Retention and transformation system of polluting substances generated by gasoline automobiles

Martin Morales Trejo
National Network of Youth Activities in Science and Technology (la REDMEX), Mexico

Abstract: In Mexico, there are around 49M automobiles; most of them use gasoline generating polluting substances, causing health and environmental issues. In consequence, standards and new technologies have been created to solve the problem; however, they are not entirely efficient or economically feasible in Mexico. Based on that, the objective of this research is to develop an affordable system that retains and transforms the pollutants generated by the gasoline automobile, which through neutralization reactions converts the oxides into harmless salts, and adsorbs the hydrocarbons by an activated carbon porous material.

I measured and calculated the concentration of each post combustion substance emitted by a 4-cylinder gasoline automobile at neutral speed (1200 rpm), then I designed and built a prototype which would be located in the exhaust pipe of the automobile to take advantage of the velocity, temperature and pressure of the gases.

The prototype was settled up in the vehicle's exhaust pipe at neutral speed in a 5-minute test which reduced the CO_2 emissions up to 92.35%, hence generating carbonated salts from oxides (a product that could be reused for industrial purpose). However, it will still be necessary to carry out more experiments in different driving conditions and implement an HC and PM filter in the car to precisely define the efficiency of the system proposed.

1 Introduction

Internal combustion gasoline cars are the most common transportation mode in Mexico and several parts of the world. Its operation based on fuel combustion generates innocuous post-combustion substances such as N_2 (nitrogen), O_2 (oxygen) and H_2O (water). However, it also emits harmful substances, such as **CO** (carbon monoxide), CO_2 (carbon dioxide), NO_x (nitric oxides), SO_2 (sulfur dioxide), **HC** (hydrocarbons) and **PM** (soot particles)[4].

The car is the primary source of polluting emissions in Mexico[2], and responsible for up to 70% of air pollution in Mexico City[4]. However, standards and anti-pollution technologies that have been created for electric and hybrid vehicles are inefficient or economically unaffordable in countries such as Mexico[6].

Based on the Sustainable Development Goal #13 (Climate Action) of the 2030 UN agenda[7], I propose to develop and implement a system that retains polluting emissions from the fuel car and transforms them into harmless products, emitting oxygen and inert gases to the atmosphere. This system will be located in the vehicle's exhaust pipe to take advantage of the substances' constant flow.
The design consists of two processes: one retains part of the oxides, soot particles, and hydrocarbons; and the other one neutralizes the remaining oxides and transforms them into harmless salts, that can be processed and stocked in an official chemical treatment center, or reuse them for an industrial purpose [3,8].

This project complements the work of the anti-pollution car systems (OBS and electrolytic converter), retaining and transforming the compounds to process them as environmentally safe products. The process could benefit the car driver, generating economic savings in technologies and contributing to compliance with environmental standards[1]. It also presents a possible solution to air pollution.

2 Materials and Methods

For this research, an automobile with the following characteristics was selected:

- Sedan of 4 cylinders, 1.6 liters, 106 HP.
- Efficiency: 14.60 Km/L in the city. APPENDIX A.

A pilot test was performed with the engine running at a minimum speed (900-1300 rpm) and the emissions were measured and calculated with a portable gas analyzer APPENDIX B.

With these data, a system for the retention and transformation of polluting substances was designed, which would be located in the exhaust pipe of the automobile to take advantage of the velocity, temperature, and pressure of the gases APPENDIX C.

