Ethanol VW Report 32 – Long-Term Surveillance   Gary W. Johnson   7-4-09

Objective / Purpose

The overall objective of this experiment is to demonstrate that this type of equipment can successfully be operated on E-85 ethanol blend fuel instead of gasoline. The objective of this report is to document the condition *and performance* of the vehicle after nearly 3 years of ethanol-fueled operation (since October 2006).

Equipment

The equipment is a 1973-vintage Volkswagen Type 1 standard "beetle", in more-or-less factory configuration. The vehicle is fitted with an intake manifold vacuum gage, and the trigger and power wires for an ignition-driven tachometer. A Solex 30PICT-2 carburetor was selected for both the gasoline baseline and for E-85 documentation. This carburetor required an adapter plate to fit the 34 mm manifold flange pattern, which in turn required the accelerator pump cover and linkage rod assembly off a Solex 30/31 carburetor in order to fit the adapter plate.

The 1973 "Ethanol VW", in its new paint job

This vehicle is an extremely high-time piece of equipment. Current odometer reading is nominally 249,000 miles. Many major items are near, at, or beyond the intervals of repair or replacement that were expected from prior experiences operating on gasoline. In particular, at conversion, dry compression readings indicated cylinder #2 was alarmingly weak, and that all but cylinder #4 were detectably worn (bad rings leading to low dry compression, and poor control of oil and of blow-by gases, see Ethanol VW Report 22 "Tune-Up Results", 9-8-07.

The modifications for operation on E-85 ethanol were threefold and simple. (1) Mixture ratio had to be modified for both cold start and steady running, by the simple expedient of drilling out the main jet, the idle jet, and the accelerator pump discharge nozzle. This was a trial-and-error process, "creeping up" on the correct sizes. (2) The timing had to be advanced substantially to make up for the longer ignition delay of ethanol vs gasoline. This was based on experimental coast-down vacuum tests. (3) Extra air intake heat had to be added, obtained by drawing some or all of the intake air from a heat exchange "glove" on the muffler, depending upon climate. This cut-and-try experimental work is documented in Ethanol VW Reports 6-10 (11-25-06) and Ethanol VW Report 23 "Documentation of Configuration 5", 9-8-07.

An additional change was made to counter the low and unbalanced dry compression results. The crankcase oil charge was changed from straight Castrol 20W-50 SH+, to an 80-20 blend of that oil (80%) with Lucas Oil Stabilizer (20%). The same Lucas product was added in small quantity to "top up" the transmission oil charge. See also Support Report 2 "Lubricant Blends", 9-9-07.

Theory

Ethanol has the reputation of causing corrosion and dissolving rubber and plastics. Its cousin methanol is well-known and well-documented as causing exactly these effects. Yet many studies have shown that ethanol is far less corrosive and damaging than methanol.

The "ethanol VW" experiment established suitability and performance of a modified VW Type 1 ("beetle" or "bug") to run on E-85 fuel. No materials compatibility problems were observed during that experiment, but long-term surveillance was both recommended and prudent.

Items of concern include enhanced corrosion or deposits on exposed metallic components (steel, brass, and especially aluminum), solvent attack effects upon exposed rubber components, solvent attack upon exposed plastic components, and embrittlement of paper components (gaskets). This was investigated and reported as not a problem in Ethanol VW Report 31 "First Surveillance", dated 1-21-08.

The final "interaction" to be evaluated long-term is the effect of different physical chemistry and combustion product formation of ethanol vs gasoline. Ethanol burns with an almost soot-less flame, whereas gasoline flames have copious amounts of thermally-radiating soot in them. This is why straight ethanol fires are almost invisible in daylight, while gasoline fires are very visible in all lighting conditions. This difference is why longer term surveillance with careful attention to component wear indications is so important, which is documented herein.

Long term averages of performance indicators such as mileage and throttle position are of considerable interest, with respect to previously-published experimental data (see Ethanol VW Report 30 "Summary Results, Both Studies", 12-26-07). So also are inferences to be made concerning emissions, since this project had no access to direct emissions measurements. These performance indicators and inferred emissions "results" are also documented herein.

