The Study and Design of a System for the Capture of Diesel Soot Particles through the Chemical Treatment of Exhaust Gas

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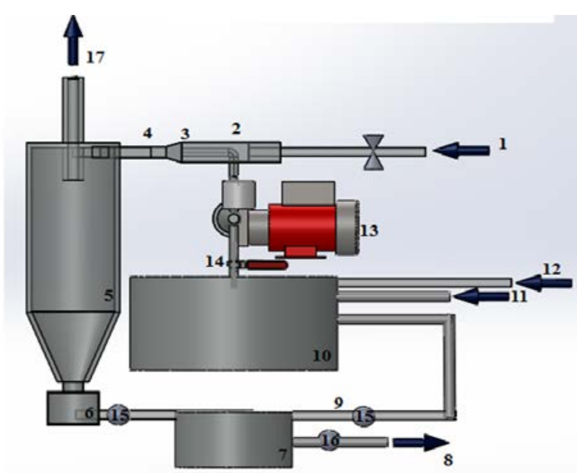
Abstract :The research aims to study and design a system of capture of the soot particles of combustion gases generated by diesel power generators through a new design for the HydroCyclone in addition to the chemical treatment of gas in the simplest ways and the lowest cost and wastewater. The efficiency of soot capture is around 90% from the total mass of soot and with minimum flow rate of 0.62-liter liquid / m^3gas compared to the values recommended globally.

Keywords: Chemical Treatment, Diesel Soot Particles, flow rate of liquid to gas.

1 INTRODUCTION

THe diesel soot particles emissions from the exhaust gas stream are often captured according to the traditional filters technology (DPFS) Diesel Particulate Filters , which has demonstrated a high efficiency of up to 99% for particles with a diameter greater than 4 μm [12], mainly based on filter quality and lifetime Operation, engine size and others. On the other hand, these filters have low operating life due to their ease of rupture as well as problems related to reactivation and reuse of the filter. More importantly, the filters are low efficient for capturing fine particles [15]. Dilip [6], studied the technique of re-heating the filter of stainless steel for reuse, concluded the need for additional heat, which requires high energy (greater than 3KW) in addition to the low pressure in the filter, which requires increasing the work of the engine pump and thus increase in diesel consumption.

Because of the urgent need for long-term soot particlees capture technology, the following system designed as follows:



1- Diesel exhaust gas ,2- venturi , 3-One spray flask ,4- inlet of hydrocyclone , 5- hydrocyclone, 6- waste water container , 7- filtratin tank , 8- soot removal for industry , 9 – pump wastewater to basic wash liquid tank , 10 – wash liquid tank , 11 – water suply , 12- alkaline liquid, 13- high pressure water pump , 17 – clean gas , 15,16 pumps.

A method and apparatus for removing soot from an exhaust gas stream wherein the exhaust gas stream is contacted with higly pressure liquid strem (mist) at least 140 bar to produce a substantially liduid saturated exhaust gas stream, particles and droplets in the water saturated gas stream then are separated in hydrocyclone Under the influence of gravity and centrifugal forces.

We provide a good mixing of gas with the washing liquidwithin the Venturi constriction to match diameters of the washing alkaline liquid which not exceeding 0.3 micrometer with the mean diameter of the soot particles, which estimated at 0.2 micrometer.

The filtration system produces a cooled gas stream free partially of soot and the combustion gases.

The waste liquid is filtered and reused in the washing option, in the wash liquid tank where modified and raised the pH values.

In this paper, we will present the method of selecting the optimal design for cyclon with the results of chemical treatment in soot capture in hydrocyclone.

1 CHOOSING THE BEST DESIGN FOR CYCLONE:

There are several standard eng designs for Cyclone Separator CS. These designs differ mainly between the ratio of cyclon dimensions to the cyclon diameter or diameter of the outer vortex. The best design selected according to the purpose of the cyclone either for the process of production or for use in the purification of the resulting gases and therefore the basic criterion is the effectiveness of removal [10].

