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Technical Report

Emission-Related Maintenance Intervals for Light-Duty Trucks and Heavy-Duty Engines

by

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Office of Air, Noise and Radiation
U.S. Environmental Protection Agency

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I. Background

The EPA will soon issue two Notices of Proposed Rulemaking (NPRM) concerned with gaseous emission standards for: 1) light-duty trucks and 2) heavy-duty engines. The NPRM concerned with light-duty trucks will propose more stringent emission standards for hydrocarbons, carbon monoxide and nitrogen oxides. The NPRM concerned with heavy-duty engines will propose a new transient test procedure for gaseous emission testing of heavy-duty engines and more stringent standards for hydrocarbon and carbon monoxide emissions. A new definition of the useful life of an engine coupled with a new durability test procedure will also be proposed in both packages. These last two changes necessitate a revision in the current provisions governing the maintenance of durability-data engines. Useful lives determined under the regulations to be proposed will likely exceed the limits of the current maintenance provisions.

Both NPRMs will also propose new definitions for emission-related maintenance and non-emission related maintenance. The new definitions are:

"Emission-related maintenance" means that maintenance which does substantially affect emissions or which is likely to have a lasting effect on the deterioration of the vehicle or engine with respect to emissions even if the maintenance is performed at some time other than that which is recommended;

"Non-emission-related maintenance" means that maintenance which does not substantially affect emissions and which does not have a lasting effect on the deterioration of the vehicle or engine with respect to emissions once the maintenance is performed at any particular date.

Under these new definitions maintenance restrictions would be limited to fewer maintenance items than are currently restricted (only those which are emission-related). Non-emission related maintenance could be performed at the manufacturer's recommended intervals. Only those maintenance items which qualify as emission-related under the new definitions will be addressed in this report.

A replacement of the air cleaner would be an example of non-emission related maintenance. A dirty air cleaner may affect emissions to some extent by richening the fuel-air mixture, but the effect would not be expected to be a large one. The effect of a dirty air cleaner could also be completely reversed by replacement with a clean air cleaner. A dirty air cleaner should not cause any component to be permanently damaged. Spark plug replacement would be an example of emission-related maintenance, since a malfunctioning spark plug can greatly increase hydrocarbon emissions. A malfunctioning spark plug can also cause catalyst activity to deteriorate at a faster rate than normal and such deterioration would not be reversed by replacement with a good spark plug.

II. Potential Intervals for Emission-Related Maintenance

The following maintenance items are considered to be emission-related under the definitions stated in the preceding section. The reasons why these maintenance items are considered to be emission-related are also shown.

Gasoline-fueled engines:

1. Cleaning or replacement of spark plugs - misfiring substantially increases hydrocarbon emissions and can overheat the catalyst, speeding up its deterioration.

2. Replacement or adjustment of O_2 sensor - failure has a substantial effect on emissions; a key component to the three-way catalyst system.

3. Cleaning or replacement of PCV and EGR valves - malfunction can substantially affect crankcase and NOx emissions, respectively.

4. Replacement of emission-related hoses and tubes - rupture or plugging can disable emission control devices causing substantial increases in emissions (e.g., EGR vacuum lines).

5. Inspection or replacement of ignition wires - faulty wires can cause misfiring of spark plugs (see #1).

6. Cleaning of injector tips - improper injection can cause substantial increases in emissions.

7. Replacement of catalyst - failure or loss of activity can cause substantial increases in emissions.

8. Adjustment of the idle air-fuel mixture - maladjustment can cause substantial increases in hydrocarbon and carbon monoxide emissions.

Diesel-fueled engines:

1. Cleaning of injector tips - same as #6 above.

2. Cleaning or replacement of PCV and EGR valves - same as #3 above.

3. Servicing or replacement of turbocharger - malfunction can significantly change air-fuel ratio and substantially increase emissions.

4. Replacement of injectors - same as #6 above.

Other maintenance items, such as oil filter, air filter, fuel filter, and drive belt replacements, adjustments of the idle speed, valve lash, and engine bolt torque and cooling system maintenance are not considered to be emission-related maintenance under the definitions of Section I. None of them are believed to have a lasting effect on the durability of the engine with respect to emissions. That is, once the maintenance is performed, even belatedly, the deterioration of emissions will return to normal. Also, while some of the above items can affect emissions, the effect is not large enough to merit an emission-related designation.

