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 particular report is to document experimental blend results in the unmodified vehicle.

Equipment

This vehicle is a 1995 F-150 XLT long bed ½-ton pickup, powered by a 302 V-8 rigged with electronic fuel injection (EFI), distributor-based ignition (no mechanical points), and featuring a 4-speed automatic transmission, and LT235/75R15 tires. The nominal-capacity 18.2 gallon rear fuel tank is used for blends, while the nominal-capacity 16.5 gallon front fuel tank is retained as gasoline-only. This vehicle was not manufactured to be flex-fuel.

Theory

There are three modification items identified for operation on straight E-85 fuel: (1) revision of the fuel metering ratio delivery for both cold and warm engine conditions, (2) a change in the ignition timing to extra advance, and (3) extra intake air stream heat. The first is required because of the drastic change in ideal air / fuel ratio, in turn directly proportional to lower heating value with ethanol. The second is required because of the longer ignition delay associated with ethanol. The third is required because ethanol is substantially harder to vaporize than gasoline.

For lesser blends than E-85, some or all of these may be ignored, up to a point. However, there exists some blend strength at which modification becomes necessary, for a non-flex fuel vehicle. Below that strength, performance may equal straight gasoline in many ways. Of interest are the following six items:

Cold start (ignition) in approximately-freezing weather (winter tests only)

Cold drivability (operating “open-loop” on stored map data in the EFI chip)

Cold passing and hill-climbing power (“open-loop” on stored map data in the EFI chip)

Warm drivability (operating “closed-loop” on the O_2 sensor in the EFI)

Warm passing and hill-climbing power (closed-loop on the O_2 sensor in the EFI logic)

Fuel mileage as compared to a suitable reference

All of these indices but one are subjective driving impressions, and thus pass / fail items. The criterion is a miss, stumble, or other underperformance perceived by the driver. These perceived phenomena were quite easily observed during the “ethanol VW” and “ethanol Farmall” experiments. The numerical comparison is fuel mileage.

As regards mileage, one might expect a declining trend of mileage as blend strength increases, due to the lower heating value of the ethanol. However, previous results with straight E-85 in the “ethanol VW” indicate a compensating efficiency increase due to the ethanol. In any event, we are looking for a sudden downturn of mileage performance that would indicate an engine failing to adapt to the fuel properties in some way, most likely due to timing advance or vaporization.

Blend strength is measured by ethanol concentration as the E-designation; e.g., E-85 is 85% ethanol and 15% gasoline by volume, presumed dry. If there is pre-existing water content absorbed into the fuel, it gets lumped in with the ethanol concentration, as measured by the simple water separation test.

In Texas, it may be presumed that there is no pre-existing ethanol already in the gasoline (unleaded regular, or ULR, 87 grade). This would not be true in the corn belt, where the octane additive of choice is ethanol, instead of methyl tertiary butyl ether (MTBE), as is generally used in Texas. Most gasolines contain the higher alcohol butanol as a blending agent, at perhaps 4%.

Procedure – Drivability (pass/fail)

Cold Start:

The vehicle should start and idle well, including a transition from fast idle to slow idle, on a cold-soaked engine and fuel. Ambient conditions for this check should be at least as cold as the 20-40 F range, but the colder the better. Record impressions in the logbook.

Cold Drivability:

The vehicle should be driven on the highway while still cold, looking for hesitations or lean miss. Record impressions in the logbook.

Cold passing / hill-climbing power:

Same as warm, except done during the first 2-5 miles of driving. Slow down to about 50 mph on approach to a hill. Go gradually to full power, forcing downshift to 3000+ rpm, driving up the hill. Test may terminate at 65 to 75 mph. Look for hesitation on rapid throttle-up, and for lean miss at full power. Record impressions in the logbook.

Hopefully this will be executed while operating on the stored map before going closed loop on the O_2 sensor. (This was not done with the first 3 test blends, but was added for the E-41 test and some of the subsequent blends. Most of the time this is precluded by geography close to home.)

