RSV}, {BV + RSV}, {BV} and {CON}, respectively. The C:N ratio is an indication of litter degradation in soils and it is an indicator of efficient and effective composting that plays an important role as a soil amendment for the cultivation of crops. Very high C:N ratio greatly reduced the rate of natural composting. In this case, earthworms have effectively increased the rate and thus having a greater turnover [17].

**Table 2** Comparison of cow dung and vermicomposts from different substrates (mean  $\pm$  SD)

Parameter	{Con}	{BV}	{RSV}	{BV + RSV}
pH	7.40 $\pm$ 0.01	7.28 $\pm$ 0.03	7.51 $\pm$ 0.01	7.59 $\pm$ 0.01
EC	1733.33 $\pm$ 24.09	533.33 $\pm$ 4.16	615.67 $\pm$ 7.09	563.67 $\pm$ 5.51
Organic carbon%	17.95 $\pm$ 0.73	6.52 $\pm$ 0.56	6.24 $\pm$ 0.46	6.64 $\pm$ 0.66
Nitrogen (%)	1.90 $\pm$ 0.03	0.92 $\pm$ 0.04	1.14 $\pm$ 0.06	0.96 $\pm$ 0.05
Phosphate (ppm)	190.78 $\pm$ 5.37	143.16 $\pm$ 1.94	178.97 $\pm$ 8.79	156.51 $\pm$ 19.29
Calcium (ppm)	5.65 $\pm$ 0.21	5.51 $\pm$ 0.04	6.35 $\pm$ 0.73	5.05 $\pm$ 0.06
Magnesium (ppm)	17.29 $\pm$ 2.11	16.43 $\pm$ 0.72	18.27 $\pm$ 2.02	14.66 $\pm$ 0.47
Potassium (ppm)	62.10 $\pm$ 0.46	147.83 $\pm$ 5.34	25.47 $\pm$ 2.27	174.00 $\pm$ 4.19
Zinc (ppm)	62.90 $\pm$ 0.21	69.96 $\pm$ 0.22	79.64 $\pm$ 0.36	68.90 $\pm$ 0.44
Iron (ppm)	36.32 $\pm$ 1.74	11.92 $\pm$ 0.93	12.17 $\pm$ 0.68	8.45 $\pm$ 0.50
Copper (ppm)	1.23 $\pm$ 0.05	0.52 $\pm$ 0.18	0.55 $\pm$ 0.07	0.42 $\pm$ 0.02
Manganese (ppm)	251.38 $\pm$ 4.89	59.69 $\pm$ 0.17	83.01 $\pm$ 0.45	54.19 $\pm$ 0.08

{Con} = Control; {BV} = Bagasse vermicompost; {RSV} = Rice straw vermicompost;  
 {BV + RSV} = Bagasse + rice straw vermicompost

The greatest increase in plant height was observed with treatment {BV+RSV}, followed by {RSV} and {CD} (Table 3). Vermicomposts apart from macro and micro nutrients also have essential growth promoter hormones like auxins, cytokinins, gibberellins, ethylene, and enzymes, vitamins that are induced by microbial activity and excreted by earthworms along with useful microorganisms like bacteria [18, 19] in the form of earthworm cast. Chemical fertilizers on the other hand constitute mainly macronutrients and soluble salts with no hormones. Also these nutrients have a high solubility rate and are lost through the process of leaching. This results in fast growth in the initial stages of planting and reduces subsequently, due to lack of nutrients [17]. Treatment {CHM} had a significant increase in the number of leaves, followed by {RSV}, {BV}, {BV + RSV} and {CD} (Table 3). The highest number of leaves in {CHM} is due to availability of nitrogen and phosphate in the chemical fertilizer. The leaves had a higher surface area and were much greener. {CHM} treatment plant appeared healthier at the beginning but fade out to yellowing which is evident due to lack of micronutrients [17]. The treatment {BV + RSV} had the thickest circumference because of its ability to retain nutrition for longer periods [10]. The number of leaves, the nodal count was also highest in the {CHM} treated plants, followed {BV + RSV}, {BV}, {RSV}, and {CD} (Table 3).