The rest of the report will be devoted toward determining the potential intervals between the performance of these maintenance items. The method used to determine these potential intervals is a very simple one. If a vehicle currently exists which utilizes a given interval for a maintenance item, that interval would be assumed to be potentially available to all vehicles. An exception to this would be a case where it was known that the reason this particular vehicle was able to have such a long maintenance interval was either: 1) not available to all vehicles, or 2) prohibitively expensive to be extended to all vehicles. The time and resources available for this study did not allow any durability testing of components, either in-use or in the laboratory. Data from other sources on the durability of emission-control systems is not readily available, but what data were available have been incorporated into the discussion.

Spark plugs

The use of unleaded gasoline has allowed extended intervals for spark plug replacement, primarily due to the absence of lead deposits on the spark plug tip. Prior to 1975, when light-duty vehicles and trucks were still being operated on leaded gasoline, their spark plug replacement intervals were around 12,000-15,000 miles. With the use of unleaded gasoline, these intervals have been extended to 30,000 miles for many vehicles (e.g., all of Chrysler's 1978 vehicles with domestic engines). California also recently received a waiver from the U.S. EPA regarding the requirement of more restrictive maintenance intervals for light-duty vehicles and light-duty trucks (1).* The interval for the replacement of spark plugs that California found to be technologically feasible was also 30,000 miles. A potential interval for spark plug replacement for light-duty trucks should then be 30,000 miles.

Most heavy-duty engine manufacturers currently recommend spark plug replacement every 12,000 to 18,000 miles. These engines are operated on leaded gasoline. Since their spark plug replacement interval corresponds to that of light-duty vehicles and trucks using leaded gasoline, it would appear that the spark plug replacement interval is independent of vehicle type. Because the heavy-duty engine emission standards to be proposed for 1983 should require catalysts on all gasoline engines, unleaded gasoline will be used in all these engines. This should allow spark plug replacement intervals to be extended to 30,000 miles for heavy-duty engines.

An exception would have to be made for any light-duty trucks or heavy-duty engine which could meet the standards to be proposed without the use of catalysts. These vehicles could still be operated on leaded gasoline and there is no guarantee that spark plugs could last 30,000 miles under these conditions without an increase in cost.

Oxygen sensor

Oxygen sensors are a recent addition to motor vehicles in the U.S. They are an integral part of a three-way catalyst system which is used to reduce NOx emissions as well as hydrocarbon and carbon monoxide emissions. In early 1977, the California Air Resources Board (CARB) found that it was technologically feasible to produce an oxygen sensor that would only need replacement every 30,000 miles (2). This determination was not successfully challenged in the hearings that followed its proposal (1). Recently, Ford certified a 1979 Pinto equipped with a three-way catalyst system having a 50,000-mile replacement interval for its oxygen sensor, demonstrating that a 50,000 mile oxygen sensor is technologically feasible for light-duty vehicles.

To extend this finding to light-duty trucks and heavy-duty vehicles, the mode of sensor failure should be examined. The most common modes are electrical failure and thermal cracking, due to sudden cooling (i.e., water splash) and load cycling of the engine. There is no reason to expect that oxygen sensors on light-duty trucks and heavy-duty vehicles should experience any more electrical failures or water splashes than light-duty vehicles. Failures by these modes should be just as likely in either case. It may be possible, though, that a heavy-duty oxygen sensor may experience more extreme temperature cycling due to the more extreme loads experienced by heavy-duty engines. This difference should not be large, though, and should be able to be handled by sound sensor design. There appears to be no significant problems in applying light-duty sensor technology to heavy-duty applications. Thus, oxygen sensors should be able to last 50,000 miles on light-duty trucks and on heavy-duty vehicles as well as on light-duty vehicles.

