Evaluation and Development of an On-Highway Motorcycle Evaporative Emission Reduction Strategy

United States
Environmental Protection
Agency

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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Executive Summary

The US EPA National Vehicle and Fuel Emissions Laboratory participated in an evaporative testing effort with the Manufacturers of Emissions Control Association and the California Air Resources Board. The goals of this work included reduction of evaporative emissions from an on-highway motorcycle through application of a canister design criteria. The canister design criteria is a linear relationship of canister Working Capacity/Fuel Tank v 3-day diurnal emission total and was developed by CARB based on their SHED testing of several Class III on-highway motorcycles. For this work a goal of 3g over the three day SHED test was utilized. If a motorcycle's emissions were higher than 3g over the three day SHED test, then evaporative emissions would ideally be reduced by using a canister with a higher working capacity which was determined from the canister Working Capacity/Fuel Tank ratio which yielded the 3g value. If a motorcycle's three-day evaporative emissions were below the 3g, then it was noted as a system which proved the feasibility of the evaporative emission level and subsequent test fuel/test cycle comparison testing was performed.

EPA conducted multiple three-day diurnal evaporative emissions tests on three on-highway motorcycles that incorporated electronic fuel injection and three-way catalyst which are the technologies used to meet the Euro5 exhaust emission levels. The newly purchased motorcycles included a Honda Metropolitan (49cc), a Honda Super Cub (125cc) and an Alliance Powersports Wolf 300 (278cc). The vehicles were aged to 600 miles prior to the first SHED test and manufacturer maintenance was performed. The <50cc engine was chosen for evaporative emission baselining and had no canister. Results of three-day diurnal SHED testing of the Super Cub showed that it met the goal of less than 1g/day of evaporative emissions over the three days. This means that the existing canister is of sufficient design and no changes to the system are required. The Wolf 300 exceeded the goal of 1 g/day over three days and the canister design approach to evaporative emission reduction was applied and tested.

Due to the low evaporative emissions from the Super Cub, additional evaporative emission comparisons were made which included a change of the preparatory cycle from the FTP to the WMTC as well as the use of LEV III, E5 and Tier 3 test fuels with the WMTC cycle. SHED temperatures were set using the automotive relationship of LEV III with CARB temperatures and Tier 3 and E5 with EPA temperatures due to the respective fuel RVP values. Differences in evaporative emission levels were seen in the three-day diurnals from use of the different preparatory cycles. The FTP is a 30-minute cycle and the WMTC is a 20-minute cycle and hence more canister purge is realized with use of the FTP cycle thereby resulting in lower evaporative emissions than with the WMTC. Using the WMTC preparatory cycle, evaporative emission differences were seen in the LEV III/CARB temperatures and E5/Tier 3/EPA temperatures and were identified as being emissions released during the cooling times of the diurnal test which were observed from a cumulative data figure. All emission test results were below the 1g/day goal.

The canister design criteria was used to determine a higher canister working capacity level for the Wolf 300 to achieve 3g or less evaporative emissions over a three day diurnal. Testing of the

Wolf 300 with several higher working capacity motorcycle canisters did not yield the expected results. Snoop testing of the motorcycle revealed that there was a leak at the fuel tank cap keyhole area and measures to reduce evaporative emission reductions were not successful to achieve the goal. The findings of the testing on the Wolf 300 were used to develop a list of design/test considerations whose use could more assure reduced evaporative emissions from this motorcycle. An attempt was made to develop a leak test using a measurement tool however was unsuccessful and further evaluation is required.

Introduction

The California Air Resources Board (CARB) conducted an On-Road Motorcycle Workshop on November 17, 2020 in which they stated that they are looking at more stringent evaporative emission regulations for On-Road Motorcycles. CARB currently has a one-hour heat build evaporative emission test requirement which is met with the use of evaporative canisters. A longer evaporative emission requirement may require changes to the current canister designs. For the 2020 Workshop, CARB performed multiple-day diurnal emission tests on several Class III ON-HMC[i] and found a linear relationship between the canister Working Capacity/Fuel Tank versus the 3-day total diurnal evaporative emissions (g). Additional testing and evaluation were performed by a group that included the Manufacturers of Emissions Controls Association (MECA), the US Environmental Protection Agency (US EPA) and the California Air Resources Board (CARB). MECA's work[ii] included the evaluation of properties of existing evaporative canisters on several of the CARB and EPA tested ON-HMCs as well as the conduct of bleed emission testing on a number of fuel systems. This report describes EPA's efforts which include the performance of several three-day diurnal evaporative emission tests on three Class Ia-II low exhaust emission on-highway motorcycles (ON-HMC)[iii,1] and the conduct of Butane Working Capacity (BWC) studies on two canisters. The baseline 3-day diurnal emission results, along with the BWC/Fuel tank(L) ratio, for each motorcycle were added to the data which formed a linear relationship from the Class III motorcycle evaporative test results by CARB. The Metropolitan (49cc) was tested for baseline evaporative emissions for it did not have a canister since it is not regulated by CARB. The Super Cub (125cc) met the 1g/day (3g over three day) evaporative emission goal and so additional SHED testing was also performed. Testing included a comparison of 3-day diurnal evaporative emission results from the use of two preparatory cycles - the World Motorcycle Test Cycle (WMTC) and the Federal Test Procedure (FTP). A comparison of evaporative emission results from the use of three different test fuels along with the WMTC preparatory cycle was also performed. EPA applied CARB's canister design criteria to the Wolf 300 which proved to be a high evaporative emission motorcycle on the three-day evaporative emission test. The goal was to see if its use would result in the motorcycle evaporative emissions meeting of the three-day total of 3g (1g/day over three days). Lastly, a leak test was performed to determine if the amount of leak could be characterized.

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[1] Emission levels on this motorcycle were similar to those of Euro5 emission levels as tested on the FTP with Tier 2 (E0) certification test fuel. Fueling system is electronic fuel injection which means the higher evaporative emissions from carbureted fueling systems is not of concern. EPA evaporative emission requirements include permeation limits for fuel tank and hoses.

Importance of Evaporative Emission Reduction from ON-HMC

CARB noted in their 2020 On-Highway Motorcycles Workshop that their current EMission FACtor (EMFAC) modeling illustrated that evaporative emissions are the largest contributor to Reactive Organic Gases (ROG) emissions from ON-HMC in California, see Figure 1[i,2]. Currently motorcycles sold in California must meet CARB's evaporative requirements for motorcycles which result in the use of an evaporative canister to meet the 2 gram standard in the 1-hour heat build test[iii].[3]

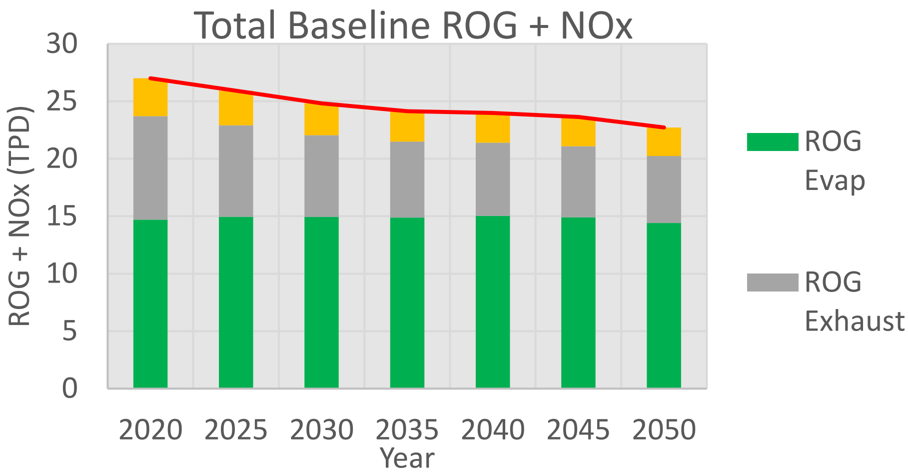

Figure 1: CARB Evaporative ROG Contribution to overall ROG+NOx from ON-HMC in CA[i]

This study focuses on small displacement motorcycles that have exhaust emission levels similar to Euro5 implemented in Europe in 2020/2021. Electronic fuel injection, three-way catalyst and closed loop fuel control are some of the technologies that bring motorcycles into compliance with Euro5 regulations[4]. A summary of exhaust emission standards for the European Union and the US EPA/CARB[5] is shown in Table 1. The US EPA hydrocarbon and carbon monoxide certification levels for the study motorcycles are also listed. Nearly all of the emission standards/levels are based on the FTP test cycle and Tier 2 (E0) test fuel. Euro5 exhaust standards are based on the WMTC and E5 test fuel and therefore are not directly comparable to the EPA/CARB standards.

[2] The exhaust emission values decrease over time in Figure 1 due to the implementation of Euro5 emission levels in 2020/2021 for motorcycles sold in Europe and the reality that these ON-HMC, or slightly modified version of, are sold in California. For many in the motorcycle industry, the same motorcycle designs are sold throughout the world. Modifications to the same design for areas with lower emission requirements would include less catalyst efficiency depending on the respective exhaust emission requirements in the specific country, or the removal of a canister.

[3] CARB does not have the fuel tank and hose permeation requirement as required by the US EPA, however it is plausible that manufacturers utilize the same fuel tank and hose in California sold motorcycles to make uniform products across North America.

[4] The Euro5 standards are based on the World Motorcycle Test Cycle and use of E5 test fuel while the EPA/CARB standards are based on the FTP and Tier 2 (E0) test fuel.

[5] At the time of this report, CARB is working towards a new regulation for ON-HMC which may include the adoption of Euro5 standards and WMTC test procedure.

Table 1: Exhaust Emission Standards for Euro5 and EPA/CARB

Emissions Standards (g/km)	HC	NOx	CO	NMHC	Test Fuel	Test Cycle
Euro5	0.1	0.06	1.0	0.068	E5 (5% ethanol)	WMTC
EPA/CARB – Class III	HC+NOx: 0.8		12	-	Tier 2 (0% ethanol)	FTP
EPA/CARB – Class Ia, Ib, II	HC: 1.0 or HC+NOx: 1.4		12	-	Tier 2	FTP
STUDY MOTORCYCLES (US EPA Online Emission Certification Data[iv], NOx data was not listed):						
Honda Metropolitan	0.2		0.7	-	Tier 2	FTP
2019 Honda Super Cub	0.1		0.6	-	Tier 2	FTP
Alliance Powersports Wolf 300	0.1		0.7	-	Tier 2	FTP

Canister Design Requirement: Starting Point

CARB performed multiple day diurnal evaporative emission tests on a number of Class III motorcycles. The emission results for the first 3 days were totaled and plotted versus canister Working Capacity*(g)*[6]/Fuel Tank (L). The resultant graph shared at the CARB 2020 Workshop[i] is shown in Figure 2.

A linear relationship is discovered for most of the data. Ideally, the linear relationship could be used as a canister design requirement to achieve reduced evaporative emissions from on-highway motorcycles. The Working Capacity of a canister divided by the fuel tank volume should ideally yield the 3-day emissions level on the y axis. Figure 2 shows that the value of 1.6 Working Capacity/Fuel Tank (L) would yield a 3-day emissions level of 3 g (1g/day over three days).

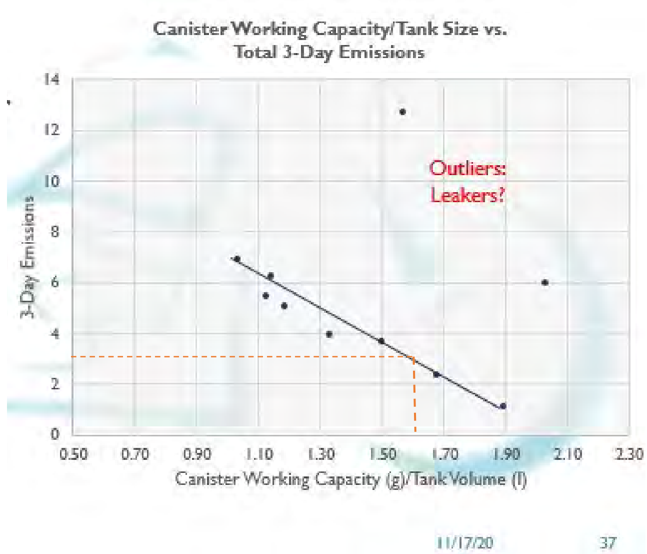

Figure 2: Canister Working Capacity(g)/Fuel Tank Size(L) vs Total Three-Day Hydrocarbon Diurnal Emissions[i]

[6] The Working Capacity of an evaporative canister is determined through a specific test on the canister using either Butane or Gasoline. The procedure for the Butane Working Capacity (BWC) used in this report is listed further into the report. The Working Capacity values for this figure were obtained by OEMs from the canister manufacturers and were not individually tested by the engine manufacturers. The values are understood to be Gasoline Working Capacity or possibly a mix of BWC and GWC test results as the basis for Working Capacity was not defined in the submittals by the OEMs to CARB.

One of the objectives of the EPA project is to determine whether the multi-day diurnal evaporative emission results from several smaller low emitting On-Highway Motorcycles (one each of Class Ia, Ib, II), with electronic fuel injection (EFI) and a three-way catalyst (TWC), have the same linear relationship[7] as the Class III motorcycles. Another objective is to find out if the ideal relationship is realized in practical application.

Motorcycle Canister Evaluation and Development Program Goals

EPA performed three-day diurnal evaporative emission tests on three smaller displacement ON-HMC. Two of the ON-HMC, one Class Ib and one Class II, were equipped with canisters to meet CARB's current evaporative requirements [iii]. The third motorcycle, a Class Ia, does not have a canister for CARB currently does not regulate motorcycles below 50cc. Several details on the three on-highway motorcycles are listed in Table 2.