**Table 3** Plant morphometry (Mean  $\pm$  SD)

Treatment	Plant height (cm)	Number of leaves plant <sup>-1</sup>	Plant circumference (cm)	Number of nodes plant <sup>-1</sup>	Leaf abscission plant <sup>-1</sup>
{CON}	175.00 $\pm$ 15.72	67.00 $\pm$ 15.39	2.43 $\pm$ 0.21	21.67 $\pm$ 5.13	8.33 $\pm$ 0.58
{BV}	215.33 $\pm$ 14.64	92.00 $\pm$ 9.64	3.37 $\pm$ 0.31	30.00 $\pm$ 3.61	7.33 $\pm$ 1.53
{RSV}	247.67 $\pm$ 42.77	93.33 $\pm$ 1.53	3.73 $\pm$ 0.32	27.00 $\pm$ 6.08	7.33 $\pm$ 1.53
{BV + RSV}	250.67 $\pm$ 44.43	90.33 $\pm$ 8.62	3.99 $\pm$ 0.32	34.33 $\pm$ 153	6.67 $\pm$ 0.58
{CD}	227.67 $\pm$ 31.13	79.67 $\pm$ 8.62	2.30 $\pm$ 0.10	27.33 $\pm$ 3.79	7.67 $\pm$ 0.58
{CHM}	224.00 $\pm$ 73.78	111.00 $\pm$ 8.66	2.97 $\pm$ 0.12	36.33 $\pm$ 2.89	17.0 $\pm$ 1.41

{Con} = Control; {BV} = Bagasse vermicompost; {RSV} = Rice straw vermicompost; {BV + RSV} = Bagasse + rice straw vermicompost; {CD} = Cow dung; {CHM} = Chemical fertilizer

Leaf abscission was minimum in {BV+RSV} (Table 3). Vermicompost from combination of substrates releases nutrients that promote effective plant growth along with enhanced microbial activity that made the nutrients available [11]. It is evident that chemical fertilizer disrupts natural biological activity (inhibition of *Rhizobium* and nitrifying bacteria in the soil) [11].

The highest marketable yield of fruit was observed with treatment {BV}, followed by {RSV} and {BV + RSV} (Table 4). Organic fertilizers (like vermicompost) have been known to promote growth of nitrogen fixing and phosphate solubilising bacteria. These are critical in overall plant growth thus, influencing fruit development [6]. Protein content of the fruits was consistent for treatments {CON}, {RSV}, {BV + RSV} and {CD} while lower levels were observed in {BV}, followed by {CHM} (Table 4). *Phaseolus vulgaris* L. is known to have high amount of protein content. The amount of fat present in the fruit was variable but consistent with all the treatments.

**Table 4** Biochemical analysis of fruit and marketable yield (mean  $\pm$  SD)

Treatment	Protein (%)	Fat (%)	Marketable yield (g plant <sup>-1</sup> )
{CON}	31.71 $\pm$ 0.47	2.14 $\pm$ 0.00	9.32 $\pm$ 0.94
{BV}	25.40 $\pm$ 2.69	2.13 $\pm$ 0.16	12.57 $\pm$ 1.61
{RSV}	31.65 $\pm$ 11.67	2.07 $\pm$ 0.06	11.30 $\pm$ 1.52
{BV +	31.55 $\pm$ 0.04	2.61 $\pm$ 0.42	9.90 $\pm$ 3.32
{CD}	31.51 $\pm$ 0.75	2.45 $\pm$ 0.11	6.15 $\pm$ 5.66
{CHM}	21.52 $\pm$ 1.00	2.25 $\pm$ 0.06	7.05 $\pm$ 1.94

{Con} = Control; {BV} = Bagasse vermicompost; {RSV} = Rice straw vermicompost; {BV + RSV} = Bagasse + rice straw vermicompost; {CD} = Cow dung; {CHM} = Chemical fertilizer