PCV and EGR valves, emission-related hoses and tubes, and ignition wires

The inspection, cleaning, or replacement of PCV valves, EGR valves, emission-related hoses and tubes, and ignition wires were all examined by the CARB in their analysis of automotive maintenance (2). The CARB found that it was technologically feasible for a light-duty vehicle or truck to go without this maintenance for 50,000 miles. As was the case with oxygen sensors, this determination was not successfully challenged in numerous CARB and EPA hearings held afterward (1). With respect to heavy-duty engines, General Motors did not recommend any maintenance on their 1979 EGR system through 50,000 miles, and Ford did not recommend any maintenance on their emission-related hoses and tubes or their ignition wires through 50,000 miles. Since a PCV valve on a heavy-duty engine carries the same compounds as a PCV valve on a light-duty vehicle, there should be no reason for the former to have more plugging problems than the latter. It then appears that PCV valves, EGR valves, emission-related hoses and tubes, and ignition wires on light-duty trucks or heavy-duty engines only require maintenance at 50,000 mile intervals. If it is assumed that there is no difference between gasoline-fueled and diesel-fueled engines with respect to the durability of these items, then the above conclusion can apply equally well to diesel-fueled engines.

Injectors

Injectors can require periodic cleaning and possibly even replacement if they fail to function properly. Cummins recommends that the injector tips on their heavy-duty engines be inspected and cleaned every 90,000 - 150,000 miles depending on the specific engine being serviced. Caterpillar recommends this same maintenance every 100,000 miles. Using Cummins recommendations, 150,000 miles should be a feasible interval between injector inspection and cleaning for some, and possibly all applications. A more conservative figure which would apply to all heavy-duty applications would be 100,000 miles, using the Caterpillar recommendation. It also appears that most heavy-duty diesel manufacturers, including Cummins, do not recommend the periodic replacement of the injectors. Thus, no periodic replacement should have to be allowed in the maintenance provisions of the NPRMs for heavy-duty engines or light-duty trucks.

The maintenance schedules for light-duty trucks usually only extend to 50,000 miles. Throughout this interval, it would appear that no injector maintenance is needed. For example, neither General Motors nor Volkswagen recommend any injector maintenance on their vehicles through 50,000 miles. To project past this mileage, the heavy-duty experience must be extrapolated to light-duty trucks. Periodic cleaning of the injector tip is usually required because of coking which occurs during the combustion process. This coking predominantly occurs at light loads (i.e., idling). It would be expected that diesel engines in light-duty trucks would undergo less idling than those in heavy-duty applications; such as diesels in tractor-trailers which are idled during rest stops or delivery trucks which are idled during deliveries. Injectors in light-duty trucks may even need less frequent maintenance than injectors in heavy-duty vehicles. To estimate any increase in maintenance interval for light-duty injectors over the heavy-duty interval would be impossible, though, without more data. Thus, the maintenance interval for cleaning injectors on light-duty engines should be able to be at least as long as the heavy-duty intervals, which is 100,000 miles.

Catalysts

In their analysis of light-duty vehicle maintenance requirements, the CARB determined that catalysts did not require maintenance over 50,000 miles (2). The CARB did not attempt to show feasibility past this point, though. Because the useful life of light-duty trucks and heavy-duty engines will likely be greater than 50,000 miles under the proposed regulations, it is important to determine if catalysts can go longer intervals without replacement.

Two sets of data are available from light-duty vehicles which show that current catalysts do not deteriorate at a faster rate after 50,000 miles than before 50,000 miles. The first study consisted of two certification-type vehicles run over the AMA durability schedule for 100,000 miles (4). A Dodge Aspen and a Ford Pinto were both equipped with catalysts which do not require maintenance over 50,000 miles. A comparison was made between the average emissions over 100,000 miles using the current EPA certification method and that using an integral method. The EPA certification method consists of fitting a least-squares line through all of the data between 5,000 and 50,000 miles. The point where the line crosses 50,000 miles then becomes the average emission level over 100,000 miles. It is assumed that the emissions continue linearly through 100,000 miles. The integral method simply connects each consecutive pair of data points between 0 and 100,000 miles with a straight line and finds the integral beneath the curve. This area under the curve is then divided by 100,000 miles to find the average emissions per mile. If the two methods yield the same result, this would mean that the deterioration rate from 50,000 to 100,000 miles was about the same as that from 0 to 50,000 miles.

