Design, Fabrication and Experimentation of Aqua Silencer for Diesel Genset

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Abstract Air pollution is rising day by day and it is a serious threat to society and the environment. One of the main reasons for air pollution is exhaust gas emission from automobiles and industries. To reduce air pollution from the exhaust emission a device is introduced called Aqua silencer. With the help of this air is purified from the pollutants such as Carbon monoxide, Unburnt Hydrocarbons, Oxides of Nitrogen, etc. and it also reduces the damping noise. In this present paper, designing, fabrication, and testing of modified aqua silencer for the diesel Genset are discussed. Moreover, testing was conducted for three different conditions of silencers and the result shows that the exhaust emission of the aqua silencer with and without lime water reduces considerably.

Keywords Aqua silencer · Air pollution · Emission · Pollutants · Diesel engine

1 Introduction

At present, air pollution is a serious problem faced by the environment. The main sources of air pollution are Automobile, Power generators, Industrial and domestic fuel consumption, etc. and among all of these automobiles cause more air pollution in the atmosphere. Also, to admit the fact that these industries have been the major source of livelihood for a large number of common people throughout the world. The exhaust gases from the mentioned industries are polluting the environment rapidly,

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which ultimately deplete the ozone layer of the atmosphere, which inturn become a cause of natural disasters in the upcoming years. In recent years, the world is facing the scarcity of fossil fuel and parallelly the excess utilization of fossil fuels in industries causes a tremendous amount of air pollution. But, nowadays the diesel engines are playing an important role in transport industries and as well as in other industries like agriculture, minning, etc. Considering, the available fuel resources and the present technological developments the diesel fuel is evidently indispensable. In general, the feeding of fuel is an index for finding out the economic asset of any country. In spite of this, no one can ignore the lethal effects of the exhaust gases, which vanishes the cleanliness and freshness of our environment. Automobiles contribute dangerous pollutants like Unburnt Hydrocarbons (UHCs), CO, Pb, CO_2, SO_2 and NO_x etc. into the atmosphere. These gases are very harmful to the environment and for human health. So, serious steps must be taken in the direction to save the environment from degradation and conservation of energy from exhaust gases. The present work is an effort in this direction, which mainly deals with emission control, noise pollution & with the extra arrangement for the conservation of energy from the exhaust gases.

2 Literature Review

This section includes the International and National authors reported works related to present experimental investigation. Rawale et al. [1] have conducted the trails on aqueous ammonia in Silencer to remove the CO_2, SO_2 and NO_x from exhaust gases of I. C. Engines. It was observed that ¼ part of carbon-dioxide is reduced from the exhaust gases compared to the ordinary silencer. Also, no such improvement in reduction was observed for other gases from the exhaust gases. Hatami et al. [2] used SST k–ω and RNG k–ε model to recover the engines exhaust waste heat using the finned type heat exchangers numerically. Two HEXs is used in a SI and CI engine with H_2O as a cold fluid, and with a mixture of 50% H_2O and 50% ethylene glycol as cold fluid. Results show that the viscous models have the best heat recovery and the experimental results are better than the RSM results. Zhang et al. [3] have done the mathematical modelling on diffused pneumatic silencer to know the flow structure and gas flow through the interior and exterior of the silencer to understand the mechanism of the silencer's noise reduction. The porous media model and the Darcy–Forchheimer principle is applied to the model and found that the experimental result fits well with the numerical results. Mankhiar et al. [4] used a combination of titanium nano-tubes and charcoal in aqua silencer to overcome the drawback of charcoal and the reduction in noise pollution. Patel et al. [5] and Sharma et al. [6] worked on aqua silencer for two-stroke engine using water as a fluid and activated carbon pallets instead of charcoal for reduction noise pollution and emission control and observed the reduction in emissions. The researchers developed the aqua silencer [7–25] using adsorption technique with charcoal, lime water for automobile, diesel engine and portable twin filter aqua silencer found that the reduction in noise and

emission in the I. C. engines. The authors have conducted review [26–31]on reported studies of aqua silencer and suggested that it should be utilized in mass quantity in the engines so as to minimize the noise and air pollution. Mohamed et al. [32] analyzed the back pressure fault in motorcycles using new wedge system and accordingly found the exhaust gas back pressure using ANSYS software to which the non-return valve to be designed and to be used. After the extensive study of reported works, it is clear that no discussion was included in finding the water quantity for moving vehicles, which is to be overcome! Also, few researchers are focused on with and without lime water, emission analysis for the various engine load and, the low power consumption from the exhaust gases and also from the activated carbon charcoal. The current research paper experimentally investigated the effect of lime, engine load based emission analysis with the low power generation system, i.e. Vapour adsorption with the use of high-pressure exhaust gases of the diesel genset engine.