2.1 Development of the retention and transformation system.

A prototype was adapted to the test car. It has two main processes: **Adsorption of hydrocarbons** and **transformation of oxides into salts**. Therefore, the research was divided into the next stages:

STAGE 1. Neutralization system.
In this system, most of the chemical reactions of retention and transformation of polluting compounds (such as CO, CO_2, NOx, and SO_2) took place. For the retention and transformation of oxides, the system has a basic chemical solution composed of sodium hydroxide and water (NaOH + H_2O). The chemical process is as follows (APPENDIX D):

- The pollutants from the car's exhaust pipe bubble in the chemical solution inside the system; then, the oxides react with water to generate acids in liquid form.
- Subsequently, the acids generated from equations 1, 2, and 3 react with NaOH (base substance with pH 13).
- This acid-base interaction produces a neutralization reaction, generating harmless salts and water.
- If exposure to CO_2 is prolonged, Na_2CO_3 (sodium carbonate) may continue reacting and generating $NaHCO_3$ (sodium bicarbonate).

a. The neutralization system design.
The design seeks to extend the reaction time among the compounds through a *serpentine mechanism* APPENDIX E (Figure 3).

Subsequently to separate the solids from the inert gases (O_2 and N_2) by a negative mechanism APPENDIX E (Figure 4) which precipitates vapors and liquids to retain the generated compounds within the system in a homogeneous mixture where the pollutants are picked up in the form of salts.

- To evaluate the behavior of the fluids inside the neutralization system, simulations were carried out.
- The body and mechanisms of the system were built of 304 stainless steel sheets (3.57 mm) because of its properties such as its affinity with the chemical solution. The total prototype costs are in APPENDIX L.

b. Experimentation with the neutralization system installed in the test vehicle.
For this section, a portable gas analyzer was used, to measure: CO, CO_2, lambda factor, NOx, NO, HC, and O_2. The conditions are described in APPENDIX F.
Based on the above conditions, each of the following tests represents an independent variable.

- **TESTS 1 AND 4. Control tests.** These tests were made to establish a reference of before and after implementing the system, without the prototype connected APPENDIX G (Figure 5).
- **TEST 2.** This test was made to investigate the gases' behavior inside the prototype. The neutralization system was implemented without the chemical solution inside.
- **TEST 3.** This test was made to know the neutralization system efficiency. The neutralization system was implemented now charged with the chemical solution inside APPENDIX G (Figure 6).
  The system was filled with a chemical solution (57.97% NaOH and 42.03% H_2O) to cover a volume of 10.84 cm^3.

c. Efficiency of the chemical solution to transform oxides into salts.
This experiment was carried out in a regulated research institute (UNAM) to check the chemical solution of NaOH + H_2O efficiency to transform CO_2 from the test vehicle into carbonate salts.

STAGE 2. HC and PM filter.
This stage of the research seeks to develop a filter that will be connected between the neutralization system and the exhaust pipe of the vehicle to retain the hydrocarbons, soot particles, and part of the oxides using a filter with an activated carbon porous material. The design and simulations are done, however, its manufacture and implementation are planned for future experiments in test vehicles that require a significant reduction in HC emission levels.

3 Result Analysis and Discussion

3.1 STAGE 1. Development of the neutralization system for oxides.

The design software (SOLIDWORKS) allowed me to develop a detailed model with internal mechanisms as well as simulate the behavior of fluids within the system. The simulations proved that the prototype could be connected to the car's exhaust pipe and it could dissipate the turbulence of the gases and support the speed, temperature, and pressure of the gases without damaging the vehicle's systems APPENDIX H (Figure 7).

The materials used for the construction of the prototype (304 stainless steel & CPVC) interacted according to the process; the pipe supported the gases activity while the steel distributed the temperature throughout the system, which along with the mechanisms, increased the speed (kinetic) of the reactions.[8] APPENDIX I (Figure 8-10).

After connecting the prototype with the NaOH + H_2O chemical solution in it (during test 3), the system was able to reduce 92.35% of total CO_2 emissions and 56.52% CO emissions compared to test 1. On the other hand, when the neutralization system was connected to the exhaust pipe (tests 2 and 3), an increase of the hydrocarbons was observed. APPENDIX J.