The results of the comparison are shown in Table 1. The two methods yield quite similar results. The certification method tends to overestimate the actual emissions of the Aspen (i.e., the deterioration over the last half of the useful life is less than that over the first half). This is reversed in the case of the Pinto. For hydrocarbon and carbon monoxide emissions, which are the only ones affected by the catalyst, the certification method underestimates emissions by an average of 3.5%. From this limited data base, it would appear that the deterioration rate over a vehicle's second 50,000 miles, including the catalyst, is no different than that over the first 50,000 miles. Thus, under current test procedures, catalysts in light-duty vehicles appear to be durable over 100,000 miles.

The second set of data was available from the EPA's Restorative Maintenance program. In this program in-use vehicles are first tested in an as-received condition and then tested after various stages of repair and maintenance. Along with 300 low-mileage vehicles, nine high-mileage catalyst-equipped vehicles were tested (average mileage of 105,000 miles). No data was available on the low-mileage emissions from these high-mileage vehicles, so an attempt was made to find low-mileage data from other vehicles of the same engine family. Data of this kind could be found for only four of the high-mileage vehicles. Both the low- and high-mileage data for these four vehicle-engine types are shown in Table 2.

TABLE 1

Average 100,000 Mile Emissions in Grams per Mile

Vehicle		Current Cert. Method	Integral Method	Difference[1] (Percent)
Dodge Aspen	HC	0.41	0.40	-2.5%
	CO	4.46	4.01	-11.2%
	NOx	1.69	1.69	0 %
Ford Pinto	HC	0.28	0.30	6.7%
	CO	1.29	1.63	20.9%
	NOx	1.58	1.66	4.8%

1 $\frac{\text{Integral-Cert}}{\text{Integral}} \times 100$

TABLE 2

Emission Deterioration of Well-Maintained
In-Use 1975 Model-Year Vehicles

Vehicle	Mileage	FTP Emissions HC	FTP Emissions CO
Plymouth Duster	4,922[1]	0.65 g/mi	9.4 g/mi
	8,789[2]	0.55 g/mi	5.42 g/mi
	138,000[3]	3.00 g/mi	22.9 g/mi
	In-use d.f.[4]	2.48	1.76
	Cert. d.f.[5]	2.31	1.41
Plymouth Station Wagon	10,968[2]	0.48 g/mi	6.87 g/mi
	77,000[3]	0.74 g/mi	4.60 g/mi
	In-use d.f.	1.40	0.77
	Cert. d.f.[5]	1.30	0.93
Mercury Monarch	13,135[2]	1.33 g/mi	7.28 g/mi
	104,000[3]	1.52 g/mi	8.03 g/mi
	In-use d.f.	1.08	1.05
	Cert. d.f.[5]	1.67	0.92
Ford LTD	12,375[2]	1.23 g/mi	11.2 g/mi
	13,135[2]	1.33 g/mi	7.28 g/mi
	111,000[3]	2.04 g/mi	11.0 g/mi
	In-use d.f.	1.29	1.09
	Cert. d.f.[5]	1.17	1.04

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1 "Evaluation of Restorative Maintenance on 1975 and 1976 Light-Duty Vehicles in Chicago, Illinois", EPA, January 1977, EPA-460/3-76-030.

2 "Evaluation of Restorative Maintenance on 1975 and 1976 Light-Duty Vehicles in Washington, D.C.", EPA, March 1977, EPA-460/3-76-031.

3 Results from testing of high-mileage catalyst-equipped vehicles performed under Work Effort #6, Contract 68-03-2612 by Automotive Testing Labs for the EPA in St. Louis, 1978.

4 d.f. = deterioration factor, ratio of emission rate at 50,000 miles to that at 4,000 miles.

5 Durability test results from EPA certification of 1975 model-year vehicles.

Data was chosen from the Restorative Maintenance program because the vehicles are in-use vehicles and show in-use deterioration, but at the same time the effects of maladjustments and failed components (excepting catalysts) have been removed. In determining catalyst durability from whole vehicle data, it is important to remove the effects of rich idle-mixture settings, plugged EGR valves, etc. The data shown in Table 2 are from tests of vehicles which have been "restored" in this way unless the vehicle was already meeting all emission standards. No maintenance was performed on the catalysts. The deterioration seen on these vehicles includes the deterioration of the catalyst, plus the basic deterioration of the engine (rings, valves, pistons, etc.). While it would be preferable to have low- and high-mileage data on the same vehicle, using data from two or three different vehicles of the same engine family can affect the results in either direction. It is expected that on the average this effect would tend to cancel itself and be negligible.