Procedure

An enhanced tune-up that included a spark plug removal and compression check was done at nominal odometer 249,000 miles. The oil had just been changed a thousand miles earlier. Those observations were logged, and are reported herein.

The logbook was inspected for mileage trends over the longer term, which included seasonality effects. These can be compared with earlier similar gasoline experience in the logbook. A comparison of seasonalities reflects upon the adequacy of the added-heat modification to the intake. A numerical comparison of mileage levels and fuel volumetric heating values provides insight into the relative average energy conversion efficiency experienced with each fuel.

Simple "average" operating experiences with the vacuum gage in place can provide similar insight into the relative energy conversion efficiency with both fuels. For the same speeds and conditions, road loads and required torque (and power) are the same. If the "throttle position" as measured by intake vacuum is different, then there has been a change in total torque (and power) available. The only way this can have happened is if there has been a change in the overall energy conversion efficiencies between the two fuels.

Data Collected

The carburetor was not torn down during this enhanced tune-up. That had been done earlier, and already reported. All indicators of materials compatibility were well documented in Ethanol VW Report 31, already cited. No changes of any kind were seen in any of the exposed materials at that time, and none have been seen since. The only "exception" is a very clean carburetor assembly, inside and out, and that is a good thing. The materials compatibility issue is now closed: E-85 ethanol fuel is quite benign, *even beneficial*, for this application.

This enhanced tune-up included a dry compression check. Standard tune-up items included a dead cold valve adjustment, maintenance on the distributor, checking the carburetor bolts and screws for tightness, checking the high-voltage circuitry for 20 KV capability, checking the air cleaner and the fan belt, and checking ignition timing. Because there were (for a time after conversion to E-85) unpredictable changes between tune-ups in the valve lash settings, this tune-up procedure was run every 1000 miles, instead of the 2000 mile interval used years ago on gasoline.

This enhanced tune-up included a brake fluid level check (OK as-is), but not an oil change. The oil change was done during the previous tune-up at 248,000 miles. That oil change data will be included in this assessment.

During this enhanced tune-up, the wheel bearings were also checked (OK as-is), and the steering gear adjusted (slightly). These last two items have nothing to do with tune-up, and nothing to do with the fuel.

compression

The dry compression data collected during the recent enhanced tune-up, plus the earlier data in the logbook, show the effectiveness of the Lucas additive at correcting combustion gas and lube oil leakage past the worn rings. A 5-to-10 psig variance in compression pressures is within typical shop experimental error, more than that is not. Cylinder 4 appears to be still in the best shape, but not by any truly significant amount. The near-20-psig improvement in cylinder 2 is very real, and very significant. "Jugs" and rings were last replaced at odometer 118,000, *some 131,000 miles ago!* Here are the data:

Dry psig for cylinder no.:		1	2	3	4
This tune-up at	249,000	118	122	110	127
Last checked	236,000	124	116	118	127
Pre-Lucas	233,000	117	97	117	117

valve lash

Valve lash settings were found to be "nominal" at 0.006" intake and 0.008" exhaust, and required no changes. This has been the pattern of the last several tune-ups, since 7-12-08, odometer 242,000 miles. It is most likely that the variation in lash from tune-up to tune-up before that date was due to carbon cleaned from valves and seats by the solvent action of the ethanol fuel. (This cannot be confirmed until the engine is actually torn down for repair, though.) Last valve and head work was done at odometer 166,000 miles, *some 83,000 miles ago!* Prior gasoline experience suggested a maximum life interval in the 80,000 mile range, and really the same life limit for "jugs" and rings.

crankcase oil

There is absolutely nothing to indicate any problems with oil pressure or crankcase bearing wear. Oil pressures as reflected by the warning light look good, even at very hot idle conditions after a long highway run, the prime indicator during prior gasoline experiences. In fact, the oil runs far more "transparent" for a much longer time, than in any previous experience on gasoline. There are no sludge, no wear particles, and no visible solid contaminants of any kind in the oil!