The above was the result of slight obstructions generated by the connection of the system to the vehicle, and some straight angles of the prototype (due to manufacturing limitations). Even so, HC rate was within an acceptable level based on the standard NOM-EM-167-SEMARNAT-2017.[1]

3.2 STAGE 2. Development of HC and PM filter.

The design and simulations of the fluids show advantageous conditions to perform the retention of HC and PM. Nevertheless, the filter still needs to be built and incorporated into the test vehicle. It is estimated that with its implementation, it can significantly reduce the emission of hydrocarbons into the atmosphere APPENDIX K.

The previous information leads to the following discussion:

The formation of salts is possible; therefore, these can be discarded in an innocuous way, or processed and reused in several areas such as in the agriculture, pharmaceutical or cleaning industry, by following the principle of mineral carbonation.[10] The prototype can also be adapted to the range of cars with 4-cylinder engines (the test car belongs to this category).

3.3 FUTURE RESEARCH

The next step in this research is to improve the efficiency of the proposed system through an aerodynamic redesign and adapted to the structure of the gasoline car. Likewise, more experiments in several driving conditions (road, traffic, slopes, etc.) are planned to obtain precise and efficient data.

I seek that the process of retention and transformation of polluting substances has a greater scope, based on the Sustainable Development Goal #13 of the United Nations agenda[7]. In consequence, I plan to implement this technology in the entire range of cars with fuel engines (4, 6, and 8-cylinder engines) and then apply it to diesel engines (which have higher NO_X and CO emissions).

On the other hand, the chemical process of oxide neutralization may have high efficiency in industrial chimneys with emissions of oxide gases. To implement our technology, we would make mechanical adaptations.

4 Conclusions

- The objective was achieved by designing and building a prototype that retains the pollutant oxides of a gasoline car and transforms them into harmless salts with the use of neutralization reactions.
- When the prototype was connected to the exhaust pipe of the test vehicle, the emissions were held in acceptable ranges based on NOM-EM-167-SEMARNAT-2017[1].
- The proposed hypothesis was proven correct by the reduction of CO_2 (92.35%) and CO (52%) emissions, and the generation of treatable carbonated salts.
- However, it will still be necessary to carry out more experiments in different driving conditions (road, city, etc.) and implement the HC and PM filter in the car to precisely define the efficiency of the complete system proposed.

References

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Appendix A

Figure 1 shows the test car.

Figure 1. Test car, automatic, gasoline, 4-cylinders, 106 HP, size of 1.6 L.

Appendix B

Table 1. Concentrations	
Parameter	Results ralenti
NO	0.0 ppm
NO_x	0.0 ppm
HC	109 ppm
CO	0.05%
CO_2	14.90%
O_2	0.20%
Lambda	1.006

Based on Table 1, approximately 1142 grams of H_2O are generated, which is equivalent to 6.86%, and the remaining percentage corresponds to the inert gas N_2 (77.9791%).

Appendix C

Figure 2 shows the system location.

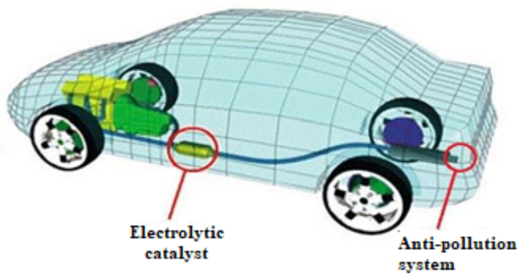

Figure 2. The System location.

Conditions In the exhaust pipe (Table 2).