To show that catalysts can (and do) operate for 100,000 miles, the deterioration of emissions up to the high mileage data point (average of 107,500 miles) is compared to the deterioration determined over 50,000 miles in the EPA certification process. To put both measures of the deterioration in the same format, the in-use deterioration was put in the format of the certification deterioration factor (i.e., ratio of emissions at 50,000 miles to that at 4,000 miles). Only hydrocarbon and carbon monoxide emissions have been shown since these are the only emissions affected by oxidation catalysts. The averages of the ratios of in-use deterioration to certification deterioration are nearly equal to unity; 0.975 (HC) and 1.066 (CO). This result shows that the average deterioration rate of the catalyst and engine over 100,000 miles in-use is the same as that over 50,000 miles using the EPA's durability test procedure. The conclusion would appear to be that current-technology catalysts can last for 100,000 miles with the same deterioration rate (per mile basis) as occurs over 50,000 miles.

While the above two sets of data seem to indicate that current technology catalysts can operate 100,000 miles with the same deterioration rate as over 50,000 miles, some data examined by the California Air Resources Board (CARB) seem to indicate that the deterioration rate increases after 50,000 miles. The CARB examined the carbon monoxide and hydrocarbon emissions of 256 1975 and 1976 catalyst-equipped vehicles of all makes, sizes and mileage (5). About 19% of the vehicles had mileages over 50,000 miles and 11% had mileages over 55,000 miles. A quadratic curve was fit to the data using two techniques; 1) weighted least-squares, and 2) log-transformed least-squares. Both of these techniques weighted the more consistant data more heavily, which was the data at low mileages. Extreme scatter in the data was found at high mileage. The resulting curves showed positive quadratic terms, indicating that emissions deterioration was increasing with mileage. This result was vehicle dependent, with some engine families and product lines showing very poor high-mileage emissions and some showing very good high-mileage emissions. This was evidenced in the resulting coefficients of correlation of the regression curves, which were very low. Mileage was not the primary factor affecting the emissions of the vehicles in this study.

The above studies indicate that catalysts can last 100,000 miles on light-duty vehicles, though they do not indicate that the current catalysts of all manufacturers can operate efficiently through 100,000 miles. Some manufacturers may have to upgrade the durability of their catalyst systems. However, no similar data are available on catalyst life in light-duty trucks or heavy-duty vehicles, so extrapolation will have to be made from light-duty vehicle experience. There are two potential causes of catalyst deterioration, poisoning and over-heating (6,7). Poisoning here does not only include gross poisoning (i.e., continued use of leaded gasoline), but also includes gradual poisoning from small amounts of lead, phosphorus, and other metals contained in unleaded gasoline and motor oils. Over-heating can occur when exhaust that is too rich in hydrogen, carbon monoxide, or hydrocarbons, reaches the catalyst. The ignition of these compounds releases enough energy to raise the temperature of the catalyst high enough to sinter the alumina substrate. This drastically reduces the conversion efficiency of the catalyst.

The occurrence of poisoning should not be any different for either light-duty trucks or heavy-duty vehicles than for light-duty vehicles, since poisoning is primarily related to fuel and oil use and not engine size or operating conditions. However over-heating occurs during specific operating modes of the engine (6). These modes are sustained engine misfiring and high-speed, closed-throttle coasting. A well-maintained heavy-duty engine should not misfire any more than a light-duty engine. Neither is it expected that light-duty trucks would undergo prolonged motoring any more than light-duty vehicles. The EPA tests both light-duty vehicles and light-duty trucks over the same driving cycle, so this would imply that both types of vehicles would experience the same amount of motoring. However, heavy-duty vehicles may be motored in-use more than the other two classes of vehicles. While heavy-duty vehicles are driven on the same roads and must follow the same general traffic patterns as light-duty vehicles and trucks, there are two differences in heavy-duty drive trains which could result in increased motoring. One is the predominance of standard transmissions in the heavy-duty fleet, which results in engine motoring when current automatic transmissions would not. The other difference is that heavy-duty vehicles usually have higher gear ratios than light-duty vehicles which could result in higher engine speeds during motoring. These two factors could result in a somewhat more severe environment for catalysts. With the lead time available, though, it is expected that any increase in severity can be overcome and that heavy-duty catalysts can be made as durable as light-duty catalysts. Thus, heavy-duty catalysts should be able to last 100,000 miles without maintenance or replacement.