Table 2: Details of Three On-Highway Motorcycles for EPA Test Program

ON-HMC #	Manufacturer	Model	Weight (dry)	Engine Size/Class	Fuel Tank Size (gal/L)	Canister Dimensions
1	Honda	Metropolitan	179 lbs	49cc/ Class Ia	1.2/4.5	No canister
2	Honda	Super Cub	240 lbs	125cc/ Class Ib	1.0/3.8	2" dia x 5" long
3	Alliance Powersports	Wolf 300	388 lbs	278cc/ Class II	3.7/14	2.5" dia x 3.5-5.0" long

The goals for the EPA test program include:

1) EVAPORATIVE CANISTER PLACEMENT AND OUTER DIMENSION MEASUREMENT
    - Identify the placement of the canister on each ON-HMC and the location to the engine/fuel tank.
    - Measure outer dimensions of canisters.

2) BASELINE EVAPORATIVE EMISSIONS
    - Perform multiple three-day diurnal evaporative emission tests, on ON-HMC #2 and 3, to determine if the current canisters are sufficient to meet a 1g/day maximum.

3) WORKING CAPACITY/FUEL TANK vs THREE DAY EMISSION TOTAL RELATIONSHIP FOR SMALLER ON-HMC SAME AS FOR CLASS III:
    - Calculate the BWC(g)[8]/Fuel Tank(L) for ON-HMC #2 and 3 in Table 2
        - Utilize the BWC(g) from MECA testing of new canisters

[7] Note that during this project it was determined that the Working Capacity values obtained by CARB were mostly/all Gasoline Working Capacity. A figure based on Butane Working Capacity (BWC) was assembled using BWC test results from MECA.

[8] It is assumed that the Working Capacity = Butane Working Capacity and not Gasoline Working Capacity. CARB noted that the Working Capacity value was not identified in the submissions by the OEMs.

- Plot BWC/Fuel Tank (L) vs. 3-day evaporative emission results from ON-HMC #2 and 3 and compare to the linear relationship found by CARB for Class III ON-HMC (Figure 2).

4) PREPARATORY CYCLE COMPARISON:
   - Perform three-day diurnal emission SHED tests using WMTC and LEV III on an ON-HMC that meets1g/day maximum for three days.
     - Note any emission differences to FTP and LEV III emission test results.[9]

5) TEST FUEL COMPARISON WITH WMTC PREPARATORY CYCLE:
   - Perform three-day diurnal emission SHED tests using WMTC and E5 test fuel[10] on an ON-HMC that meets the 1g/day maximum for three days.
     - Compare to results from WMTC and LEV III.
   - Perform three-day diurnal emission SHED tests using WMTC and Tier 3 test fuel on an ON-HMC that meets the 1g/day maximum for three days.
     - Compare to results from WMTC and LEV III as well as E5.

6) APPLY CANISTER DESIGN CRITERIA TO PROVE FEASIBILITY OF METHOD:
   - For the ON-HMC which exceeds 1g/day emissions over three days, determine the appropriate canister BWC(g) for meeting the goal of 1g/day. Use the BWC/Fuel Tank ratio from Figure 2 that may bring the bike into compliance (1.6 or greater).
   - Determine if an existing canister is available with the appropriate BWC or if a prototype canister is needed. MECA performed BWC testing on a number of canisters from CARB and EPA test programs.
   - Retest the ON-HMC with the new canister to confirm passing of 1g/day max over each of the three days.
   - If does not meet the target emission level then investigate the ON-HMC for additional sources of evaporative emissions.
   - List additional criteria needed for canister design specification list (not including a SHED test).

7) PERFORM BUTANE WORKING CAPACITY TEST ON TWO ON-HMC CANISTERS
   - Two canisters are to be tested – one new and one used (for different ON-HMC)
     - Compare results to MECA testing on a similar new canister
     - Comment on any findings on canister capacity reduction (BWC) with testing of one used canister and compare to like new canister tested by MECA.

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[9] Note that the WMTC will be a shorter length test (20 min) than the FTP (30 min) for ON-HMC #2 and will be the same length for ON-HMC #3. The shorter time can mean less canister purge time.

[10] E5 has RVP in the range of EPA Tier 2 RVP levels and LEV III fuel has lower RVP than EPA Tier 2 RVP. Based on the relationship of RVP and test temperatures for LDV, tests with E5 will utilize EPA temperatures and Tests with LEV III will utilize CARB temperatures.

Table 3 shows the test matrix for this study. The Metropolitan does not have a canister and so the canister related tests do not apply to this ON-HMC. The Triumph Triple Street CARB canister[11] and a used canister for a Super Cub were tested with BWC protocols.

Table 3:On-Highway Motorcycles and Planned Testing

On-Highway Motorcycle	Baseline 3-Day Diurnal	Goal: 1 g/day or less 3-Day Diurnal			Butane Working Capacity Testing of Canister
	FTP	WMTC			
	LEV III CARB TEMP	LEV III CARB TEMP	E5 EPA TEMP	Tier 3 EPA TEMP	
Metropolitan (49cc) 4.5L Fuel Tank (no canister)		NA	NA	NA	NA
Super Cub (125cc) 3.8L Fuel Tank					NA
Wolf 300 (278cc) 14L Fuel Tank					NA
Grom/Super Cub Used Canister (1068 miles)	NA	NA	NA	NA	
Triumph CA canister	NA	NA	NA	NA	

Test Program: Motorcycle Detail

The following describes details of the ON-HMCs used in this study. If applicable, the placement of the canister is identified on each bike. Initial outer canister dimensions are also noted.

On-Highway Motorcycle Descriptions

1. Metropolitan (49cc)
   The Metropolitan by Honda is shown in Figure 3. This ON-HMC is currently not regulated by CARB and therefore does not employ an evaporative canister[12]. This vehicle was chosen for this study in order to characterize the evaporative emissions from <50cc ON-HMC. The fuel tank holds 1.2 gallons and is located at the feet of the rider. The engine is located next to the rear wheel on a similar level to the fuel tank.

[11] The Triumph Triple Street was found to have a European canister and a California (CARB) canister which were different designs and a BWC was determined for each. EPA tested the CA canister while MECA tested the European canister.
[12] The ON-HMC does employ components which comply with the EPA permeation tank and hose requirements.

Figure 3: Honda Metropolitan (49cc)

2. Super Cub (125cc)
   The Super Cub by Honda is shown in Figure 4. The fuel tank on the Super Cub is one gallon (3.78L) and is located under the seat. Location of the evaporative emission canister is near the footrests as shown in Figure 5. A comparison of the two figures shows that the ON-HMC has a shroud covering the canister. It appears that there is sufficient room for a larger canister, if needed.

Figure 4: 2019 Honda Super Cub

Figure 5: Placement of Canister on 2019 Super Cub

Outer dimensions of the canister on the Super Cub (125 cc) are 2” in diameter and 5” long as shown in Figure 6.

Figure 6: Super Cub Canister Outer Dimensions

3. WOLF 300 (278 cc)
   The Wolf 300 by Alliance Powersports[13] is shown in Figure 7. The Wolf 300 was chosen for this study for it is a non-US or Japanese manufacturer Class II ON-HMC and it was EPA/CARB certified to near Euro5 exhaust emission levels, as shown in Table 1. The fuel tank on the Wolf is 14L.

   The location of the canister on the Wolf 300 is tucked tightly below the fuel tank and above the engine, see Figure 7 and Figure 8. Moving the existing canister or incorporating a larger one would likely require some reconfiguration of the motorcycle.

[13] The Wolf 300 motorcycle was discontinued in the US in 2021.

Figure 7: Wolf 300 Showing Canister Placement

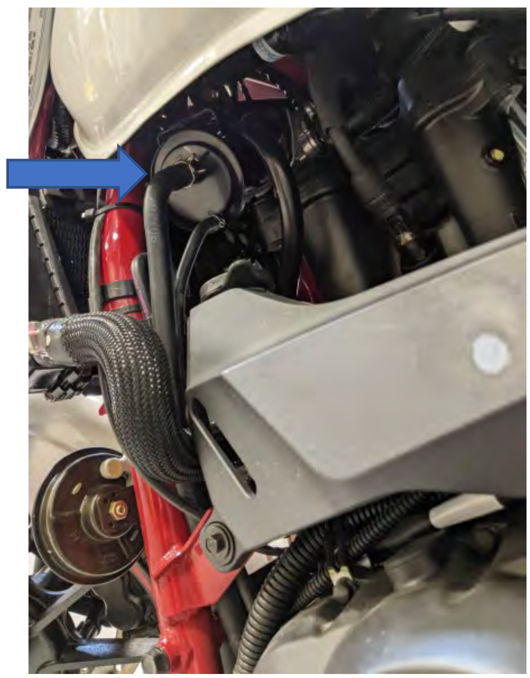

Figure 8: Close up of location of canister on Wolf 300 – below the fuel tank

Vent hoses from the canister are seen in Figure 9. These hoses are close to the ground where dust and water can possibly find its way inside the hoses.

Figure 9: The canister has two vent hoses that are directed downward.

The outer canister measurements are 2.5 inch diameter and 3.5-5 inches long, as shown in Figure 10. The canister body appears to be smaller than that used on the Super Cub and the fuel tank is much larger on the Wolf 300 (14L) than on the Super Cub (3.78L), in Figure 6, so it is expected that this canister is sized only to meet the current 1 hour diurnal requirement from CARB.

Figure 10: Outer Dimensions of the Evaporative Canister from the Wolf 300

Vehicle Preparation

The vehicles were prepared for evaporative emission testing as follows.

1. Visual inspection of ON-HMCs
   a. Confirm the motorcycle has a canister system, if the engine was greater than 50 cc.

   b. Confirm that the motorcycle had an engine which was low emitting according to EPA/CARB certification database engine family name on the engine label.
   c. Examine for visual leaks
2. OEM procedures for vehicle break-in were followed
   a. Drive each motorcycle for 1000 km
   b. Change the engine oil and check all fluids and filters, adjust as needed
3. Inspect the motorcycles to ensure they were safe to operate on a dynamometer

Methods

Preparatory Test Cycles

The Federal Test Procedure (FTP), Figure 11, and the World Motorcycle Test Cycle (WMTC), Figure 12, were utilized for this test program as the preparatory cycles for the SHED tests. The WMTC[v] is of interest for CARB is considering this test cycle for their next motorcycle regulation[14].

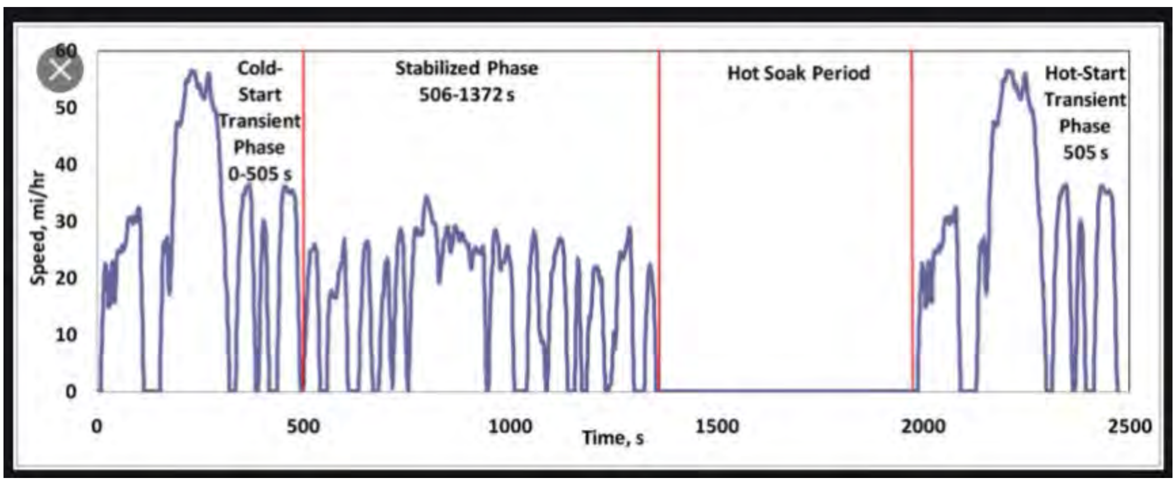

Figure 11: Federal Test Procedure (FTP) for On-Highway Motorcycles (mph)[vi]

[14] Emission regulations from other countries for two- and three-wheeled vehicles/motorcycles utilize this test cycle including Euro5 and those countries that adopt UNECE GTR2.

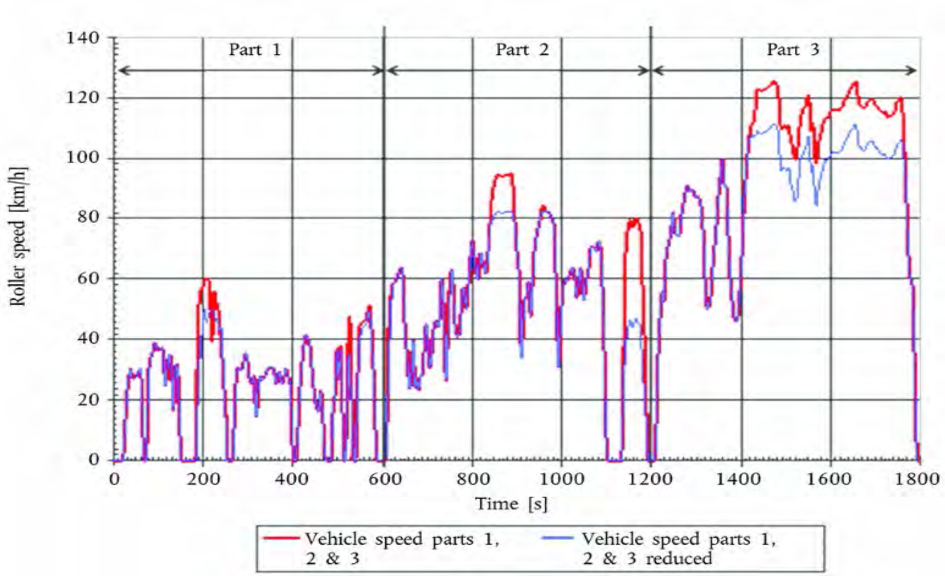

Figure 12: World Motorcycle Test Cycle (WMTC) (kmph)[vii]

The FTP, Figure 11, is operated the same for each motorcycle. The one exception is that the top speed is adjusted to the vehicle's top speed if a vehicle is not able to reach the FTP maximum speed of nearly 57 mph. The Metropolitan falls into this category as its top speed was found to be 37 mph according to EPA testing. The total time of the test cycle is 30 minutes for all motorcycles. The FTP is 11.4 miles in length.