Soil pH significantly increased for all the vermicomposts treatments while {CD} had insignificant increase (Table 5). {CHM} resulted in a decrease in the pH thereby making the soil more acidic. Soil pH is one of the most important soil properties that affect the availability of nutrients. Macronutrients tend to be less available in soils with low pH and micronutrients tend to be less available in soils with high pH [17]. Treatments {BV + RSV}, {RSV} and {BV} indicated significant increase in organic carbon (Table 6). Vermicompost is rich in organic carbon content that facilitates the slow release of nutrients into the soil. Significant increases in nitrogen were observed in [BV] may be attributed to enhanced activity of nitrogen fixing bacteria [11] (Table 5). Significant increase was observed for treatments {BV + RSV} and {RSV} with regards to phosphates (Table 5). It may be because of the presence of phosphate solubilizing bacteria that increases the phosphate content of the soil. There were significant increases in magnesium concentration for {BV + RSV}, {RSV} and {BV} (Table 5). All the samples except {CHM} indicated an increase in calcium concentration though not significant. {CHM} had reduced calcium because of it is highly soluble in  $Ca^{2+}$  form that has been used by the plant and the rest leached out of the soil zone [17, 18] (Table 5). Thus vermicompost produced from combination of sugarcane bagasse and rice straw {BV + RSV} showed better results in terms of productivity of vermicompost and its subsequent application on *Phaseolus vulgaris* L in plant growth parameters and productivity levels that is substantiated by available nutrients in vermicompost {BV + RSV} thereby played critical role in improving soil quality [19]. The treatment {BV + RSV} was observed to be highly significant with improvement of soil physical and chemical properties. This is established by composite index (Table 6).

**Table 5** Soil chemical analysis of different treatments

Treatment	% increas e in pH	% increas e in OC	% increas e in N	% increas e in P	% increas e in K	% increase in Mg	% increas e in Ca
{CON}	0.00	3.68	1.57	-135	11.18	2.97	0.72
{BV}	0.50	6.12	2.62	4.48	8.88	5.51	0.79
{RSV}	0.58	11.97	1.48	152.48	12.13	6.35	1.35
{BV + RSV}	0.69	15.83	1.23	404.2	14.28	7.53	1.57
{CD}	0.24	6.60	0.97	-94.87	22.48	3.05	6.77
{CHM}	-0.30	6.09	1.04	-162.51	105.63	2.11	-0.02

**Table 6** Composite index based on soil chemical analysis

Treatments	pH	OC	N	P	Mg	Ca	Composite index	Rank
{CON}	5	6	2	5	5	5	28	5
{BV}	3	4	1	3	3	4	18	3
{RSV}	2	2	3	2	2	3	14	2
{BV + RSV}	1	1	4	1	1	2	10	1
{CD}	4	3	6	4	4	1	22	4
{CHM}	6	5	5	6	6	6	34	6

(-) Indicate decrease

## CONCLUSION

The results indicated that the physicochemical properties of the rice straw and the combinations were conducive and enhanced growth and yield of *Phaseolus vulgaris* L. The final soil analysis also indicated significant signs of improvement in nutrient content. It can be concluded that organic waste can be successfully recycled by using appropriate technology like Vermitech that could result in production of organic fertilizers to be used for organic farming. Its would lead to important contribution towards low carbon development and green technology that could influence the policies in developing countries where zero waste technologies could become part of the development strategies in long term.

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# EFFECT OF SODIUM BICARBONATE TREATMENT ON THE NUTRITIVE VALUE OF SOYABEAN STRAW

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**Key words:** Soyabean Straw, Neutral Detergent Fibre, Digestibility, Animal Feeds

## Abstract

*The objective of this study was to conduct a nutritional evaluation of soyabean straw under various treatments using Sodium Bicarbonate. Soyabean straw was treated with sodium bicarbonate at different inclusion rates of 0 %, 1 %, 2 %, 3 %, 4 % and 5%). The straw, for each concentration, was incubated at different lengths of time (weeks 1, 2, 3 and 4). The straw was then analysed for crude protein, in vitro dry matter digestibility, in vitro organic matter digestibility, neutral detergent fibre and acid detergent fibre. Neutral detergent fibre, in vitro organic matter digestibility (23 % for the 0 % sodium bicarbonate treated straw incubated for 3 weeks to 57.1 % for the 5 % sodium bicarbonate treated straw), in vitro dry matter digestibility (20 % for the 0 % sodium bicarbonate treated straw incubated for 1 week to 51.5% for the 5 % treated straw incubated for 4 weeks) were significantly ( $P < 0.01$ ) affected by an interaction between sodium bicarbonate concentration and length of time of incubation. The lowest neutral detergent fibre value obtained was for 5 % concentration and incubated for 28 days. Neutral detergent fibre content decreased with an increase in concentration and an increase in time of incubation. In vitro organic matter digestibility and in vitro dry matter digestibility followed the same trend. These improvements in feed value can allow soyabean straw to be used as a feed instead of being thrown away or burnt. Communal farmers have easy access to sodium bicarbonate which they use as “soda” when cooking tough vegetables or meat. Animal response trials especially on palatability needs to be conducted.*

