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FABRICATION OF COST EFFECTIVE DPF AND ANALYSIS OF ITS PERFORMANCE AND SOOT LOAD PATTERN

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Abstract:

Diesel vehicles are the core of transportation system. They are even more enticing due to their innate fuel efficiency. On the other hand they are also considered as one among the serious contributors to air pollution. Contemplating the increase of greenhouse gases from automotive vehicles the government has come up with stringent pollution norms. Government decided to leap-frog to BS-VI directly from 2020 which makes installation of Diesel particulate filters in all vehicles mandatory. Some companies have started manufacturing DPF with materials like silicon carbide, cordierite and aluminium titanate. Each having its own advantages and disadvantages but the problem here is increase of cost of DPF. Main objective of this paper is to fabricate ingenious flow through filters using materials that are used in our daily routine. These filters are equipped to a diesel engine to collect the particulate matter and analysing the soot loading pattern across the filters. Also, the performance variation of the engine has been studied.

Keywords: Diesel particulate Filter; Emission; Soot; Back pressure.

Back Ground: Exhaust gas from diesel engines includes black smoke, SOF (soluble organic fraction), unburned fuel, lubrication oil, etc. in the form of PM (particulate matter), as shown in Fig. 1. Airborne fine particles contained in the PM are feared to cause bronchitic asthma and lung cancer [1]. However, it is crucial to implement environmental measures for diesel-powered automobiles also, including the reduction of particulate matter (PM) and nitrogen oxide (NOx) discharged from diesel engines. Considering these problems government has set stringent rules about emission requirements. The latest norms and its requirements are given in below table [2]. As part of these environmental measures, studies of the exhaust gas after-treatment systems for diesel engines have been actively conducted for quite some time, mainly in Europe and America. Particularly for the PM issue, the adoption of diesel particulate filters (hereinafter referred to as “DPF”) has enabled us to obtain certain prospective solutions [3].

Introduction: The diesel particulate filter (DPF) is a device designed to remove diesel particulate matter or soot from the exhaust gas of a diesel engine thereby preventing the emission of exhaust gas pollution into the atmosphere.

There are three main technologies used to reduce particulate matter emissions from diesel engines [4]. Using these technologies many types of filters have been developed out of which most significant types of filters are the wall-flow (DPF), flow through (FTF) and monolithic reactor. A monolithic catalyst reactor is made of porous material as a cylinder which constitutes many small parallel channels running in the axial direction. Wall flow diesel particulate filters (DPF) are one of the most effective types of particulate filters especially in diesel application. In this type of filter, channels are alternatively plugged at the end. Flow through Filters (FTF) is exactly designed as a monolithic reactor but the idea is to decrease the particulate load of the flow [5]. Not only the type of filter but the material used in making filter can be varied. A partial list of available commercially or as prototypes filter media is shown in below table [6]. Now-a-days manufacturing DPF has become a costly affair. In this paper we have attempted to make a cost effective DPF using materials that are used in day to day life.

Fabrication of Filter: The filter size is determined based on the swept volume of the engine. Keeping in mind the excessive costs incurred in fabrication of the filters for DPF, a low cost filter is fabricated and studied for its performance. The filter is made using a metallic scrub used in our daily life application for cleaning utensils which is sandwiched between two metal meshes. The figure [1] gives the exact construction of the filter. Instead of using a single block of filter, 3 blocks of filters have been stacked together to make the whole filter. Each specimen is named so as to track the changes during the usage. Specimens A1, A2, A3 are combined to form the first filter while Specimens B1, B2, B3 to form the second filter. A suitable casing was made to enclose the filter with provisions for pressure measurement before the filter to check for the increase in backpressure with time.

Dimensions of the Filters:

Diameter = 70mm
Thickness of each block = 15mm
Number of blocks per filter = 3

Experimental Setup: The casing is fitted in the exhaust line of an engine. The specifications of the engine are provided in Table [5].

Procedure: Initially the baseline readings were taken for the engine to measure the performance of the engine before the DPF has been fitted to it. Then, the first set of filters (A1, A2, A3) were tested for 30 minutes of engine run time and the second set of filters (B1, B2, B3) were tested for 1 hour both at 14 kg loading condition. Readings of the key parameters were noted for every 10 minutes and were tabulated to get a good idea of the performance of both engine and the filter. The filters were then removed and weighed to check the increase in mass. Each block of filter is weighed separately and the values are noted. Also the size of the soot particles was determined using Scanning Electron Microscope.