The WMTC, Figure 12, has a different number of parts and different maximum speeds for different vehicle Classes as identified in Euro5[viii] and UN ECE GTR2[ix]. The tests are different lengths of time depending on the vehicle Class designation which is based on vehicle maximum speed and in some cases engine displacement. Each part is 10 minutes in length. The full WMTC (all three parts) is approximately 13.2 miles.

- The Metropolitan (49cc, v_{max}=64.4 kph (Honda)) is a Class I according to WMTC protocol for it is <150cc and v_{max} 50-100km/h. This motorcycle is tested with two runs (cold and hot) of part 1 with reduced vehicle speed for a total test length of 20 minutes. The maximum speed is 50kph or 31mph.

- The Super Cub (125cc, v_{max}=88 kph (EPA test)) is a Class 1 according to WMTC protocol, <150cc and v_{max} 50-100km/h, and therefore would have the same test cycle as the Metropolitan. However, for the EPA testing the ON-HMC was tested as a Class 2-1 with part 1 and part 2 both with reduced max speed. CARB is considering vehicles with maximum speeds of 85km/h or higher to be in Class 2-1[15] This test length is also 20 minutes.

[15] The Super Cub was able to reach speeds of 88 kph and therefore had sufficient room to meet the maximum speed of 82.5 kph in the part 2 with reduced speed. If tested at only part 1 speeds, then this 88kph ON-HMC would only be tested at a max speed of 50kph/31 mph which is not representative of the vehicle's capability and is less than the current FTP.

- The Wolf 300 (Vmax=137 kph) is a Class 3-1 according to WMTC protocol, v_{max}=130 to <140 km/h, which means the WMTC cycle for this motorcycle would include all three parts with part 3 having reduced speed. The length of the WMTC test for this motorcycle is 30 minutes which is the same length of time as the FTP. The WMTC includes higher test speeds, in the third part, than the FTP which is more representative of real-world use in North America.

For the WMTC, the smaller bikes have shorter length (time) test cycles compared to the larger bikes. While this will influence the amount of purge a canister sees compared to the FTP, which has the same test length for all bikes, the real-world use of the smaller bikes should be considered. In the US, scooters with engines <50cc are used on college campus's due to the fact that the rider may not need a motorcycle license to drive such a vehicle. These operation times could be 5 to 10 to 20 minutes depending on the size and sprawl of the campus. Motorcycles able to reach 88kph/55mph are still not sufficient for federal highways however may be used for longer secondary road trips however very likely are not used for highway travel or cross country trips as are larger motorcycles.

Dynamometer

The dynamometer used for this test program was an EPA light duty vehicle dynamometer (48" roll with 6000lb capacity). The specific dynamometer and analyzers had been proven in a previous test program on a 300lb child atv to drive the atv sufficiently to result in expected exhaust emission results for this vehicle in a round robin test program. The motorcycles used in this test program weighed(dry) 178, 240 and 388 lbs as shown in Table 2. The dynamometer was successful in putting the motorcycles through the various FTP and WMTC test cycles to result in appropriate vehicle warmup.

The equivalent inertia mass (EIM) dynamometer settings (A and C coefficients) from the FTP were utilized for both the FTP and WMTC. For the Super Cub and the Wolf 300 the calculated force from the EIM's for the WMTC were near equal compared to those for the FTP. The Metropolitan was only run with the FTP for baseline evaporative emission testing. No exhaust emission data was collected in this test program.

Test Fuels

The test fuels used in this test program include LEV III, E5 and Tier 3. Several specific fuel properties are listed in Table 4. Full test reports for each fuel by the EPA Chemistry Laboratory are contained in Appendix B.

Table 4: Test Fuel Properties for LEV III, E5 and Tier 3[x]

Analysis Parameter	Unit	LEV III Value	E5 Value	Tier 3 Value
Ethanol confirmatory	Volume%	9.84	5.2	9.5
Dry Vapor Pressure Equivalent	Psi	7.01	8.6	8.9
Distillation Initial Boiling Point	F	109	95	99
10% evaporated	F	137	122	129

50% evaporated	F	209	205	202
90% evaporated	F	320	324	321
Evaporated final boiling point	F	358	393	386
Total Aromatic Hydrocabons	Volume%	21	32	24
Research Octane		92	99.7	92
Hydrogen	Weight %	13.68	13.54	13.76
Density, 60F	g/mL	0.7484	0.7554	0.7459

SHED Testing Protocol

The SHED tests were done using the protocol listed below for the baseline 3-day diurnal emission testing.

1. Drain and 50% fill with test fuel (if changing test fuel be sure to operate the vehicle for 15 or more minutes).
2. Soak the vehicle at 68 °F for 6 to 36 hours.
3. The prep is either "UDDS" for any test involving the FTP or the actual WMTC cycle for a test involving the WMTC cycle on test day
4. Drain and 50% fill with current test fuel.
5. Perform a canister loading using 50/50 butane/nitrogen to 2 gram breakthrough.[16]
6. Soak the motorcycle at 68-86 °F for 6 to 36 hours.
7. Prep 2 – Drive an FTP 3-bag or WMTC drive cycle (whichever test cycle is specified for the specific test) on the dynamometer
8. One hour EPA hot soak test in the VT SHED at 68 -86 °F.
9. Leave vehicle in SHED if possible and allow temperature to stabilize to diurnal start temperature for a minimum of 6 hours.
10. Run 3-day diurnal test with specified temperature profile. [17]
    a. California LEV III fuel cycling of temperatures are 65-105-65 °F.
    b. E5 and Tier 3 test fuel cycling temperatures were 68-96-68F.
11. Determine results in grams for hot soak and diurnal tests.

Butane Working Capacity (BWC) Testing Protocol

Two canisters were tested using the Butane Working Capacity (BWC) protocol. These included a used canister from a Honda Grom (same canister is used on the Honda Super Cub) and a canister from a Triumph Triple Street with a 765cc engine (California bike version – not European). The Triumph had sufficient BWC and so was deemed a match for the Wolf as a prototype canister.

[16] The protocol was slightly different for baseline 3-day evaporative SHED testing and for SHED testing with a prototype canister. The prototype canister tests including a purging of the canister prior to the SHED test due to the fact that the ON-HMC was not designed with the prototype canister in mind.

[17] E5 and Tier 3 test fuel cycling temperatures were 68-96-68F were used in place of the CARB temperatures of 65-105-65 due to the fact that the E5 and Tier 3 test fuel had similar RVP. LDV testing showed this relationship to yield equivalent results. Note that the LDV diurnal standard is 0.3g which is much less than the 1.0g being considered for ON-HMC by CARB at the time of writing of this report.

The protocols were as follows[18]:

1. Purge canister
   a. Using fresh air volume equal to the equivalent of 300 times the canister carbon bed volume. Rate for purge is 22.7 L/min unless otherwise specified in the specific test described herein.
   b. Weigh canister and record
2. Load canister
   a. BWC: 15 grams per hour butane with 50/50 butane/nitrogen mix until 2g breakthrough
   b. Weigh canister and record
3. Repeat steps 1-2 as necessary for repeat tests

Results

The evaporative test protocol is begun with motorcycles having a 50% fill fuel tank and a preparatory test cycle of either the FTP or WMTC. The ON-HMCs used in this study have high fuel efficiency and as a result it means that a small amount of fuel is used over the preparatory cycle. The FTP covers 11.4 miles and the WMTC is approximately 13.2 miles on the full WMTC (all three parts). Evaporative emissions are typically higher when there is more open space in the fuel tank as more vapors are generated.

Metropolitan 49cc

The Metropolitan is not currently emission regulated by CARB, for it is below 50cc, and as a result does not have a canister on the bike for evaporative emissions. The vehicle does comply with EPA requirements for hose and fuel tank permeation. The Metropolitan has a 4.5L fuel tank and has been reported to get 117 mpg[xi]. At 50% fill, the fuel tank will have approximately 2.3L of fuel and 2.3L of free space prior to the dyno test.

SHED Test with FTP and LEV III

Two tests were performed on the Metropolitan using the FTP preparatory cycle. One test was with the LEV III test fuel and CARB diurnal temperatures and the other test was with the Tier 3 test fuel and EPA diurnal temperatures. The evaporative emission results are listed in Table 5 and the single test results show that the total diurnal emissions with the Tier 3/EPA temperatures were 25% lower than the LEV III/CARB temperatures.[19]

[18] Canister Butane Working Capacity was determined following the EPA light-duty test procedures outlined in 40 CFR § 86.132-96(h)(1)(i-iv) with some modifications for motorcycles including not including the 2g breakthrough in the reported numbers.

[19] Multiple tests were not performed so statistical significance cannot be determined.

Table 5:Evaporative Emission Results for the Honda Metropolitan (no evaporative canister) with FTP Preparatory Cycle

Test	LEV III fuel CARB temperatures	Tier 3 fuel EPA temperatures
Hot Soak (g/1 hour)	0.017	0.05
Day 1 (g)	2.84	2.084
Day 2 (g)	2.72	1.965
Day 3 (g)	1.89	1.555
Total Diurnal (g)	7.45	5.604

Super Cub 125cc

The Super Cub meets the current CARB evaporative emission requirements (2-hour test including one hour diurnal) and employs an evaporative canister. The fuel tank on the Super Cub is 3.8L. According to Honda UK Media Newsroom[xii], the Super Cub is able to achieve 1.5L/100km (157mpg) (WMTC mode) with a 3.78L/1 gallon fuel tank. For the FTP preparatory cycle, the 3.78L fuel tank will be filled to 1.9L and use 0.27L during the FTP preparatory test with a resultant 1.6L of fuel in the fuel tank and 2.2L of free space during the SHED test. Due to only a 20 minute test with use of the WMTC (part 1 and 2), there should be more slightly fuel in the fuel tank than with the FTP. Three different fuels (LEV III, E5 and Tier 3) were used in the evaporative tests for this ON-HMC.

SHED Test Results

FTP and LEV III

The Super Cub was tested two times using the FTP with LEV III test fuel. In the first test the fuel tank was near full and the second test the fuel tank was near empty. Due to the unique design of the fuel tank there was difficulty initially in verifying the fill in the fuel tank prior to the test. The SHED results for a one hour hot soak and the three days of diurnal testing are shown below.

Table 6: Super Cub SHED Test Results with FTP, LEV III Test Fuel and CARB Temperatures

Test #	1	2	**Average**
Hot Soak (g/1 hour)	0.021	0.024	**0.023**
Day 1 (g)	0.325	0.381	**0.353**
Day 2 (g)	0.276	0.368	**0.322**
Day 3 (g)	0.193	0.154	**0.174**
Total Diurnal (g)	0.794	0.903	**0.849**
Fuel to fill after evap test	0.1L	0.9L	

Honda was contacted regarding the proper technique to drain the fuel tank of the Super Cub ON-HMC. It was learned that a smaller hose and increased attention to removing fuel around the fuel pump was needed in order to remove all of the fuel from the fuel tank. This was employed and hence the fuel tank was filled to 50% for the remainder of the tests.

WMTC and LEV III

The Super Cub was tested using the WMTC on LEV III fuel. The WMTC stipulates only part1 for this WMTC classified Class 1 bike (50-150cc, <100kph). However, given that the part 2 of the WMTC has a reduced speed of 82.5 and this bike can reach 88 kph then the part 1 and part 2 with reduced speeds were utilized.[20] Diurnal testing in this manner was completed on one two-day test and two three-day tests. Results are shown in Table 7.

Table 7: Super Cub SHED Test Results with WMTC, LEV III Test Fuel and CARB SHED Temperatures

Test # (3-day)	-	1	2	Average (1&2)
Hot Soak (g/1 hour)	0.01	0.017	0.0176	0.017
Day 1 (g)	0.41	0.54	0.546	0.54
Day 2 (g)	0.53	0.83	0.837	0.83
Day 3 (g)	Na	0.87	0.909	0.89
Total Diurnal (g)	Na	2.24	2.29	2.27

Evaporative emission results for each day on each preparatory cycle were below the 1g/day maximum and as such no changes are needed in the fueling system. Differences are observed in the evaporative emission results from the tests with the FTP compared to the WMTC.

1. The evaporative emission results with the FTP cycle show lower daily emissions compared to those resulting from the WMTC cycle, as shown in Table 6 and Table 7, respectively.
   a. The 3-day total diurnal average with the FTP cycle is 0.85g and with the WMTC cycle is 2.27g.
   b. The results for the 2nd and 3rd day, from the WMTC, were closer to the 1g/day maximum standard and were within 16% and 9% respectively.
2. A decrease in evaporative emissions from day 1 to day 3 occurs with the FTP while there is an increase in evaporative emissions from day 1 to day 3 with the use of the WMTC.
3. The hot soak emission levels from the two part WMTC cycle (.017g) are lower than from the FTP cycle (.023g) and as such may reflect a slightly lower effort on the ON-HMC to run the two part WMTC compared to the FTP. Test to test variability may also be a factor due to the low emissions measured.

These differences in evaporative results can be explained through a reduced amount of canister purge that occurs with running of the ON-HMC over the WMTC compared to the FTP. Purge of the canister occurs when a vacuum is created from the engine speed and engine speed is determined by the cycle over which the ON-HMC is operated. Part 1

[20] WMTC part 1 average speed is approximately 30 kph, refer to Figure 12, which will not test a 88 kph max bike to its representative use as is done with other vehicles using the WMTC. Only using part 1 would result in a test cycle that is less stringent than the FTP.

of the WMTC is at much lower speeds than the FTP and part 2 is similar to the FTP and has a near equal top speed, when compared on the same unit basis. The length of time for purge is also a factor and for the Super Cub, the FTP test is 30 minutes long while the WMTC (part 1 and part 2) is only 20 minutes, as shown in Figure 11 and Figure 12 respectively.