## Background

As crops mature the digestible components of protein and soluble carbohydrates are translocated from the leaves and stems to the seeds, leaving the more fibrous structural cell-wall material to increase and concentrate in the stems and leaves. Other than the low content of desirable chemical constituents, utilization of the residues is further limited by low voluntary intake and digestibility. Low digestibility is associated with the high lignin and silica content [2].

This implies that there is a need to treat straws in order to avail the small amount of nutrients in them to animals. This can be achieved by treatments that increase surface area, make cellulose less crystalline, more swollen or less affected by components such as lignin and silica. Alkali treatments are known to allow greater diffusion of cellulolytic enzymes [7].

Sodium bicarbonate seems promising due to the following reasons: Housewives usually use it where only a knife-edge quantum is added to soften vegetables and therefore little quantities of the sodium bicarbonate may be required to treat the straw. It has an additional property that it turns to soften the product it works on. It is cost effective and is therefore ideal for

smallholder farmers who cannot afford expensive treatments. It is non toxic and therefore should not be washed away after treatment.

The objective of this study was to determine the effect of sodium bicarbonate at varying inclusion rates on nutritive value of soyabean straw.

## **MATERIALS AND METHODS**

Soyabean straw was physically broken to short pieces of about 5 cm in length. Eight samples were subjected to each treatment. The actual treatment involved dissolving the weighed sodium bicarbonate in 250 ml of water followed by sprinkling of the solution onto the sample and, at the same time, mixing the contents of the sample. Mixing was done for three minutes to ensure even distribution of the sodium bicarbonate water mixture. The samples were put in dry plastic bags measuring 150 X 120 cm and 100  $\mu$ m in thickness. The contents were tightly compressed, by hand, to keep air out before sealing. The bags were then stored in a room and the day of incubation was recorded as day 0. The samples were checked daily for any colour changes and development of moulds. On day 7 after incubation, 2 samples from each sodium bicarbonate inclusion level were randomly sampled and stored in the freezer. This process was repeated on days 14, 21 and 28 after incubation. After incubation, the samples were air dried for 8 days (when they achieved a constant weight). Grinding of the samples using a Wiley Mill with a 3 mm sieve followed. To determine DM, the samples were dried at 105°C for 24 hours. The Kjeldahl method was used to determine the protein content of the soyabean straw [1]. Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined according to Goering and Van Soest [4]. Dry matter digestibility and organic matter digestibility of the straw were determined using the Tilley and Terry method [9].

The design of the experiment was a 6 X 4 factorial arrangement of treatments in a completely randomised design. There were 6 inclusion levels of sodium bicarbonate and 4 periods of incubation. The samples were duplicated at both incubation and analysis level.

Results of the NDF, ADF, crude protein and in vitro dry matter digestibility (IVDMD) and in vitro dry matter digestibility (IVOMD) of the treated and the untreated straw were analysed using a one way analysis of variance in a completely randomised design using the General Linear Models (GLM) procedure of the SAS institute, inc. [8]. Multiple comparisons of means were done using the Tukey's studentized range test of SAS [8]

## **RESULTS**

The dry matter content and crude protein content of the sodium bicarbonate treated soyabean straw and the control were not significantly different ( $P > 0.05$ ). Sodium bicarbonate significantly ( $P < 0.01$ ) reduced the NDF content of the straw. There were highly significant ( $P < 0.01$ ) differences in NDF content among treatments. The concentration of sodium bicarbonate used to treat the straw significantly reduced the level of NDF in the straw. The reduction in NDF content was inversely related to the concentration of the sodium bicarbonate. The length of time of incubation also affected the content of NDF in the straw ( $P < 0.01$ ). However, an interaction existed ( $P < 0.01$ ) between incubation time and concentration of sodium bicarbonate on NDF content of the treated straw. Figure 1 shows the effect of the interaction between length of time of incubation and concentration of sodium bicarbonate on NDF content of the treated straw.