Warm drivability:

The vehicle should be driven on the highway once fully warmed (about 10 miles for the tires), looking for hesitations or lean miss. Pay particular attention to the rpm vs. speed on flat road: should be 1800 rpm at 65-68 mph in high gear with the stator locked, in torque converter mode. Other possible observation points include 1500 rpm at 55 mph, and 1750 rpm at 64 mph (all indicated speeds). Record impressions in the log.

Warm passing / hill-climbing power:

Slow down to about 50 mph on approach to a hill. Go rapidly to full power, forcing downshift to 3000+ rpm, driving up the hill. Test may terminate at 65 to 75 mph. Look for hesitation on rapid throttle-up, and for lean miss at full power. Record impressions in the log.

Procedure – Mileage (numerical comparison)

Using the front tank as an easy reversion to straight gasoline, the rear tank must be "calibrated" for estimated fuel remaining on board versus the marks on the fuel quantity gage. It is the rear tank with the larger capacity that is used as the experimental blend tank.

Vehicle is driven to exactly one of the gage level marks, then switched over to the front tank until it can be refilled with an appropriate blend in the rear tank. Then it is switched back to the rear tank for the next mileage test.

Odometer readings from one fill-up to the next must be corrected by subtracting miles spent driving on the front tank. Total fuel burn from the rear tank includes both the added E-85 gallons and the exact gasoline gallons added, less the volume of any samples withdrawn for blend testing. The fill-up standard is always the "standard overfill" condition, where the filler neck is completely full. This was chosen because it is the only observable and repeatable standard available. The foaming action of gasoline pumps varies, precluding a reliable fill level at "first click". Experience says "first click" varies by more than a gallon on the rear tank of this vehicle.

Do not use miles spent on the front tank for a gasoline mileage, as the driving is too short and cannot approximate either driving cycle.

The driving cycles are two-fold:

TSTC commute, which is 30 miles 1-way, and mostly freeway or open road

SRMcL commute, which is around McLennan county, 1-way 20 miles or less

Data not collected on the TSTC cycle should be compared to the SRMcL cycle. An off-cycle combination may be interpolated between the two baselines, based on the odometer miles recorded as spent on each, but this procedure is not really recommended.

Blends should be reported as "wet E", meaning any pre-existing water in the blend is lumped with the ethanol. The simple water separation test results may be used, without any hydrometer correction. Every tank should be blend-tested, although the first two were not, being "post-predicted" after-the-fact from the third tank, which was the first tank actually blend-tested. Texas gasolines may be presumed not to contain any ethanol as finished, unless there is no "ether smell" to the fuel on fueling. Experience shows this to be extremely rare.

Procedure – Simple Water Separation Test:

This is done shortly after the final fill-up of a desired blend, but long enough for fuel rail contents to be cycled back to the tank and mixed. It was originally presumed that this would happen within several seconds to a minute of operation, so that a mile or two of driving from the fill-up location would be sufficient. Experience later showed this to be more on the order of 5 miles driving at highway speeds to fully purge the fuel rail and replace its contents with tank fuel. Experience also shows that ethanol and gasoline "splash blend": no agitation or "mixing time" is needed in the tank itself.

Using the hoses from a standard fuel injection pressure test kit, and laboratory-grade graduated cylinders of 100 cc and 25 or 30 cc size, a sample of 55-70 cc is drawn from the Schrader fitting on the fuel rail into the 100 cc cylinder. Any excess is poured back into the test tank, using a funnel. About 15-22 cc of clean potable water is measured into the small graduated cylinder. These volumes are measured as bottom-of-meniscus and recorded. (If the blend tank has not been used, then an alternative source is the tank filler itself. The "standard overfill" condition guarantees fuel level to be above the anti-siphon restriction built into the filler neck assembly.)

The water is poured into the fuel sample, and allowed to stand and separate. Settling time varies, but one must allow all the entrained air to bubble out. This requires close observation, as the air bubbles are very tiny. Backlighting the cylinder helps. Total wetted sample is measured as bottom-of-meniscus and recorded. The interface between the dry hydrocarbon layer on top, and the wet ethanol layer underneath, is a truly flat plane. That volume is read directly against the scale and recorded. Then the sample may be discarded properly. Texas law requires that the fuel be poured onto an impermeable surface and allowed to evaporate, to prevent soil contamination.

