Environmental Emissions Assessment of Coal and Refuse Derived Fuel Incineration Processes by Simulation

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ABSTRACT
Coal has been the predominant source of energy for electricity production in South Africa. Coal combustion process for energy recovery is regarded as heavy pollutant emissions process. Waste derived alternative fuels are widely used for substituting the thermal energy requirement from fossil fuels and reducing the pollutant emission. This paper is a comparison between the burning of coal and RDF as far as fuel qualities and emissions. The ignition of fuel derived from MSW is a promising low-cost retrofitting procedure for coal power plants, having the additional advantage of lessening the volume of waste transfer in landfills. Moreover, co-burning of RDF and coal, as opposed to changing to RDF ignition alone straight from the onset of devoted power plants, permits plant administrators to be adaptable to varieties in the RDF supply.

CCS Concepts
• **Computing methodologies- Modelling and Simulation-Simulation evaluation**

Keywords
Municipal solid waste; refuse derived fuel; emissions; greenhouse gases; global warming; waste-to-energy.

1. INTRODUCTION
The conversion of Municipal Solid Waste (MSW) in Waste-to-Energy facilities has been perceived globally as a way to save fossil fuels and enhance ecological quality by decreasing the measure of waste to be landfilled [1]. 130 million tons of MSW globally are combusted yearly in WTE facilities that create power, also steam for region warming. In the US alone, around 30 million tons of MSW are combusted in WTE plants to create around 2.8 GW of power and some steam for region warming [2], which is roughly 0.3 % of aggregate US power generation. The WTE emissions of concern are trace organic compounds, especially polychlorinated dioxins and furans, unstable trace metals, for example, mercury, lead and cadmium, total particulate matter, and acidic gases, for example, hydrogen chloride, hydrogen fluoride, sulfur dioxide and nitrogen oxides [2].

IEEA'18, March 28–31, 2018, Beijing, China.

ACM ISBN 978-1-4503-6362-4/18/03…$15.00
DOI: https://doi.org/10.1145/3208854.3208870

An expansion in ozone harming substance discharges because of burning of non-renewable energy sources for the production if fuels and electricity has brought about outflows of around 25 billion tons of carbon dioxide (CO2) per annum [3]. Greenhouse gas emissions from anthropogenic sources have expanded from 27 gigatons CO2 proportionality for every year (GtCO2/yr.) to 49 GtCO2/yr. amid the time of 1970 to 2010 with the expansion being most astounding in mankind's history amid the time of 2000-2010 [4]. Future projections show that Africa will be a standout amongst the most influenced mainland's by environmental change due to its helplessness to other financial and social difficulties, for example, destitution and illnesses [5]. According to the United States Environmental Protection Agency [6]; 46 billion tons were evaluated to have been sourced from human exercises in 2010, speaking to a 35% expansion when contrasted with 1990. CO_2 is a noteworthy anthropogenic ozone-harming substance and has contributed an aggregate of 75% to worldwide aggregate emissions in 2010 [7]. The ignition of petroleum products for power generation is the biggest contributor to worldwide CO_2 emissions. Figure 1 shows a comparison of natural greenhouse gases to man-made depicting CO_2 as the highest contributor in manmade emissions.

South Africa is the 13th biggest emitting nation considering 2008 petroleum product CO_2 outflows and the biggest radiating nation on the landmass of Africa. With a local economy controlled by coal, South Africa has encountered a seven-overlap increment in non-renewable energy source CO_2 emanations since 1950, with 80-90% of outflows from coal. For 2008, 85% of South Africa's petroleum product CO_2 outflows of 119 million metric tons of carbon was from coal, another 11.6% were from oil utilization, and the rest of from cement making and flammable gas and coke-broiler gas utilization [8].

1.1 Greenhouse Gas Effect on Climate Change
Greenhouse gasses retain and transmit long-wave (infrared) radiation, in this way catching and holding heat inside the climate. Greenhouse gasses aggregately make up under 1% of the Earth's environment. The greenhouse gasses which have the biggest warming impact inside the air are water vapor (mists) and carbon dioxide. Other greenhouse gasses incorporate methane and nitrogen oxides – these have less effect on the general warming

impact. Water vapor is the richest ozone-depleting substance in the air, yet isn't delivered as a result of human action [9].

