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The link to this publication is https://ajoeer.org.ng/otn/ajoeer/qtr-2/2020/01.pdf

African Journal of Engineering and Environment Research Vol.1(2) 2020 pp 2 - 17

ISSN: 2635-2974

Dilute caustic and water comparisons as solvents in the removal of acidic gases from combustion exhaust stream of a boiler

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ABSTRACT:

This work focused on the comparative analyses between the use of dilute caustic with a composition of 1.84% and using water alone (pH=7) that have the potential to remove SO_2 completely from the exhaust flue gas of a combustion system and H_2S in the incomplete reaction scenario. Two reaction pathways were utilized for the study, the complete combustion pathway as well as the incomplete combustion pathway. ASPEN HYSYS 8.6, a process simulation software, was used to simulate conditions with PENG-ROBINSON utilized as the vapour-liquid equilibrium (VLE) data prediction tool of the software. For the complete combustion pathway, a complete removal of SO_2 was achieved using caustic while with the same conditions, utilizing water as solvent achieved a reduction of 90%. For the incomplete combustion pathway, using caustic gave about 53% removal efficiency for H_2S while the water only showed a poor 16% increase of H_2S. The study recommended the use of the dilute caustic for the following reasons; it gave a better removal percentage than using water alone, the use of the caustic will not contribute to caustic corrosion because of the low composition of the dilute caustic that will be used in the absorber, the choice of the caustic was also observed to be economical.

Keywords: Caustic, Absorption, Emission, Simulation, Combustion, Solvents.

1.0 INTRODUCTION

The absorber has proven to help in the removal of debilitating emissions from the exhaust streams of boiler combustion systems [1]. The treatment of the emissions must be guided by the flue gas characteristics [2]. A veritable accessory to accomplish absorption of the emissions are solvents [3]. These solvents must have an array of parameters to ensure safe and effective use. Therefore, toxicity, flammability as well as economics amongst other variables are crucial in the choice of solvents in the absorption system [4].

The use of caustic has been successful in the removal of acidic gases especially SO_2 and H_2S [5] & [6] that is detrimental to industrial processes owing to its harming effects on human, animal, plants and materials [7]. Increase in the concentration of solvent concentration has a corresponding increase in the removal percentage of the emissions from combustion streams [8]. These increases in composition enables the efficiency of the absorber by providing adequate contact between the solvent liquid and the gaseous emissions through the increase of the surface area of contact [9]. Further increases in the composition of the alkali medium necessitates an equal increase in the volume of the caustic utilized in the operation hence a high cost of the absorption operation.

In order to reduce cost, water have also yielded considerable success in the removal of acidic gases from combustion streams. These operations guarantees that the operation is cost effective as a result of nil purchase required for operation compared to that of caustic. The disadvantage of opting for water when the cost of production of water as well as its treatment is highly expensive. Some operations have resorted to the use of sea water [10] & [11], however, the location of the facility must be close to the coastal region where the water is sourced. It is worthy to note that the use of water and caustic as solvents in the removal of acidic gases from combustion systems have been observed to be feasible.

The study under review sought to investigate the different removal efficiency between caustic and water. The water is produced and treated in-plant while the caustic is a low composition caustic generated from the treatment of demineralized water used in the production of boiler feed water which is at no extra cost if that option were more feasible.

2.0 MATERIALS AND METHODS.

This study culled emission rate acquired by the estimation of the combustion yields from a combustion exhaust stream [12]. The simulation was evaluated using HYSYS 8.6. Two solvents were studied, dilute caustic with a composition of 1.84% available as a waste stream from a water demineralization treatment unit as well as a proposition to use water only as the solvent. The simulation was gotten using the PENG-ROBINSON fluid package in the HYSYS 8.6 software to estimate the vapour liquid equilibrium data.

The studies were conducted maintaining the composition of dilute caustic at 1.84% for both reaction pathways while water was assumed to have a pH of 7. The flue gas temperature of 181^{o}C was reduced by a cooler to 120^{o}C for the complete combustion while that of the incomplete combustion pathway reduced from 181^{o}C to 150^{o}C.

