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Mr. Wehrly:

Request for GHG Credit for Variable Crankcase Suction Valve Technology

Pursuant to the provisions of 40 CFR § 86.1869-12(d), General Motors requests off-cycle greenhouse gas credit of 1.1 grams CO2 per mile for the use of the Denso SAS air conditioner compressor with variable crankcase suction valve technology. This improved air conditioner compressor was first used by GM on the 2013 model Cadillac ATS. It was then implemented on the 2013 Chevrolet Traverse, Buick Enclave and GMC Acadia vans. In addition to these models in 2014, the SAS compressor was added to all the GM 2014 full-size trucks, including the Chevrolet Silverado, Tahoe and Suburban, GMC Sierra, Yukon and Yukon XL, and Cadillac Escalade and Escalade ESV. In addition to these models, in 2015 model year the SAS compressor will be used on the Cadillac CTS and Cadillac XTS limousine. It will be used even more widely in the future.

Background

EPA currently provides Mobile Air Conditioner (MAC) greenhouse gas credits for reduced reheat using an externally-controlled variable displacement compressor (EVDC), which provides significant efficiency improvements compared to the baseline fixed displacement compressors that were the industry norm at the time that EPA created its vehicle greenhouse gas regulatory program. Traditional fixed compressors operate at a single displacement all the time that the compressor is switched on. The capacity of the system is only controlled by cycling the compressor clutch on and off, which creates waste in two ways. Energy is wasted by continuously warming and cooling the MAC system components and by accelerating and decelerating the compressor rotating mass as the clutch cycles. Further, traditional fixed displacement compressor systems require reheating the cooled air under mild ambient conditions when slightly warmer air is required to keep passengers comfortable. In contrast, EVDC technology allows the air conditioner compressor to moderate cooling capacity and work less under mild ambient conditions to avoid cycling the compressor clutch. When slightly warmer air is needed, EVDC compressors can reduce capacity further to cool the air to the required amount and reduce the need to reheat the air.

The final rule for the 2012-2016 light duty vehicle greenhouse gas program created MAC credits as part of the first-ever overarching national framework for vehicle greenhouse gas regulation in the U.S. Following initial discussions, on May 19, 2009, ten automobile manufacturers and the UAW joined President Obama at the White House to announce the initial proposal for the greenhouse gas regulation, including MAC credits, with the final rule subsequently published on May 7, 2010. At the time the regulation was developed in 2009 and 2010, EVDC technology was evaluated to be the most efficient technology available for air conditioner compressors, and was therefore awarded a credit of 1.7 grams of CO_2 per mile, which was the largest credit created for any air conditioning technology. Much of the technology development and demonstration work supporting the MAC credits had been done through the SAE IMAC Cooperative Research Program, a partnership between EPA, DOE and 28 corporate sponsors, which published its final report in 2006 demonstrating the potential for a 30% MAC efficiency improvement using EVDC and other MAC technologies.

Technology Description

Since that time, additional technological progress has occurred, producing significant additional potential efficiency improvements in mobile air conditioner compressors. The Denso SAS compressor is a new EVDC design that improves the internal valve system within the compressor to reduce the internal refrigerant flow necessary throughout the range of displacements that the compressor may use during its operating cycle. This is achieved though the addition of a variable crankcase suction valve (variable CS valve). Conventional compressors have a fixed crankcase to suction bleed that regulates the flow of refrigerant exiting the crankcase. The sizing of the bleed is a compromise among the conditions when either a high rate of flow or a low rate of flow would be more ideal. In conditions where maximum air conditioner capacity is not needed, this fixed bleed creates an unnecessary reduction of volumetric efficiency for the compressor. In contrast, a variable CS valve can provide a larger mass flow under maximum capacity and compressor start-up conditions, when high flow is ideal, then reduce to smaller openings with reduced mass flow in mid or low capacity conditions. Thus, the refrigerant exiting the crankcase is optimized across the range of operating conditions, creating significant benefits for the energy consumption of the air conditioning system.