Table 2. Car conditions	
Parameter	Unit
Velocity	24 k/h
Temperature	110 C
Presion	2.2 atm

Appendix D

Chemical equations.

$$CO_2 + H_2O \rightarrow H_2CO_3 \quad (1)$$

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO \quad (2)$$

$$SO_2 + H_2O \rightarrow H_2SO_3 \quad (3)$$

Chemical products nomenclature: (1): H_2CO_3 = Carbonic acid. (2): HNO_3 = Nitric acid. (3): H_2SO_3 = Sulphurous acid.

$$H_2CO_3 + 2NaOH \rightarrow Na_2CO_3 + 2H_2O \quad (4)$$

$$HNO_3 + NaOH \rightarrow NaNO_3 + H_2O \quad (5)$$

$$H_2SO_3 + 2NaOH \rightarrow Na_2SO_3 + 2H_2O \quad (6)$$

Chemical products nomenclature: (4): Na_2CO_3 = Sodium carbonate. (5): $NaNO_3$ = Sodium nitrate. (6): Na_2SO_3 = Sodium sulfite.

$$Na_2CO_3 + H_2O + CO_2 \rightarrow 2NaHCO_3 \quad (7)$$

Chemical products nomenclature: (7): $NaHCO_3$ = Sodium bicarbonate.

Appendix E

The figures 3 and 4 display the prototype mechanisms.

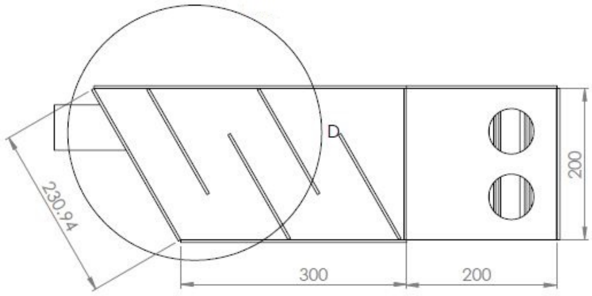

Figure 3. Serpentine mechanism.

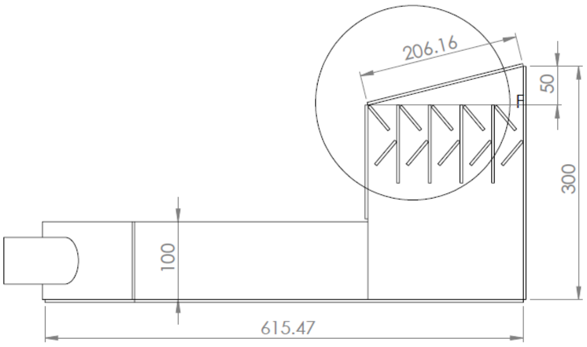

Figure 4. Negative mechanism.

Appendix F

- All tests were made with the test car in minimum gear (900 - 1200 rpm).
- The experimentation was done under the time parameters stipulated by DOF (5 minutes per test); also, the concentrations of the substances were registered every minute.
- For the composition of air, it is considered: 78.09% N_2, 20.95% O_2, 0.93% argon, 0.04% CO_2 and 0.4% water vapor (density- 1.1743 kg / m^3).
- Altitude of 1,820 m above sea level, pressure 101500 Pascals, at a temperature of 27 ℃ and relative humidity of 26%.
- The CO_2 value generated per liter of gasoline used is 2482 grams.
- For calculations, the lambda factor is considered 1 (stoichiometric air-fuel mixture 14.7: 1).
- The connection to the exhaust pipe car was made with a 2" diameter CPVC HS 80 pipe.

Appendix G

Gas analyzer connected to the exhaust pipe (Figure 5).

Figure 5. Tests 1 and 4.

System connection to the exhaust pipe (figure 6).

Figure 6. Test 2 and 3.

Appendix H

Figure 7 displays the resultant variants of pressure, speed, and temperature during the simulation of the fluids with O_2, N_2, and CO_2.

