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Date: Dec 13, 2019

Mr. Linc Wehrly
Director, Light Duty Vehicle Center
Compliance Division
Office of Transportation and Air Quality
Environmental Protection Agency
2000 Traverwood Drive
Ann Arbor, Michigan 48105

Subject: Request for GHG credit for Hanon A/C Compressor with Variable Orifice Valve Technology

Dear Mr. Wehrly:

Pursuant to the provisions of 40 CFR § 86.1869-12(d), 49 CFR § 531.6(b), and 49 CFR § 533.6(c), Kia Motor Company (KMC), represented by the Hyundai America Technical Center, Inc. (HATCI), requests greenhouse gas (GHG) off-cycle credit for the use of a Hanon air conditioner compressor with variable orifice valve (VO valve) technology. Based on the test results and analysis provided in Attachment A, B and C, KMC requests credits equal to 1.8 grams CO_2 per mile for HV14i, 1.7 grams CO_2 per mile for HV16i, and 1.5 grams CO_2 per mile for HV17i applied in KMC production vehicles. KMC intends to apply credits for 2021 and subsequent model year KMC vehicles sold in the U.S. equipped with Hanon air conditioner compressor with variable orifice (VO) valve technology. KMC also plans to submit a similar credit request to NHTSA for off-cycle CAFE credits.

Background

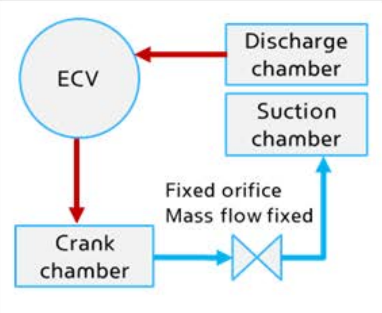
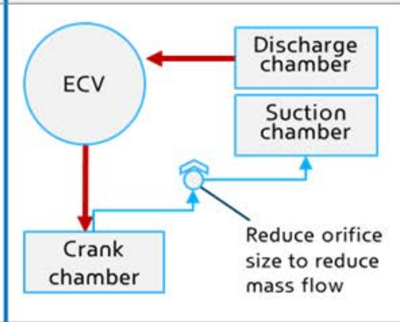
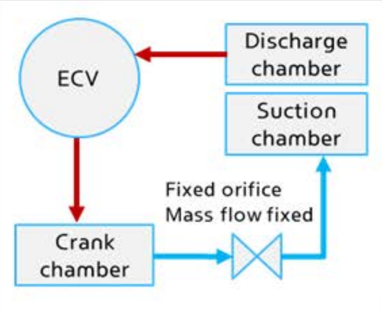
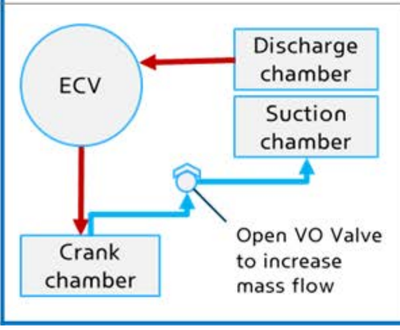
Greenhouse gas emission standards through 2025 represent a major initiative in US energy and climate policy. EPA and DOT have issued a joint rulemaking that set greenhouse gas emissions and fuel economy standards for the largest sources of greenhouse gases from transportation, including cars, light trucks, and heavy-duty trucks. Over the course of the program, light-duty GHG regulations are projected to: cut 6 billion metric tons of GHG emissions, nearly double vehicle fuel efficiency while protecting consumer choice, reduce America's dependence on oil and provide significant savings for consumers at the fuel pump. To achieve these worthy goals, a key regulatory element is the ability for manufacturers to have a variety of options and flexibilities in meeting the standards.

A key flexibility is the off-cycle credits provision; off-cycle credits are an opportunity for manufacturers to generate credits for technologies that provide CO_2 reductions not captured by the traditional 2-cycle (FTP, HWFET) emissions tests conducted on a chassis dynamometer. There are three pathways by which a manufacturer may accrue off-cycle credits. The first is a pre-determined menu of credit values for specific off-cycle technologies. In cases where additional lab testing can demonstrate emission benefits of a technology, a second pathway allows manufacturers to use a broader array of emission tests known as 5-cycle testing, which captures more elements of real-world driving, including high speeds and hard acceleration (US06), solar loads, high temperature, and A/C use (SC03), and cold temperatures (cold FTP). The third pathway allows manufacturers to seek EPA approval to use an alternative methodology for determining the off-cycle credits.