The volume of gasoline in the wetted sample is the volume of gasoline in the original fuel sample, and may be most accurately computed as wetted sample volume less wetted ethanol volume. Then the ethanol volume in the original fuel sample may be most accurately computed as original sample volume less measured gasoline volume. The mixing of ethanol and water does not quite conserve volume: one will always note a lost cc or two in this test, as described for the 55-70 cc sample sizes and 15-22 cc water volumes.

The E-designation of the test blend is then:

E designation = 100% * (ethanol volume / original sample volume)

Any water in the original fuel will get included in this "ethanol" volume. Experience to date with commercial E-85 (seeing E-87 or 88 results instead of the expected E-85) indicates this will be a small percentage, perhaps 2-3%.

If there is ethanol or methanol in the dry gasoline formulation, this will also get carried into the "ethanol" detected by this test. Blending-agent butanol and octane-booster ethers seem to remain with the hydrocarbon gasoline material.

If octane-booster alcohol is suspected in the dry gasoline, its presence can be detected by performing this test directly upon a straight gasoline sample.

If significant water is suspected in the E-85 blend, it can be detected by first separating the hydrocarbon component with a water addition, decanting that layer, then running a hydrometer test on the wet ethanol layer to determine proof. That proof result is applied as a percentage to the wet ethanol sample to determine water and ethanol volumes.

Correcting the water volume so obtained, by the volume of water added to separate the sample, will reveal a rough estimate of water in the original fuel. However, this estimate is imprecise by the 1-2% non-conservation of volumes that invariably happens when mixing ethanol and water.

Data collected

Raw data for blend strength as-tested are as follows:

raw data taken (NA = not applicable):									
test #	nom E	basis	est wet E	basis	act wet E	est dry E	basis	calc date	day/year
1	20	cal 1	17	cal 2	16	14	scaled	12/18/2007	352
2	30	cal 1	27	cal 2	26	24	scaled	12/24/2007	358

3	40	cal 1	36	cal 2	35	33	plain sep	12/29/2007	363
4	40	NA	NA	NA	41	38	plain sep	1/3/2008	3
5	36	NA	NA	NA	37	34	plain sep	1/9/2008	9
6	45	NA	NA	NA	45	42	plain sep	1/14/2008	14
7	36	NA	NA	NA	36	33	plain sep	1/19/2008	19
8	30	NA	NA	NA	29	26	plain sep	1/26/2008	26
9	20	NA	NA	NA	17	14	plain sep	2/9/2008	40

Data as computed for mileage are as follows:

mileage (numerical):				TSTC	SR McL
act wet E	mpg	c'mpare to	baseln	mpg/base	mpg/base
16	16.51	TSTC	15.75	1.05	
26	13.91	SRMcL	14.11		0.99
35	13.57	SRMcL	14.11		0.96
41	14.97	SRMcL 3	14.11		1.06
37	16.94	TSTC	15.75	1.08	
45	10.9	TSTC	15.75	0.69	
36	14.96	TSTC	15.75	0.95	
29	14.55	SRMcL	14.11		1.03
17	14.95	SRMcL	14.11		1.06

Data collected for driving impressions are as follows:

drivability (pass-fail P or F):					
act wet E	cold ign	cold drv	warm drv	hill/pass	cold hil/pa
16	P	P	P	P	not done
26	P	P	P	P	not done
35	P	P	P	P	not done
41	F ? 1	P	F ? 2	P	P
37	P	P	P	P	not done
45	F ? 4	F ? 5	P	P	not done
36	P	F 6	P	P	not done
29	P	P	P	P	not done
17	P	P	P	P	not

					done

There are these further notes regarding those impressions, which provide some temperature dependence to these problems.