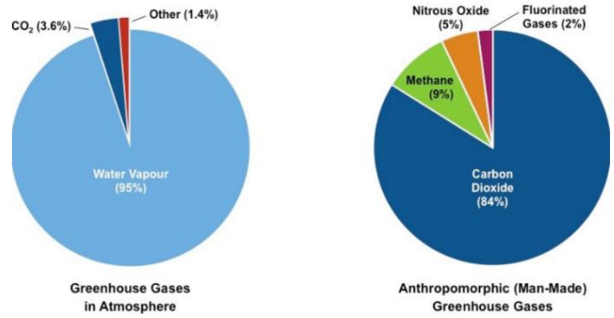

Figure 1. Proportion of greenhouse gases (natural vs anthropomorphic) [9].

There are two elements which decide the amount of the effect an ozone harming substance will have in warming the climate, these elements are also graphically represented in Figure 2:

1. Capacity to ingest long-wave radiation

Gasses that have a more prominent ability to ingest long-wave radiation will have a more prominent warming effect (per atom)

2. Fixation inside the climate

The more noteworthy the centralization of a gas, the more noteworthy its warming effect will be inside the environment.

The greenhouse impact functions to trap warmth in the atmosphere and thus counteract fast temperature fluctuations.

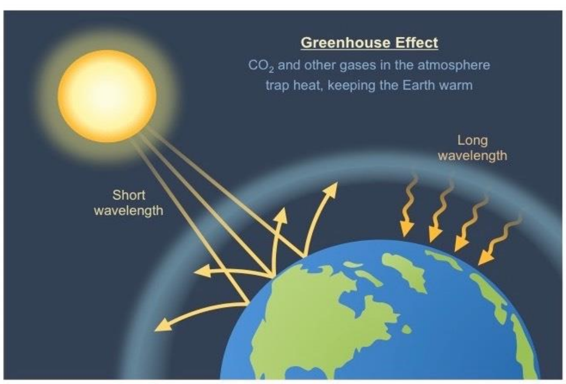

Figure 2. The greenhouse effect [9].

While greenhouse gasses happen normally, man is expanding ozone-depleting substance emissions by means of various exercises, including deforestation and expanded cultivating/agribusiness. The ozone-harming substance that is expanding most quickly in the air is carbon dioxide and the primary driver is burning. The expanded dependence on petroleum products following the mechanical upheaval has brought about ~38% expansion in CO2 levels [9].

Greenhouse gasses assume an urgent part in deciding worldwide temperatures and climate patterns because of their ability to hold warmth. As these gasses trap warmth, increments in ozone-depleting substance concentrations should connect with an expansion in worldwide temperature. Long-term climate patterns (atmosphere) may likewise be impacted by ozone-harming substance concentrations. Researchers foresee that increments in ozone-depleting substance concentrations will prompt an increased greenhouse impact, bringing about:

More incessant outrageous climate conditions (e.g. warm waves, violent winds, more powerful typhoons, and so forth.).

Some areas to become more drought affected, while different territories turn out to be more inclined to times of substantial rainfall.

Changes to circulating ocean currents – which may cause longer El Nino (warming) and La Nina (cooling) conditions [9].
This has been experienced severely in South Africa during the past year with the rainfall received during October 2017 was near normal to above normal over large parts of the country. Only a few isolated areas across the country received below-normal rainfall. During the 3-month period from August to October 2017, large parts of the western half of the country received below-normal rainfall. The eastern half of the country received mostly near normal to above-normal rainfall; however, isolated areas received below-normal rainfall. During October 2017, isolated areas across the country experienced somewhat dry conditions. During the three-month period from August to October 2017, moderately dry to severely dry conditions were mostly experienced in isolated areas of the Northern and Western Cape. Somewhat dry conditions occurred in isolated areas across the rest of South Africa [10].

