Universidad Centroccidental "Lisandro Alvarado"
Decanato de Agronomía
Programa de Ingeniería Agroindustrial
Revista Científica Agroindustria, Sociedad y Ambiente (A.S.A)
ISSN: 2343-6115 Deposito Legal No ppl201302LA4406

Mejoras en las emisiones de gases y en la eficiencia de una caldera con la introducción de la tecnología magnética

Arias Gilart Ramón[1*], Fong Casas Fredy[2], Rojas Lores Yuliani[2], Conde García Rebeca[1], Melek Campos Sofia[1]

[1]National Center for Applied Electromagnetism, Universidad de Oriente, Santiago de Cuba, Cuba
[2]Santiago de Cuba Rum Factory, Santiago de Cuba, Cuba

https://orcid.org/0000-0003-2050-9712 ramonariasgliart@gmail.com
https://orcid.org/0000-0002-3821-5117 fredyfong@cubaron.com
https://orcid.org/0000-0002-9216-1762 yuliani@cubaronstgo.co.cu
https://orcid.org/0000-0003-2810-4525 rebeca@uo.edu.cu
https://orcid.org/0000-0003-2741-8821 melek@uo.edu.cu

ASA/Artículo
doi: http://doi.org/10.5281/zenodo.7365150
Recibido: 29-01-2022
Aceptado: 26-09-2022

RESUMEN

La aplicación de tratamientos magnéticos a los combustibles es una de las alternativas más utilizadas en la actualidad con el objetivo de reducir las emisiones de gases contaminantes y aumentar el ahorro de combustible. En este trabajo se evaluó el efecto del tratamiento magnético del fuel oil utilizado en una caldera de producción de vapor. Se utilizaron dispositivos con una inducción magnética promedio de 0,36 T. Con la introducción de la tecnología magnética en una caldera para el tratamiento de fuel oil, se redujeron las emisiones de CO_2 en aproximadamente un 10,18 %, lo que contribuye a reducir la carga contaminante de estos equipos. Las emisiones de CO de este equipo disminuyeron aproximadamente un 60,07 %, por lo que se obtiene una combustión más completa. El tratamiento magnético utilizado provocó una disminución del 13,84 % en la temperatura de los gases de escape, por lo que se reducen las pérdidas de calor latente en los gases de escape. En las condiciones experimentales, la tecnología magnética permite aumentar la eficiencia del proceso de combustión en un 1,6 %, lo que podría significar un mayor aprovechamiento de energía en el sistema y un potencial ahorro de combustible.

Palabras Clave: Tratamiento magnético, tratamiento de fuel oil, emisiones de calderas.

Improvements in exhaust gas emissions and boiler efficiency with the introduction of magnetic technology

ABSTRAC

The application of magnetic treatment to fuels is one of the most widely used alternatives today with the aim of reducing polluting gas emissions and increasing fuel savings. In this work, the effect of the magnetic treatment of fuel oil used in a steam production boiler was evaluated. Devices with an average magnetic induction of 0.36 T were used. With the introduction of magnetic technology in a boiler for the treatment of fuel oil, CO_2 emissions were reduced by approximately 10.18 %, which contributes to reducing the contaminant load of these equipments. The CO emissions of this equipment decreased by approximately 60.07 %, so a more complete combustion is obtained. The magnetic treatment used caused a decrease of 13.84 % in the temperature of the exhaust gases, so the latent heat losses in the exhaust gases are reduced. Under the experimental conditions, the magnetic technology allows to increase the efficiency of the combustion process by 1.6 %, which could mean a greater use of energy in the system and potential fuel savings.

Keywords: Magnetic treatment, fuel oil treatment, boiler emissions.

INTRODUCTION

Fossil fuels account for 80% of the world's energy supply; however, detectable oil fields are expected to decrease over the years (Mutezo & Mulopo, 2021). World oil production could begin to decline rapidly as early as 2022. In addition, approximately 65% of the world's oil reserves are in Middle Eastern countries, and this is expected to accelerate the imbalance between supply and demand. non-producing countries, since they depend heavily on oil imports (Demirbas, 2007). The consumption of alternative energy sources globally is increasing sharply due to depletion of oil resources and serious environmental pollution caused by exhaust gases in fossil energy use (Lee et al. 2021). Another of the reasons that multiplies the use of renewable energy sources is that strict rules are applied that regulate and control the emissions of this type of polluting gases; fundamentally in European countries, but with a great tendency to generalize worldwide.