This is very probably due to the lack of carbon sooting in the flame with ethanol, leading to far less soot in the blow-by gases that get into the oil. Less carbon "grit" in the oil means far less cold start wear on the bearings. At the 248,000 mile tune-up, the drained synthetic blend oil was still less dark than previous gasoline experience, and still passed the "finger test" for cold start lubricity, after some 8000 miles of service, *twice anything ever seen before!*

There is an odd yellowish "scum" or "slick" that occurs on top of the drained oil when the Lucas additive is present in the blend. This turns out to be entrained air from the final dripping phase of draining the crankcase. It is completely harmless, and otherwise completely irrelevant. But it is something to be aware of, so that one does not overreact to a startling but meaningless change.

Prior gasoline experience with plain Castrol 20W-50 SH+ showed a maximum lubricant life just beyond 4000 miles, with darkening-to-black color in less than 300 miles. Obviously, both the ethanol and the presence of the Lucas additive contributed to the far longer useful service life of the crankcase oil found here. *The upper life limit has not yet been found*, as the drained oil was so obviously still "good". It would appear likely that engine bearing life may well be substantially longer than previously thought, because of the fuel and lubricant selections being used in this vehicle. Last crankcase and bearing work was done at odometer 118,000, some 131,000 miles ago, same as the "jugs" and rings. Prior gasoline experience suggested a maximum crankcase bearing service interval near 160,000 miles.

spark plugs

The spark plugs had been in service for some 7000 miles at the time of the 249,000 mile enhanced tune-up. They were quite clean, and completely unworn *even though they were <u>not</u> new 7000 miles ago*, and the gap settings were still as-installed. Unlike gasoline experience, there were almost no sooting or carbon deposits anywhere on the plugs. The center electrodes and insulators were quite clean and pristine. Around the rims there was a slight "patina" of tan cooked-on carbon, but it is definitely not gray or black, and it is a very, very thin layer. It is not removable by fingernail, but grit-blasts away in seconds. (The E-85 fuel is 15% gasoline, after all, so there is a small amount of soot in the flame, just far less than straight gasoline, by crudely an order of magnitude.)

The spark plugs had on them a silvery-gray hard deposit on the outside surfaces near the gasket. This turned out to be a cooked-on deposit from leaking oil in this aging engine. It causes the plugs to remove at higher-than-expected torque, but without any signs of thread damage to plugs or heads. This is probably the Lucas additive in the leaking oil, getting cooked into a hard material by the intense heat in this zone. Somewhat similar hard black deposits have been seen on exhaust pipes where leaking oil has dripped. If this is the only “downside” to using the Lucas additive in the engine oil, it is tolerable.

transmission

The Lucas additive was used in half-cup quantity to top up the SAE 90 hypoid gear oil in the transmission some time back. At about 30 mph, in 3rd gear particularly, there had been a sort of resonant moaning sound from the transmission. After Lucas addition, that sound effect quieted, but has not gone entirely away. There is still no popping out of gear, and no other obvious “bad noises” in spite of the age of the transmission: 249,000 miles on the original equipment installation. The maximum expected service life is supposedly 250,000 miles. That is therefore of some concern here, as also is the aging engine.

long term fuel mileage trends

A perusal of the logbook reveals that for the commuter cycle still driven, winter mileages are typically 22 to 23 mpg, while summer mileages are typically 23.5 to 24.5 mpg. The winter-summer seasonality effect is only about 2.5 mpg total, and that is only slightly larger than random variation in the mileage figures. No real “experiment” was ever conducted for seasonality in the gasoline mileages prior to the conversion experiment. The basic random variation was around plus and minus 1 mpg or so, with any seasonality effects “hidden” in the randomness at about that same magnitude. In similar highway usage in a similar speed range, prior gasoline experiences with this vehicle suggest a basic mileage near 28 mpg.

long term intake vacuum trends

Typical intake vacuum figures on this commute vary widely with road slope and wind, but at 55 mph on level ground in light-to-no wind, they are typically around 13-15 inches. Prior gasoline experiences were nearer 12 inches at the same conditions. Higher “typical” vacuum is associated with higher summer mileage readings. The nature of the timing curve modification was to enforce the same coast-down vacuum curve with both fuels. Typical full-throttle “zeroes” at 55 mph are near 1.5 inches, and typical no-throttle “full-scales” at 55 mph are 24 to 24.5 inches.