Results: The following are the observations made from the tests.

1. Soot Loading Pattern
2. Back Pressure
3. Engine Performance

Soot Loading: The specimens were weighed before and after the test and it was seen that there was an increase in weight of the specimens. This increased weight is a measure of soot trapped in the specimen.

The total amount of soot trapped is 53 milligrams when the test was performed for 30 minutes using the first set of filters. Then the filters were removed and replaced with the second set of engines and the test was now carried out for 1 hour and the soot trapped was 85 milligrams.

The soot loading pattern was studied for each and every block of the filter and a graph has been plotted to understand the same. Hence it is seen that the filter block that is placed first in line of the exhaust flow trapped the highest amount of soot and this keeps decreasing and the last block shows the least amount of soot being trapped.

Back Pressure: The pressure build-up due to the soot loading in the filters has been measured and tabulated at every 10 minute interval. It is observed from the graph [2] that the backpressure increases with time. This is because as the engine is running, due to the soot loading in the filters, the pores get blocked. As a result of this, the flow of exhaust gases is obstructed and hence the backpressure increases.

Engine Performance: Engine performance was monitored by collecting the data at regular intervals of 10 minutes for both filters 1 and 2. Specific fuel consumption at each point was calculated and the graphs are plotted.

As seen from the graph [3] that the specific fuel consumption increases slightly with respect to time. This is due to the excess work that the engine has to do in the exhaust stroke to pump out the exhaust gases through the filter.

So as the time increases, the filter clogging due to soot increases and more effort is put in by the engine and hence the specific fuel consumption of the engine also increases.

SEM Analysis: Soot particles trapped in DPF are collected and analysed in a Scanning Electron Microscope to a magnification of 3000x. Different sizes of carbon particles are observed varying from 50 to 90 microns.

Table 1: Emission Norms.

Stage	Date	CO	HC	HC+NOx	NOx	PM	PN
		g/km					#/km
COMPRESSION IGNITION (DIESEL)							
BS IV	2010	0.5	-	0.3	0.25	0.025	
BS VI	2020	0.5	-	0.17	0.08	0.0045	6.0×10^{11}
Euro 6	2014	0.5	-	0.17	0.08	0.005	6.0×10^{11}

Table 2: Particulate Matter Abatement Technology.

Technology	Particulate emission reduction potential	
	Mass	Number
Wall-Flow Filter	>95%	>99%
Partial Flow Filter	30-60%	No data
Diesel Oxidation Catalyst	<25%	No impact

Table 3: Available Media for DPF.

Ceramic
• Cordierite (extrudates)
• Mullite (extrudates, foams, fibers, infiltrates)
• Silicon Carbide (extrudates, foams, felts, infiltrates)
• Tialite (extrudates)
• Mullite/zirconia (extrudates, foams)
• Mullite/tialite (extrudates, foams)
Metallic
• Sintered metal
• Wire mesh
• Metal foam

Table 4: Mass of Different Specimens.

Specimen	Mass of Specimens
Filter 1	
A1	24.059
A2	23.374
A3	18.626
Filter 2	
B1	22.306
B2	21.447
B3	19.265

Table 5: Engine Specifications.

Make	Kirloskar
Number of cylinders	1
Bore Diameter	0.068 m
Stroke Length	0.045 m
Rated Power	3.7 kW

Table 6: Comparison of Soot Loading In Various Specimens.

Specimen	Mass Before Testing (Grams)	Mass After Testing (Grams)	Mass Of Soot Trapped (Mg)
Filter 1			
A1	24.059	24.082	23
A2	23.374	23.392	18
A3	18.626	18.638	12
Filter 2			
B1	22.306	22.347	41
B2	21.447	21.474	27
B3	19.265	19.282	17

Table 7: Backpressure With Respect To Time for Filters 1 and 2.

Time (Minutes)	Backpressure In mm of Water
Filter 1	
10	12.1
20	12.5
30	12.6
Filter 2	
10	12.8
20	12.9
30	13.2
40	13.7
50	14.6
60	15.3

Table 8: Specific Fuel Consumption for Filters 1 and 2.