In addition to renewable energy sources, several alternatives or innovations are currently being investigated that allow the reduction of polluting gas emissions caused by the combustion of fossil hydrocarbons. The boilers or steam generators used in the production of heat and steam are some of the main causes of pollution associated with gas emissions from combustion. These equipments fundamentally use fuel oil or diesel as fuel and are used in most of the world's industries.

In recent decades, one of the technologies proposed to reduce the consumption of fossil fuels and the reduction of gas emissions resulting from combustion is the application of magnetic treatment to fuels. Current studies suggest that magnetic technology has a positive effect on combustion processes because it modifies some of the physical and chemical properties of fuels (Arias et al. 2018b; Arias et al. 2018c; Dinza et al. 2020; Gilart et al. 2020; Niaki et al. 2020; Sidheshware et al. 2020). Most of the studies on this subject have been carried out on internal combustion engines, in which considerable reductions in polluting gas emissions and a reduction in fuel consumption are obtained (Arias et al. 2018a; Chandrasekaran et al. 2020; Khajure et al.; 2014; Notti & Sala, 2014; Tipole et al. 2017).

In boilers or steam generators, this technology has been used with the aim of reducing scale in the pipes that transport water (de la Cruz & García, 2016; Esmaeilnezhad et al. 2017; Vidaurre, 2015). Salih and Ahmed (2016) explored the effect of magnetized fuel on the combustion performance of a diesel fuel fired boiler. The analysis was made from fuel consumption and exhaust emissions. The magnetic field was placed in the diesel supply line to the burner. In this study, gas emissions and fuel consumption decreased after the application of the magnetic field (Salih & Ahmed, 2016). However, no research reports have been found that evaluate the influence or effect of magnetically treated fuel oil on gas emissions from this type of equipment. That is why the objective of this work is to evaluate the effect of applying magnetic technology to fuel-oil fuel on gas emissions from a boiler or steam generator.

MATERIALS AND METHODS

This research includes two measurement stages, the determination of gas emissions before and after the installation of magnetic conditioners for fuel treatment in the boiler. The subsequent analysis of the data allows elucidating the effect that this type of technology produces on the combustion processes and on the levels of pollution that they generate. The equipment and procedures used are described below.

Magnetic devices

To produce the static magnetic field, magnetic conditioners made from permanent Neodymium-Iron-Boron magnets were used (Figure 1). The average magnetic induction of these conditioners is 0.36 T, with a deviation of 0.005 T. A dipole configuration was used to ensure even distribution of field induction lines throughout the fuel flow area. The magnetic devices were in the pipe that leads the fuel oil to the burner at the pump outlet and as close as possible to the fuel atomization. The selection of the material of the devices and of the magnetic induction was carried out considering the most relevant results described in the consulted literature (Kartik et al. 2019; Kushal & Basavaraj, 2015; Salih & Ahmed, 2016). Higher inductions are very difficult and expensive to obtain using permanent magnets.

Figure 1. Novamag magnetic conditioner

Steam generator

The boiler or steam generator used in the study carried out (Figure 2) is located in the Base Business Unit (UEB) Distillery, belonging to the Santiago de Cuba Rum Factory of the CubaRon.SA Corporation. Its characteristics are shown in Table 1.

Figure 2. Image of the boiler used

Table 1. Characteristics of the Boiler used in the test

Parameter	Boiler
Brand	LEON
Type	Firetube
Model	CFDC-350
Country of origin	Mexico
Nominal Production (t)	5
Nominal Pressure (Kg/cm^2)	8
Fuel type	Fuel oil

Gas measurements

A Testo 350 Gas Analyzer was used to measure the concentration of the gases produced by combustion CO, CO_2, NO_X and the temperature of the gases. This equipment is a professional instrument for gas analysis. It has been designed for the following applications:

• Service and adjustment of industrial incinerators

• Control of emissions and verification of compliance with regulatory emission values.

• Service and commissioning of burners and industrial boilers.

- Measurements in gas turbines, boilers and industrial stationary engines.

The measurement ranges and the resolution of the equipment are shown in Table 2.