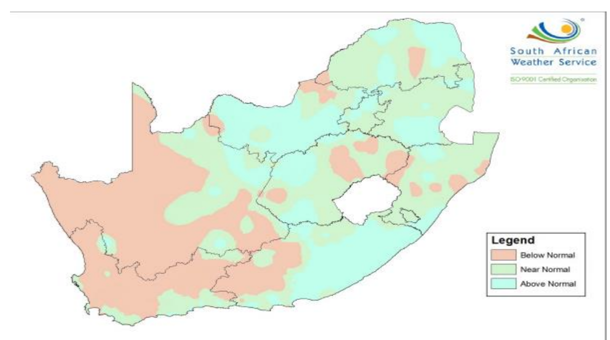

Figure 3. Assessment of rainfall for August 2017 to October 2017 [10].

The 12-month (November 2016 to October 2017) as well as 24-month (November 2015 to October 2017) SPI maps give an indication of areas where prolonged droughts exist, in other words, where below-normal rainfall occurred over a period of one year or longer. On the 12- month SPI map presented on Figure 3, severely dry to extremely dry conditions are most noticeable in the Western Cape as well as adjacent areas of the Northern Cape. On the 24-month SPI map as shown in Fig. 4, moderately dry to severely dry conditions are most noticeable in the Northern, Western, and Eastern Cape, but also in isolated areas of the Free State and Mpumalanga [10].

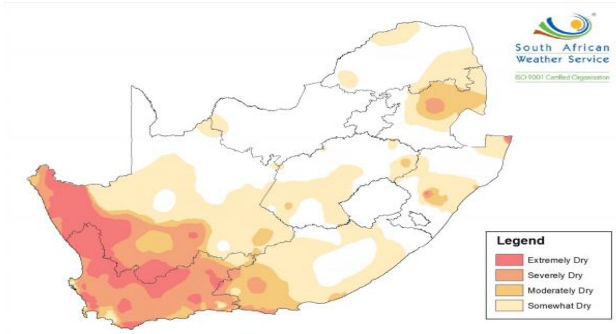

Figure 4. Standardize precipitation index for November 2016 to October 2017 [10].

The connection between worldwide temperatures and carbon dioxide concentrations as shown in Fig. 5 was built up by breaking down information over a long-time period. Ice cores taken from the Vostok station in Antarctica give proof of the natural conditions at the season of solidifying. Information gathered from the Vostok ice core exhibits that there is a strong positive correlation between carbon dioxide concentrations and temperature (↑ CO_2 levels $\propto$ ↑ temperature).

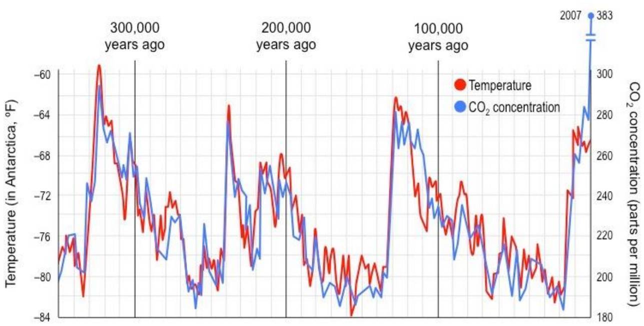

Figure 5. Vostok ice core data – temperature versus carbon dioxide concentration [9].

1.2 Electricity Generation and CO2 Emissions

CO_2 emissions from power generation and heat represented the biggest ozone harming substance outflows in 2013 as this area is high carbon intensive. Universally, total essential energy supply in 2013 represented 44% of CO_2 outflows, for the most part because of the high carbon content per unit of energy discharged. Therefore, CO_2 discharges emerging from the burning of coal for power generation expanded by 4.9% to 13.7 $GtCO_2$ in 2013 [3]. Coal at present takes care of the developing demand for power generation in South Africa where there are extensive coal holds and restricted assets of other energy sources. Coal stays to be South Africa's most abundant energy source and a large portion of the coal that ESKOM utilizes is of low quality, low calorific incentive at 15-16 MJ/kg and high ash content of around 42% [5]. ESKOM depends on this coal to generate 90 % of South Africa's power supply [6]. Be that as it may, South Africa's coal quality results in various burdens with respect to waste and discharges originating from sulphur, nitrogen oxides, natural mixes, substantial metals, radioactive components and greenhouse gases [11], [12].