The study based on the cyclone with tangential inlet fig.2

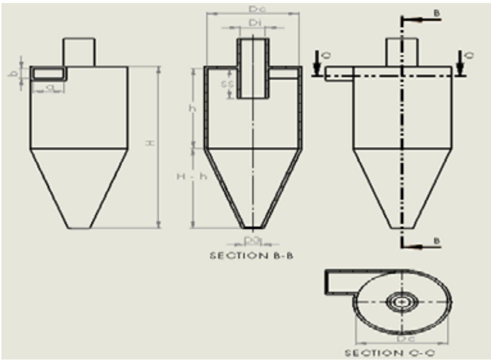


Fig.1. the cyclone separator dimensions

The cyclone design according to the geometrical parameters:
1. The body diameter (barrel diameter) D_c.
2. The total height of the cyclone (from roof to dust exit) H.
3. The vortex finder diameter Di.
4. The vortex finder length (from the roof of the separation space) SS.
5. The inlet height a.
6. The inlet width b.
7. The height of the conical section hc or the height of the cylindrical section h.
8. The cone-tip diameter (dust exit diameter) D_3.

Foue models compared to choose the best designe of CS:
- Muschelknautz and Kambrock] 17].
- Barth [21].
- Mothes-Löffler [22].
- Salcedo [22, 23].

Table (1) shows the design criteria adopted in the mathematical models used to calculate the removal efficiency of the soot particles produced by the diesel engine:
Table 1:

	a/Dc	b/Dc	D3/Dc	Di/Dc	H/Dc	SS/DC	h/Dc
Muschelknautz and Kambrock	0.5	0.333	0.433	0.333	1.667	1.133	0.5
Barth	0.53	0.13	0.33	0.33	2.58	0.73	0.69
Mothes-Löffler	0.333	0.333	0.433	0.333	1.667	1.333	0.5
Salcedo	0.11 -0.17	0.11-0.17	0.14-0.18	0.1-0.17	3.9-4.3	0.5-0.54	2.2-2.7

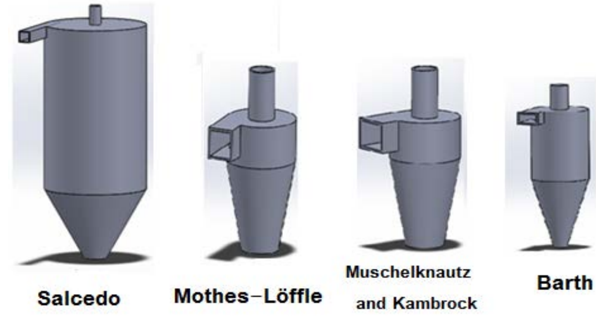


Fig. 2 Representative dust cyclone designs.

Assuming the diameter of the vortex finder for the four cyclones is uniform (D = 0.02 m) .
Table .2 the four cyclone designs:

	a	b	D3	Di	H	SS	h	Dc
Muschelknautz and Kambrock	0.03	0.02	0.03	0.02	0.1	0.07	0.03	0.06
Barth	0.03	0.01	0.02	0.02	0.1	0.04	0.04	0.06
Mothes-Löffler	0.02	0.02	0.03	0.02	0.1	0.08	0.03	0.06
Salcedo	0.02	0.02	0.04	0.02	0.5	0.07	0.35	0.16

The experimental study was applied to the Perkins diesel engine (120KW / 150KVA Perkins generator). Table 3 shows the output of the diesel engine:

Table .3 exhaust gas from diesel engine:

motor load	Tgas	d [15]	gas density	gas viscosity	Q_{gas}	dust loading	dust density [15]
%	C°	μm	kg/m³	Pas	m³/h	mg/m³	kg/m³
75-80	250-340	0.2	0.67	2.81E-05	30	1200	500

The following diagram fig.3 shows the theoretical of the cyclones capture of the soot diesel particles after applying the mathematical range using the four mathematical models. The equations for each mathematical model applied separately due to the difference in the diameter distribution of the molecules (d μm).

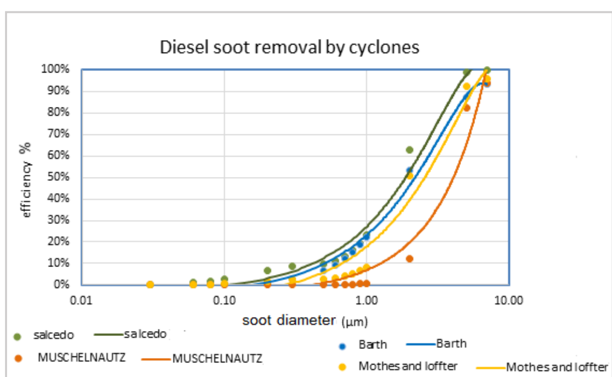


Fig.3 Theoretical Diesel Soot Particles Collection Efficiency by cyclones.