There was no significant difference between the ADF content of the sodium bicarbonate treated straw and the untreated straw ( $P > 0.05$ ). Generally, there was an increase in IVDMD

with increase in time for the 1%, 2 %, 3%, 4% and 5% sodium bicarbonate treated straw. There was no increase ( $P>0.05$ ) in IVDMD for the 0 % sodium bicarbonate treated straw. For the sodium bicarbonate treated straw, at any time of incubation, IVDMD was higher for the stronger solutions than the weaker solutions. The highest values for IVOMD, for each particular time period of incubation, were for the 4 % sodium bicarbonate treated straw.

The 0 % sodium bicarbonate treated straw had moulds, was moist and rotting from day 6 and 8 days after incubation. It had an unpleasant smell and the straw remained hard to break. The straw was also the darkest of all the other treatments. A comparison between the 0 % sodium bicarbonate treated and the 4 % and 5 %. The 0 % was the darkest of the three. The 4% sodium bicarbonate treated straw was deep brownish in colour. However, the 5% sodium bicarbonate treated straw was even darker than the 4% sodium bicarbonate treated straw. Both straws were dry and no moulds developed on them. The straw could easily be bent and had no smell.

## **DISCUSSION**

DM, CP and ADF were not affected by the treatment of straw using sodium bicarbonate. Treatment of straw using sodium bicarbonate and length of time of incubation, however, had an effect on NDF, IVDMD and IVOMD.

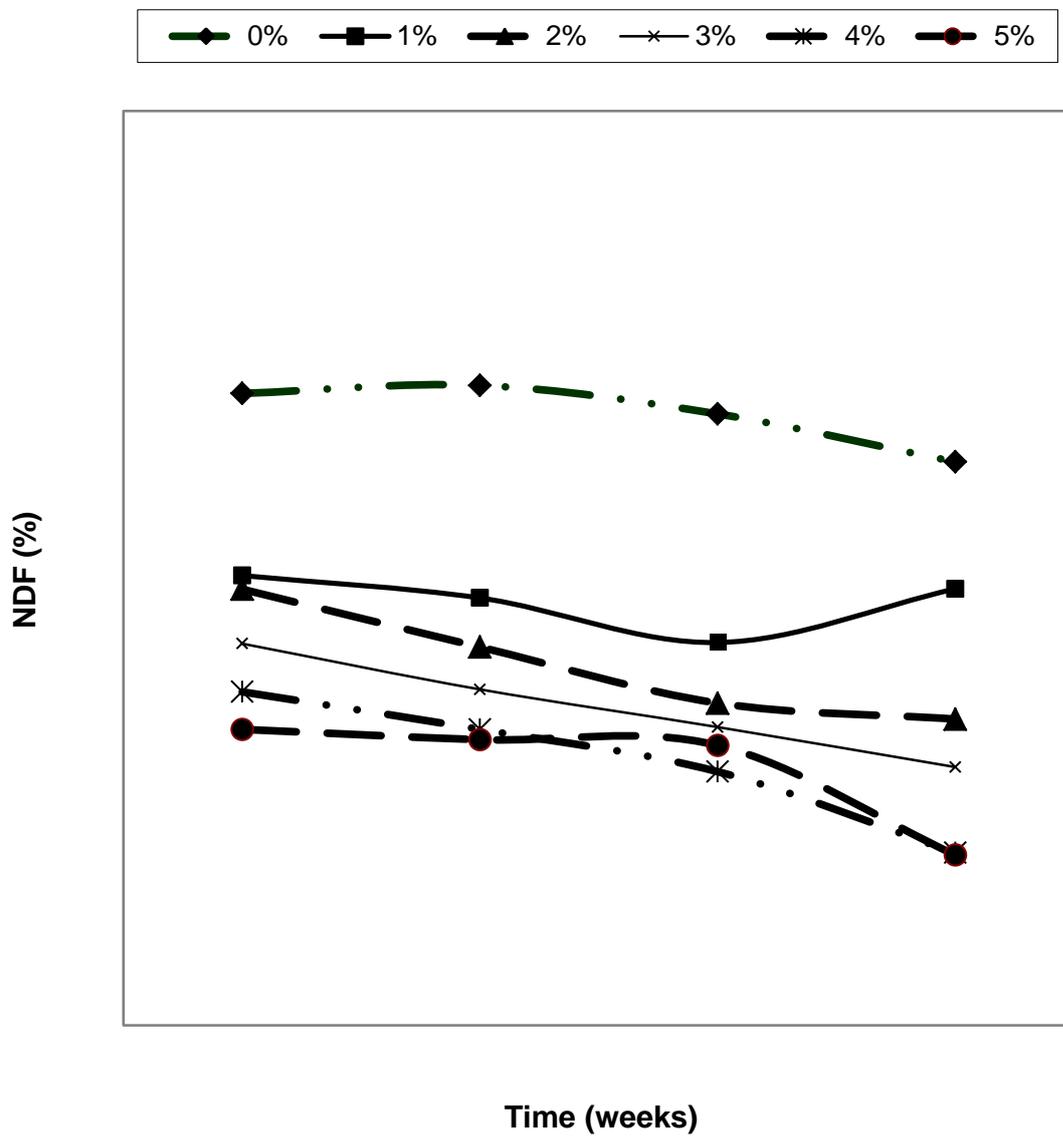
Treatment with sodium bicarbonate resulted in increased IVDMD and IVOMD. This is because of the negative correlation that exists between NDF components of the cell and digestibility parameters of the straw. The reduction in the fibres is most likely to be based on displacement of intra fibril hydrogen linkages by much larger sodium ions and breakage of bonds between lignin and cellulose [5]. This implies that treatment of straw using sodium bicarbonate resulted in an increased surface area of the material and partial hydrolysis of hemicellulose. The interaction between the concentration of sodium bicarbonate used for the treatment of the straw and the length of time of incubation of soyabean straw had an effect on the breakage of the covalent bonds between hemicellulose and lignin and the hydrogen bonds between cellulose and hemicellulose before partial solubilisation of the hemicellulose. Since sodium bicarbonate is a weak alkali, it requires a long reaction time. However, with higher concentrations, a shorter time would compare fairly well with lower concentration at a longer time of incubation. This might be because straw treated with a stronger solution of sodium bicarbonate had more sodium ions to displace hydrogen ions than straw treated with a weaker solution hence the increased digestibility. This was also observed by Chaudhry [3] who used calcium hydroxide on wheat straw and observed an increase in digestibility with time.