While a catalyst may last 100,000 miles with no maintenance, its activity does not remain constant. A 100,000 mile emission standard would need to take into account the added deterioration of the catalyst occurring over the second 50,000 miles. The deterioration rate shown in Table 2 includes that of the engine in addition to the deterioration of the catalyst, so it would only show an upper limit for catalyst deterioration. Any improvement in catalyst activity and durability over 1975 technology that would occur by 1983 would, of course, reduce the need to take the deterioration over the second 50,000 miles into consideration.

Air-Fuel Mixture

The CARB examined the need for adjusting the idle air-fuel mixture and found that it was technologically feasible that a light-duty vehicle or truck not require such an adjustment over its useful life (50,000 miles). A survey of the adjustment intervals recommended by heavy-duty engine manufacturers shows that no Ford engines, and only one Chevrolet engine require this adjustment over 50,000 miles. It appears that a 50,000 mile adjustment interval for the air-fuel mixture should be easily attainable for either light-duty trucks or heavy-duty engines.

Turbochargers

Caterpillar currently recommends an inspection of the turbochargers on all of their heavy-duty engines so equipped at 200,000 miles with possible rebuilding or replacement, if necessary. Other heavy-duty manufacturers recommend this maintenance earlier, between 90,000 and 150,000 miles. At this time, no inherent and immutable differences between Caterpillar and other heavy-duty engines are known to exist which allow Caterpillar to have a more durable turbocharger. Thus, 200,000 miles should be an acceptable maintenance interval for turbochargers on heavy-duty engines.

No light-duty trucks are currently equipped with turbochargers, so no in-use experience can be cited in this area. Turbochargers usually fail because of bad bearings or because of wear on the turbine blades from particle impingement. Neither of these problems should be more likely to occur in light-duty applicatons than in heavy-duty applications. Light-duty diesels currently must control crankcase emissions, while heavy-duty diesels are not currently rquired to control these emissions, and this could cause more foreign matter to be introduced to the inlet of the turbocharger. With these changes in allowable maintenance intervals will also be a proposed change to control of crankcase emissions from heavy-duty diesels, removing any differences in this area. For both classes of vehicles it should be possible to filter out any foreign matter from crankcase blow-by and also from any recirculated exhaust gas which may arise due to future control of nitrogen oxides. There seems to be no reason, then, that turbochargers on light-duty trucks should not be able to have the same maintenance interval as those on heavy-duty vehicles, 200,000 miles.

Most light-duty trucks are not expected to have useful lives in excess of 200,000 miles, so to prohibit maintenance over the useful life might have the same effect as a 200,000 mile maintenance interval. However, to protect any light-duty trucks with useful lives in excess of 200,000 miles, the 200,000 mile maintenance interval should be kept for light-duty trucks.

III. Summary

The previous section investigated the maintenance intervals of certain emission-related components which should be achievable by heavy-duty engines in 1983. These maintenance intervals are shown in Table 3. Some extrapolations have been made from light-duty vehicle experience due to a lack of light-duty truck or heavy-duty engine experience. This notwithstanding, given the current level of technology and the lead time available, these intervals should be technologically feasible by 1983 or the time that the certain emission-related components are necessary to meet emission standards (e.g., 1985 for heavy-duty oxygen sensors).

TABLE 3

Intervals for Emission-Related Maintenance Items
Which Should be Achievable by
Light-Duty Trucks and Heavy-Duty Engines in 1983

Maintenance Item	Interval-Miles
Spark Plugs - clean or replace	30,000
Oxygen Sensor - adjust or replace	50,000
PCV and EGR Valves - clean or replace	50,000
Emission-Related Hoses and Tubes - replace	50,000
Air-Fuel Mixture - adjust	50,000
Injector Tips - clean	100,000
Catalyst - replace	100,000
Turbocharger - rebuild or replace	200,000
Injectors - replace	Total Useful Life

References

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