3.0 RESULTS AND DISCUSSION

3.1 Complete Combustion Pathway

The data used in these analyses were simulated studies recorded from the studies conducted with the complete combustion scheme to generate the performance of the absorber using both water and dilute caustic to compare the best option of solvent to use, see [12].

3.1.1. Water Alone

Table 1 demonstrates the simulated outcomes of the effects on the success accomplished by the absorber using only water as the solvent.

Table 1: Using only Water as Solvent

Compositional Mole Fraction	Flue Gas	Solvent	Vapour	Liquid
SO_2	0.000416	0	0.00004	0
H_2O	0.04812	1	0.30359	0.150592
NO_2	0.004585	0	0.00079	0.000267

Table 1 depicts the key parameters portraying various variables using water alone as the solvent without any caustic addition. The data shows a significant reduction of the SO_2 present in the flue gas from a composition of 0.000416 to 0.00004 marking a profound 90% reduction rate of SO_2 in the flue gas. There is also the added reduction of CO_2 from the flue gas from a composition of 0.946879 to 0.69558 marking a 27% reduction of CO_2 in the exhaust stack after the absorption process. The introduction of the solvent also contributed to about 83% reduction on the NO_2 from the exhaust stream.

It is a clear demonstration of the simulation studies that water having a prominent removal of 90%, 27% and 83% of SO_2, CO_2 and NO_2 respectively is a veritable solvent for use in the removal of gaseous emissions from these proposed retrofitted unit. These studies however, have concentrated on simulating the complete combustion of fuel oil as contained in Harry-Ngei [12].

Table 2 evidently displays the parameters of different variables for the deployment of water alone as the solvent devoid of any additional caustic composition at a temperature of 120^{o}C in the simulation.

Table 2: Material Balance Data Using only Water as Solvent

	Unit	Flue Gas	SOLVENT	Vapour	Liquid
Vapour Fraction		1	0	1	0
Temperature	*C*	181	30	71.32011	92.80787
Pressure	*kPa*	101.3	101.325	101.3	121.59
Molar Flow	*kgmole/h*	749.8141	280	1023.674	6.139936
Mass Flow	*kg/h*	32074.14	5157.479	37006.26	225.5181
Liquid Volume Flow	*m^3/h*	38.63177	5.077023	43.57337	0.135651

The temperature of the flue gas was brought down to 120^{o}C from the combustion stream outlet of 181^{o}C with the benefit of a cooler in the proposed unit. The solvent temperature was maintained at 30^{o}C. The liquid outlet temperature was 93^{o}C in contrast to that of the vapour outlet of 71^{o}C. The flue gas inlet as well as that of the vapour outlet pressures of the absorber was 101.3Kpa in contrast to the pressure of 121.59Kpa at the absorber liquid outlet of the absorber. The liquid volume flow of the solvent recorded was 5m^3/h compared to 0.14m^3/h of the absorber liquid outlet.

3.1.2 Dilute Caustic as Solvent

Table 3 shows the compositional removal efficiency of the absorber using the dilute caustic with a composition of 1.84% as the solvent.

Table 3: Dilute caustic as Solvent

Compositional Mole Fraction	Flue Gas	Solvent	Vapour	Liquid
CO_2	0.946879	0	0.693503	0.010045
SO_2	0.000416	0	0	0
NO_2	0.004585	0	0.003357	0.000267

Table 3 shows the removal efficiencies for CO_2, SO_2 and NO_2 with regards to the use of dilute caustic as solvent with a composition of 1.84% to cut down on emissions from a combustion waste stream. For CO_2, the reduction efficiency of the solvent is 28% while that of NO_2 is an insignificant 27%. An observation of 100% removal of SO_2 was also recorded from a composition of 0.000416 to 0.00. The study's interest was the total elimination of SO_2 from the flue gas stream which the solvent (caustic) have been observed to deliver best results of complete elimination of the SO_2.

The composition used is a combination or mixture of NaOH 1.84% because of the availability of the bulk caustic volume after demineralized treatment. Increasing the composition of caustic will have a profound effect on the absorber efficiency, however, this study was interested in the available caustic with a fixed 1.84% composition of NaOH.

Table 4 shows the parameters obtained from the simulation study for the utilization of caustic as solvent for the removal of emissions in a complete combustion reaction scenario.