Time (minutes)	SFC (g/kW-sec)
Filter 1	
10	0.0661
20	0.0696
30	0.0714
Filter 2	
10	0.0656
20	0.0704
30	0.0736
40	0.0736
50	0.0757
60	0.0821

Fig.1 Components of Diesel Exhaust Gas.

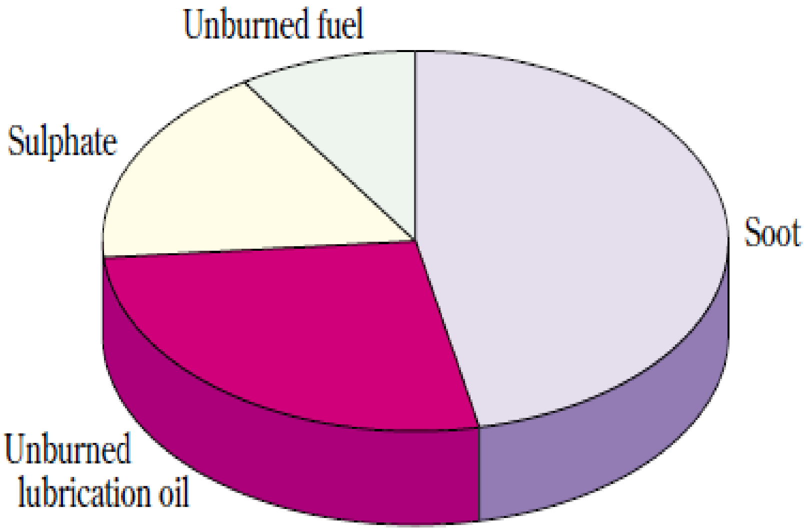


Fig. 2: Filters.

Fig. 3: Experimental Setup.

Fig. 4: DPF Casing.

Fig. 5: Soot Accumulated on casing before and after filters.

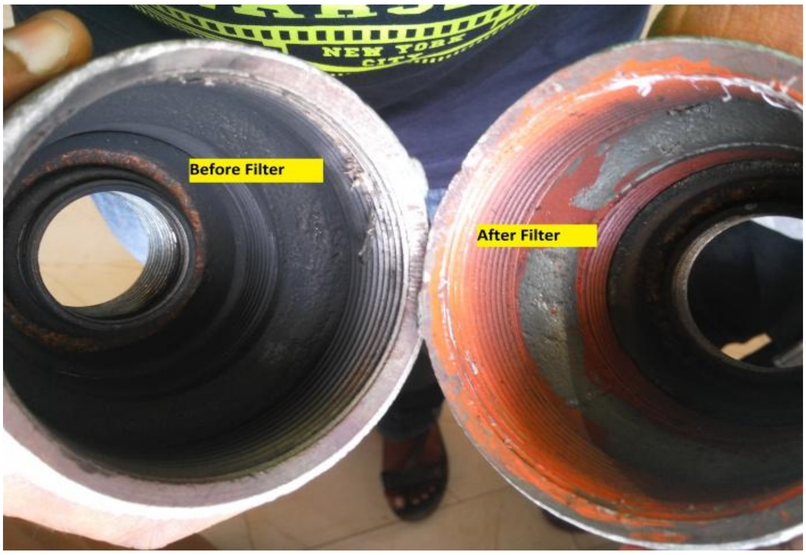


Fig 6a: SEM analysis of carbon particles at 10k x.