Off Cycle Condition

EPA created the off cycle credit program to incentivize the implementation of technologies which reduce greenhouse gas emissions in the real world by a greater amount than would be captured in the two cycle test program. The EPA's two cycle test program for city and high way drive schedules is conducted without the air conditioner switched on, so air conditioner efficiency technologies clearly address an "off cycle" condition, since none of the benefits of MAC technology improvements are captured by the two cycle tests. Correspondingly, credits for thermal control technologies have been included in EPA's list of pre-defined and pre-approved off cycle credits based on the greenhouse gas reductions expected from reduced air conditioner usage on vehicles equipped with these thermal control technologies, such as solar reflective glass and paint, ventilated seats, active cabin ventilation and passive cabin ventilation.

Alternative Methodology Requirement

EPA's five cycle test program would not adequately measure the real-world greenhouse gas reduction benefits of either EVDC or the variable CS valve. Only one of the five tests is conducted with the air conditioner switched on. This is the SC03 test, which is conducted at a very high

ambient temperature of 95°F, high solar load of 850 W/m^2, and high relative humidity of 40%. The relatively short 10-minute duration of the SC03 test and the extremely demanding climatic conditions result in the vehicle air conditioner systems being operated at maximum capacity essentially throughout the test. Indeed, the SC03 procedure specifies that manual controls be set to a mode of maximum cooling and a temperature of full cool for the entire test. Technologies such as EVDC and the variable CS valve provide their benefits under milder ambient conditions when the air conditioner is not forced to operate at maximum capacity. Therefore, no substantial portion of the real world benefits of these technologies can be measured on the SC03 test. As a result, the five cycle test program cannot be used to evaluate these off cycle technologies, and an alternative methodology must be used instead.

Bench Tests

The Denso SAS compressor used on the 2013 and 2014 Cadillac ATS was evaluated by Denso using the methodologies that were developed and used during the SAE IMAC Cooperative Research Program for its evaluations of U.S. average system efficiency. These methodologies have been formally adopted as publicly available SAE standards. The SAE J2765 standard specifies a series of 40 bench tests at various compressor speeds to measure the system coefficient of performance (COP). Twenty five of these bench test conditions are then selected as inputs to the GREEN MAC Lifecycle Climate Change Performance (LCCP) model jointly developed for comparative evaluations by General Motors, EPA, the Japanese Automobile Manufacturers Association, and SAE (GREEN is an acronym for Global Refrigerants Energy and Environmental). These twenty five data points replicate a broad range of operating conditions for various ambient climate conditions and air conditioner system modes. This LCCP model has been adopted as the SAE J2766 standard and can be accessed at the following link:

http://www.epa.gov/cpd/mac/compare.htm

The GREEN MAC LCCP model includes U.S. climate data for numerous U.S. cities as well as vehicle on-road operation parameters. Data sources are thoroughly documented within the model, but some of the key parameters are temperature and humidity data from a U.S. Department of Energy (DOE) database that contains U.S. National Climatic Data Center data, annual driving distances for each city from the U.S. Energy Information Agency (EIA), and percentage of drive time at different ambient conditions based on research by the National Renewable Energy Laboratory (NREL). Combining the J2765 bench test COP data with the NREL, EIA and DOE climate and vehicle on-road data provides a simulation of annual U.S. average greenhouse gas emissions for an air conditioning system.

This full analysis was performed for the Denso SAS compressor, resulting in a U.S. average LCCP of 17.6 grams CO_2 per mile per vehicle. The same analysis was then performed for the Denso SBU compressor, which is a modern EVDC design that does not have the variable CS valve technology. The SBU compressor is currently used on a variety of vehicles, such as the Chevrolet Impala Classic, Holden Commodore, Chevrolet Equinox, and GMC Terrain. The SBU compressor qualifies for the 1.7 grams CO_2 per mile MAC credit under the EPA regulation, and, as such, constitutes a valid comparative baseline to determine if the SAS compressor with variable CS valve technology deserves an additional off cycle credit for emission reductions beyond those already achieved by compressors that qualify for the EPA EVDC MAC credit. (Both compressors also feature integrated oil separators, and both qualify for the MAC credit of 0.6 grams CO_2 per mile.) The SBU

compressor achieved an LCCP result of 18.7 grams CO_2 per mile, which is 1.1 grams CO_2 per mile higher than the SAS compressor. Based on this analysis, vehicles equipped with the SAS compressor featuring variable SC valve technology should receive an off cycle credit of 1.1 grams CO_2 per mile.