Figure 13 illustrates the cumulative diurnal hydrocarbon emissions (g) over time of the three-day diurnal run with the WMTC. It is seen that there are HC emissions during the cooling phase of the diurnal test (at 720, 2160 and 3600 minutes)[21]. Reduction or elimination of these will provide additional compliance margin for this ON-HMC when tested with the WMTC preparatory cycle.

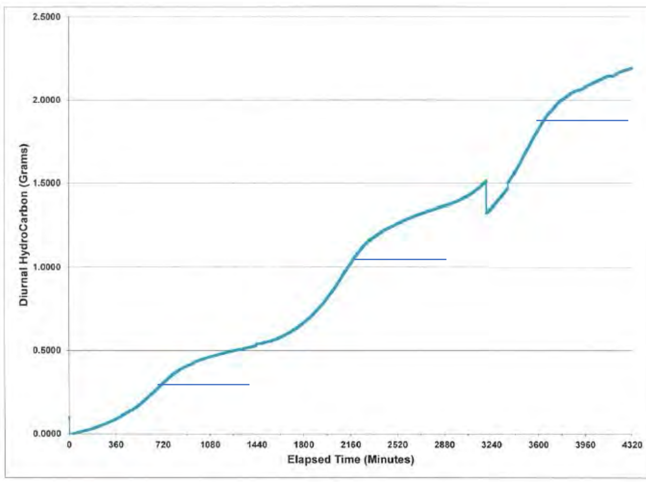

Figure 13: SHED Cumulative Emissions from Super Cub Run on WMTC, LEV III Test Fuel with CARB Temperatures

WMTC and E5 Test Fuel (with EPA temperatures)

Euro5 emission regulations utilize the WMTC with E5 (5% ethanol) test fuel in its testing for exhaust and evaporative emission requirements. Testing over the WMTC with E5 test fuel is included in this test program is to see if similar evaporative emission results are obtained when testing with the E5 test fuel as compared to the LEV III (10% ethanol) test fuel. Based on a relationship established on light duty vehicles for RVP and SHED temperatures, EPA SHED temperatures (68-96-68F) are used for fuels with EPA Tier 3 RVP levels (ex: 8.7 psi) compared to CARB SHED temperatures (65-105-65F) when using LEV III with RVP level (ex: 7.0 psi). EPA temperatures of 68-96-68F are used for testing of E5 due to the fact that the RVP of the E5 test fuel is similar to EPA Tier 3 test fuel as shown in Table 4.[22] Results from testing of the Super Cub with E5 test fuel, WMTC and EPA SHED temperatures are shown in Table 8.

[21] The dip near 3200 seconds is a factor of switching analyzers and not of the emissions from the Super Cub.
[22] The LDV standards are lower than those considered for ON-HMC (LDV: 0.1g/day, ON-HMC standard consideration: 1.0g/day).

Table 8: Super Cub SHED Test Results with WMTC, E5 Test Fuel and EPA SHED Temperatures

Test #	1	*2*[23]	3	**Avg (1,3)**
Hot Soak (g/1 hour)	0.016	*.014*	0.016	**0.016**
Day 1 (g)	0.320	*.233*	0.344	**0.332**
Day 2 (g)	0.460	*.292*	0.484	**0.472**
Day 3 (g)	0.629	*.3435*	0.669	**0.649**
Total Diurnal (g)	1.425	*0.96*	1.513	**1.469**

Comparison of the average three-day emission results on the Super Cub using the WMTC with LEV III/CARB temperatures and E5/EPA temperatures, in Table 7 and Table 8[24], reveals that the emissions from the LEV III fuel/CARB temperatures (2.27g) are higher than those with the E5/EPA temperatures (1.469g). The difference in results from the E5/EPA temps test is 0.8g (35%) lower than the LEV III/CARB temp tests with low variability of data sets within each fuel type/temperature set.

In addition, comparison of the average results in Table 7 and Table 8 show that the same relationship of fuel RVP and SHED temperatures similarity for LDV does not currently hold for motorcycles. The evaporative systems for LDV have been developed over many years and the standard is 1/10 of that being considered for ON-HMC. The canister systems have also been designed to collect refueling emissions which may also contribute to their improved performance on LDV.

WMTC and Tier 3 Test Fuel (with EPA temperatures)

EPA utilizes Tier 2 test fuel currently in its motorcycle compliance testing, however Tier 3 fuel will be considered when ON-HMC emission regulations are updated. The Super Cub was tested with Tier 3 fuel/EPA temperatures with the WMTC and the results are presented in Table 9. The second test was subject to a humidity control issue and hence is not included in the overall average emissions. The average of the first and third three-day diurnal tests are very similar to the average results shown in Table 8.

Table 9: Super Cub SHED Test Results with WMTC, Tier 3 Test Fuel and EPA SHED Temperatures

Test #	1	*2*[25]	3	**Avg (1,3)**
Hot Soak (g/1 hour)	0.015	*0.015*	0.017	**0.016**
Day 1 (g)	0.311	*0.433*	0.297	**0.304**
Day 2 (g)	0.470	*0.586*	0.443	**0.457**
Day 3 (g)	0.597	*0.990*	0.664	**0.631**
Total Diurnal (g)	1.378	*2.009*	1.404	**1.391**

[23] This test was performed in a different SHED from the other tests in this report. Both SHEDs were calibrated and cause of difference is unknown and may just be test to test variability.
[24] Test #2, of Table 7, was run in a different SHED than the rest of the test points and so it is removed from the average.
[25] This test was done over a weekend that had some extreme humid weather and the SHED control was subject to lab humidity which had an issue that weekend.

The results in Table 9 with Tier 3 fuel are very close to those in Table 8 with the E5 test fuel. This illustrates the similarities in results when using test fuels with like RVP in tests with the same test temperatures on today's evaporative system on the Super Cub.

Butane Working Capacity (BWC)

EPA had ordered a number of new canisters for the Honda Super Cub for BWC testing, however during this test program the supply chains had been impacted severely due to the COVID 19 pandemic. Only three canisters were received and included two new canisters and one used canister from a Honda Grom (the same canister is used for the Super Cub). The two new canisters were sent to MECA for canister teardown and evaluation. EPA kept the used canister for BWC testing. Testing of a used canister would give insight into the durability of the carbon used in the canister and the likelihood that the ON-HMC would meet the evaporative emission standards over the useful regulatory life.

The used canister was from a Honda Grom[26] which had 1068 miles on it (regulatory useful life for the Class Ib bike is 12,000km/7456mi). EPA performed a number of BWC tests on the canister and did not count the first 12 tests prior to the test results recorded in Table 10. The initial tests resulted in the removal of any moisture that may have collected in the canister over its time of non-use as the grams increased over time.

The results from Butane Working Capacity (BWC) testing of the used canister are shown in Table 10. Initial testing utilized a 15 g/hr loading with 22.7 liters per minute flow rate purge which is typical in Light Duty Vehicle testing. An average result of 3.8 g was achieved. The last five tests were done using a lower purge rate due to consideration that the canister was purged at a slower flow rate on a motorcycle compared to a light duty vehicle. A purge rate of 5 L/min was used. The BWC of the canister did increase slightly to an average of 4.0g with the lower purge rate.

Table 10: BWC for Used Canister for Super Cub[27]

Used Canister for Super Cub – 1068 Miles BWC			
Cycle	After Purge (g)	After Load (g)	Net Load (g)
15 g/hr loading for BWC with 22.7 L/min purge rate			
13	191.7	195.2	3.5
14	192.2	196.3	4.1
15	192.3	196.3	4.0
16	192.5	196.1	3.6
17	192.4	196.2	3.8
18	192.4	196.2	3.8
19	192.3	196.1	3.8

[26] The Honda Grom has a 5.8L fuel tank versus a 3.8L fuel tank on the Super Cub.

[27] The canister was from a Honda Grom (1.5gal fuel tank) with 1068 miles. This canister is also used on the Super Cub. The initial tests, 1-12, were used to remove any moisture buildup from the canister non-use.

20	192.4	196.3	3.9
		Average	3.8
15 g/hr loading for BWC with 5 L/min purge rate			
21	191.9	195.9	4.0
22	191.7	195.2	3.5
23	191.7	195.9	4.2
24	191.6	196.2	4.6
25	191.6	195.4	3.8
		Average	4.0

Carbon Durability

The data in Table 10 show that with a purge rate of 22.7 L/min, the used canister showed an average BWC of 3.8g. The BWC of the new canister was determined through testing by MECA and was found to be 5.5g[xiii] with the same procedure as EPA and a purge rate of 22.7 L/min. As a result, it appears that degradation of 25% did occur in the ability of the canister/carbon to hold onto vapors under the test parameters[28]. The useful life for this 125cc motorcycle is 12,000 km (7456mi) according to EPA definition. The aged canister was from a motorcycle with 1068 miles which is just 14% of the useful life miles. Any evaporative emission standards will be required to be met throughout the useful life and the data from Table 7 (WMTC preparatory cycle, LEV III fuel and CARB temperatures) shows that the third day is close to the 1g/day maximum value. For additional compliance room improvements in the canister performance over time may be required. Potential causes and possible remedies for longer life of the carbon are listed in Table 11.

Table 11: Potential Cause and Possible Remedy for Carbon Life in an Evaporative Canister

Potential Cause	Possible Remedy
Carbon quality was sufficient for only the current two-hour CARB evaporative test. Higher quality carbons may be available.	Carbon qualities exist which have shown less than 10% deterioration over time.
The simple straight flow design of the canister resulted in the creation of a flow through path through the carbon and as such not all of the carbon was exposed to the vapors and as such only a portion of the carbon was actively working.	The existing canister interior design results in a low L/D (length of vapor flow path to diameter of canister). Increasing the length of time vapors are in the canister can be achieved by using a non-flow through design, such as a U shape or S shape design.
There is no active pressure on the carbon to keep it in place (ie: spring with plate) and as such the pellets can rub against	Include a coil spring at the end of the canister to put some pressure on the carbon so that there is less movement.

[28] Some difference could be due to part manufacturing variance.

each other and break down into powder and become less effective.	
Low purge rate	Higher purge rates would clean out the canister more effectively and thereby allow higher vapor capture in the canister. Improved engine controls for purge.
Small canister	Larger canister would allow for higher BWC and better evaporative emission control.

Wolf 300 (278cc)

The Wolf 300 meets the CARB evaporative emission requirements (2 hour test including one hour diurnal) with a canister although is on the higher end of emissions for compliance according to CARB. The Wolf 300 has a 14L fuel tank and is noted to achieve 85 mph(137kph) and 85 mpg[xiv]. Three parts of the WMTC are utilized for this vehicle[29] and as a result has a 30 minute test cycle for both the WMTC and the FTP. The WMTC is 13.2 miles for all three parts and therefore approximately 0.6L of fuel may be used from the fuel tank of the Wolf 300 prior to going into the SHED. As a result, there could be 6.4L of fuel with 7.6L of free space for vapors. These volumes are much higher than that for the Super Cub 3.78L fuel tank. The canister on the Wolf 300 is near the same size as that on the Super Cub and so it is expected that this ON-HMC will have higher evaporative emissions than the Super Cub due to the larger fuel tank.

SHED Test Results

FTP and LEV III

Production Canister

EPA conducted a three-day SHED test using the FTP, LEV III test fuel and CARB tempertaures and the total evaporative emission result was 9.57g, as shown in Table 12.[30] The results from this motorcycle exceeded the 3g total over the three-day diurnal (1g/day max) and therefore a higher capacity canister is required.

Table 12: Three Day Diurnal Emission Measurement of Wolf 300 with Production Canister on the FTP, LEV III Test Fuel and CARB Temperatures

Test #1	HC (g)
Hot Soak	0.05
Total 3-day Diurnal	9.57
Fuel to fill after evap test	7 L

[29] With the Part 3 being at reduced speed for the Wolf 300 has vmax under 140 kph.
[30] The analyzers were not setup to do daily readings for such high evaporative emissions and so this test result did not yield daily emission results.

Feasibility of Canister BWC/Fuel Tank v Three Day Emission Total

A higher BWC canister is needed to reduce evaporative emissions from the Wolf 300. This can be determined by addressing the initial goal of this project which was to determine if smaller displacement ON-HMCs would fall on a similar Working Capacity to Fuel Tank Ratio versus the 3-day total emission linear relationship shown at CARB's 2020 Workshop.

Prior to adding the BWC data points to the CARB figure, the data in the original CARB figure was checked for "Working Capacity' – Butane or Gasoline. Investigation revealed that a number of the Working Capacities on the CARB figure were actually Gasoline Working Capacities. Hence a new figure was created, Figure 21, for several of the Class III ON-HMCs for BWC/Fuel Tank versus 3-day emissions using BWC measurements results from MECA testing[31].

The points for BWC/Fuel Tank versus 3-day emission results from the two study bikes with canisters (Class Ib and II) were then calculated and added to Figure 21. The figure shows that the two BWC points from the smaller ON-HMC did fall in the linear line with the Class III ON-HMC. This relationship can then be used to choose a higher BWC canister for application to the Wolf 300, keeping in mind that several canisters may have to be utilized for the relationship is not perfect as there is one point above the 3g line having a BWC higher than the 1.41 BWC/Fuel Tank ratio shown in Figure 14.