The Salcedo design gives the highest efficiency of diesel particle capture compared to the mathematical models.
The Salcedo design predicts the capture efficiency of no more than 5% for the median diameter of diesel soot particles (d = 0.2μm).
The numerical simulation of cyclones flow carried out and predicted the soot collection efficiency using CFD Computational Fluid Dynamics.
The computer simulations of each design applied individually as shown in fig. 4:

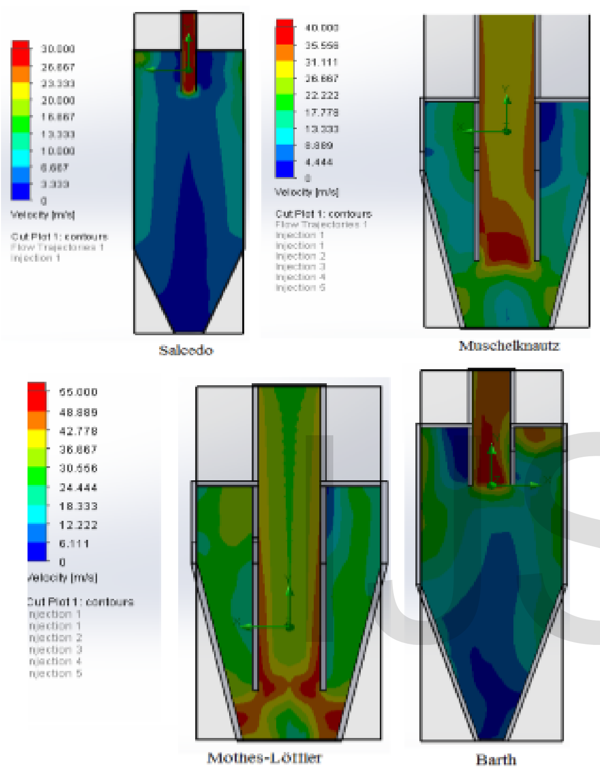


Fig.4: The distributed velocity in the cross section of each cyclone.

The maximum velocity ranges from 30 to 55 m/s in the four designs. Salcedo design gives the lowest entry speed of the exhaust gas. This is a good indicator because low speeds maintain the soot agglomeration chain and prevent its disintegration.

Figure 5 shows the results of the Fluid Flow Simulation Software (CFD). The Salcedo model design achieves high capture efficiency ranging from 8% to 25% for the diesel soot particles, most of whose diameter ranges from 1-0.08μm.

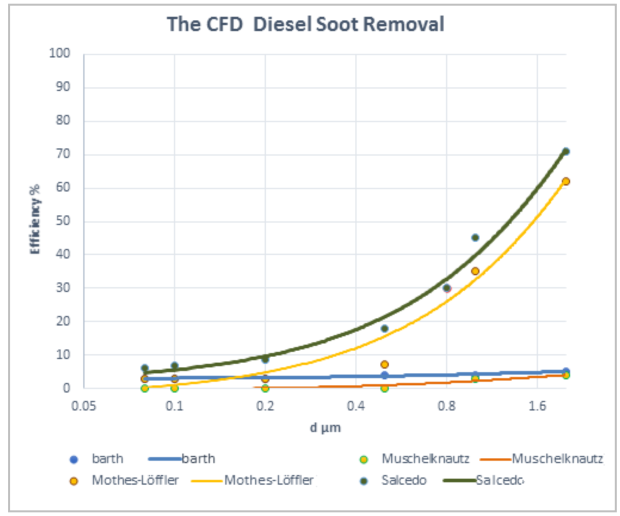


Fig.5: CFD predictions soot removal efficiency

The Theoritical study and Computational Simulation CFD confirmed that the design proposed by Salcedo achieves the highest efficiency of the capture of the diesel soot particles, which adopted in the pilot study. Figure 6 shows the Cyclone Separator dimensions:

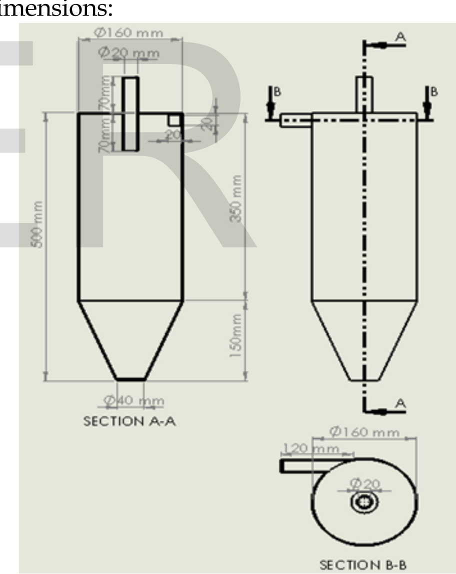


Fig.6: the Cyclone Separator dimensions

The venturi designe in fig .7:

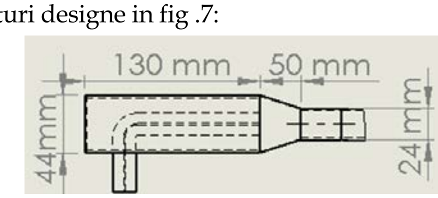


Fig .7 the venturi dimentions

2- EXPERIAMENTAL STUDY:

The washing liduid pumped using a high-pressure pump: Operating pressure 140 bar.
Ons Spray flask used in the inlet of venture ,is made of stainless steel, spray angle: 60 ° C.

The pH of the wash water is increased by (14-26 - 33 - 40%) for the pH of the drinking water using $Ca(OH)_2$ calcium hydroxide solution.

Fig .8 shows the effectiveness of HydroCylone soot removal after injection with a stream of liquid spray at a maximum engine loading level of about 80%, equivalent to 1200 mg soot/m^3,with the pH change of washing water and the ratio of mist to exhaust gas :

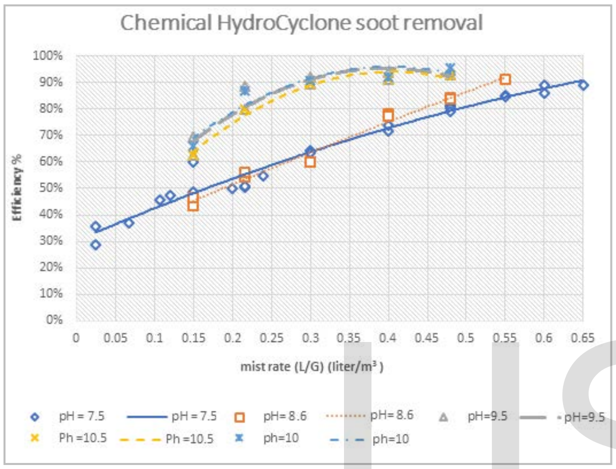


Fig.8 Chemicla HydroCyclone Soot Removal.

Chemical treatment as a result of increasing the pH of washing water with a lime-based solution increased the efficiency of soot removal by increasing the alkalinity of washing fluid [8.6 to 10.5] to an increase of [4-16%] for loading rate (0.48 liter / m^3) compared to wet filtration (washing by drinking water pH=7.5).

The efficiency of the diesel soot capture in the HydroCyclone is increased with the increase of alkaline washing fluid and the efficiency of the collection of soot exceeds 90%. Table 4 summarizes the area of comparison between the capture of soot in washing with drinking water and chemical treatment:
Table .4:

	mist rate (liter /m3)	pH washing liquid	efficiency %
pH= 7.5 (drinking water)	[0.48 – 0.15]	7.6 -7.5	[79 – 48]
chemical treatment	[0.48 – 0.15]	8.6	[83 – 49]
	[0.48 – 0.15]	9.5	[94 – 62]
	[0.48 – 0.15]	10	[95 – 66]
	[0.48 – 0.15]	10.5	[91 – 69]

3- CONCLUSION:

The study was applied to the Perkins (120KW / 150KVA Perkins generator) diesel engine for a high load rate of 1200 soot mg /m^3.
The design of the Hydrocyclone includes both cyclon design and Venturi contraction design.
According to the theoretical and computational studies using CFD, design by model Salcedo gave the best soot capture efficiency, which does not exceed 5% compared with other mathematical models: Barth ,Mothes-Löffler ,Muschelknautz and Kambrock .

Wash the gas with a stream of mist using a single spray flask with at least a high pressure 140bar.

The liquid washing pH was increased and the results summarized as follows:

The results of the new HydroCyclone design resulted in the soot capture efficiency of at least 90% for wet filtration (washing with drinking water mist) at a flow rate of (0.62 liter / m^3) Below the universally recommended values (1.7 - 0.67 liter water / m^3).

Chemical treatment within the new HydroCyclone design resulted in a higher capture efficiency than water filtration with lower values of washing liquid.

4- RECOMMENDATIONS:

- Filterate the wastewater and reuse in closed –cycle.
- Using the soot in the tire industry.
- Determination of the efficiency of combustion gases absorption in HydroCyclone after chemical treatment.

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