F ? 1: 20 F died once, 30 F OK
F ? 2: check engine came on & went out after a stumble
3: not a good overfill, increased fuel burn by est. shortall 1.67 gal
F ? 4: rpm stumble but did not die upon cold start at 40 F
F ? 5: rpm stumble briefly, but did not die, in parking lot, 60 F
F 6: accel in rev, let off, & it stumbled, almost died, before running OK; 40 F humid

Calculations

Miles traveled on the test tank are computed from the odometer difference at fill-up on the test fuel tank, which is filled to the same mark every time. Miles traveled on the other tank are recorded in the log and deducted from this total. For better control of mixture computations, this is done only at the 3/4, ½, or ¼ tank marks on the fuel quantity gage.

Fuel burned from the test tank is computed from the E-85 test fuel measured as a fuel addition, and the gasoline required to top-off the tank at fill-up, “to-the-mark”. These are summed, and any fuel sample volumes drawn are deducted from this total. Conversion from cc (ml) to gallons for the mileage correction is:

Sample gallons = sample cc / [(16.387 cc/cu.in)*(231 cu.in / gallon)]

Mileage is total test tank miles divided by total test tank fuel volume (gallons) burned.

For mixture computations, the second version of the tank calibration is used. Although not exact, this comes very close. That calibration is:

REAR TANK RE-CAL

fill level	gal remain	
overfill	21.34	**std o'fill actual capacity**
full	18.66	
1st click	**18.2**	**1st click = nominal capacity**
75%	16.07	
50%	12.95	
25%	8.72	
12.50%	6.96	
empty	0	

Whatever fuel remaining on board (X gallons, from the calibration) has an ethanol concentration fraction E1. The number of ethanol gallons still on board is then X*E1

The effective capacity at overfill is estimated as 21.34 gallons, as listed in the table. For the next test, the ethanol concentration fraction is to be E2. The final desired ethanol gallons is then 21.34*E2.

The difference between these ethanol gallon quantities is the ethanol to be added via an E-85 addition. This E-85 is presumed to be dry, and its ethanol concentration fraction is presumed to be 0.85. Thus, the volume of E-85 to be added (Y) to form the test blend desired is:

Y = (21.34*E2 – X*E1)/0.85

… which is added before driving to the final fill-up location, on the front tank (non-test tank). This prevents use of a too-rich ethanol blend, if the E-85 addition is done at a separate location.

Since the gallons remaining (X), the gallons of E-85 to be added (Y), and the gallons of gasoline to be added (Z) must add to the effective tank capacity at the fill-up mark (21.34 gallons), we can estimate the make-up gasoline as:

Z = 21.34 – X – Y

… and compare this to what is actually added at the fill-up. These should compare to within a fraction of a gallon for confirming good results at controlling test blend.

Since there are two driving cycles, each with its own historical gasoline baseline mileage, the best comparison is to ratio blend mileage to the corresponding gasoline baseline mileage. This ratio is then plotted versus blend strength, with the driving cycle source identified as a parameter. In that way, all of the data can be compared fairly.

Presentation of Results:

The basic presentation for all but the mileage data are the tables of collected data as already given above. For the mileage, it is instructive to compare mileage ratio vs blend strength, knowing that most flex-fuel vehicles get 85% of their gasoline mileage when operating on straight E-85. Thus we are looking for a significant mileage fall-off of, say, 5-10% or more, as an indicator of mismatch between the engine systems and the blend fuel.

The figure below shows little difference between ratioed mileage data from the two driving cycles, and no sense of a trend versus blend strength up to just over 40% ethanol. This was not expected. Beyond that point, mileage suddenly crashes (the E-45 blend trial) by around 30%. This “crash” is very significant. One strong possibility is that ignition delay “caught up with us”, and the timing needs advancement. Another is that vaporization is inadequate and extra intake is needed. Because of the good warmed-up driving impressions, it seems far less likely that the closed-loop fuel injection controls cannot handle the mix. Those are the only known possibilities.

The other five driving impressions listed in table form above show that this vehicle has almost no flow capacity problems operating in closed loop on the O_2 sensor, as warm drivability and hill-climbing / passing power seem to be unaffected all the way through 45% ethanol. However, there is that “check engine” light that came on briefly more than once, just about the time the fuel injection was going closed-loop. Furthermore, the mileage plot shows something is wrong, so 45% is definitely “too much” for this particular vehicle, unmodified. Mileage data indicate a limit of about 40% (E-40 blend).