Calculations

Calculations are insightful for both average mileage and typical intake vacuum. At the same speed and road loads, the ratio of average mileages ethanol-to-gasoline is proportional to the ratio of gravimetric heating values ethanol-to gasoline, the ratio of energy conversion efficiencies ethanol-to-gasoline, and inversely proportional to the ratio of specific gravities ethanol-to-gasoline.

At the same speed and road loads, intake vacuum is linearly related to manifold absolute pressure, in turn directly proportional to brake mean effective pressure (BMEP) and torque. For the same speed, percent torque is also percent available power at that speed.

long term mileage

Typical ethanol mileage is 23-23.5 mpg, typical gasoline mileage is near 28 mpg (both at 55 mph on the highway). Gravimetric heating value divided by density is volumetric heating value, matching the volume basis of fuel mileage. Data from the ethanol properties document on the website (http://www.txideafarm.com) provides the ratio of volumetric heating values E-85 to unleaded regular gasoline as 0.71 (71%). If the conversion efficiency were the same on both fuels (as is commonly assumed), this would be the mileage ratio as well. It is not. See:

mpg E-85/mpg gasoline = 23.25/28 = 0.83 (83%)

The conversion efficiency ratio ethanol-to-gasoline is then the actual achieved mileage ratio divided by the volumetric heating value ratio:

efficiency E-85/efficiency gasoline = 0.83/0.71 = 1.17 **≈ 1.2** (2 significant figures)

typical intake vacuum trends

Raw intake vacuum has to be "calibrated" into a "percent sweep" between full-throttle and closed-throttle readings. This "percent sweep" is then the percent of MAP, which is equal to the percent BMEP (in turn percent torque and percent power) at the observation-point road loads. For steady 55 mph on level ground with light or no winds, the percent sweep data are:

%sweep = 100%*(vacuum - closed throttle)/(full-throttle - closed throttle)

E-85: %sweep = 100%*(avg 14 - avg 24.25)/(avg 1.5 - avg 24.25) = 45%

Gasoline: %sweep = 100%*(avg 12 - avg 24.25)/(avg 1.5 - avg 24.25) = 54%

Efficiency E-85/efficiency gasoline = 54%/45% = 1.20 **≈ 1.2** (2 significant figures)

seasonality effects

One is concerned about the max - min range of mileage at otherwise similar conditions. Minimum mileage is usually associated with winter, when fuel vaporization is more difficult. Half this range divided by the overall average is a good relative measure of this vaporization-connected seasonality effect.

Fuel	range	average	percent seasonality
E-85	2.5 mpg	23 mpg	11% (plus and minus)
Gasoline	2 mpg	28 mpg	7% (plus and minus)

Presentation of Results

materials compatibility

There is no evidence of any kind of corrosive or solvent attack, anywhere in the fuel system, engine, or exhaust. There is evidence of a beneficial cleaning action in the carburetor.

component life

Fears of a deleterious effect upon valves and valve seats now appear to be unfounded.

The combination of the cleaner ethanol fuel and the Lucas oil additive seems to have greatly extended the lifetime of the crankcase oil charge. The "life" of such a charge is not yet known, but *it is at least twice* the previous 4000 miles with plain Castrol 20W-50 SH+ oils.

The lack of flame soot in the blow-by gases has reduced the soot load in the oil, and therefore has reduced cold start bearing and cylinder wear. The amount of that wear reduction (as a component life extension) is as yet unknown, but it is real, and it depends upon both the fuel and the oil additive. Most of the engine components were near end-of-life when this experiment began, but have not gotten "any worse" after many thousands of miles of experimental driving.

Adding the Lucas additive to the oil really helps with worn rings. It helps eliminate blow-by and improve oil control. There is now no fuel smell in the oil, when there was, with plain oil.

performance

Overall average mileage agrees with the independent data from spot throttle-setting (vacuum) observations. This vehicle's overall energy conversion efficiency is factor 1.2 better on E-85 than it was on plain gasoline. This is reflected in lower throttle settings at the same speeds, and in getting about 83% of gasoline mileage, when one would have expected only 71% of gasoline mileage based upon heating values alone.