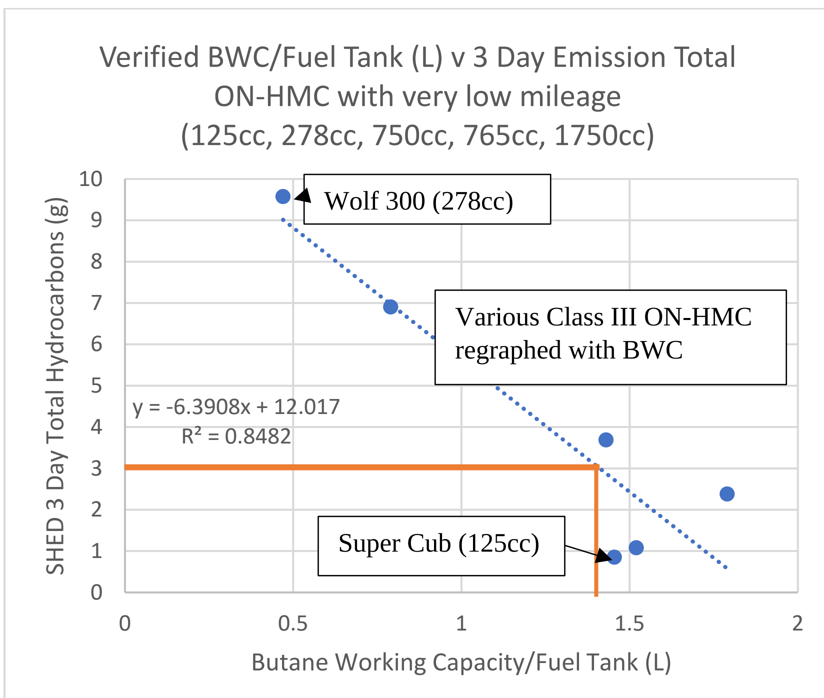

Figure 14: BWC/Fuel Tank vs SHED 3-Day Total Hydrocarbons (g) for Various Size ON-HMC

[31] The original WC/FT v 3-day emissions from CARB Workshop was found not to be based on BWC and so a new linear relationship was found using BWC information from MECA.

Prototype Canisters

Since the 3-day diurnal testing of the Wolf 300 exceeded the desired 1g/day (3g/3days) then it is a candidate to apply the canister design criteria idea presented earlier in this paper as shown in Figure 14.

According to Figure 14, the BWC/Fuel Tank ratio of 1.41 or higher is to be used to achieve an evaporative emission 3 day total of 3g. Therefore, the minimum BWC of the new canister is to be 14*1.41=19.7g.

In this test program, EPA performed BWC testing on a canister for a Triumph Triple Street sold in California which yielded a BWC of 21g (see Appendix A). This canister was chosen as the first prototype canister candidate for the Wolf 300.

Since the OEM canister on the Wolf 300 (14L fuel tank) was nearly the same size in outer dimensions as the Super Cub (3.8L fuel tank), see Table 2, an assumption was made that the purge strategy on the Wolf 300 would not be sufficient for purging the larger canister so that it would operate at is highest capability. As a result, functional changes were made to the canister setup and SHED testing of the Wolf 300 in order to accommodate the prototype canister. Changes included the following:

1. A manually operated valve for canister purge was added and the vacuum purge from the engine was eliminated.
2. Fuel tank fill of 40% fill (not 50%) was done for a preparatory cycle would not be run due to purge rate assumed to be insufficient for the larger canister (purge control is a factor the OEM would have to develop).
3. The prototype canister was purged manually and not connected to the fuel tank until the SHED test had achieved set temperature of 68F. This is an optimum procedure to achieve low evaporative emissions and would be adjusted in future testing if it was shown that the standard of 1g/day over three days had been achieved.

Prototype canister test results on FTP with LEV III Test Fuel

The following describes the findings of working to reduce evaporative emissions on the Wolf 300 in a SHED three-day diurnal test using three different canisters.

1. <u>Canister #1:</u> The evaporative canister from the Triumph Street Triple (California version, BWC=21g, 13.2L fuel tank) was applied to the Wolf 300 (14L fuel tank). Three SHED tests were performed.

    a. The first SHED test with the Triumph canister yielded the same level of emissions as the base canister test of approximately 10g over the three days. A sniffer was used to determine the source(s) of the evaporative emissions. It was determined that the key lock on the fuel tank was the source of the emissions.

The key hole in the fuel tank cap was taped over, with appropriate tape for evaporative testing, and the ON-HMC was retested. The resultant emissions from the three-day SHED test was 24g. This is 2.4x the emissions from the tests with the OEM and first test with the Triumph (CA) . The ON-HMC was analyzed again for leaks and it was found that the gasket for the fuel tank cap was cracked, see Figure 14, and not sealing correctly. No other leak areas were identified. This ON-HMC was purchased new, aged 1000km on nearby pump fuel (E10), and then sat for several months prior to evaporative emission testing. While the cause for the condition of this fuel tank cap gasket is unknown, this type of deterioration in rubber gaskets can be expedited in materials that are not ethanol compatible.

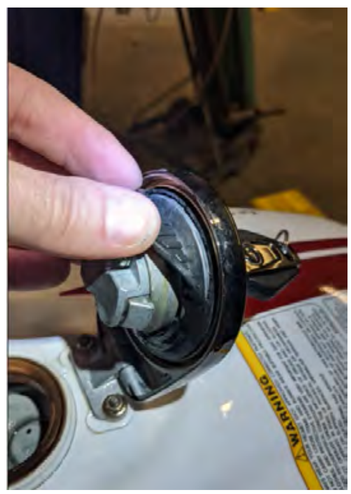

Figure 15: Fuel Tank Cap on Wolf 300 Showing Deterioration (Splitting, Cracking)

b. The fuel tank cap was replaced with a tightly fit rubber plug and a SHED test was rerun. The first day showed 0.5g however the second day showed higher emissions, similar to the previous SHED test with the original Triumph (CA) canister, and the test was stopped. It was determined that the change in temperature may have edged the plug from its snug position in the fuel tank and hence allow vapor leakage from the fuel tank. This result showed that with a completely sealed fuel tank cap on the fuel tank then emissions were reduced substantially.

2. <u>Canister #2:</u> In order to determine the amount of vapor coming out of the canister during the three day test, an overcapacity automotive canister (BWC=80g) was applied to the Wolf 300 and a three-day diurnal was performed, with canister being weighed before and after the test. Table 13 lists the results from this test and shows that the three-day SHED emission result was 1.54g and the canister gained 16g[32]. Use

[32] The canister was emptied prior to being applied to the Wolf 300 and being put in the SHED. As noted previously, there was no loading of the canister and preparatory cycle due to the unknown as to the purge procedure for the base

of this canister achieved the goal of maximum 1g/day. The automotive canister has very little load flow restriction due to the onboard vapor recovery systems included in today's automotive canister designs. It is expected that the first prototype canister (Triumph Street Triple-CA) had higher load flow restriction than the automotive canister which resulted in leakage in other areas of the fuel system which also had less pressure.

Figure 16: Automotive Canister on Wolf 300

The 1Hz data from the SHED test with the automotive canister was utilized to create a cumulative hydrocarbon emission curve as shown in Figure 16. The figure shows that the SHED emissions increased with each heat build. In addition, the figure reveals that the evaporative emissions did not level off when the SHED was in a cooling mode of going from 105F to 65F (CARB SHED temperatures when using LEV III fuel). The cooling temperature emission increases are lower than those found on the Super Cub cumulative graph in Figure 13.

canister being sufficient to clean out the larger automotive canister. The rubber plug was reapplied to the fuel tank and was used for the SHED test.

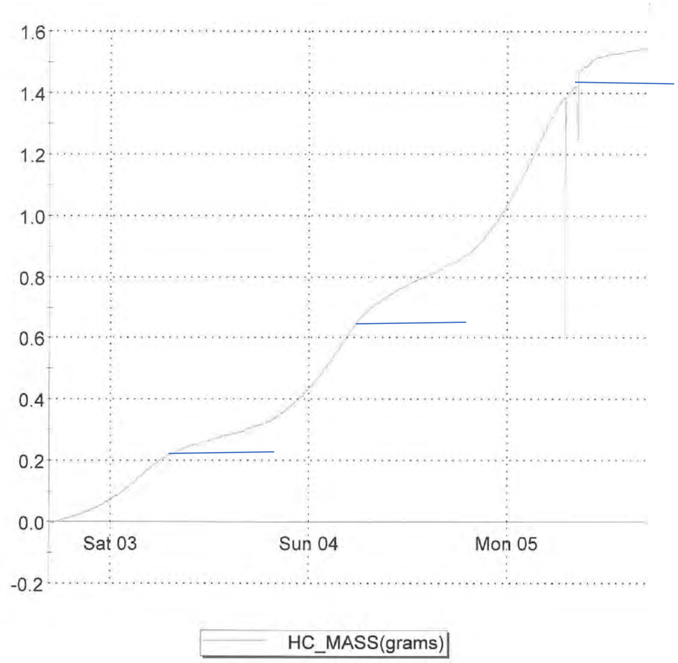

Figure 17: Hydrocarbon emissions from the Wolf 300 with Automotive Canister over a Three-Day Diurnal Test

3. <u>Canister #3:</u> A second canister from an ON-HMC with an equivalent fuel tank size (14L) was chosen, see Figure 17. The new canister was from an ON-HMC whose evaporative emission test results met the 1g/day from the CARB dataset of Class III ON-HMCs. The canister had an automotive internal design and its BWC was 20.8g as measured by MECA. MECA also measured that the canister had low load flow restriction (for an on-highway motorcycle canister) and high-quality carbon. Four BWC tests were run on the new canister to degreen the canister (get around the heel and come to a repeatable level). As shown in Table 13, results from the first three-day diurnal emission result totaled 4.4g and the canister held 10g instead of the 16g by the larger automotive canister (Canister #2). It is assumed that the higher emissions are due to leakage in the ON-HMC from the higher load flow restriction of this canister compared to the larger automotive canister, Canister #2, as the vapors found another way out of the fuel system rather than through the canister. As a result, the canister didn't collect as much vapor. The load flow restriction of this canister was half that of the original Wolf 300 canister and slightly less than half of Canister #1.

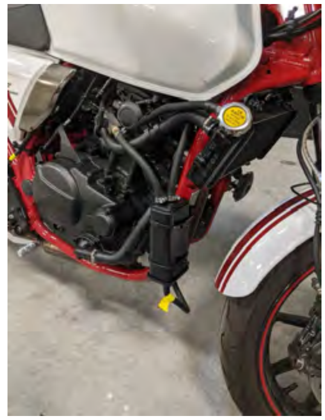

Figure 18:Wolf 300 with On-Highway Motorcycle Automotive Style Canister

Review of the fuel tank plug revealed that it was deteriorating and so it was replaced with a new Wolf fuel tank cap. A two-day test was run and results of 1.2 and 1.3g/day were measured. Improvements were made to reduce evaporative emissions, however the goal of less than 1g/day maximum was not achieved.

Table 13: LEV III Test Fuel, with Prototype Canister[33]

Test #	Automotive canister (BWC 80g)	ON-HMC Automotive Design Canister (BWC: 20.8g)	2-day test with ON- HMC Automotive Design Canister (BWC: 20.8g) – new fuel tank cap
Day 1	0.304	-	1.2
Day 2	0.524	-	1.3
Day 3	0.716	-	-
Total Diurnal	1.544	4.4 – 3 day	2.5g – 2 day
Fill of Fuel Tank	40%	40%	40%
Fuel	LEV III	LEV III	LEV III
Additional weight of canister after test	16g	10g	-

SHED Test of the Wolf 300 Without the Fuel System

To confirm that hydrocarbon emissions were not being greatly emitted by the non-fuel system components on the Wolf 300 (plastics/rubber/etc.), the ON-HMC without the fuel system was put into the SHED for a two-day diurnal, see Figure 18. HC emissions of 0.18g were measured (0.11g first heat build and 0.07g second heat build), see Figure 19.

[33] These three day shed tests were run with an optimized cleaned out canister and the ON-HMC was not run on the preparatory cycle which would have exposed the fuel tank and canister to higher temperatures.

Due to these low emissions from the non-fuel system parts, it is clear that the majority of emissions are originating in the fuel system (fuel tank, hose, canister) of the Wolf 300.

Figure 19: Wolf 300 Without Fuel System Went into the SHED

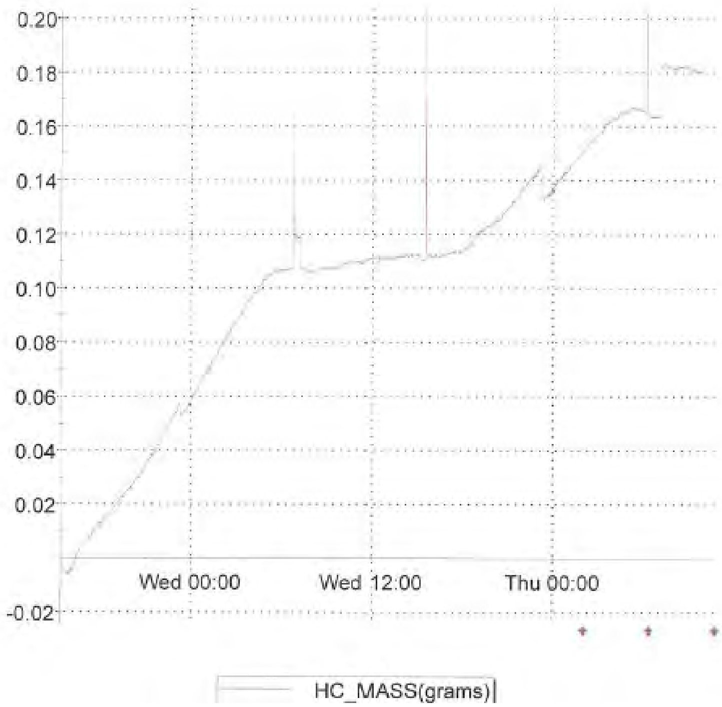

Figure 20: Hydrocarbon (g) Results versus Day of Test from the Wolf 300 Without Fuel System in a Two Day SHED Test

Summary of Findings

Testing of the Wolf 300 ended without the emission test comparison of the LEV III/CARB temperatures and E5/Tier 3/EPA temperatures comparison as performed on the Super Cub since the existing fuel system (in particular the fuel tank cap) was not able to be sealed sufficiently to allow an upgraded motorcycle evaporative canister to bring the ON-HMC to the 1g/day level.[34]

The fuel system of the Wolf was examined through pressurization of the fuel system from the outlet of the canister with the purge hose plugged. Emissions were found coming from the fuel tank cap as well as the crimped area of the fuel tank. The fuel tank cap was noted to be hinged on one side which does not allow it to seal evenly around the whole cap. One solution is to use a screw on fuel tank cap which would allow better sealing of the fuel tank cap to the fuel tank. This approach has been incorporated on nonroad motorcycles for compliance with the three-day diurnal SHED test.