In addition to these variables, the Combustion Performance (REN) was also determined, using the parameters provided by the Testo 350 Gas Analyzer and the following equations (González-González et al. 2014):

$$REN = 100 - qA - qI \quad \text{.......... (1)}$$

Where REN is the efficiency of the combustion process, qA and qI are the sensible heat losses in the chimney and unburned, respectively. These losses are calculated using the following mathematical expressions:

$$qA = K\frac{FT - AT}{CO_2} \quad \text{......................(2)}$$

$$qI = 60\frac{CO}{CO + CO_2} \quad \text{.................... (3)}$$

Equation 2 is used to calculate the sensible heat losses in the exhaust gases, expressed in % relative to the Lower Caloric Value of the fuel, FT and AT being the exhaust gas temperature and the atmospheric temperature, respectively. K is the specific factor of the fuel used. Equation 3 calculates the unburned losses (qI) expressed in % with respect to the lower calorific value. CO and CO_2 are the contents of these elements in the exhaust gases, expressed in ppm and volume percentage, respectively.

Table 2. Characteristics of the gas analyzer used

Parameter	Measuring range	Resolution
O_2	0-25 Vol. %	0,01 Vol. %
CO	0-10000 ppm	1 ppm
NO_2	0-500 ppm	0,1 ppm
CO_2	0-25 Vol. %	0,01 Vol. %
Gas Temperature	-40 - 1200 ^{0}C	1 %

Procedure

The analyzes were carried out in two moments, under normal operating conditions of the boiler, working in the same work regime. Determinations made before the installation of magnetic technology are represented by the letters (STM) which stands for No Magnetic Treatment. The measurements made after the installation of the magnetic technology are represented by the letters (TM) which means with Magnetic Treatment and were made three months after the installation of the magnetic devices in the pipes.

In total, 20 concentration values of the analyzed gases, temperature and combustion performance were obtained for both moments (STM and TM). With these data, the statistical comparison of the average values was made using a probability value of $p \leq 0.5$.

RESULTS AND DISCUSSION

The gas emissions, temperature and combustion performance obtained with the fuel without magnetic treatment (STM) were used as control in all the analyzes carried out. CO_2, CO and NO_X emissions were considered due to their importance from the environmental and combustion efficiency point of view. Figure 3 shows the CO_2 emissions obtained in the two conditions in which the boiler operated.

The CO_2 gas is one of the most damaging greenhouse gases (GHG), but it is also one of the most important combustion products.

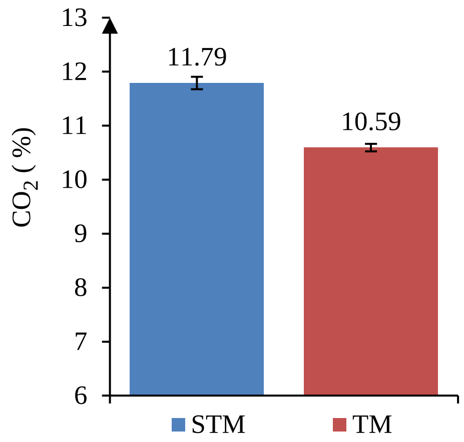

Figure 3. Behavior of CO_2 emissions from the boiler in the conditions analyzed

In Figure 3 it can be seen that CO_2 emissions decrease after applying the magnetic treatment. The boiler was operating under normal operating conditions in both conditions (STM and TM) the same amount of steam was produced. This means that the decrease in CO_2 emissions obtained with the TM is due to a reduction in the fuel consumption of the boiler. Several authors associate these results with an improvement in the atomization process and a reduction in the size of the fuel droplets after receiving the magnetic treatment (Arias et al., 2018c; Gilart et al., 2020). These changes are also explained due to the differences in the physical-chemical properties of the hydrocarbons that have been magnetically treated. Some of these properties that are affected by magnetic fields and that influence the combustion process are: surface tension, viscosity and rheological behavior (Arias et al. 2018b; Arias et al. 2018c; Jiles et al. 2015).