3 Calculation of Dimensions for Designing

The Diesel engine was considered for further dimensions calculation for Aqua Silencer. The consider parameters and its dimensions are Bore (D)—0.073 m, Stroke (L)—0.0795 m, No. of Cylinder—3, Engine Power—67.07 bhp @ 6200 rpm, Max. RPM (N)—8000 rpm, Transmission Loss Noise Target—30 dB.

1. **To find Fundamental Frequency**:

$$\begin{aligned}\text{Cylinder Firing Rate(CFR)} &= 8000/120\,(\text{for } 4-\text{cycle engines}) = 66.67\ \text{Hz}\\ \text{Engine Firing Rate(EFR)} &= \text{No. of Cylinder} \times \text{CFR}\\ &= (3 \times 66.67)\ \text{Hz} \approx 200\ \text{Hz}\end{aligned}$$

2. **Muffler Volume Calculation**:

$$\begin{aligned}\text{Swept vol.}(V_s) &= \left(\pi \times D^2 \times L\right)/4\\ &= \left(3.14 \times 0.073^2 \times 0.0795\right)/4\\ &= 3.32569 \times 10^{-4}\ \text{m}^3\\ &= 0.33261\\ \text{Vol. of cylinder}(V) &= \text{No. of cylinder} \times V_s\\ &= 3 \times 0.3326 = 0.9978 \approx 11\end{aligned}$$

3. **Silencer Volume (V_m)**:

$$\begin{aligned}&= \text{Factor}^* \times \text{vol. of the cylinder}(V)\\ &= 40 \times 11\\ &= 40{,}000\ \text{cc}\end{aligned}$$

*Assumed factor = 40, i.e. for the volume of silencer the factor should be at least 30 to 40 times to the volume to be considered. Volume can be changed considering space constrain.

4. **Internal Configuration of Muffler and Concept Design**:

$$\begin{aligned}&\text{Vol. taken by Air filter and Perforated tube}\\&= \left(\pi \times 0.06^2 \times 0.41\right)/4\\&= 1158.66\,\text{cc}\end{aligned}$$

where, dia. of air filter = 0.06 m, Length of air filter = 0.41 m.

$$\begin{aligned}\text{Vol. taken by inlet pipe} &= \left\{\pi \times 0.036^2 \times (0.15 + 0.044)\right\}/4\\&= 197.4\ \text{cc}\end{aligned}$$

where, dia. of inlet pipe = 0.036 m, Length of inlet air pipe of exhaust pipe = (0.15 + 4.4) m.

Now, Vol. taken by a charcoal layer of 0.03 m thickness, around the air filter of dia. 0.06 m

$$\begin{aligned}&= \left[\pi \times \left\{(0.06 + 0.03)^2 - 0.06^2\right\} \times 0.41\right]/4\\&= 1448.32\,\text{cc}\\&\text{Total vol. needed for cylinder}\\&= (40{,}000 + (1158.66 + 197.4) + 1448.32)\\&\approx 42804\,\text{cc}\end{aligned}$$

Now, after studying various cylinder dimensions, we selected the length of the cylinder as twice of the dia. of the cylinder, $L = 2\text{D}$.

$42{,}804 = (\pi \times D^2 \times L)/4$ or

$$\begin{aligned}42{,}804 = \left(\pi \times D^2 \times 2D\right)/4 = 42{,}804 \text{ or}\\D^3 = 27{,}263.69\,\text{cc or}\\D = 30.09 \sim 0.3\,\text{m}\\\text{Therefore, } L = 2D = 2 \times 0.3 = 0.6\,\text{m}\end{aligned}$$

As per the calculated dimension for Aqua silencer and the available dimension for a tail pipe of considering model is 0.036 m and accordingly, the 2D model is designed as shown in Fig. 1. The details dimensions considered for fabrication are postulated in Table 1 along with the selection of material.