The solution to bringing the Wolf 300 into compliance with a 1g/day level over three days may include the following:

a. Eliminate leaks: Evaluate system for leaks. One possible source is the fuel tank cap. A new fuel tank cap design (without hinge on one side), and possibly a new fuel tank design (remove crimped area or assure no leaks). Assure durable gasket material is used in the fuel tank cap that can hold up to fuel with ethanol. Leaks may have to be evaluated in warm/just after operating conditions.
b. Reduce pressure buildup in the fuel tank: The on-highway motorcycle automotive style canister (canister #3) connector hose to the canister from the fuel tank was 1mm larger than that on the Wolf. The smaller opening in the fuel tank can result in an indirect pressure build mechanism and put more pressure on the fuel tank cap and other potential leak areas.
c. Increase canister size and amount of carbon: The canister on the Wolf 300 was sized for meeting the current evaporative requirements. The canister is undersized for its fuel tank size to meet a three-day diurnal SHED test. Comparing changes in canister size of the motorcycle evaporative canister with automotive design to the original Wolf 300 evaporative canister, the new canister is larger by 1.85x and has 2.2x increase in carbon volume.
d. Utilize a larger canister that has a higher length to diameter ratio. One possible design is a u-shape design for better flow of vapors and exposure to more of the carbon.
e. Utilize high quality carbon.

[34] Feasibility was shown using an automotive canister with very low load flow restriction (due to ORVR requirements when refilling at gas pump). The automotive canister is oversized for the application.

f. Utilize a canister with a low load flow restriction. The motorcycle canister with automotive design had a load flow restriction of just less than half that of the Wolf canister according to testing by MECA.
g. Assure sufficient purge. The feasibility of achieving 1g/day over three days on an ON-HMC that has a 14L fuel tank is shown by one ON-HMC in the CARB evaporative test program as shown in their Workshop in 2020[i] (second lowest line in Figure 20). However, the engine (765cc, 5500 rpm) was just over 2.5 times larger than the Wolf 300 (278cc) with a maximum speed at 2/3 the maximum rpm of the Wolf (8000 rpm). The larger engine would likely be able to provide a stronger vacuum for the purge system.
h. Reduce fuel tank size. The fuel tank on the Wolf is 14L which is large for a 278cc engine. Given the purge strategy determined in item ‘g’ to clean out the canister, the fuel tank may need to be made slightly smaller.

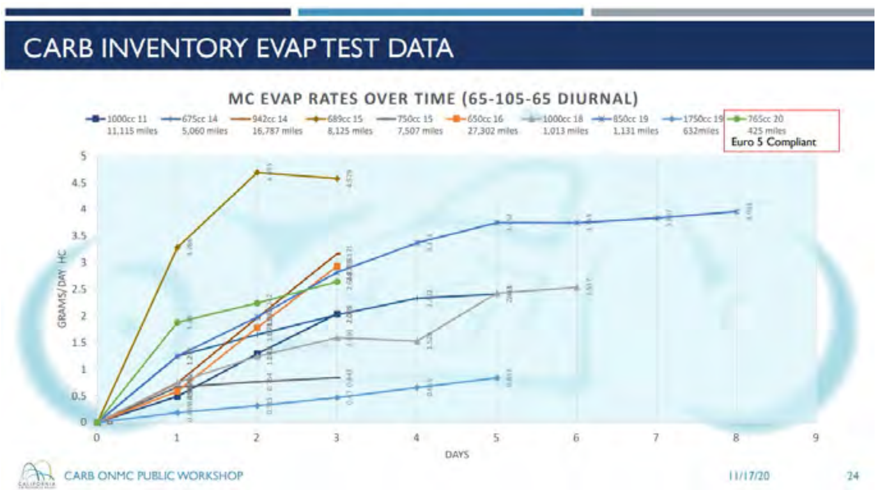

Figure 21: Two Motorcycles Passed CARB 1g/day shown at CARB Workshop November 17, 2020[i]

Leak Test

This report shows that several attempts at reducing leaks from the Wolf 300 (with a 14L fuel tank) were unsuccessful at achieving the desired 1g/day. Notable evaporative emission reductions were seen on this vehicle when a new fuel tank cap was used along with a larger motorcycle canister (#3).[35] The program for Light Duty Vehicles includes a leak check test as well as a SHED test for evaporative emission testing requirements. EPA performed subsequent testing on the Wolf fuel tank (with cap) using a leak measurement snap-on tool. Findings showed no measurable leaks. This area is one for additional study as we know leaks exist due to the findings in this study. Influences of temperature or vibration may need to be included in the testing and/or influences of the fuel pump/fuel injector system within the fuel tank need to be evaluated. The feasible measurement range is to also be evaluated. If developed, a leak test

[35] The larger motorcycle canister was taken from a motorcycle with a 750cc engine and a similar sized fuel tank, 14L, which did achieve the desired 1g/day in SHED testing with its production canister in the CARB test program, seen in Figure 20.

would be of great importance to perform quick in-use testing to assure durability of the evaporative system on motorcycles and thus reduce the time of testing of a three-day diurnal SHED test.

Conclusions

The following findings were realized from this study in the order of the goals identified at the beginning of this report:

1) EVAPORATIVE CANISTER PLACEMENT AND OUTER DIMENSION MEASUREMENT: The placement of the canisters on the ON-HMCs in this study were found to be in different locations.[36] The Wolf and the Super Cub each had canisters located below the fuel tank. The canister on the Wolf 300 was tightly wedged above the engine and below the fuel tank and the lack of available space may have contributed to its small size in comparison to the 14L fuel tank[37]. The Super Cub had the canister behind the footrest which was easily accessible and was not so space constrained as that on the Wolf 300.

2) BASELINE EVAPORATIVE EMISSIONS: Three low exhaust emission (near Euro5 exhaust standards) on-highway motorcycles were tested in baseline condition for evaporative hydrocarbon emission levels:
    1. The 50cc Honda Metropolitan did not have a canister for <50cc are not regulated by CARB and do not have to meet CARB evaporative requirements. A baseline three-day diurnal value was measured for inventory purposes.
    2. The 125cc Honda Super Cub met the three-day diurnal 1g/day goal each day with the existing canister on all fuels and with each preparatory test cycles.
    3. The 278cc Alliance Powersport Wolf 300 did not meet the three-day diurnal 1g/day goal in its certified condition.

3) WORKING CAPACITY/FUEL TANK VS THREE DAY EMISSION TOTAL RELATIONSHIP FOR SMALLER ON-HMC SAME AS FOR CLASS III: Initially, use of the BWC/Fuel Tank ratio, shown Figure 21, was to be a main part of canister design criteria option to limit emissions from 3-day SHED testing. However, it was determined through this work that specifying this criteria alone would not be sufficient to assure evaporative emission compliance due to leaks in the fuel systems cap for the higher emitting ON-HMC such as the Wolf 300 from this test program. In addition, one concern arose on the use of the relationship in Figure 21 which was that the choice of a BWC/Fuel Tank ratio value slightly above 1.41 (solution to equation for a total 3 day emissions of 3g), could yield points above the 3g line as this line is not an exact fit to the data.

[36] The Metropolitan had no canister.
[37] The Wolf 300 was certified to applicable CARB evaporative emission standards.

A better relationship amongst the data was found using a BETP/Fuel Tank with 300 bed volumes of purge, see Figure 22. Three day evaporative emission data was collected by MECA[xiii] on several leakless fuel systems using the Bleed Emission Test Procedure (BETP) in a mini SHED using 100 and 300 bed volumes of purge. The first step of conducting the test was to assure the fuel systems had no leaks. A leak test was performed on the fuel tank/hose/canister setups at ambient temperatures using a snoop tool test and any leaks were addressed (tape/glue where necessary). Graphing of the BETP 3-day emission results versus BWC/Fuel Tank, when done with 300 bed volumes of purge through the canister, yielded a higher correlation fit than using SHED test information (g), see Figure 22 (blue line).

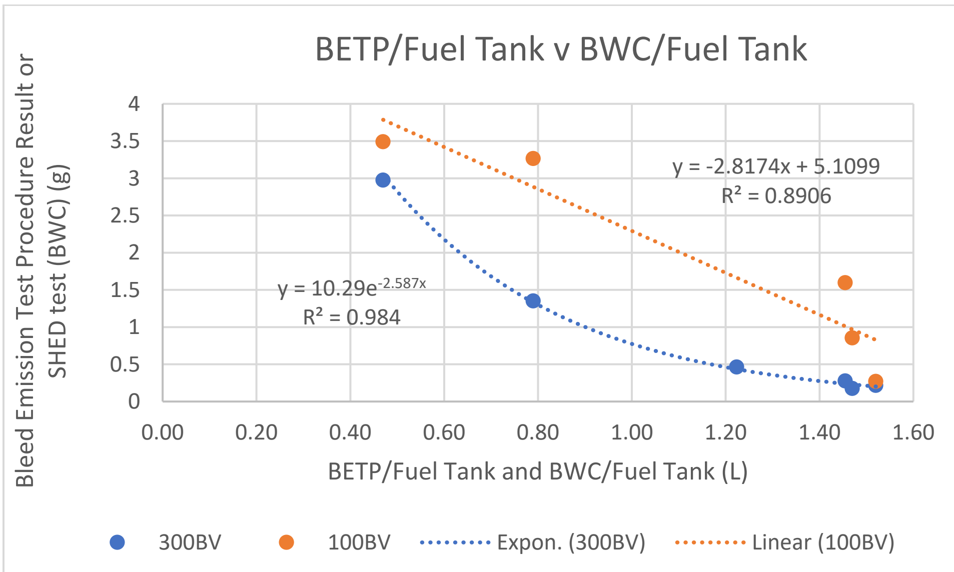

Figure 22: Revised Graphing for Various ON-HMC Sizes: BETP Emission Test Result (300 Bed Volume Canister Purge) for Various BWC/Fuel Tank

4) PREPARATORY CYCLE COMPARISON: The Honda Super Cub was utilized to perform 3-day diurnal emission testing using different preparatory cycles (FTP and WMTC). Evaporative emissions using the FTP preparatory cycle were less than those with the WMTC cycle. This is assumed to be due to the amount of purge that happens over the cycles which is governed by the length of the test cycle and the speeds of the traces within each cycle. The FTP is a 30 minute cycle and the WMTC for the 125cc Super Cub is only 20 minute cycle with an overall lower speed trace than the FTP.

5) TEST FUEL COMPARISON WITH WMTC PREPARATORY CYCLE: The Honda Super Cub was utilized to perform 3-day diurnal emission testing using as test fuels LEV III, E5, and Tier 3.
   1. Comparison of emissions from the tests using LEV III, E5 and Tier 3 fuels with the WMTC preparatory cycle showed that the emissions with LEV III test fuel

(7.0 psi RVP and CARB temperatures) were higher than the E5 and Tier 3 test fuels (8.4psi RVP and EPA temperatures).

2. The E5 (5% ethanol) and Tier 3 (10% ethanol) resulted in very similar evaporative emission results over the three-day diurnal.

6) APPLY CANISTER DESIGN CRITERIA TO PROVE FEASIBILITY OF METHOD: The Wolf 300 was fitted with a canister sufficient for the two-hour evaporative requirement currently in place. In order to meet a three-day diurnal with a goal of 1g/day, a larger canister is required. It was also noted that the fuel tank had multiple leaks including through the gas cap as well as crimped areas. A new fuel tank is needed along with a new canister. One of the Class III ON-HMC tested at CARB had a 14L fuel tank and met the goal of less than 1g/day. The canister was 1.85x larger, had 2.2x more carbon and 0.44x the load flow restriction of the current Wolf canister. The interior designs of the canisters were similar on both ON-HMC. A smaller fuel tank would also assist in meeting the target 1g/day maximum by generating less vapors.

7) PERFORM BUTANE WORKING CAPACITY TEST ON TWO ON-HMC CANISTERS:
    1. The as-received aged canister for a Super Cub, 1068 miles on a Honda Grom (same canister), was shown to have notable lower BWC compared to the new canister tested by MECA. Assuming this BWC difference is outside of canister to canister variation, then for longer canister active life a table was assembled giving ideas on improvements which includes higher carbon quality and canister design to reduce carbon physical bumping and crumbling.
    2. The Triumph Triple Street (California version) canister was tested by EPA. BWC results were similar results to the MECA tested canister.

NEW CANISTER DESIGN CRITERIA RECOMMENDATIONS:

This work as a whole shows that the use of a BWC/Fuel Tank vs 3 day emissions total is not sufficient to assure reduced evaporative emissions from motorcycles. If a canister design criteria is utilized to reduce evaporative emissions from On-Highway Motorcycles, then the following areas should be considered:

1. Gasket material requirement
    - Stated that E10/E15 durable gaskets be required throughout the fuel system. Areas include, but not limited to, the fuel tank cap and fuel pump gasket areas.
2. Design criteria based on the relationship between BETP and BWC/Fuel Tank
    - A very high correlation coefficient (R^2 value) was achieved when graphing the results from the BETP (based on 300 bed volume purge) versus the 3-day total evaporative emission results. This test requires a fuel system with no leaks which should reflect the production motorcycle.

- It is understood that canister manufacturers utilize a BETP test on the largest canister of a canister family and so these results may be useful for some. OEMs will likely have to perform a BETP test using their specific canister design.

3. Canister Load Flow Restriction
   - The load flow restriction of the canister should be such that the vapors will flow into the canister and not seek other avenues for escape. Successfully designed systems (at or very near 1g/day maximum evaporative emissions) from the MECA study[xiii] show values less than 2.7 kPa with 20 l/min flow.
4. Carbon quality and canister design requirements
   - Durable carbon is to be utilized to assure reduced evaporative emissions throughout the life of the bike.
   - U shape and flowthrough shapes were found, with a properly sized and carbon filled canister, to bring ON-HMC into compliance with a 1g/day test over three days in CARB testing of Class III motorcycles.
5. Establish a leak measurement test of the fueling system.
   - A leak measurement standard should be created. A simple device, such as a snap-on tool as developed for light-duty vehicles, would be key to assure low evaporative emissions during the certification/production line testing/in-use phases for on-highway motorcycle production. The snap-on tool for light-duty vehicles would have to be modified to be routed through the canister vent hose rather than the fuel tank cap in order to detect leaks in the fuel tank cap.
   - Testing by EPA and CARB noted no measured leaks in ON-HMC which had high emissions in SHED testing and showed leaks by other means. Further research is required in this area to develop an official leak test.