Table 4: Material Balance Data of the Caustic as Solvent

	Unit	Flue Gas	Solvent	Absorber	Vapour	Liquid
Vapour Fraction		1	0	1	1	0
Temperature	*C*	181	30	120	71.32011	92.80787
Pressure	*kPa*	101.3	101.325	101.3	101.3	121.59
Molar Flow	*kgmole/h*	749.8141	280	749.8141	1023.674	6.139936
Mass Flow	*kg/h*	32074.14	5157.479	32074.3	37006.26	225.5181
Liquid Volume Flow	m^3/h	38.63177	5.077023	38.63199	43.57337	0.135651

Figure 1 shows the comparative analyses of the absorber performance between the utilization of water alone and dilute caustic used as solvent in the control of emissions from the complete combustion pathway of the study.

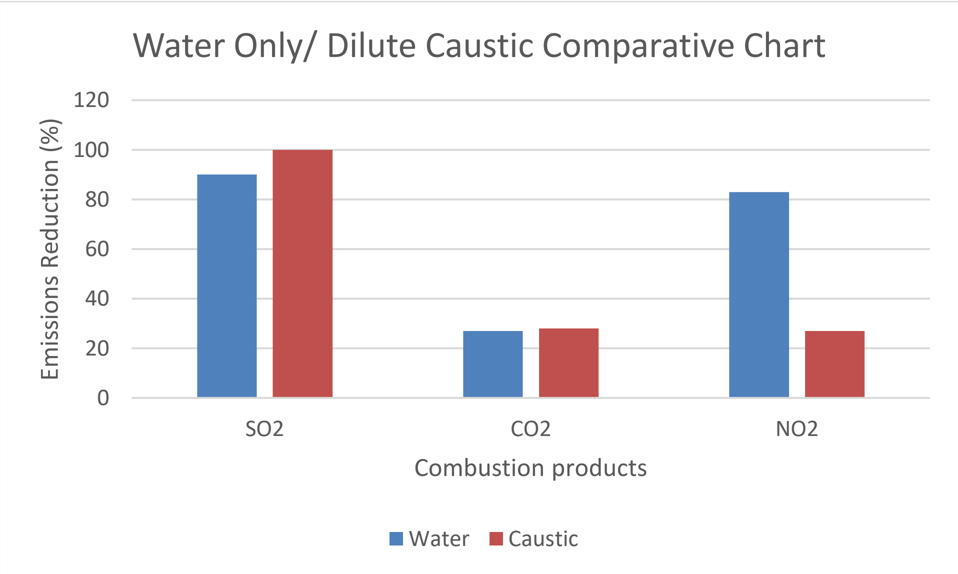

Fig 1: Water Only/ Dilute Caustic Comparative Chart for the complete combustion pathway

In the analyses displayed in Figure 1, it is clear that both water and caustic used as a solvent in the absorption of gaseous emissions is very effective. While 90%

of the SO_2 content in the flue gas was removed only 10% escaped into the environment whereas the caustic used had a profound complete removal of all contents of the SO_2 from the exhaust stream of the combustion stack. Apart from the SO_2, there was other emissions that had differing removal effects with respect to the type of solvent. For CO_2, there was no significant difference between both water and caustic, while the water showed 27% removal of the CO_2, the caustic showed similar effects with only 28% removed from the exhaust stream. There was tangible difference in the effect of the solvents on the removal of NO_2 however, while water demonstrated a high removal efficiency of 83%, using caustic was observed to highlight a paltry 27% removal efficiency. The study's major purpose was a complete removal of SO_2 from the stream. Therefore, the dilute caustic is a better proposition as it gave a better result with respect to the removal of SO_2. It is worthy to note that most combustion burners have effective NO_X controlled capabilities hence the target removal of SO_2 was a given priority in this research.

3.2 Incomplete Combustion Pathway

The data used in these analyses were simulated studies recorded from the studies conducted with the incomplete combustion scheme to generate the performance of the absorber using both water as well as dilute caustic to compare the best option of solvent to use, see [12].

Table 5 represents the simulated results of the emissions removed from flue gases in an incomplete combustion process scheme with compositional changes with respect to the absorber performance occasioned by using water as the solvent.