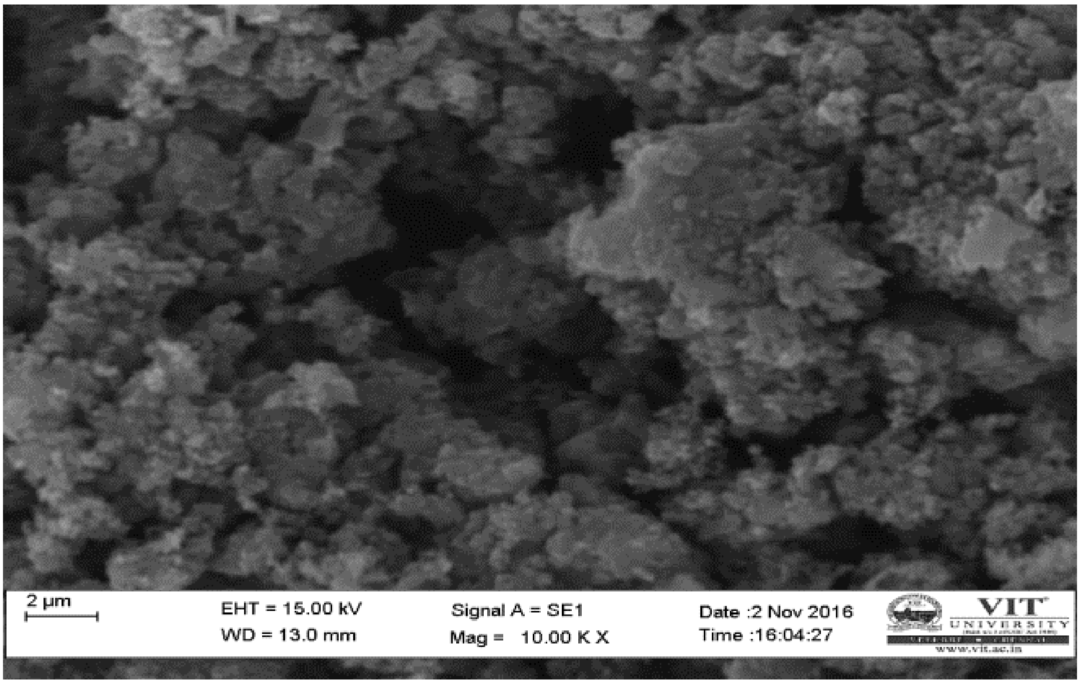


Fig 6b: SEM analysis of carbon particles at 3000x.