Appendix A: Triumph BWC Testing

A new canister was needed for the Wolf 300 according to the 3-day emissions results of the new ON-HMC being significantly greater than1g/day (total 3 g for three days). Using CARB's linear relationship and BWC/Fuel Tank relationship, the calculation of 1.4[38]=BWC/Fuel Tank (L) means BWC needs to be 1.4*14= 19.6g. EPA's BWC testing of the Triumph Triple Street canister for the ON-HMC sold in California showed that this canister would be a solution for the Wolf 300.

Results from the BWC testing for the Triumph canister are shown in Table 15 and Figure 23. The first BWC test from the new canister shows a net load of 43g with the following tests showing less than half of that number. This showed that the heel was overcome very quickly. Initial BWC testing was performed at 10 lpm for an estimated carbon volume. Starting with Test #6 the purge rate was increased to 22.65 lpm. After Test #7, MECA[xiii] had a chance to tear down the canister and acquire the exact carbon volume information for the canister. This information allowed us to adjust the bed volume for the 390ml of carbon in the canister. The canister was found to have an average of 21g BWC (avg of tests 8-14).

Table 14: BWC Testing of Triumph Canister for California Market

BWC Results from a New Triumph Canister			
Cycle	After Purge (g)	After Load (g)	Net Load (g)
Purge Rate: 10 lpm, Bed Volume Estimated Initial tests for getting over heel			
1	305.3	348.3	43.0
2	331.5	350.5	19.0
3	330.9	349.5	18.6
4	331.5	350.8	19.3
5	330.6	346.4	15.8
Purge Rate Increased to 22.65 lpm			
6	330.3	349.8	19.5
7	329.5	349.2	19.7
Bed Volume increased to actual 0.39L			
8	330.3	351.3	21.0

[38] This is an updated number from the 3-day emissions v BWC/Fuel tank figure in this report. Additional data and information had been collected since this original figure was created.

9	327.7	348.8	21.1
10	328.5	348.7	20.2
11	327.7	349.7	22.0
12	326.3	349.0	22.7
13	328.6	348.4	19.8
14	328.4	349.8	21.4

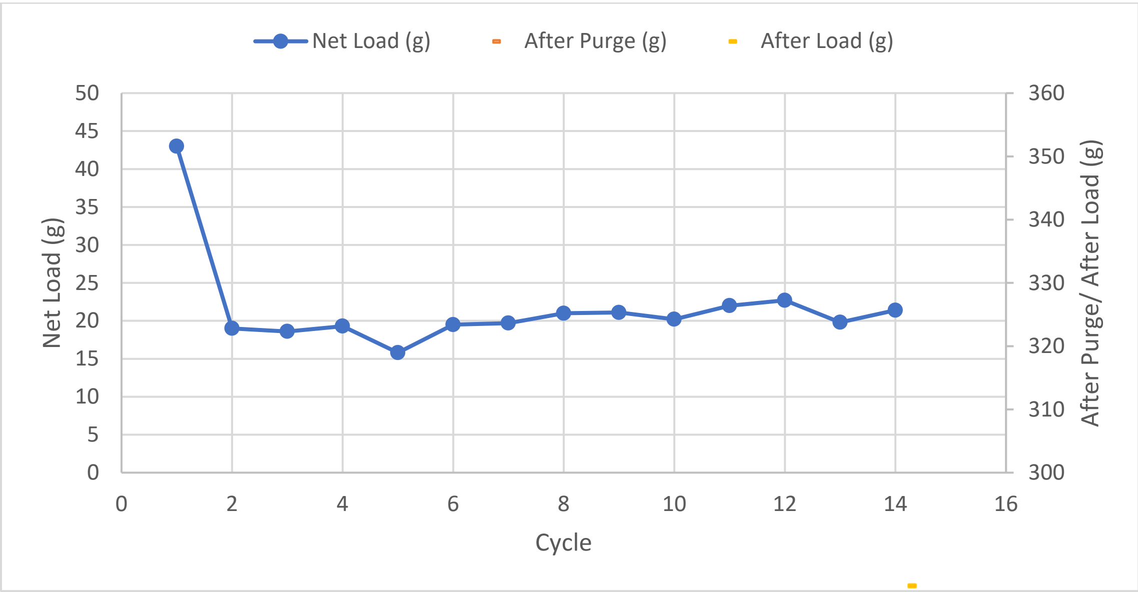

Figure 23 BWC Testing of a new Triumph Triple Street Canister Over 14 Cycles

Figure 24: Triumph Canister on the Triumph Street Triple

Appendix B: Test Fuels and Parameters

LEV III Test Fuel

EPA analyses for LEV III test fuel.

23-Apr-18

NVFEL Fuel Analysis Report 26757 Page 1 of 3

LEV III Batch#

Facility Name: US EPA NVFEL Facility Type: In House
Owner: USEPA Phone: (734) 214-4881
2565 Plymouth Road
Ann Arbor MI 48105-2425 Washtenaw County US
Inspector: N. Tschirhart Inspection Date : 6/6/2013 Time In: 00:00 Time Out: 00:00
Samples Type: Test Fuel VOC
Inspection information logged in by NST on 6/7/2017. **Season:**

LEV III-Tank 30C 6-7-17 **FTAG: 26757** **Comments:** **Regular**

Test Code	Test Method	Results	Units	Fuel_ Code:	64	Analyst	Analysis Date
595	Total Oxygenates Volume Percent from D4815	9.84	Volume Percent			HS	6/16/2017
5900	Oxidation Stability by D525	1440.0	minutes			Paragon	6/21/2017
428	Sulfur in Gasoline by D5453	9.72	Parts Per Million			NS	6/28/2017
5809	t-Amyl Alcohol in Fuel by D4815	0.00	Volume Percent			HS	6/16/2017
594	Total Oxygenate Weight Percent by D4815	10.43	Weight Percent			HS	6/16/2017
590	Total Oxygen Weight Percent by D4815	3.62	Oxygen Weight Percent			HS	6/16/2017
5807	iso-Propanol in Fuel by D4815	0.00	Volume Percent			HS	6/16/2017
5804	Oxygen in sec-Butanol by D4815	0.00	Oxygen weight Percent			HS	6/16/2017
5803	sec-Butanol in Fuel by D4815	0.00	Volume Percent			HS	6/16/2017
600	DIPE in Fuel by D4815	0.00	Volume Percent			HS	6/16/2017
596	MTBE in Fuel by D4815	0.00	Volume Percent			HS	6/16/2017
598	TAME in Fuel by D4815	0.00	Volume Percent			HS	6/16/2017
597	ETBE in Fuel by D4815	0.00	Volume Percent			HS	6/16/2017
5806	n-Propanol in Fuel by D4815	0.00	Volume Percent			HS	6/16/2017
5810	n-Butanol in Fuel by D4815	0.00	Volume Percent			HS	6/16/2017
62	Vapor Pressure by D5191 (Modified)	7.01	PSI			NST	6/12/2017
62	Vapor Pressure by D5191 (Modified)	7.01	PSI			NST	6/12/2017
65	Percent Evaporated at 200 Degrees F D86	47.3	Volume Percent			RG	6/13/2017
65	Percent Evaporated at 200 Degrees F D86	48.1	Volume Percent			RG	6/13/2017
66	Percent Evaporated at 300 Degrees F D86	83.3	Volume Percent			RG	6/13/2017
66	Percent Evaporated at 300 Degrees F D86	83.0	Volume Percent			RG	6/13/2017
48	Aromatics in Gasoline MSD D5769	21.21	Volume Percent			TW	6/19/2017
48	Aromatics in Gasoline MSD D5769	21.15	Volume Percent			TW	6/19/2017
49	Olefins in by FIA D1319	5.0	Volume Percent			RCG	6/21/2017
63	Benzene in Gasoline by GC/MSD D5769	0.66	Volume Percent			TW	6/19/2017
46	Aromatics by FIA D1319	20.1	Volume Percent			RCG	6/21/2017
630	Toluene in gasoline by MSD D5769	5.36	Volumn Percent			TW	6/19/2017
63	Benzene in Gasoline by GC/MSD D5769	0.67	Volume Percent			TW	6/19/2017
630	Toluene in gasoline by MSD D5769	5.35	Volumn Percent			TW	6/19/2017
69	Specific Gravity @ 60 deg F D4052	0.74915	60/60F			NT	6/12/2017

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NVFEL Fuel Analysis Report 26757

692	Degrees API D4052	57.38	Degrees API	NT	6/12/2017
691	Density @ 60 deg F D4052	0.74841	g/cm-03 @ 60 deg F	NT	6/12/2017
101	Initial Boiling Point D86	109.6	Degrees F	RG	6/13/2017
101	Initial Boiling Point D86	109.4	Degrees F	RG	6/13/2017
110	10 Percent D86	136.8	Degrees F	RG	6/13/2017
110	10 Percent D86	137.3	Degrees F	RG	6/13/2017
150	50 Percent D86	207.9	Degrees F	RG	6/13/2017
150	50 Percent D86	210.6	Degrees F	RG	6/13/2017
190	90 Percent D86	319.6	Degrees F	RG	6/13/2017
190	90 Percent D86	320.7	Degrees F	RG	6/13/2017
200	End Point D86	353.1	Degrees F	RG	6/13/2017
200	End Point D86	363.2	Degrees F	RG	6/13/2017
201	Residue D86	1.0	mL	RG	6/13/2017
201	Residue D86	1.0	mL	RG	6/13/2017
202	Total Recovery D86	97.8	mL	RG	6/13/2017
202	Total Recovery D86	98.4	mL	RG	6/13/2017
203	Loss D86	1.2	mL	RG	6/13/2017
203	Loss D86	0.6	mL	RG	6/13/2017
533	Ethanol in Fuel by D4815	9.84	Volume Percent	HS	6/16/2017
542	Methanol in Fuel D4815	0.00	Volume Percent	HS	6/16/2017
582	t-Butanol in Fuel by D4815	0.00	Volume Percent	HS	6/16/2017
583	iso-Butanol in Fuel by D4815	0.00	Volume Percent	HS	6/16/2017
30	Lead in Gasoline by D3237	0.00	Gram Pb per Gallon	Paragon	6/22/2017
32	Weight Fraction Carbon D3343	0.82700	Weight Fraction	HS	
227	Gum Content Washed	1.8	mg/100ml	Paragon	6/27/2017
228	Gum Content Unwashed	10.8	mg/100ml	Paragon	6/27/2017
991	Phosphorus in Gasoline by D3231	0.0008	Grams per Gallon	Paragon	6/22/2017
221	Motor Octane	84.3	Motor Octane Number	Paragon	7/12/2017
218	Sensitivity	7.7	RON-MON	CPU	7/12/2017
219	Antiknock	88.15	(RON+MON)/2	CPU	7/12/2017
220	Research Octane	92.0	Research Octane Number	Paragon	7/12/2017
225	Copper Corrosion D130	1a	Designation	Paragon	6/21/2017
230	Net Heating Value D240	17958.00	BTU/lb	Paragon	6/25/2017
231	Carbon Content D5291	82.70	Weight Percent	Paragon	6/21/2017
232	Hydrogen Content D5291	13.68	Weight Percent	Paragon	6/21/2017
581	C9+Aromatics in Gasoline D5580	8.46	Volume Percent	TW	6/13/2017
581	C9+Aromatics in Gasoline D5580	8.48	Volume Percent	TW	6/13/2017
580	Toluene in Gasoline D5580	5.20	Volume Percent	TW	6/13/2017
580	Toluene in Gasoline D5580	5.22	Volume Percent	TW	6/13/2017
60	Benzene in Gasoline D5580	0.66	Volume Percent	TW	6/13/2017
58	Aromatics in Gasoline D5580	21.11	Volume Percent	TW	6/13/2017

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58	Aromatics in Gasoline D5580	21.06 Volume Percent	TW	6/13/2017
60	Benzene in Gasoline D5580	0.66 Volume Percent	TW	6/13/2017
492	Olefins by D6550	4.8 Weight Percent	LS	6/13/2017
492	Olefins by D6550	4.7 Weight Percent	LS	6/13/2017

E5 Test Fuel

EPA fuel analyses for Euro V test fuel.

Type of Fuel	Euro V	FTAG	28631
Date Received	1/7/2021	Date Processed	6/8/2021

Property	Unit	Value	Specification Minimum	Specification Maximum	Reference procedure
Dry Vapor Pressure Equivalent (DVPE)	psi	8.6			ASTM D5191
Distillation Initial Boiling Point	°F	95			ASTM D86
10% evaporated	°F	122			
50% evaporated	°F	205			
90% evaporated	°F	324			
Evaporated final boiling point	°F	393			
Residue	milliliter	1			
Total Aromatic Hydrocarbons	volume %	32			ASTM D5769
C6 Aromatics (benzene)	volume %	0.1			ASTM D5769
C7 Aromatics (toluene)	volume %	13.6			
C8 Aromatics	volume %	0.4			
C9 Aromatics	volume %	15.5			
C10 + Aromatics	volume %	2.1			
Multi-substituted Aromatics	volume %	15.7			
Olefins	wt %	8			ASTM D6550
Ethanol confirmatory	volume %	5.2			ASTM D4815
MTBE	volume %	0.0			
Total Content of Oxygenates other than Ethanol	volume %	0.04			
Total Oxygen	wt %	1.91			
Sulfur	mg/kg	1.3			ASTM D2622, D5453 or D7039
Lead	g/liter	<0.0027			ASTM D3237
Phosphorus	g/liter	<0.00005			ASTM D3231
Copper Corrosion		1a			ASTM D130
Solvent-Washed Gum Content	mg/100 milliliter	2.6			ASTM D381
Oxidation Stability	minutes	>1440			ASTM D525
Motor Octane		87.7			ASTM D2700
Research Octane		99.7			ASTM D2699
Antiknock Index (R + M)/2		93.7			calculated
Sensitivity (R-M)		12			calculated
Carbon	%	84.55			ASTM D5291
Hydrogen	%	13.54			ASTM D5291
Net Heating Value	BTU/lb	18079			ASTM D240
Specific Gravity, 60°F		0.75544			ASTM D4052
API	API	55.81			ASTM D4052
Density, 60°F	g/mL	0.75469			ASTM D4052
CWF		0.8455			calculated
CMF		1			calculated
HMF α, H-to-C ratio		1.91			calculated
OMF β, O-to-C ratio		0.017			calculated
SMF		5.54E-07			calculated

FTAG ID	Fuel Name	Sulfur (ppm)	Specific Gravity	CWF	Net Heating Value (BTU/lb)	α, H-to-C ratio	β, O-to-C ratio	Ethanol (vol %)
28631	**Euro V**	1.3	0.7554	0.8455	18079	1.91	0.017	5.2

Tier 3 Test Fuel

EPA fuel analysis for Tier 3 fuel.