The Hanon air conditioner compressor with variable orifice valve (VO valve) technology is not included in the EPA's pre-determined menu. Additionally, the five-cycle test option would not adequately measure the real-world GHG reduction benefits of the technology. Only one of the five tests is conducted with the A/C switched on. Since it is conducted at a high ambient temperature of 95F, high solar load of 850 W/m^2, and high relative humidity of 40%, the demanding climatic conditions result in the air conditioning systems being operated at maximum capacity throughout the test. The technology under investigation provides their benefits under milder ambient conditions when the A/C is not operating at maximum capacity. For these reasons, HATCI is pursuing additional off-cycle credits via the alternative methodology pathway.

Technology Description

The Hanon compressor design improves the internal valve system to reduce the internal refrigerant flow necessary throughout the range of displacements that the compressor uses during its operating cycle. This is achieved through the addition of a variable orifice valve.
Conventional compressors have a fixed orifice, so the flow of refrigerant exiting the crankcase is fixed. The sizing of the orifice is a compromise among the conditions when either a high or low rate of flow would be more ideal. However, VO valve technology can provide a larger mass flow under maximum capacity and compressor start-up conditions by opening the valve, when high flow is ideal; it can then reduce to smaller openings with reduced mass flow in mid or low capacity conditions. Thus, overall, the refrigerant exiting the crankcase is optimized across the range of operating conditions, improving system efficiency and therefore lowering indirect CO_2 emissions due to use of the air conditioning system.

Condition	Current Compressor (HV Compressor w/o VO Valve)	New Compressors (HV Compressor w/ VO Valve)	Benefit of Variable Orifice Valve
Variable (Mid) Capacity			▪ Reduce orifice size → Reduce gas flow → Reduce internal compressor loss → <u>Improving efficiency</u> → Reducing indirect AC system CO_2 emissions
Max Capacity and Compressor Start-Up			▪ Increase orifice size → Allow large mass flow → Maintain stable max capacity condition and achieve max capacity more quickly at compressor start-up

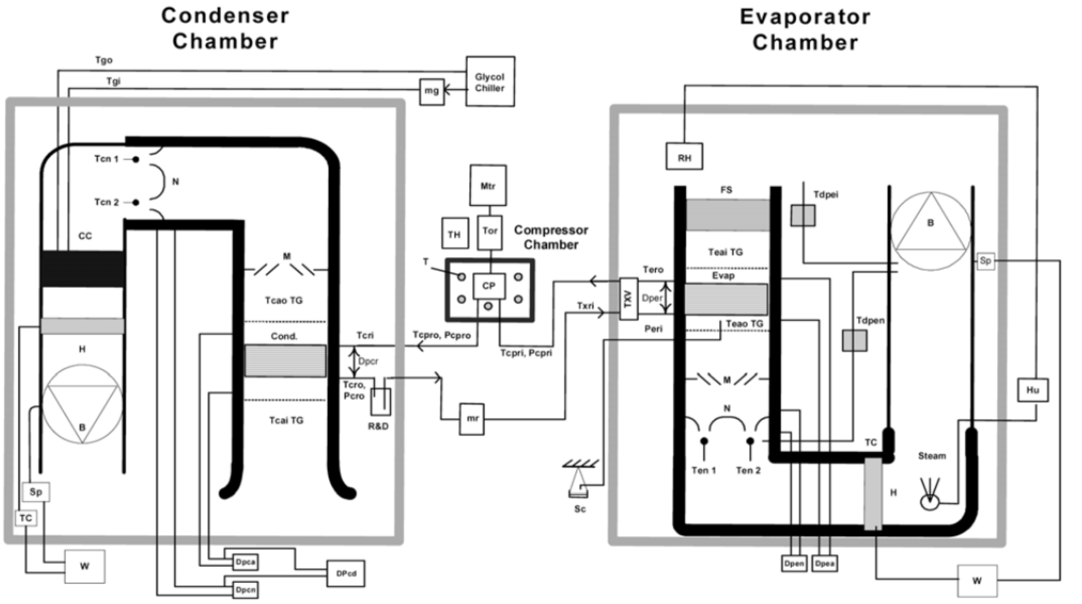
Test Methodology

The test methodology used to quantify the technology benefit consists of 4 steps:

1. Bench testing (SAE J2765) – Measure coefficient of performance (COP) at various (40) conditions
2. Life Cycle Climate Performance (LCCP) modeling and analysis (SAE J2766) – convert COP to gCO_2/mile based on climate data and vehicle and A/C usage across the United States
3. LCCP weighted average – weight results of model to a single representative value
4. AC17 confirmatory testing – Measure vehicle-level A/C impact in a lab setting

① Bench testing (SAE J2765)

SAE standard J2765 is a procedure for measuring system COP of a mobile air conditioning system on a bench testing. It covers 40 different operating conditions at various compressor speeds, temperatures, and humidity levels. The procedure was designed to give maximum repeatability and minimum error in determining cooling capacity and efficiency of the entire refrigeration system. A sample configuration of the test facility is provided below (Credit: SAE J2765 standard).

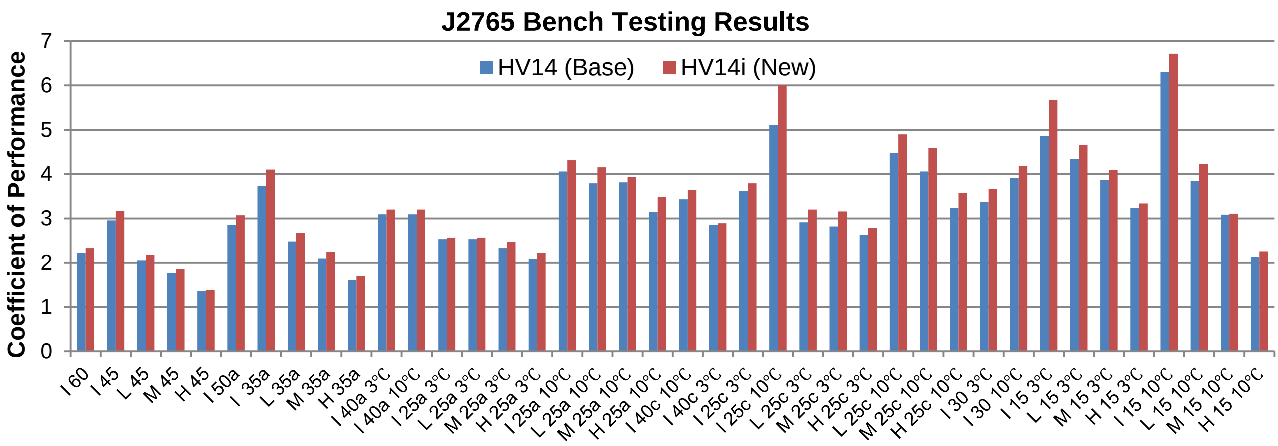


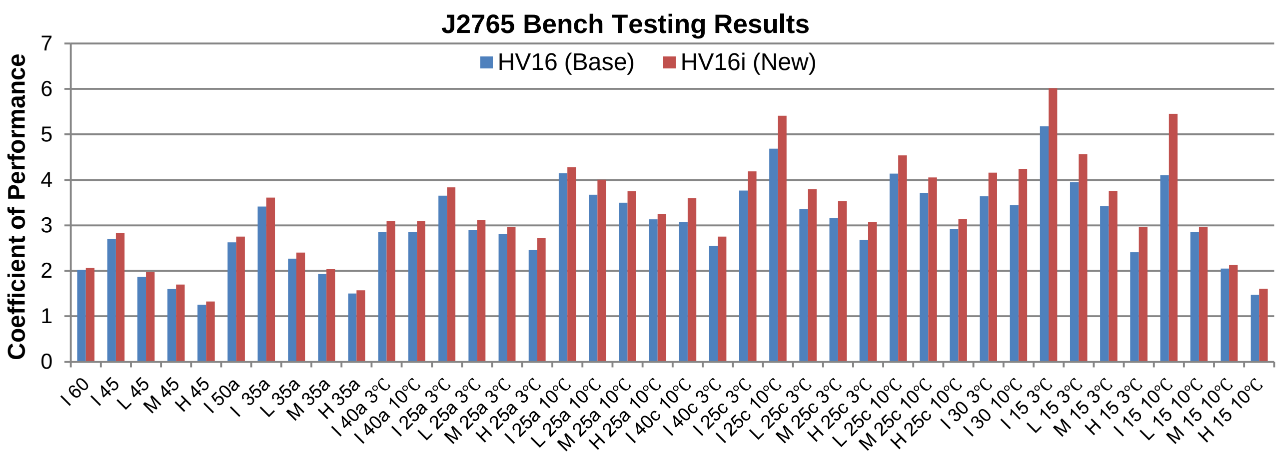
B - Blower, **CP** - Compressor, **CC** - Cooling Coil, **CH** - Glycol Chiller, **Cond** - Condenser, **Dp** - Differential Pressure Transducer, **Evap** - Evaporator, **FS** Flow Straightener, **H** - Heater, **Hu** - Humidifier, **mg** - Glycol Mass Flow Meter, **mr** - Refrigerant mass Flow Meter, **Mtr** - Motor, **N** - Nozzle, **P** - Pressure Transducer, **RH** - Relative Humidity Probe, **Sc** - Condensate Scale, **Sp** - Speed Controller and Tachometer, **T** - Thermocouple, **TC** - Temperature Controll **TG** - Thermocouple Grid, **Tor** - Torque Transducer, **W** - Watt Transducer, **TXV** - Thermal Expansion Valve
Indices : **a** - air, **c** - condenser, **cp** - comp ressor, **e** - evaporator, **g** - glycol, **I** - inlet, **n** - nozzle, **o** - outlet, **r** - refrigerant,