From the environmental point of view, a decrease in the emissions of this gas indicates that the pollutant load of this boiler is considerably reduced, as it stops emitting 10.18 % of this GHG. Similar results have been obtained in several investigations but using internal combustion engines in the experiments, such is the case of (Chen et al. 2017; Kushal & Basavaraj, 2015). These authors attribute the reduction in emissions to greater combustion efficiency, which is caused by the action of the magnetic field by weakening intermolecular interactions in hydrocarbons, improving the atomization and mixing process, as well as increasing their reactivity with oxygen from the air (Chen et al. 2017). Other authors have obtained contradictory results, that is, increases in CO_2 emissions with magnetic technology, but using other magnetic configurations and different types of fuel (Al-Khaledy, 2008; Faris et al., 2012). The contradictions in the results are due to the dissimilar magnetic treatment systems used and the structural differences between the fuels used in the experimentation. In our research, the effects of the application of magnetic technology in boilers or steam generators fed with fuel oil are reported for the first time. Under these conditions, the combustion process was more efficient, so a greater use of the fuel's chemical energy was achieved.

In the combustion process of the different types of fuel, the chemical reaction is not complete, so gases such as CO are obtained. The behavior of the CO emissions from the boiler with and without the application of magnetic technology is shown in Figure 4.

With the magnetic treatment of fuel oil, the CO emissions generated by the boiler are reduced by 60.07 %, so a more complete combustion is obtained, and the quality of this process is increased. In addition, energy losses due to incomplete combustion are considerably eliminated, which can lead to considerable fuel savings in this process.

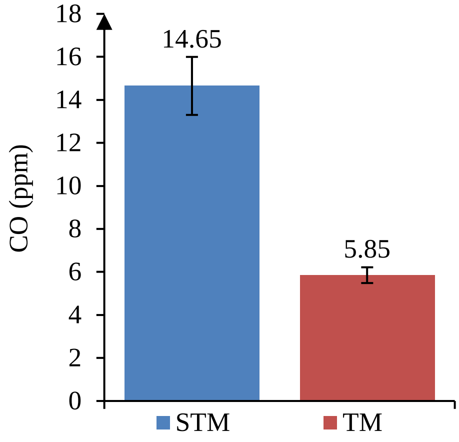

Figure 4. Behavior of CO emissions from the boiler in the conditions analyzed

With the application of magnetic fields in the pipes through which the fuel flows, the molecular associations in the form of a cage present in the hydrocarbons are broken down into smaller particles; which causes, among other things, the decrease in viscosity and surface tension (Patel et al. 2014). That is why smaller droplets are produced in the atomization process and the fuel-air mixture becomes more homogeneous. This process allows a greater penetration and reaction of oxygen, thus producing a more complete combustion inside the boiler. Similar results have been described by dissimilar researchers using internal combustion engines, generally diesel engines, and various types of magnetic treatments for experimentation (Dinza et al. 2020; Gilart et al. 2020; Niaki et al. 2020; Oommen & GN, 2020; Perdana et al. 2020; Samadi & Heidarbeigi, 2020; Wibowo et al. 2020).

Other GHGs produced in combustion processes are NO_X (NO and NO_2). The chemical mechanism for the formation of these gases during combustion processes is due to more than 100 elementary chemical reactions. These reactions fundamentally depend on changes in temperature, the stoichiometric ratio and the nitrogen species present in the combustion chamber (Yamin, 2017). The behavior of the emissions of this gas in the boiler with and without the application of the magnetic treatment is shown in Figure 5.

These gases are produced by excess air, by the high temperature of the gases in the post-combustion zone and by the chemical compounds present in the mixture after combustion (Patel et al. 2014). NOx emissions generally do not depend on the physical chemical characteristics of the fuel, which is why, as Figure 5 shows, the emissions of this gas with and without the application of magnetic technology are similar.

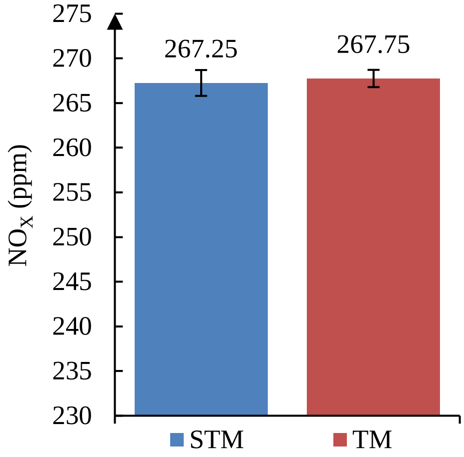

Figure 5. Behavior of NOx emissions from the boiler in the conditions analyzed

Another important parameter in the evaluation of boilers is the temperature of the exhaust gases (TGE). Figure 6 shows the variation of this parameter in the boiler with and without the use of magnetic fuel treatment.