This means the engine full-throttle power curve with rpm should be higher on E-85 than on gasoline. There is definitely a sense of lots of unexpected pep when driving, in spite of the advanced age and worn condition.

An increase in the overall energy conversion efficiency means that there is some decrease in the total waste heat production (this would also depend greatly upon the absolute level of energy conversion efficiency, a number not determined in this experiment). Such would be consistent with the notion of greatly reduced radiation heating from the nearly sootless flame. A similar conclusion for aircraft engines operated on an E-95 ethanol was drawn in “Effects of Flame Sooting and Intake Charge Cooling On Spark Ignition Aircraft Engine Performance”, a dissertation by this author, approved 7-13-00 for the PhD degree in General Engineering.

A decrease in waste heat should show up as cooler hardware temperatures (it did in the aircraft), something not measured in this experiment. Cooler components are stronger and therefore should last longer. In particular, this may apply to the valves and valve seats, which previously were the limiting component life items in gasoline service with this vehicle.

seasonality

Seasonality effects are larger with the harder-to-vaporize E-85 as compared to gasoline. This probably means that the intake heater glove modification is not yet quite adequate, but it is close.

inferred emissions effects

A factor 1.2 increase in overall energy conversion efficiency is also a factor 1.2 decrease in intake airflow for the same output power. At the same pollutant concentrations, a decrease in airflow means a decrease in pollutant mass per mile of travel.

This engine is not protected with a catalytic converter, and indeed could not even be so retrofitted. Air-cooled engine temperatures are not stable enough for the converter to actually work, as is already well-known. That is why air-cooled VW models ceased being sold in the US long ago, when the Clean Air Act "kicked in".

However, even in this unprotected car, there is a lower pollutant load per mile on ethanol than on gasoline, simply because of the efficiency improvement and concomitant air use reduction.

Oxides of nitrogen are always produced in fuel-air flames. The more efficient the flame, the hotter, and the more oxides of nitrogen. This is no longer a problem with catalytic converter-equipped modern cars. The converter takes care of it.

The other pollutants (usually carbon monoxide, unburned fuel, and soot, but also aldehydes with ethanol) decrease when efficiency increases. The mix is quite different between the two fuels: no soot, almost no monoxide, different unburned fuel species, and some aldehydes with ethanol; monoxide, soot, and hydrocarbon unburnt fuel species with gasoline.

The catalytic converter takes care of unburnt fuel species and monoxide quite well. I do not know about aldehydes, but these are not generally very toxic, compared to the other pollutants. I presume the converters take care of aldehydes, because in modern vehicles the same converters are used on flex-fuel models as plain gasoline models.

Soot is a problem for catalytic converters: over long periods of time it clogs the component and it poisons the catalyst. A total lack of soot with ethanol means that catalytic converters should last a lot longer than they do on gasoline.

Conclusions / Recommendations

Continue using E-85 with confidence there will be no materials problems or solvent attack.

Continue using 80-20 synthetic blend of Castrol 20W-50 and Lucas Oil Stabilizer, because it really is compensating for the worn components and extending the crankcase oil life.

Best-estimate gasoline-experience life expectancy nominals were max 160,000 miles on the crankcase, max 80,000 miles on the heads and valves, and max 80,000 miles on jugs/rings. Clearly, with ethanol fuels and synthetic-blend oils, these intervals will be longer. But, how much longer is not quantifiable at this time.

Pollutant load per mile with E-85 in this "unprotected" antique is lower than it was on gasoline, because of the increase in efficiency and concomitant decrease in air usage, on ethanol.

It is very likely that the near-elimination of flame soot with ethanol will extend engine component lifetimes, in this antique, or in any modern vehicle.

It is also rather likely that ethanol fuel use will extend catalytic converter lifetimes in modern vehicles by eliminating the soot-caused poisoning and clogging effects.

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