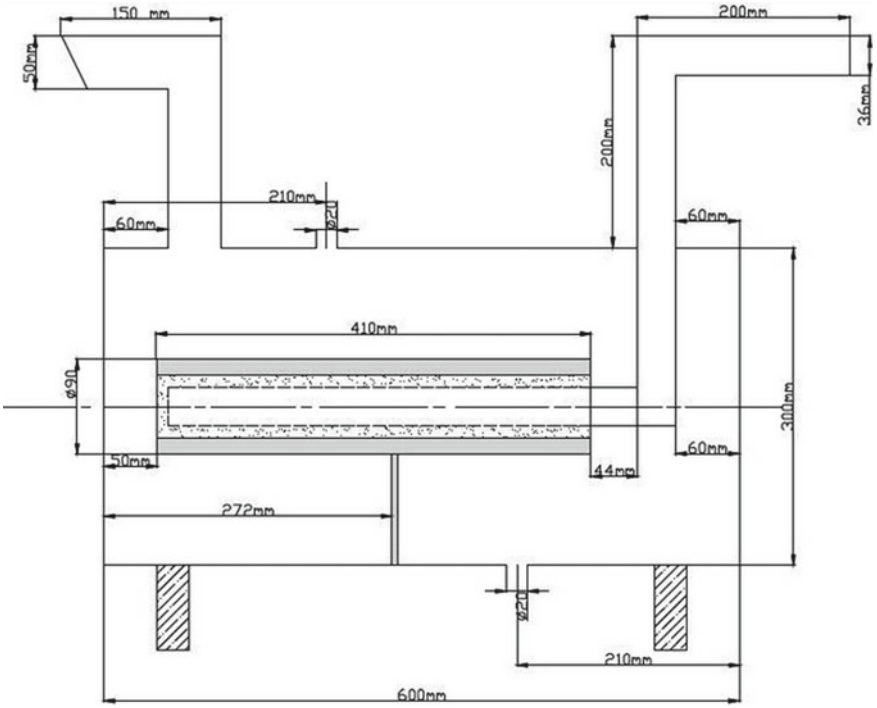

Fig. 1 Free-hand sketch of aqua silencer setup showing different parts dimension

Table 1 Dimensions used for designing the different parts for aqua silencer

Different parts	Length, m	Dia., m	Thickness, m	Proposed material
Outer shell	0.6	0.3	0.005	Cold rolled stainless steel
Perforated tube	0.4	0.036	0.004, 0.006 and 0.009	Stainless steel pipe
Water inlet/Outlet port	–	0.036	–	Stainless steel pipe
Exhaust port	–	0.050	0.005	Stainless steel pipe
Air filter	Polypropylene (product name)—Purerite PS-05 (5 μm)			

As per Fig. 1. Overall 2D drawing has been prepared, which gives a detailed study about the parts with their dimension. To fabricate the Aqua silencer different parts, the raw material has been purchased and fabrication work carried out at Central workshop, National Institute of Technology Agartala. Before the fabrication complete aqua silencer has been designed in Solid Works 2018 version, as shown in Fig. 2.

Figures 2 and 3 shows the outer shell, inlet and outlet exhaust section, water inlet and outlet port, the internal part of the perforated tube packed with activated carbon

Table 2 Engine exhaust results for normal silencer

Load (kg)	Time take to fuel consumption for 10 ml (sec)	Engine rpm	Vol % of CO	HC, ppm	Vol % of CO_2	Vol. % of O_2	NOx, ppm
0	21	1482	0.20	30	2.70	17.59	180
2	20.54	1443	0.13	50	3.50	16.22	260
4	19.93	1430	0.09	38	5.01	15.85	340
6	19.10	1422	0.07	62	5.97	16.33	420