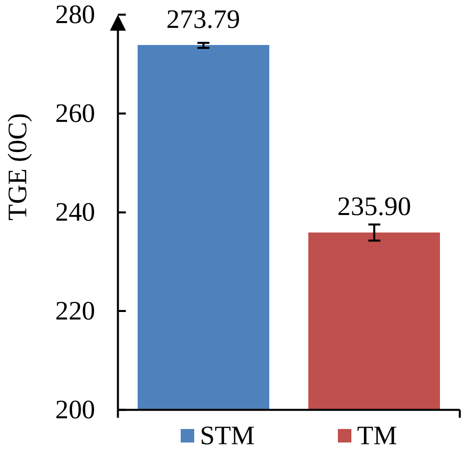

Figure 6. Behavior of the outlet temperature of the boiler gases in the conditions analyzed.

In general, the TGE decreases around 13.84 % when the magnetically treated fuel is used. In boilers, the heat losses in the exhaust gases represent approximately 50 to 80 % of the total sensible heat loss of the boiler (Jin et al. 2019).

A reduction in the outlet temperature of the gases is due to a considerable increase in the efficiency of the boiler and a reduction in fuel consumption (Fialko et al. 2019). As exhaust gas temperature decreases, dry gas loss is reduced and thermal efficiency of steam generation is improved (Habib et al. 2008). This result indicates that the magnetic treatment caused variations in the chemical-physical properties of the fuel that enabled an increase in the efficiency of the combustion process and a better use of the chemical energy of the fuel. These changes are evident in the reduction of CO emissions and in the decrease in the outlet temperature of the gases from the boiler, obtained with the magnetically treated fuel.

Another of the parameters evaluated in this investigation was Combustion performance, the behavior of this parameter is shown in Figure 7.

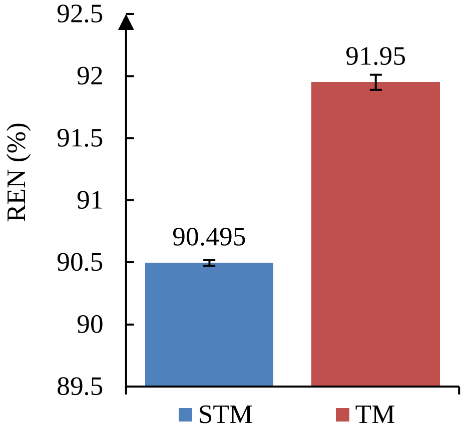

Figure 7. Combustion efficiency of the boiler in the conditions analyzed

As can be seen in the figure, with the application of the magnetic treatment of the fuel, an increase in the efficiency of the combustion process of 1.6 % was obtained. This result is related to the decreases obtained in CO emissions and in the TGE. According to equations 1, 2 and 3, a decrease in CO and TGE (which translates into a lower amount of latent heat loss, both due to unburned fuel and exhaust gas temperature) would produce an increase in process performance. An increase in the efficiency of the combustion process by 1.6 % could mean greater use of energy in the system and potential fuel savings. All of the above indicates that the magnetic treatment of the fuel can be considered as an alternative to improve the combustion process and to increase its efficiency. In addition, it also allows reducing the contaminant load that these types of equipment contribute to the environment.

CONCLUSIONS

In the present study, the effect of magnetically treated fuel oil on gas emissions from a boiler or steam generator was evaluated for the first time. The analyzes were carried out using magnetic conditioners with an average magnetic induction of 0.36 T. The determinations made in the boiler allow us to conclude that:

• The magnetic treatment of the fuel oil used in boilers allows CO_2 emissions to be reduced by approximately 10.18 %, which contributes to reducing the contaminant load that these types of equipment contribute to the environment.

• The magnetic treatment of the fuel oil used in boilers allows CO emissions of these type of equipment to be reduced by approximately 60.07 %, for which a more complete combustion is obtained.

• The magnetic treatment used caused a decrease of 13.84 % in the temperature of the exhaust gases, thus reducing the loss of latent heat in the exhaust gases.