Bench test results using the J2765 procedure for both the SAS and the SBU compressor are contained in Appendix A. Denso reviewed this data with the EPA technical specialists for mobile air conditioners in April 2013 (see Attachment B for this Denso presentation). The feedback was positive, but Denso was instructed to work with an OEM on any greenhouse gas credit request. Denso subsequently approached GM to jointly develop this credit application, and the subsequent testing and credit application preparation has been coordinated between Denso and GM technical experts.

Vehicle Tests

While this bench test procedure provides an accurate measurement of the expected benefits for U.S. national average climate conditions and driving patterns, consultation on potential off cycle credit with EPA's off cycle technical specialist revealed a desire to see the benefits documented through actual vehicle testing. As discussed previously, the SCO3 test would not be useful for this purpose, since the extreme air conditioning loads throughout that test would not allow operation in the moderate load conditions where the SAS compressor shows its benefits. The AC17 test was therefore selected to measure benefits under the more moderate ambient conditions that are more representative of average U.S. air conditioner operating conditions.

Conducting vehicle tests turned into a major endeavor, considering the difficulties of obtaining suitable baseline vehicles (without the variable CS valve technology) and comparable production vehicles with the technology, obtaining time in suitable SC03 test cells (that are also used for the AC17 test), and generating usable test results. The production vehicle was the 2013 Cadillac ATS with rear-wheel-drive and a 2.0 liter turbo L4 engine. The Denso SAS compressor with variable crankcase suction valve technology has been standard on this vehicle since the vehicle's introduction in 2013. However, no version of this vehicle had ever been built without the SAS compressor.

By coincidence, the Denso SBU compressor that was used in Australia on the Holden Commodore had similar mounting points and controls, which allowed this SBU unit, without the variable crankcase suction valve technology, to be installed in the Cadillac ATS to gather baseline data. It should be noted that it was very fortunate in this instance that a good baseline hardware set could be assembled through the use of the Holden Commodore compressor, and it is expected to be uncommon to be able gather such comparable data for the "with off cycle technology" and "without off cycle technology" cases. At a minimum, use of SBU compressors from other applications would have required fabrication of elaborate special mounting brackets, since no other version matched the ATS mounting points. This type of hardware obstacle is anticipated to be potentially prohibitive in many future situations for performing vehicle tests to evaluate off cycle technologies, and in this instance prevents ready testing of the benefits of the SAS compressor on other GM models on which it has been implemented.

For example, the GM full-size trucks which now use the SAS compressor used fixed compressors in prior years. Therefore, there is no good hardware set available to directly compare the benefits of the SAS compressor (with variable crankcase suction valve technology) on the current trucks with an externally controlled variable compressor without the variable crankcase suction valve technology, since these trucks never used that type of compressor. Due to these obstacles and the potentially high testing burden, this credit request applies the benefits measured on the Cadillac ATS to all GM vehicles using the Denso compressors with variable CS valve technology.

In addition to the test burden considerations, a relatively small vehicle such as the Cadillac ATS is relatively easy to cool, and it uses the smallest displacement of the SAS compressors. Air conditioner fuel consumption on the ATS vehicle would be expected to be relatively low compared to the larger vehicles with larger compressors comprehended in this credit petition (Chevrolet Traverse, Buick Enclave, GMC Acadia, Chevrolet Silverado, Chevrolet Tahoe, Chevrolet Suburban, GMC Sierra, GMC Yukon, GMC Yukon XL, Cadillac Escalade, Cadillac Escalade ESV, Cadillac CTS and Cadillac XTS limousine). The fuel consumption savings in grams CO_2 per mile would also be expected to low compared to the same assessment on a larger vehicle with a larger compressor. Therefore, the savings in grams CO_2 per mile measured for the Cadillac ATS represents a "worst case" measurement, since general vehicle parameters and air conditioner size would indicate larger savings and a larger credit if assessed on these larger vehicles.

Vehicle Test Results

The AC17 procedure is a complicated test, and this particular test series was conducted under especially difficult circumstances. The SC03 test chamber had been shut down for a prolonged period for upgrades to meet future, more rigorous test requirements. The chamber was reopened with a backlog of required tests, and construction was actually continuing nearby while tests were restarted to eliminate this backlog. This is worth noting since construction dust was entering the SC03 chamber, and test data for two AC17 tests with the SAS compressor were voided where it was believed the dust may have had an effect on the dyno rollers, causing tire slip and high CO_2 emissions. Once this was observed, a practice was adopted to sponge off the dust and then dry the rollers between tests.