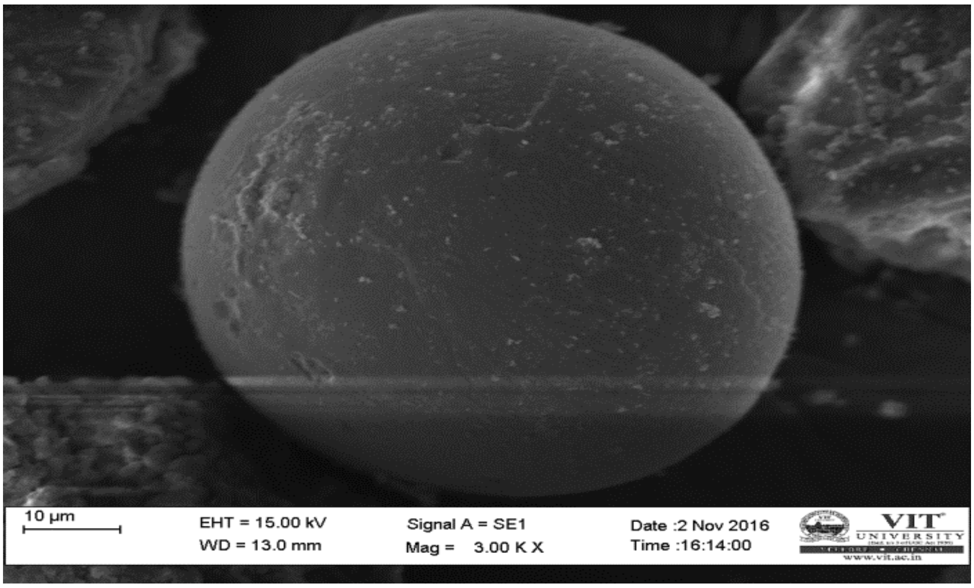
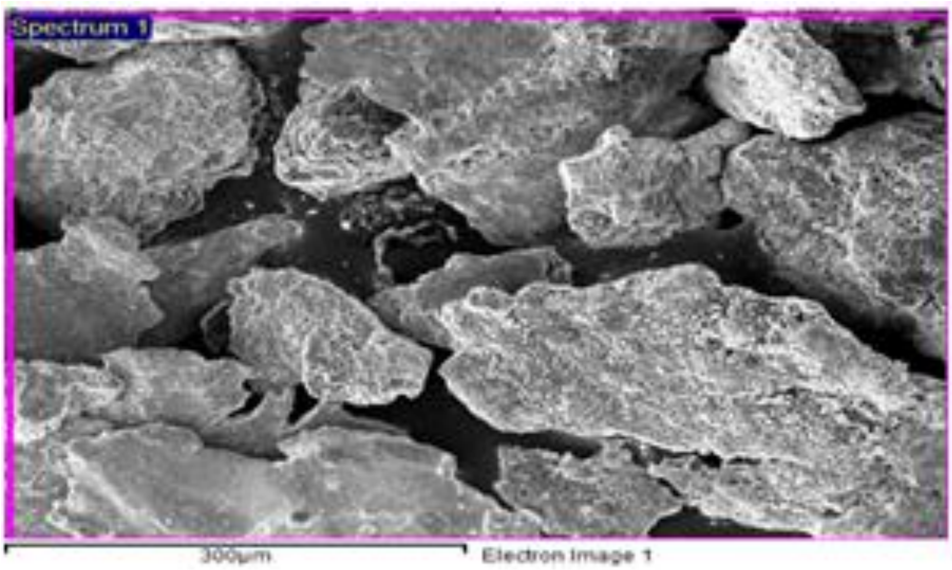
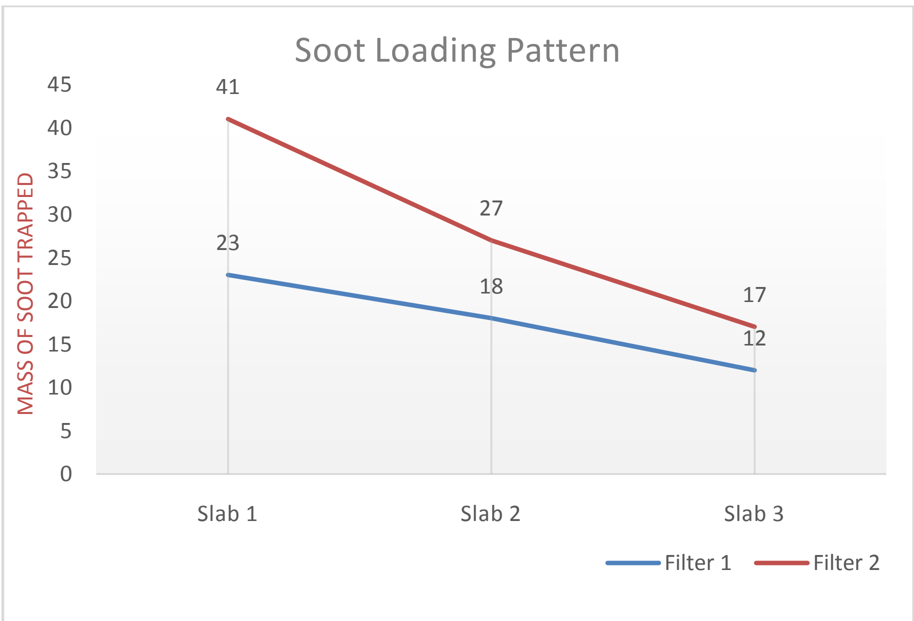


Fig 6c: SEM analysis of carbon particles at 1000x.