• The magnetic treatment, under the experimental conditions, makes it possible to increase the efficiency of the combustion process by 1.6 %, which could mean greater use of energy in the system and potential fuel savings.

ACKNOWLEDGEMENTS

The authors would like to thank the management of Santiago de Cuba Rum Factory for the support received for this work and acknowledge thankfully the permission and help provided by the management of UEB Destileria where the experimental research was carried out.

REFERENCES

Al-Khaledy, A. A. J. (2008). High performance and low pollutant emissions from a treated diesel fuel using a magnetic field. *Al-Qudsiya Journal for Engineering Sciences, 1*(2), 211-224.

Arias, G. R., Berenguer, U. M., Vázquez, N. J. A., Silveira, F. Y., & Alfaro, R. C. E. (2018a). Disminución de las emisiones de monóxido de carbono con el tratamiento magnético del combustible *Centro Azúcar, 45*(1), 21-31.

Arias, G. R., Falcón, H. J., Campos, S. M., Silveira, F. Y., & López, G. Ó. (2018b). Efecto del tratamiento magnético en el comportamiento reológico del diésel *Revista Tecnología Química, 38*(2), 412-427.

Arias, G. R., Silveira, F. Y., Campos, S. M., & Falcón, H. J. (2018c). Efecto de un campo magnético estático en la tensión superficial del diésel y su atomización *Revista Iberoamericana de Ingeniería Mecánica, 22*(1), 9-21.

Chandrasekaran, M., Prakash, K., Prakash, S., & Ravikumar, M. (2020). Influence on performance and emission characteristics of diesel engine by introducing medium strength magnetic field in fuel and air lines. *MS&E, 764*(1), 12-32.

Chen, C.-Y., Lee, W.-J., Mwangi, J. K., Wang, L.-C., & Lu, J.-H. (2017). Impact of Magnetic Tube on Pollutant Emissions from the Diesel Engine. *Aerosol and Air Quality Research, 17*(4), 1097-1104. doi:10.4209/aaqr.2016.11.0478

de la Cruz, M. d. L., & García, M. N. (2016). Incremento de la eficiencia energética con el uso de la magnetización en las aguas de alimentación a generadores de vapor en la industria azucarera. *Tecnología Química, 29*(1), 12-16.

Demirbas, A. (2007). *Biodiesel: a realistic fuel alternative for diesel engines*: Springer Science & Business Media.

Dinza, V. D. d. l. M., Arias, G. R., Alfaro, R. C. E., Silveira, F. Y., Menadier, G. R. O., & Soto, F. K. d. l. C. (2020). Evaluación de una mezcla aceite de jatropha-diésel bajo la acción de un campo magnético. *Ingeniería Energética, 41*(1).

Esmaeilnezhad, E., Choi, H. J., Schaffie, M., Gholizadeh, M., & Ranjbar, M. (2017). Characteristics and Applications of Magnetized Water as a Green Technology. *Journal of Cleaner Production, 161*.

Faris, A. S., Al-Naseri, S. K., Jamal, N., Isse, R., Abed, M., Fouad, Z., . . . Mohammad, H. (2012). Effects of magnetic field on fuel consumption and exhaust emissions in two-stroke engine. *Energy Procedia, 18*, 327-338. doi:https://doi.org/10.1016/j.egypro.2012.05.044

Fialko, N., Navrodska, R., Ulewicz, M., Gnedash, G., Alioshko, S., & Shevcuk, S. (2019). *Environmental aspects of heat recovery systems of boiler plants.* Paper presented at the E3S Web of Conferences.

Gilart, R. A., Ungaro, M., Rodríguez, C., Hernández, J., Sofia, M., & Verdecia, D. (2020). Performance and exhaust gases of a diesel engine using different magnetic treatments of the fuel. *Journal of Mechanical Engineering and Sciences, 14*(1), 6285-6294.

González-González, J., Alkassir, A., San José, J., González, J., & Gómez-Landero, A. (2014). Study of combustion process of biodiesel/gasoil mixture in a domestic heating boiler of 26.7 kW. *Biomass and bioenergy, 60*, 178-188.

Habib, M., Elshafei, M., & Dajani, M. (2008). Influence of combustion parameters on NOx production in an industrial boiler. *Computers & Fluids, 37*(1), 12-23.

Jiles, D. C., Magnell, S., & Mina, M. (2015).