Table 5: Water alone as the Solvent

Compositional Mole Fraction	Flue Gas	Solvent	Vapour	Liquid
CO	0.260341	0	0.276202	0.000002
NO_2	0.00252	0	0.002631	0.000032
H_2S	0.000237	0	0.000251	0

Table 5 highlights the details of the emissions removal efficiency of using water as the solvent. For CO, there was a rather increase in the composition from 0.260435 to 0.276239 marking a profound 6.05% increase in the CO content in the flue gas to the atmosphere. NO_2 and H_2S also displayed the same effects as there was an increase in the composition of 4.40% and 15.9% respectively. This clearly shows that the option of using water alone as the solvent in the incomplete combustion pathway would be unsuccessful for the cleaning of the emissions exhaust waste stream.

Table 6 shows the simulated conditions of using water as the solvent in the incomplete combustion

Pathway.

Table 6: Material Balance Data of Water alone as Solvent

	Unit	Flue Gas	Absorber	Solvent	Vapour	Liquid
Vapour Fraction		1	1	0	1	0
Temperature	*C*	181	150	30	78.685602	85.629078
Pressure	*kPa*	101.324997	101.324997	101.325	101.324997	121.589996
Molar Flow	*kgmole/h*	1363.0641	1363.0641	1600	1284.77843	1678.28564

Mass Flow	*kg/h*	37432	37432	28824.2	36017.938	30238.2229
Liquid Volume Flow	*m^3/h*	43.208859	43.208859	28.8823	41.791953	30.299235

Table 7 shows the overall performance of the absorber in the emissions removal using caustic with a composition of 1.84%.

Table 7: Dilute caustic as Solvent

Compositional Fraction	Mole	Flue Gas	Solvent	Vapour	Liquid
CO		0.260341	0	0.123257	0.000263
NO_2		0.00252	0	0.00119	0.000086
H_2S		0.000237	0	0.000112	0.000003

Table 7 shows the summary of the effects of the use of the dilute caustic on the overall removal efficiency of the absorber. There was a general removal of all three target harmful emissions from the incomplete combustion pathway. For CO, there was a compositional reduction of 53% with additional reduction of 53% for NO_2 and H_2S.

Table 8 noticeably shows the parameters of different variables at conditions of using dilute caustic as the solvent in the incomplete combustion pathway.

Table 8: Material Balance Data of the Caustic as Solvent

	Unit	Flue Gas	Absorber	Solvent	Vapour	Liquid
Vapour Fraction		1	1	0	1	0
Temperature	*C*	181	150	30	101.381	107.5078
Pressure	*kPa*	101.325	101.325	101.325	101.325	121.59

Molar Flow	*kgmole/h*	1363.07	1363.064	1600	2878.851	84.213
Mass Flow	*kg/h*	37432	37432	29471.31	64734.86	2168.45
Liquid Volume Flow	m^3/h	43.2089	43.20886	29.01156	70.56543	1.65499

Figure 2 shows the comparative analyses of the absorber performance between the utilization of water alone and dilute caustic used as solvent in the control of emissions from the incomplete combustion pathway of the study.