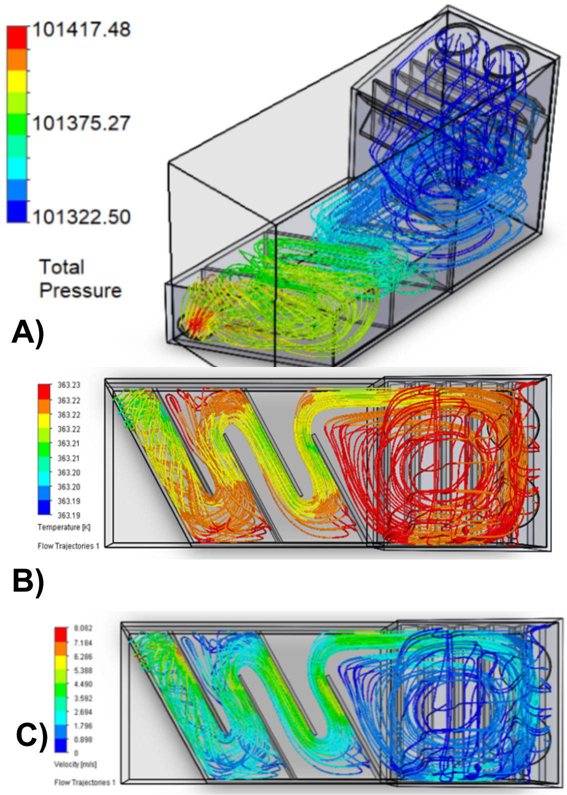

Figure 7. Fluid simulation. Isometric view of the system.

A) Total pressure (Pa). Top view of the system.
B) Temperature (K).
C) Speed (m/s).

Appendix I

Figure 8 illustrates the system external measures in millimeters.

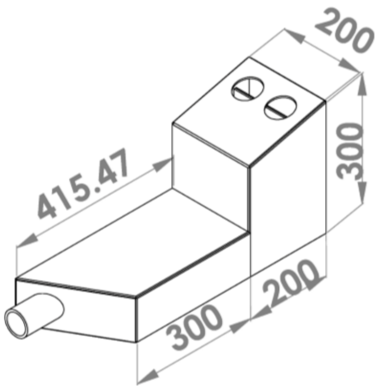

Figure 8. External measures.

Figure 9 shows the internal mechanisms of the system.

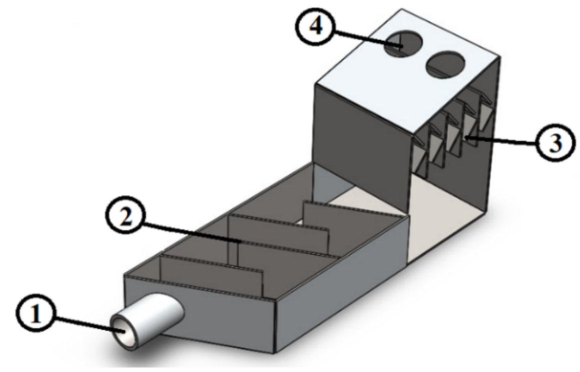

Figure 9. Internal mechanisms.

Where:

1. Neutralization system input.
2. Serpentine mechanism.
3. Negative mechanism.
4. Neutralization system output.

The steel pieces were welded together based on the previous design. Figure 10 shows the internal mechanisms of the neutralization system and the developed prototype.

Figure 10. Developed prototype.

Appendix J

The following charts show the average concentration of each compound based on the five-minute tests. It is a comparison between the results of each test. SO_2 and NO_X data were not obtained because the gas analyzer used for the tests did not detect any emissions.

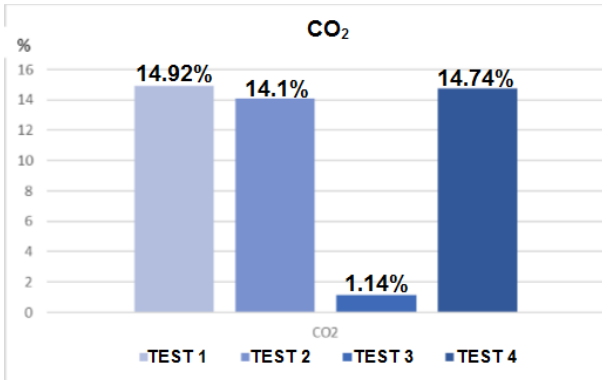

Figure 11. CO_2 emissions.