Coal supplies 33% of all energy utilized worldwide and makes up 40% of power generation, and in addition assuming a critical part in ventures, for example, iron and steel. Notwithstanding authentic worries about air contamination and ozone-depleting substance outflows, coal use will keep on being significant later. Hence more noteworthy endeavors are required by government and industry to grasp not so much dirtying but rather more proficient advancements to guarantee that coal turns into a much cleaner wellspring of energy in the decades to come [13].

A lot of power generation in South Africa will keep on being sourced from coal-fired power stations within the foreseeable future [14]. South Africa is a middle-income nation, however, has one of the most elevated amounts of CO_2 outflows per capita on the planet fundamentally because of the ignition of coal with the end goal of power generation [15]. One of the difficulties that were experienced by South Africa's fundamental power supplier in 2010 was an expansion in outright CO_2 discharges from 221.7 megatons in 2009 to 224.7 megatons in 2010 which was highlighted by the producer as a reason for great concern [16]. Clearly, South Africa needs to secure a superior comprehension of ozone-harming substance emissions from power generation because of the ignition of coal and further concentration to alleviation endeavors in this segment. The fundamental opportunity for South Africa to diminish its ozone-harming substance emissions from power generation is to execute energy productivity, demand administration and move towards a less greenhouse gas discharges concentrated energy blend. Treating residual waste with different Waste-to-Energy (WtE) advancements is a feasible choice for disposal of Municipal Solid Waste and energy generation [17]. The present pattern of monetary development and way of life of individuals increments municipal waste (MSW) generation and consequences for current landfill situation, inaccessibility of land, open burning landfill causes contamination what's more, has significantly consequences for general wellbeing. There is direness for a compelling solid waste administration because of these reasons. WTE incineration helps in diminishing greenhouse gasses by abstaining from dumping to landfill foils the methane emissions from landfill and producing renewable energy in the form of electrical power which additionally helps in diminishing reliance on petroleum products. As of now the biggest wellspring of GHGs in the form of methane (CH_4) discharges on the planet are landfills with an appraisal of almost 21% of the aggregate methane generation. As a GHG Methane is 21 times more grounded than carbon dioxide generation [18].

This paper is a comparison between the burning of coal and RDF as far as fuel qualities and emissions using an ASPEN simulation model to model the combustion of both MSW derived Refuse Derived Fuel (RDF) pellets and coal. The environmental assessment will be based on the amount of the major GHG's produced from the combustion of each fuel, namely the CH4 and CO_2 produced.

2. METHODOLGY

2.1 Model Description

In real life applications, the combustion of fuel would happen in one combustion vessel. However, since ASPEN Plus does not have a single reactor block to model a combustion process, a number of blocks in combination were used to model the combustion of coal and RDF. This combustion was adopted from the ASPEN Plus guide dealing with solids processing specifically the combustion of coal [19].

The fuel is first fed into the RStoich block of ASPEN plus to simulate the drying of the fuel being combusted, representing the first step of the combustion process (DRY-REAC). The moisture is removed from the feedstock by means of evaporation and the resultant moisture is separated from the dried feedstock by means of a Flash 2 model separator (DRY-FLSH) using the principle of split fractionation then the moisture leaves the process through the MOIST stream.

The RGibbs model is used to simulate the combustion of the dry feedstock in the BURN block. RGibbs models chemical equilibrium by minimizing Gibbs free energy. However, the Gibbs free energy of coal cannot be calculated because it is a nonconventional component in ASPEN Plus. Before feeding the dried feedstock to the RGibbs block, it is required to decompose the feedstock into its constituent elements which ASPEN will recognize as conventional components. This is done in the RYield block, DECOMP. The heat of reaction associated with the decomposition of the feedstock needs to be taken into consideration in the combustion process. Use of a heat stream to carry this heat of reaction from the RYield block to the RGibbs block is employed

Finally, the combustion gases are separated from the ash using the Aspen Plus model SSplit for this separation. The complete process flow combining all these blocks to complete the process is presented in Figure 6.