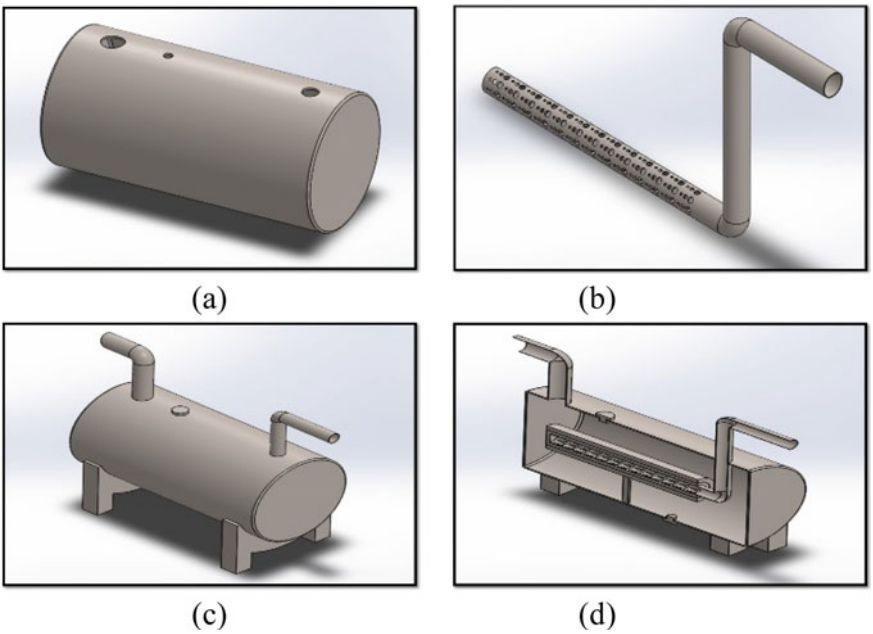

Fig. 2 3D design of **a** ouert shell, **b** perforated tube, **c** 3D view of aqua silencer, and **d** cut section of the aqua silencer

charcoal inside the tube and, also the polypropylene air filter in front of the perforated tube along with the stand arrangement.

4 Experimental Method

The experiments are conducted on a single-cylinder diesel engine test rig (Kirloskar Engine Ltd. make) as shown in Fig. 4 along with digital measuring parameters

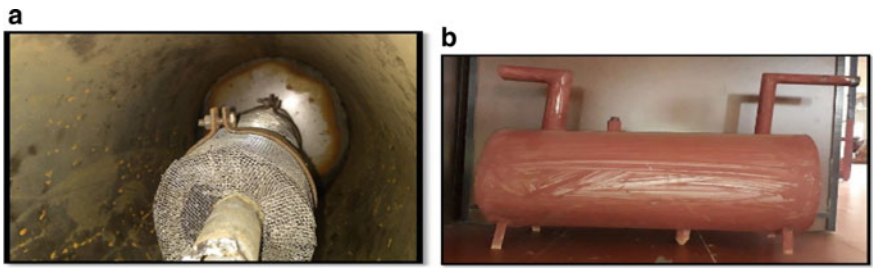

Fig. 3 Fabricated parts **a** clamp holding the perforated tube, polypropylene air filter and the charcoal layer together, **b** the final product Aqua Silencer along with the supporting stands

(a)

(b) (c)

Fig. 4 **a** Single-cylinder four-stroke diesel engine test rig, **b** digital display of test rig and **c** smoke analyser

displays (in Fig. 4b, and to assess the feasibility of the fabricated Aqua silencer. To measure the pollutants, a Smoke Analyser (AVL make) is attached in the test rig, as shown in Fig. 4c. As this is the stationary engine, the water quantity in the aqua silencer has been overcome.

The experimental procedure is followed as mentioned in reported studies [1, 4, 7] with three different conditions of silencers (a) for a conventional silencer and (b) aqua silencer without lime water, and (c) aqua silencer with lime water at 0–6 kg of engine load. Inside the tank, water is used to dissolve the unburned hydrocarbons

(UHCs). By this method, the UBHC, even if it is in glowing conditions, it is dissolved in water; thereby it is suppressing a spark, which could escape from the engine to the inflammable environment. Hence, the chemical reaction is taking parts when the exhaust gases are passing through the aqua silencer are as follows.