Cold start and cold drivability show problems with dying, or perceived lack-of-fuel behavior, that appear to be temperature dependent. The colder the weather, the more problems were encountered. In these tests, problems seem to get objectionable around 35% ethanol, so that is probably a better figure for the blend strength limit in this particular unmodified vehicle than the 40% limit just above. In colder climates, that limiting result might obtain at blend strengths closer to 30%, or maybe even 25% in the northern tier of states.

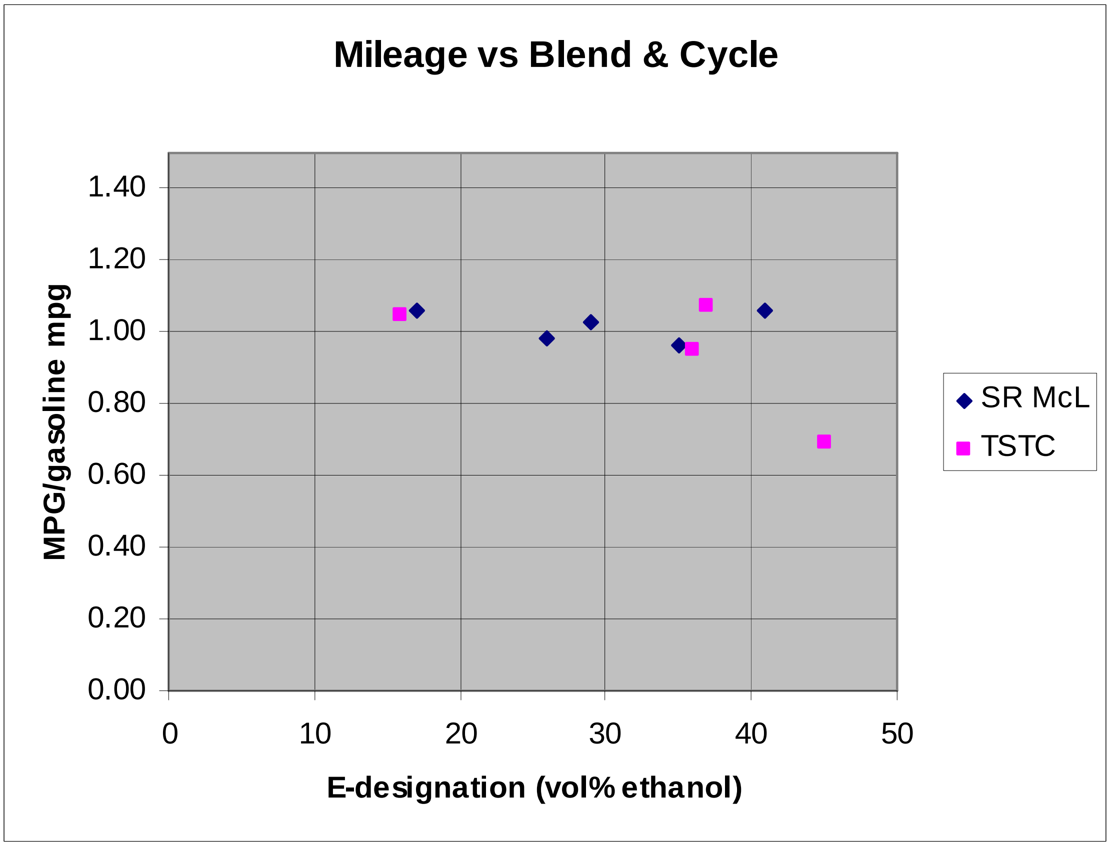

Figure 1 – Mileage Ratio Trends vs. Blend Strength

Conclusions / Recommendations:

The point at which modification appears to be needed based on mileage is about E-40.

The point at which modification appears to be needed based on cold start and cold drivability concerns (albeit minor) is about E-35, at least down to 20 F.

Questions and comments should be directed at the author/experimenter:

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