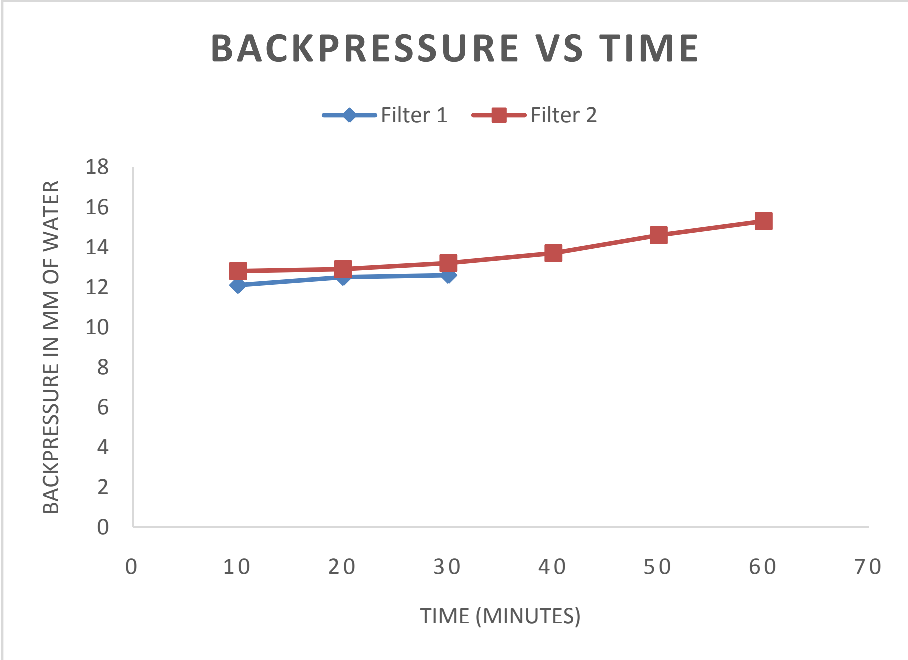


Graph 1: Soot Loading Pattern.

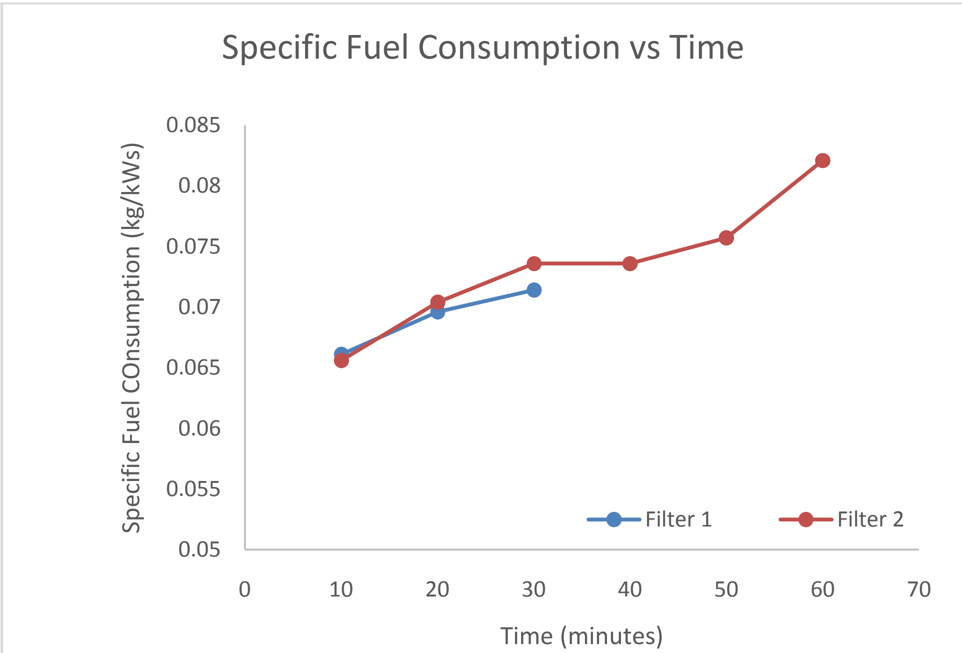


The y axis title position has been adjusted so that it is visible clearly.

Graph 2: Back Pressure vs Time for Filters 1 and 2.



Graph 3: Specific Fuel Consumption vs Time for filters 1 and 2.



Conclusion:

- The filters were made out of low cost materials and assembled in the exhaust line of the engine.
- The soot loading pattern was observed and it is seen that the first blocks of the filters A1 and B1 trapped the highest amount of soot 23 and 41 milligrams respectively while in the last blocks of the filters A3 and B3 the soot loading is minimum 12 and 17 milligrams respectively.

- It was seen that there was an increase in backpressure due to soot loading in the filters. It was seen that the surface pressure after 10 minutes of the experiment was 12.8 mm of water which increased to 15.3 mm after 60 minutes.
- The increase in backpressure was about 0.024 kPa after 50 minutes of engine running.
- There was an increase in specific fuel consumption due to the excess work the engine was doing to pump the exhaust gases past the filter blocks.
- It was observed that the specific fuel consumption was increasing with time and has increased by 0.0165 g/kWs after 50 minutes of engine run.
- The soot sample collected from the filters was analyzed using electron microscope and particles of sizes ranging from 10 to 50 micron were to be present.

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