$$NO_2 + 2H_2O \rightarrow 2HNO_3(\text{Dilute}) + 2HNO_2 \quad (1)$$

$$Ca(OH)_2 + 2HNO_2 \rightarrow Ca(NO_3)_2 + 2H_2O \quad (2)$$

$$Ca(OH)_2 + 2HNO_2 \rightarrow Ca(NO_2)_2 + 2H_2O \quad (3)$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (4)$$

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca\,(HCO_3)_2 \quad (5)$$

$$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O \quad (6)$$

$$CaCO_3 + H_2O + SO_2 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O \quad (7)$$

$$4NO_2 + 2H_2O \rightarrow 2HNO_3 + 2HNO_2 \quad (8)$$

$$CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O \quad (9)$$

$$CaCO_3 + 2HNO_2 \rightarrow Ca(NO_2)_2 + CO_2 + H_2O \quad (10)$$

The NO_2 is reacting with dissolved in the water and gives the Nitrous & diluted Nitric acid, as shown in Eq. (1).Then, Nitrous and Nitric acid will react with the lime water present in the scrubber and gives the Calcium Nitrate, as shown in Eq. (2–3).Also, the lime water will react with CO_2, which is present in the exhaust gases and will precipitate the $CaCO_3$. Thus, when the $CaCO_3$ further exposed to CO_2, $Ca(HCO_3)$ will be precipitated, as shown in Eq. (4–5). Further, the SO_2 also react with the lime water, as shown in Eq. (6) will precipitate calcium carbonate and reacts further to gives the $CaSO_3$ and CO_2 as the byproduct as shown in Eq. (7). Because CO is chemically balanced, negligible vol. (0.2%) and stable, it won't readily react with water or any bi-products, which is resulted from the above reactions. Even though the lime water absorbs a part of the oxides of N and C, the time constraint for the reaction to take place allows a considerable percentage for emission. But, the stone container, which is provided with limestone ($CaCO_3$) encourages the chemical reaction further in the presence of hot water/steam, which evaporates from the scrubber tank due to high exhaust temperature. Because of the little percentage of

SO_2 presence, the liberation of CO_2 is very less. But the liberated CO_2 will again combine with $CaCO_3$ to form $Ca(HCO_3)$ as shown in Eq. (5).The presence of hot water possibly reacts with oxides of nitrogen, as shown in Eq. (8). The $Ca(NO_3)_2$ and $Ca(NO_3)_2$ are the bi-products and carbon-dioxide is liberated, as shown in Eq. (9–10). The liberated CO_2 again combines with $CaCO_3$ to form $Ca(HCO_3)$ (Eq. 5). In this way, the actual reaction takes place inside the aqua silencer to control the emission and noise pollution.

5 Result and Discussion

The exhaust gas passed through the exhaust pipe from the diesel engine, and the nozzle part of the Smoke Analyser is placed at the exhaust port of the engine, and the readings are noted down.

1. **Observation Without Aqua Silencer**

The single-cylinder four-stroke Diesel Engine shows the emission parameter values for the different loads of the engine, as shown in Table 2.

It is observed that as the load, increases the carbon monoxides increase along with the unburnt HC, CO_2 and NO_x.

2. **Observation with Aqua Silencer (Without Lime Water)**

The polypropylene air filter is used in the silencer because of its high absorption capacity. It absorbs some portions of the toxic gas present in the exhaust. During the experimentation, it is found that certain amount of HCs and oxide of nitrogen have been reduced. This happens only because of the air filter implanted inside the silencer, which absorbed a certain amount of the gas as depicted in Table 3.

The changes in the number of other gasses are negligible. Also, Fig. 5 is drawn as a bar diagram to analyze the emission of pollutants and noise control at different load for better understanding. These results are compared with the normal silencer results, which are mentioned in Fig. 6. It is the comparative study of both the silencer

Table 3 Engine exhaust results for aqua silencer (without lime water)

Load (kg)	Time take to fuel consumption for 10 ml (sec)	Engine rpm	Vol % of CO	HC, ppm	Vol. % of CO_2	Vol. % of O_2	NOx, ppm
0	28.17	1490	0.11	21	2.60	17.03	172
2	24	1479	0.08	39	3.30	16.04	218
4	20.33	1442	0.05	31	4.20	15.02	314
6	19.40	1418	0.05	50	5.30	13.32	404