The highly ordered 3 dimensional structure of lignin confers the mechanical strength of cellulose. The disruption of this structure results in a substantial improvement in accessibility of carbohydrates hence an increase in digestibility. However, it is not the intrinsic characteristics of cellulose alone that limit its accessibility. Existence of external components such as lignin-hemicellulose closely associated with cells can also limit its accessibility. The increase in digestibility of the straw after treatment could be attributed to increased bio-utilisation of the cell components after the native cellulose structure and the associated steric lignin barriers had been disrupted [6].

The key to maximizing the nutritional value of straw is in disrupting the cell walls [5]. The treatment most likely also made cellulose less crystalline and more swollen. Sodium bicarbonate, like other alkalis, is assumed to have saponified the ester linkages between

acetic acid and phenolic acids of polysaccharides and enhanced swelling of the cell walls, thus allowing greater diffusion of cellulolytic enzymes leading to increased digestibility.

**Figure 1:** The effect of the interaction between length of time of incubation and concentration of sodium bicarbonate on NDF content of the straw



## CONCLUSION

Incubation of straw with sodium bicarbonate reduced the NDF fractions of the straw. This is attributed to partial solubilisation of hemicellulose. Length of time of incubation should also be considered since, generally, an increase in time of incubation also resulted in a decrease in NDF. An interaction existed between strength of the sodium bicarbonate used to treat the straw and length of time of incubation. This ultimately resulted in an increased digestibility and, thus, better utilization of the straw. Sodium bicarbonate exhibited a preservative property. The straw that was treated with sodium bicarbonate was free of moulds. This implies that after harvesting their soyabean grain, farmers can treat their straw using sodium bicarbonate and keep it in a safe place before feeding their animals. This is an advantage since the nutritive value of the straw improves and at the same time no moulds develop on it compared to when it is left in the field where it can develop moulds if it gets wet. These improvements in feed value can allow soyabean straw to be used as a feed instead of being thrown away or burnt. Cost benefits analysis need to be done to determine the viability of utilising this technology. Palatability studies are also recommended to determine voluntary feed intake in animals.

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