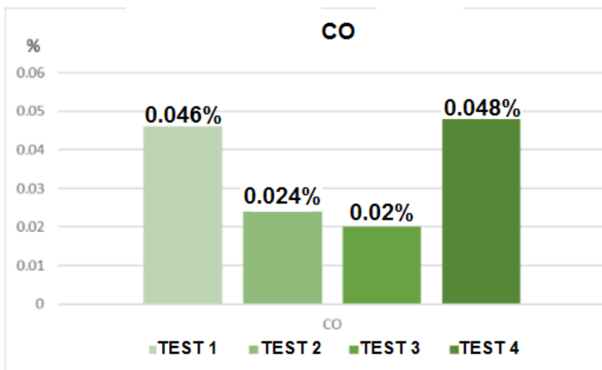

Figure 12. CO emissions.

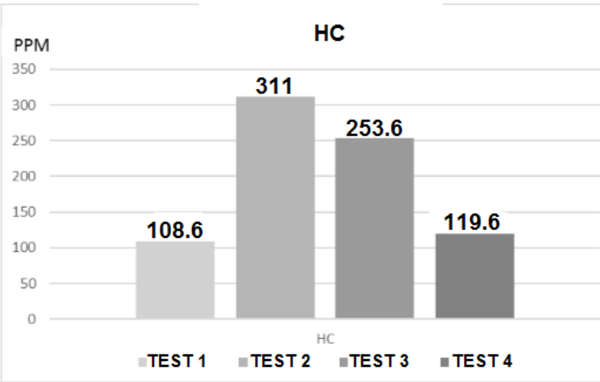

Figure 13. HC emissions.

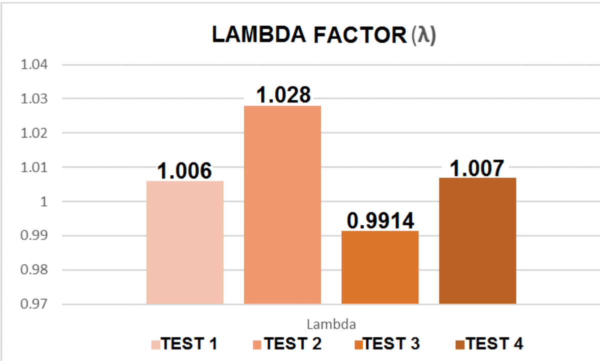

Figure 14. Lambda factor.

Tables 3 - 6 show the concentration of each post combustion substance emitted in different conditions determined by the tests 1 - 4.

Table 3. Test 1					
	Minutes				
Substances	1	2	3	4	5
CO	0.04%	0.05%	0.05%	0.05%	0.04%
CO_2	14.90%	14.90%	15.00%	14.90%	14.90%
Nox	0 PPM	0 PPM	0 PPM	0 PPM	0 PPM
HC	107 PPM	110 PPM	109 PPM	109 PPM	108 PPM
λ	1.005	1.006	1.007	1.006	1.006

Table 4. Test 2					
	Minutes				
Substances	1	2	3	4	5
CO	0.02%	0.03%	0.02%	0.02%	0.03%
CO_2	14.10%	14.10%	14.10%	14.10%	14.10%
Nox	0 PPM	0 PPM	0 PPM	0 PPM	0 PPM
HC	229 PPM	335 PPM	332 PPM	330 PPM	329 PPM
λ	1.023	1.027	1.025	1.031	1.034

Table 5. Test 3					
	Minutes				
Substances	1	2	3	4	5
CO	0.03%	0.02%	0.03%	0.01%	0.01%
CO_2	1.30%	1.20%	1.20%	1.00%	1.00%
Nox	0 PPM	0 PPM	0 PPM	0 PPM	0 PPM
HC	272 PPM	284 PPM	214 PPM	260 PPM	238 PPM
λ	0.971	1	1	0.993	0.993