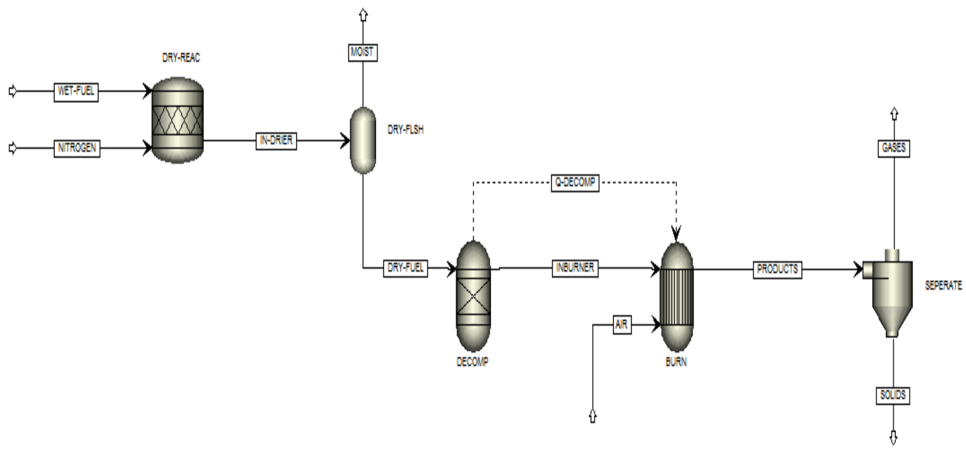

Figure 6. ASPEN Plus process flow diagram for combustion model simulation

2.2 Model Assumptions

A numerous amount of assumptions was taken into consideration during the development of the simulation model of the combustion of coal and RDF pellet feedstocks.

The process was assumed to occur at steady state in isothermal, isobaric and kinetic free conditions.

Reactions in the combustion vessel occur in an equilibrium state.

The decomposition of the feedstock tool place instantaneously and the constituents consisted of NO_2, NO, S, SO_2, SO_3, H_2, Cl_2, HCl, C, CO, CO_2, and Ash.

Gases including H_2, CO, CO_2, O_2, N_2, and CH_4 are all regarded as ideal.

The char residue is only made up of ash and carbon in solid phase.

The carbon is assumed to have completely reacted.

2.3 Initial Operating Parameters

2.3.1 Combustion vessel

Regarding the initial operating parameters for the combustion process, the following were considered:

Table 1. Combustion operating parameters

Parameter	Value	Unit
Feed Flow Rate	1000	Kg/h
Feed Pressure	1	bar
Feed Temperature	25	℃
Nitrogen Rate	5000	Kg/h
Nitrogen Temperature	132	℃
Air Pressure	1	bar
Air Temperature	25	℃
Combustor Pressure	1	bar

2.3.2 Feed characteristics

The clear majority of South Africa's coal is of a bituminous thermal grade [20]. The characteristic of South African coal adapted for the model simulation of combustion of coal were obtained from analysis conducted by Nel [21], at the North West University in South Africa. The feed characteristics in terms of proximate and ultimate analysis are presented in Figure 7.

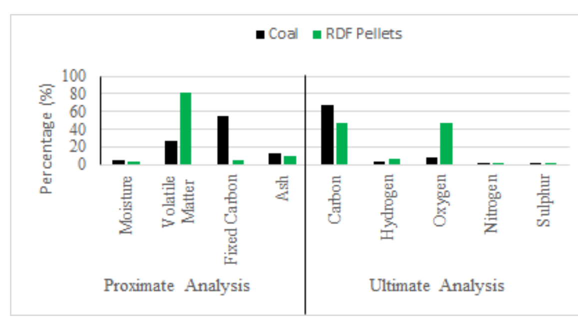

Figure 7. Proximate and Ultimate Analysis of feedstocks.

The RDF pellets were produced from Municipal Solid Waste samples collected from transfer stations and drop off sites around the City of Cape Town Municipal region. MSW in its raw form poses and handling and processing challenge due to its heterogenous nature. The pelletisation of the MSW to form RDF was performed to limit these challenges which in turn helps in terms of process control parameters and handling. The characterization in terms of proximate and ultimate analysis were conducted at Roediger Agencies cc. and the Central Analytical Facility of Stellenbosch University respectively.