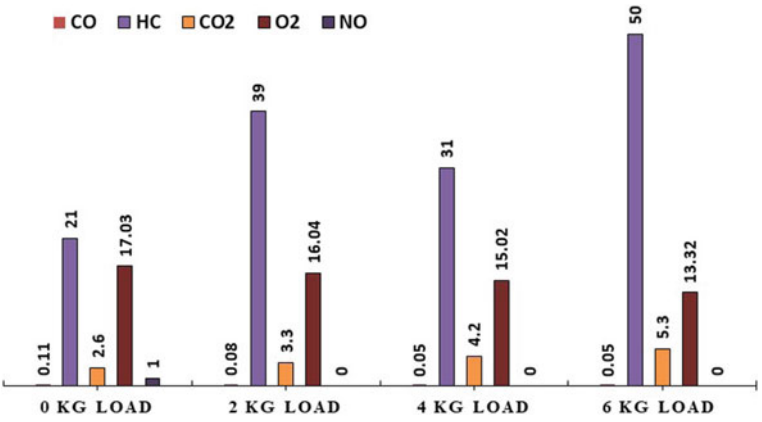

Fig. 5 Emission results at different engine load for aqua silencer (without lime water)

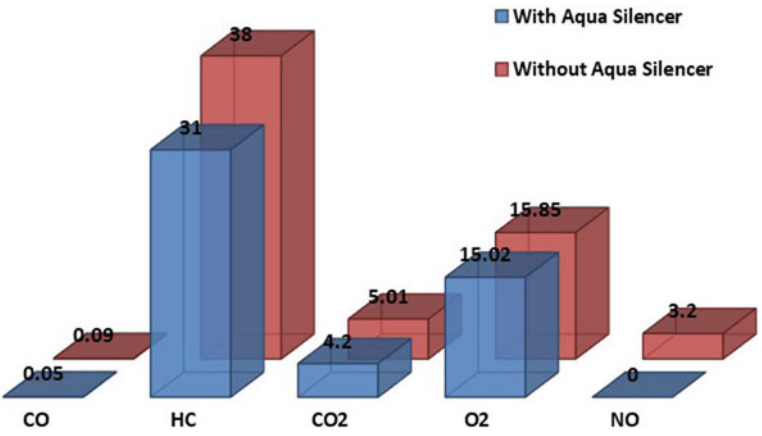

Fig. 6 Comparison between normal engine exhaust results and engine using aqua silencer exhaust results for 4 kg load

at 4 kg of the load to the effective analysis of the performance of the normal and aqua (without lime water) silencer. And, it is found that the emission of pollutants and noise of the engine reduced due to use of an aqua silencer.

3. Observation with Aqua Silencer (With Lime Water)

In this test, lime water is filled inside the silencer. This test is found to be more efficient. Approximately, no pollution is observed as depicted in Table 4.

This is because, from the previous reading, it is clear that, the air filter used in Aqua Silencer absorbs to a great extent of the pollutants in the gas, thereby decreasing the number of pollutants.

Table 4 Engine exhaust results for aqua silencer (with lime water)

Load (kg)	Time take to fuel consumption for 10 ml(s)	Engine rpm	% of CO	HC, ppm	% of CO_2	% of O_2	NOx, ppm
0	28.17	1490	–	–	–	–	–
2	24	1479	–	–	–	–	–
4	20.33	1442	–	–	–	–	–
6	18.40	1418	–	–	–	–	–

When lime water is used, then the remaining polluted gas reacts with lime water, thus again, the amount of pollutants in the gas decreases considerably. But due to the blockage in the silencer by bubble behaviour of lime water, unable to measure the exhaust gas concentration. So no pollution is observed.

6 Conclusion

It is concluded that the aqua silencer is useful for minimizing the emission of gases from the engine exhaust.

- The sound levels have been reduced by using lime water as a medium.
- It is found to be smokeless emissions and pollution-free by using Polypropylene Air Filter in water, and is also economical, considering the persistent use.
- Consumption of fuel is as same as the conventional system.
- Contamination in the water is negligible.
- No vibration is produced when the engine is running.

One can urge to a human being to use Aqua Silencer and can raise awareness about the increasing pollution that Aqua Silencer is one of the ultimate remedies to this problem.

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