Table 6. Test 4					
	Minutes				
Substances	1	2	3	4	5
CO	0.05%	0.05%	0.05%	0.04%	0.05%
CO_2	14.50%	14.60%	14.80%	14.90%	14.90%
Nox	0 PPM	0 PPM	0 PPM	0 PPM	0 PPM
HC	155 PPM	121 PPM	109 PPM	107 PPM	106 PPM
λ	1.008	1.007	1.007	1.006	1.007

Appendix K

Development of the HC and PM filter to retain the pollutants (Figure 15 & 16).

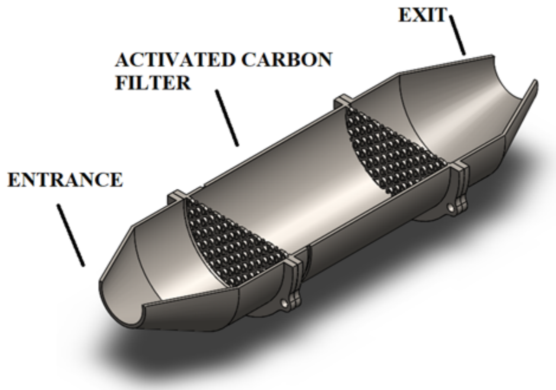

Figure 15. Design of the HC and PM filter.

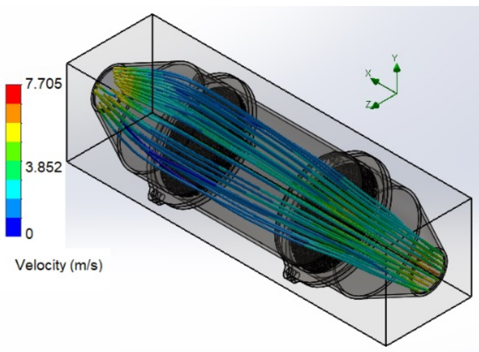

Figure 16. Fluid velocity simulation (m/s

Appendix L

Prototype costs (Table 7, 8 & 9).

Table 7. PROTOTYPE MATERIAL BUDGET					
No.	Concept	Quantity	Unit	Unit Price (USD)	Sub Total (USD)
1	STAINLESS STEEL SHEET 8FT x 11FT CAL. 10	0.5	piece	287.54	143.77
3	ELECTRODE WELDING 308L	0.8	kilogram	15.03	12.024
5	CPVC PIPE 2 '' 6.10 MTS SCH 80	1.1	meter	12.44	13.684
6	CPVC ELBOW 45 DEGREES 2'' SCH 80	2	piece	4.15	8.3
8	HIGH TEMPERATURE GLUE	1	piece	4.15	4.15
9	VULCANIZED NEOPRENE TAPETE 100CM x 50CM	0.4	meter	5.7	2.28
				Sub Total	184.208
				16% IVA	29.47328
				TOTAL	**213.68128**

Table 8. PROTOTYPE LABOR BUDGET					
No.	Concept	Quantity	Unit	Unit Price (USD)	Sub Total (USD)
1	STAINLESS STEEL SHEET CUTTING CAL. 10	10.2	meter	9.13	93.126
2	STAINLESS STEEL SHEET SOLDERING	1	kilogram	25.88	25.88
3					0
				Sub Total Material	121.8
				16% IVA	19.488
				TOTAL	**141.288**

Table 9. RAW MATERIAL BUDGET					
No.	Concept	Quantity	Unit	Unit Price (USD)	Sub Total (USD)
1	Caustic Soda - Sodium Hydroxide	10	kilogram	2.49	24.9
2	Water	30	liter	0.001	0.03
3					0
				Sub Total Material	24.93
				16% IVA	3.984
				TOTAL	**28.9188**