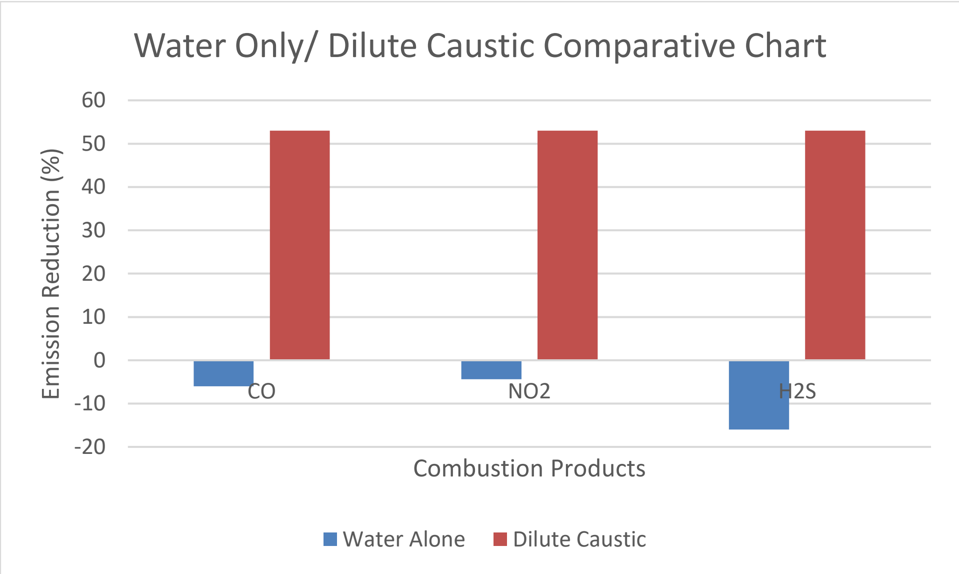

Fig 2: Water Only/ Dilute Caustic Comparative Chart for the incomplete combustion pathway

From Figure 2, it is clear that the purpose of the absorber to cut down emissions generated from the incomplete combustion scenario of the studied combustion system is best achieved using the dilute caustic as the solvent as against using only water for the purpose. For the CO, while there was a significant reduction of up to 53% from the exhaust stream for the caustic used as the absorber solvent. The success however, was not recorded using water alone as the solvent. There was a rather increase of 6% in the content of CO leaving the absorber to the atmosphere. The same scenario played out for NO_2 release where there was also a 53% reduction in NO_2 for the caustic used as the solvent in contrast to that of water used as the solvent that rather decrease the content of NO_2, there was an observation of NO_2 increases of about 4.4%. It was also same with the target emission for this pathway H_2S. For H_2S, there was a reduction of the same 53% for the dilute caustic used as the solvent compared to the use of water alone that recorded a marked increase in the H_2S content released into the atmosphere.

It is obvious that the use of the caustic used as the solvent presented a better emission removal performance compared to using water alone. The caustic presents a better option.

4.0 CONCLUSION

Solvents have proven to be effective in the removal of emissions from combustion streams in absorption systems [3]. Most running combustion units without cleaning systems can retrofit absorption systems to act towards the elimination of harmful emissions from the units [13]. This will deliver excellent air quality within the location of the facility. This improvement of air will have a profound positive health of receptors [14]; particularly the immediate environment where the facility is located.

This study have shown an edge of the dilute caustic over water in the complete removal of the SO_2 from the exhaust stream in the complete combustion pathway, whereas the caustic solvent removed 100% of all SO_2 entrainments, the water only solvent was able to remove 90% with the same conditions. For the incomplete combustion pathway, the caustic solvent also proved veritable as it presented a profound 53% removal efficiency for CO, NO_2 as well as H_2S while the water alone option rather increased the content of the combustion products. This is attributive of the caustic to act as both physical and chemical absorption process. The added neutralization reactions occasioned by the H_2S and SO_2 into sodium salts aids the general conversion of more H_2S and SO_2 from the gaseous stream. While the water only solvent uses the properties of the solubility of the gas into the liquid alone as the principle of operation, the caustic solvent uses chemical reaction as well as solubility of the gas into the liquid as the principle of operation. The choice of caustic over water is aided by other factors.

Caustic has a higher pH than water, it is utilized to increase the pH towards alkaline [15], however since the composition of the caustic is low, it will not lead to caustic corrosion [16], thereby reducing operational cost by way of constant maintenance of the absorber internals. The problem of corrosion will be a major consideration with the choice of materials of construction that the design engineer will pay less attention because of the advantage of using a dilute alkali solvent as the process solvent.

The bulk caustic volume generated from the treatment of demineralized water is neutralized with an acidic medium before channeling to the waste water treatment plant. The cost of the acidic medium is an added operational cost. By using the bulk volume for absorption operation, there is a reduction of operational cost because there shall not be any need for acidic vendor cost.

The water will be best for demineralization treatment utilized as service water or used portable water for use by the plant personnel. It is not wasted but utilized for a different function unlike the bulk caustic that will be wasted if this proposition is not considered. It is on the basis of this result that we recommend the use of caustic over water as it gives better results given the same conditions as exemplified by the data.

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