Jin, Y., Gao, N., & Zhu, T. (2019). Techno-economic analysis on a new conceptual design of waste heat recovery for boiler exhaust flue gas of coal-fired power plants. *Energy conversion and Management, 200*, 112097.

Kartik, Y., Raja, R., & Mithun, S. (2019). Experimental Investigation on the Effect of Fuel Magnetization for Improvement of Diesel Engine's Efficiency. *SASTech-Technical Journal of RUAS, 18*(1), 9-12.

Khajure, N. S., Mane, L., Attar, A., Bhojwani, V., & Jadhav, M. (2014). Reduction of harmful emission from exhaust in ic engine by application of magnetic field on fuel line. *IJMCA, 2*(2), 59-63.

Kushal, C., & Basavaraj, M. (2015). Effect of fuel magnetism by varying intensity on performance and emission of single cylinder four stroke diesel engine. *IRJET, 2*(7), 1121-1126.

Lee, T.-H., Lee, S.-H., & Lee, J.-K. (2021). Exhaust Gas Emission Improvements of Water/Bunker C Oil-Emulsified Fuel Applied to Marine Boiler. *Journal of Marine Science and Engineering, 9*(5), 477.

Mutezo, G., & Mulopo, J. (2021). A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. *Renewable and Sustainable Energy Reviews, 137*, 110609.

Niaki, S. R. A., Zadeh, F. G., Niaki, S. B. A., Mouallem, J., & Mahdavi, S. (2020). Experimental investigation of effects of magnetic field on performance, combustion, and emission characteristics of a spark ignition engine. *Environmental Progress & Sustainable Energy, 39*(2), e13317.

Notti, E., & Sala, A. (2014). *Fuel saving and emission reduction in fisheries:*

Results of the experimentation of a new magnetic device onboard fishing vessel. Paper presented at the Oceans-St. John's, 2014.

Oommen, L. P., & GN, K. (2020). Experimental studies on the influence of axial and radial fields of sintered neo-delta magnets in reforming the energy utilization combustion and emission properties of a hydrocarbon fuel. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 1-21.

Patel, P. M., Rathod, G. P., & Patel, T. M. (2014). *Effect of magnetic fuel energizer on single cylinder ci engine performance and emissions*. Paper presented at the Mechanical & Automobile Engineering ICCIET-2014, India.

Perdana, D., Yuliati, L., Hamidi, N., & Wardana, I. (2020). The Role of Magnetic Field Orientation in Vegetable Oil Premixed Combustion. *Journal of Combustion, 2020*.

Salih, A. M., & Ahmed, A.-R. M. (2016). The effect of magnetic field on the boiler performance fueled with diesel. *International Journal of Scientific & Engineering Research*, *7*(2), 406-410.

Samadi, S., & Heidarbeigi, K. (2020). Acoustic analysis of a single-cylinder diesel engine using magnetized biodiesel-diesel fuel blends. *Heliyon*, *6*(9), e05113.

Sidheshware, R. K., Ganesan, S., & Bhojwani, V. K. (2020). Enhancement of internal combustion engine efficiency by magnetizing fuel in flow line for better charge combustion. *Heat Transfer Research*, *51*(5).

Tipole, P., Karthikeyan, A., Bhojwani, V., Deshmukh, S., Babar, H., & Tipole, B. (2017). Reduction in the exhaust emissions of four-stroke multi-cylinder SI Engine on application of multiple pairs of magnets. *International Journal of Ambient Energy*, *29*(8), 1-7. doi:https://doi.org/10.1080/01430750.2017.1354321

Vidaurre, C. G. (2015). Uso del desincrustante magnético (DM) para mejorar la calidad del agua en la industria. *Ingeniería Industrial*(28), 139-154.

Wibowo, N., Utami, S., Riyanto, C., & Setiawan, A. (2020). Impact of Magnetic Field Strengthening on Combustion Performance of Low-Octane Fuel in Two-Stroke Engine. *Jurnal Pendidikan Fisika Indonesia*, *16*(1), 57-62.

Yamin, J. A. (2017). Performance comparison of a CI engine using diesel and biodiesel fuels and a magnetic fuel conditioner. *Biofuels*, 1-10. doi:http://dx.doi.org/10.1080/17597269.2017.1306682