31-May-19 **NVFEL Fuel Analysis Report** 27723 Page 1 of 4

Tier 3 Batch#

Facility Name: US EPA NVFEL Testing Fuel Group Facility Type: In House
Owner: USEPA Phone: (734) 214-4448
2565 Plymouth Road
Ann Arbor MI 48105-2425 Washtenaw County US
Inspector: Hilda Sola-Soto Inspection Date : 11/1/2017 Time In: 00:00 Time Out: 00:00
Samples Type: Test Fuel VOC
Inspection information logged in by RG on 12/3/2018. **Season:**

Tier 3-Blend 24N 12/3/18 **FTAG: 27723** **Comments:** **Tier 3 blend 776 Gal Tank 31N & 1418 Gal Tank 22**

Test Code	Test Method	Results	Units	Fuel_ Code: 74	Analyst	Analysis Date
4814	1,2,4-TRIMETHYLBENZENE	5.53	Volume Percent		MP	4/25/2019
4810	3-ETHYLTOLUENE	0.08	Volume Percent		MP	4/25/2019
4810	3-ETHYLTOLUENE	0.08	Volume Percent		MP	4/25/2019
4811	4-ETHYLTOLUENE	0.07	Volume Percent		MP	4/25/2019
4811	4-ETHYLTOLUENE	0.07	Volume Percent		MP	4/25/2019
4812	1,3,5-TRIMETHYLBENZENE	0.01	Volume Percent		MP	4/25/2019
4812	1,3,5-TRIMETHYLBENZENE	0.01	Volume Percent		MP	4/25/2019
4817	ALKYL INDANS	0.00	Volume Percent		MP	4/25/2019
4813	1-METHYL2-ETHYLBENZENE	0.08	Volume Percent		MP	4/25/2019
4808	ISOPROPYLBENZENE	0.01	Volume Percent		MP	4/25/2019
4814	1,2,4-TRIMETHYLBENZENE	5.52	Volume Percent		MP	4/25/2019
4815	1,2,3-TRIMETHYLBENZENE	0.01	Volume Percent		MP	4/25/2019
4815	1,2,3-TRIMETHYLBENZENE	0.01	Volume Percent		MP	4/25/2019
4816	INDAN	0.07	Volume Percent		MP	4/25/2019
4816	INDAN	0.07	Volume Percent		MP	4/25/2019
5900	Oxidation Stability by D525	1440.0	minutes		Paragon	12/11/2018
4813	1-METHYL2-ETHYLBENZENE	0.08	Volume Percent		MP	4/25/2019
4805	ETHYLBENZENE	0.80	Volume Percent		MP	4/25/2019
5808	Total Oxygenate Weight Percent by D5599	10.25	Weight Percent		HS	12/6/2018
5808	Total Oxygenate Weight Percent by D5599	10.00	Weight Percent		HS	12/6/2018
428	Sulfur in Gasoline by D5453	9.86	Parts Per Million		NS	3/8/2019
427	Sulfur in Gasoline by D7039	8.7	Parts Per Million		MJP	2/11/2019
427	Sulfur in Gasoline by D7039	8.6	Parts Per Million		MJP	2/11/2019
4803	BENZENE	0.52	Volume Percent		MP	4/25/2019
4809	N-PROPYLBENZENE	0.02	Volume Percent		MP	4/25/2019
4804	TOLUENE	6.02	Volume Percent		MP	4/25/2019
4809	N-PROPYLBENZENE	0.01	Volume Percent		MP	4/25/2019
4833	MSAA	15.74	Volume Percent		MP	4/25/2019
4806	M/P-XYLENE	3.92	Volume Percent		MP	4/25/2019
4806	M/P-XYLENE	3.93	Volume Percent		MP	4/25/2019

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4807	O-XYLENE	1.21 Volume Percent	MP	4/25/2019
4807	O-XYLENE	1.20 Volume Percent	MP	4/25/2019
4808	ISOPROPYLBENZENE	0.01 Volume Percent	MP	4/25/2019
4805	ETHYLBENZENE	0.80 Volume Percent	MP	4/25/2019
4803	BENZENE	0.53 Volume Percent	MP	4/25/2019
4829	Total Aromatics (vol. %)	23.50 Volume Percent	MP	4/25/2019
4823	2-METHYLNAPTHALENE	0.08 Volume Percent	MP	4/25/2019
4824	1-METHYLNAPHTHALENE	0.20 Volume Percent	MP	4/25/2019
4825	1,3-DIETHYLBENZENE	2.01 Volume Percent	MP	4/25/2019
4804	TOLUENE	6.05 Volume Percent	MP	4/25/2019
4826	C10 BENZENES	0.00 Volume Percent	MP	4/25/2019
4826	C10 BENZENES	0.00 Volume Percent	MP	4/25/2019
4827	C11 BENZENES	0.03 Volume Percent	MP	4/25/2019
4827	C11 BENZENES	0.03 Volume Percent	MP	4/25/2019
4823	2-METHYLNAPTHALENE	0.08 Volume Percent	MP	4/25/2019
4828	C12 BENZENES	0.00 Volume Percent	MP	4/25/2019
4824	1-METHYLNAPHTHALENE	0.20 Volume Percent	MP	4/25/2019
4829	Total Aromatics (vol. %)	23.49 Volume Percent	MP	4/25/2019
4830	C8	5.93 Volume Percent	MP	4/25/2019
4830	C8	5.93 Volume Percent	MP	4/25/2019
4831	C9	5.87 Volume Percent	MP	4/25/2019
4831	C9	5.87 Volume Percent	MP	4/25/2019
4832	C10Plus	5.16 Volume Percent	MP	4/25/2019
4832	C10Plus	5.11 Volume Percent	MP	4/25/2019
4833	MSAA	15.79 Volume Percent	MP	4/25/2019
4817	ALKYL INDANS	0.00 Volume Percent	MP	4/25/2019
4828	C12 BENZENES	0.00 Volume Percent	MP	4/25/2019
4819	1,2-DIETHYLBENZENE	0.01 Volume Percent	MP	4/25/2019
4822	NAPTHALENE	0.07 Volume Percent	MP	4/25/2019
4821	1,2,3,5-TETRAMETHYLBENZENE	0.00 Volume Percent	MP	4/25/2019
4821	1,2,3,5-TETRAMETHYLBENZENE	0.00 Volume Percent	MP	4/25/2019
4818	1,4-DIETHYLBENZENE & N-BUT	2.76 Volume Percent	MP	4/25/2019
4820	1,2,4,5-TETRAMETHYLBENZENE	0.00 Volume Percent	MP	4/25/2019
4820	1,2,4,5-TETRAMETHYLBENZENE	0.00 Volume Percent	MP	4/25/2019
4818	1,4-DIETHYLBENZENE & N-BUT	2.73 Volume Percent	MP	4/25/2019
4822	NAPTHALENE	0.06 Volume Percent	MP	4/25/2019
4825	1,3-DIETHYLBENZENE	2.00 Volume Percent	MP	4/25/2019
4819	1,2-DIETHYLBENZENE	0.01 Volume Percent	MP	4/25/2019
552	Oxygen in MTBE by D5599	0.00 Oxygen Weight Percent	HS	12/6/2018
552	Oxygen in MTBE by D5599	0.00 Oxygen Weight Percent	HS	12/6/2018
562	Oxygen in ETBE by D5599	0.00 Oxygen Weight Percent	HS	12/6/2018

562	Oxygen in ETBE by D5599	0.00	Oxygen Weight Percent	HS	12/6/2018
534	Oxygen in Ethanol by D5599	3.47	Oxygen Weight Percent	HS	12/6/2018
534	Oxygen in Ethanol by D5599	3.56	Oxygen Weight Percent	HS	12/6/2018
572	Oxygen in TAME by D5599	0.00	Oxygen Weight Percent	HS	12/6/2018
572	Oxygen in TAME by D5599	0.00	Oxygen Weight Percent	HS	12/6/2018
62	Vapor Pressure by D5191 (Modified)	8.9	PS I	ETS	12/4/2018
65	Percent Evaporated at 200 Degrees F D86	49.7	Volume Percent	NL	12/4/2018
66	Percent Evaporated at 300 Degrees F D86	84.7	Volume Percent	NL	12/4/2018
48	Aromatics in Gasoline MSD D5769	24.43	Volume Percent	TW	4/2/2019
48	Aromatics in Gasoline MSD D5769	24.56	Volume Percent	TW	4/2/2019
55	MTBE in Fuel by D5599	0.00	Volume Percent	HS	12/6/2018
55	MTBE in Fuel by D5599	0.00	Volume Percent	HS	12/6/2018
593	Total Oxygenates Volume Percent from D5599	9.63	Volume Percent	HS	12/6/2018
593	Total Oxygenates Volume Percent from D5599	9.40	Volume Percent	HS	12/6/2018
532	Ethanol in Fuel by D5599	9.63	Volume Percent	HS	12/6/2018
532	Ethanol in Fuel by D5599	9.40	Volume Percent	HS	12/6/2018
59	Total Oxygen Weight Percent by D5599	3.47	Oxygen Weight Percent	HS	12/6/2018
57	TAME in Fuel by D5599	0.00	Volume Percent	HS	12/6/2018
59	Total Oxygen Weight Percent by D5599	3.56	Oxygen Weight Percent	HS	12/6/2018
57	TAME in Fuel by D5599	0.00	Volume Percent	HS	12/6/2018
56	ETBE in Fuel by D5599	0.00	Volume Percent	HS	12/6/2018
56	ETBE in Fuel by D5599	0.00	Volume Percent	HS	12/6/2018
63	Benzene in Gasoline by GC/MSD D5769	0.50	Volume Percent	TW	4/2/2019
630	Toluene in gasoline by MSD D5769	6.15	Volumn Percent	TW	4/2/2019
63	Benzene in Gasoline by GC/MSD D5769	0.51	Volume Percent	TW	4/2/2019
630	Toluene in gasoline by MSD D5769	6.23	Volumn Percent	TW	4/2/2019
69	Specific Gravity @ 60 deg F D4052	0.74665	60/60F	ET	12/4/2018
692	Degrees API D4052	58.01	Degrees API	ET	12/4/2018
691	Density @ 60 deg F D4052	0.74591	g/cm-03 @ 60 deg F	ET	12/4/2018
101	Initial Boiling Point D86	99.1	Degrees F	NL	12/4/2018
110	10 Percent D86	128.7	Degrees F	NL	12/4/2018
150	50 Percent D86	201.9	Degrees F	NL	12/4/2018
190	90 Percent D86	321.4	Degrees F	NL	12/4/2018
200	End Point D86	385.9	Degrees F	NL	12/4/2018
201	Residue D86	1.1	mL	NL	12/4/2018
202	Total Recovery D86	97.3	mL	NL	12/4/2018
203	Loss D86	1.6	mL	NL	12/4/2018
543	Methanol in Fuel by D5599	0.00	Volume Percent	HS	12/6/2018
543	Methanol in Fuel by D5599	0.00	Volume Percent	HS	12/6/2018
584	Iso-Propanol in Fuel by D5599	0.00	Volume Percent	HS	12/6/2018
584	Iso-Propanol in Fuel by D5599	0.00	Volume Percent	HS	12/6/2018

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585	t-Butanol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
585	t-Butanol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
586	n-Propanol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
586	n-Propanol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
587	sec-Butanol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
587	sec-Butanol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
588	DIPE in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
588	DIPE in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
589	Iso-Butanol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
589	Iso-Butanol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
5801	t-Amyl Alcohol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
5801	t-Amyl Alcohol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
5802	n-Butanol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
5802	n-Butanol in Fuel by D5599	0.00 Volume Percent	HS	12/6/2018
30	Lead in Gasoline by D3237	0.00 Gram Pb per Gallon	Paragon	12/10/2018
227	Gum Content Washed	0.6 mg/100ml	Paragon	12/13/2018
228	Gum Content Unwashed	4.0 mg/100ml	Paragon	12/13/2018
991	Phosphorus in Gasoline by D3231	0.0000 Grams per Gallon	Paragon	12/12/2018
221	Motor Octane	83.1 Motor Octane Number	Paragon	12/13/2018
218	Sensitivity	8.9 RON-MON	CPU	12/13/2018
220	Research Octane	92.0 Research Octane Number	Paragon	12/13/2018
219	Antiknock	87.55 (RON+MON)/2	CPU	12/13/2018
225	Copper Corrosion D130	1A Designation	Paragon	12/10/2018
230	Net Heating Value D240	17954.00 BTU/lb	Paragon	12/14/2018
231	Carbon Content D5291	82.72 Weight Percent	Paragon	12/11/2018
232	Hydrogen Content D5291	13.76 Weight Percent	Paragon	12/11/2018
492	Olefins by D6550	7.7 Weight Percent	LS	12/11/2018
492	Olefins by D6550	7.8 Weight Percent	LS	12/11/2018

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