One additional source of test variability may have occurred in the SBU compressor tests on Days 3 and 4. During these AC17 tests, torque and pressure measured at the SBU compressor were unexpectedly low. This was never fully unexplained, but could be an example of the types of control issues that may be expected to arise when attempting to do this type of baseline technology testing for hardware on a vehicle that was never actually designed and optimized to use that hardware. Whatever the explanation, these test results were kept, even though the low torque and low pressure conditions would be expected to save energy for the SBU air conditioner operation on these tests, thereby making the baseline SBU compressor look more efficient. Keeping these test results therefore may have diminished the off cycle credit amount by making the baseline technology look better than it should.

The AC17 tests were conducted over four days, consisting of four AC17 tests for the SAS compressor (with the variable CS valve technology) and four AC17 tests for the baseline SBU compressor (without variable CS valve technology). Detailed test results are contained in Attachment C. As mentioned previously, two of the four AC17 tests for the SAS compressor were

voided due to tire slip. The following table summarizes the average data supporting an average savings of 1.3 grams CO_2 per mile for the SAS compressor with variable CS valve technology:

Grams CO_2 per mile	SC03 Drive Cycle	Highway Cycle	Combined
SAS Compressor (2 tests)	38.7	9.1	23.9
SBU Compressor (4 tests)	40.2	10.3	25.2
Differential (credit)			1.3

This vehicle data, measuring a 1.3 gram CO_2 per mile benefit on the AC17 test, is consistent with the credit value of 1.1 grams CO_2 per mile estimated from the bench tests data and U.S. LCCP calculations. In view of the test variability on the AC17 test and other vehicle testing difficulties and considerations, we are basing our credit request on the bench test data, which can be considered to be more precise. However, the vehicle test data provide important confirmation that the benefits of the variable crankcase suction valve compressor technology are measurable in comparable amounts on actual vehicle tests.

Durability

Durability of the SAS compressor has been thoroughly tested to meet General Motors specifications. This includes at least 14 separate durability bench test procedures, such as high refrigerant charge durability testing, low charge testing, vibration testing, corrosion testing, liquid slugging durability testing, clutch durability, resonant speed testing, control valve durability, start-stop durability, reverse torque durability, over voltage durability, jump start test, power temperature cycling, and humid heat cycling.

Perhaps most importantly, six compressors were evaluated in the Customer Usage Test, which runs the six compressors three times through a stressful 700-hour cycle of various compressors speeds. This 2,100 hours of testing is designed to simulate the wear of a normal compressor life. The components are then disassembled and examined for excess wear. The SAS compressors successfully passed all durability testing.

The objective of our durability evaluation was to predict any expected in-use emission deterioration rate, and to determine the performance level that effectively represents a significant majority of SAS compressors in actual use over the full useful life of candidate in-use vehicles of each vehicle design.

Based on these tests, GM is willing to attest that the SAS compressor is expected to meet EPA requirements for in-use durability over the complete vehicle lifetime of at least ten years for cars and eleven years for trucks, and no reduction has been applied for in-use degradation of the benefits of the variable crankcase suction valve technology. Durability test results are included in Attachment D.

Conclusion

Based on the bench test and vehicle test data presented in this petition, combined with calculation procedures in the Lifecycle Climate Change Performance tool, General Motors hereby requests that EPA approve an off cycle greenhouse gas credit of 1.1 grams CO_2 per mile for all 2013, 2014 and 2015 model vehicles equipped with the Denso SAS compressor with variable crankcase

suction valve technology. This 1.1 gram credit amount has been estimated to be representative of the fuel savings that can be expected from this technology in actual real-world usage in U.S. national average climate conditions. The relevant models and their expected sales volumes are listed in Attachment E.

Thank you for your consideration of this application for off cycle greenhouse gas credits.

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Attachment A - Compressor Bench Test Data
Attachment B - Denso Presentation to EPA, April 2013
Attachment C - AC17 Vehicle Test Data
Attachment D - Durability Tests (Confidential)
Attachment E - Sales Volumes of Models with SAS Compressor (Confidential)