3. RESULTS AND DISCUSSION

The simulation uses a pre-heated nitrogen stream in the feed to preheat the feed temperature to start the combustion process. The temperature of the combustion chamber is not set to a certain value, only the temperate of the feed was considered. It is to be noted that the emissions data received from this are compiled with no gas cleaning procedures being applied to the gas stream as it would be done in industry applications at power and heat generation facilities. The emission reported in this study focus on mainly for CO_2, NO_X, SO_2 emissions compared between the combustion of coal and RDF. The results obtained are summarized in Figure 8.

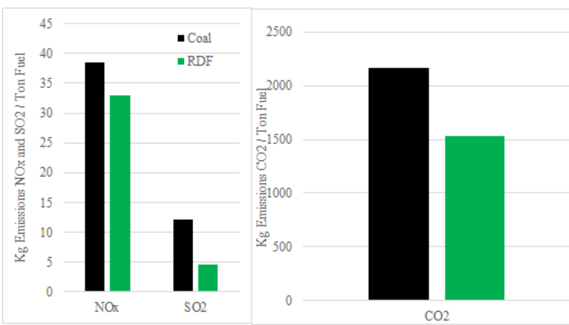

Figure 8. Emissions comparisons between coal and RDF.

The results obtained in Figure 9 show that the CO_2 emissions are inherently higher in coal combustion than with RDF combustion with no gas cleaning in both processes. The percentage saving on CO_2 emissions amounts to approximately 32.1% when using RDF in this combustion process. Kaplan, DeCarolis and Barlaz [22] reported similar finding in waste-to-energy applications while O'Brien and Swana [23] reported savings of over 60% on CO_2 emissions. The United States Environmental Protection Agency [24] reported savings of over 50% in terms of CO_2 emission and Christensen, Damgaard and Astrup [25] concluded that The more fossil fuels that are substituted in the energy sector by the electricity and heat production from the WtE plants, the larger the CO2 savings offered.

In terms of the SO_2 and NO_x, it can be distinguished from the simulation results that the NO_x emissions in kg/ ton fuel is lower in the RDF than in the coal, as well as the SO_2. Research from various others also show significantly lower NO_x and SO_2 emissions in waste-to-energy facilities than in coal fired plants [22-25], which then validates the authenticity of the results obtained. The reduction in SO_2 emissions from the coal to the RDF was found to be 62% and the reduction of NO_x was found to be 14%. Albina [26] and [27] also states that the emission factors of SO_2 and NO_x are significantly lower in waste-to-energy facilities than in coal fired plants.

4. CONCLUSION

The results obtained from the study clearly show that the combustion of RDF is a viable option for an alternative to coal in terms of the emissions contributing to the greenhouse effect. South Africa is currently facing the effects of global warming through the irregular weather patterns that have seen the Western Cape Province experience severe water shortages for almost a year now. It is evident that a solution is required and fast. As for the criteria of air toxins, waste-to-energy facilities transmit fundamentally less carbon dioxide than any of the petroleum product power plants. They radiate essentially less sulfur dioxide than coal-fired power plants. They are comparable to coal-and oil-fired power plants as for nitrogen oxide emissions. In terms of South Africa, further research into the applications of RDF as a coal substitute is required before any field applications can be investigated. A comparison of waste-to-energy and coal plant emissions is required to be conducted per unit of energy as a basis, then cost implications can follow to assess the feasibly of a complete change from coal to RDF and reduced impacts due to less landfill operations. The ignition of fuel derived from MSW is a promising low-cost retrofitting procedure for coal power plants, having the additional advantage of lessening the volume of waste transfer in landfills. Moreover, co-burning of RDF and coal, as opposed to changing to RDF ignition alone straight from the onset of devoted power plants, permits plant administrators to be adaptable to varieties in the RDF supply.

The study demonstrates that substituting some portion of the coal supply by processed high-calorific value waste.

5. ACKNOWLEDGMENTS

All the authors would like to thank the Cape Peninsula University of Technology for funding towards the project and attendance at the conference.

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