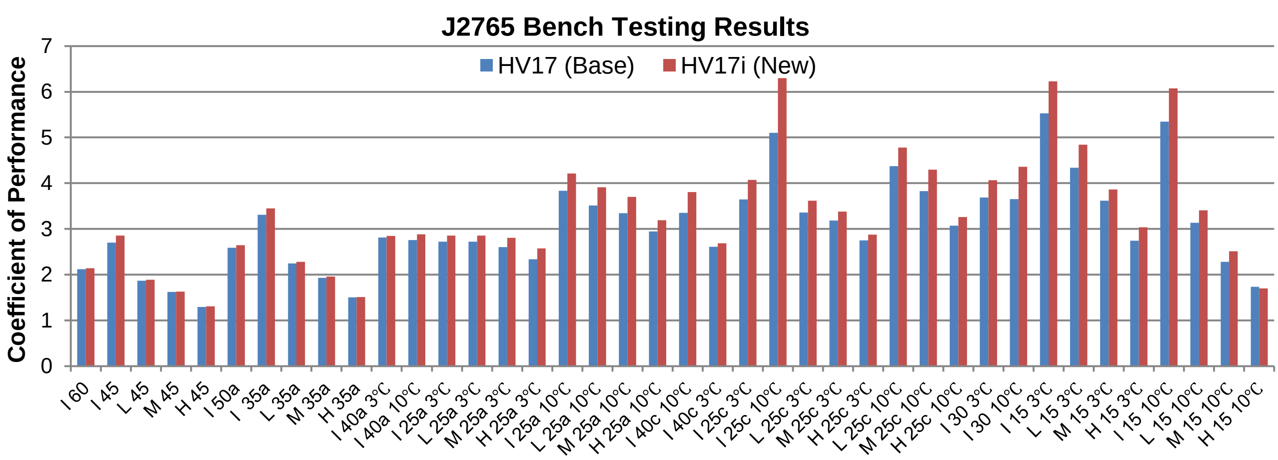
A summary of the test conditions run during standard bench testing procedure:

Test Name	Ambient Temp. [° C]	Compressor Speed [RPM]	Condenser		Evaporator				Target Air Temp. Downstream of Evap. [° C]
			Temp. [° C]	Face Velocity [m/s]	Temp. [° C]	Humidity [%]	Mass Flow [kg/min]	Simulated Air Selection	
I70	45	900	70	1.5	35	25	9.0	RECIRC	3
I60	45	900	60	1.5	35	25	9.0	RECIRC	3
I45	45	900	45	1.5	35	25	9.0	RECIRC	3
L45	45	1800	45	2.0	35	25	9.0	RECIRC	3
M45	45	2500	45	3.0	35	25	9.0	RECIRC	3
H45	45	4000	45	4.0	35	25	9.0	RECIRC	3
I50a	35	900	50	1.5	35	40	9.0	OSA	3
I35a	35	900	35	1.5	35	40	9.0	OSA	3
L35a	35	1800	35	2.0	35	40	9.0	OSA	3
M35a	35	2500	35	3.0	35	40	9.0	OSA	3
H35a	35	4000	35	4.0	35	40	9.0	OSA	3
I40a	25	900	40	1.5	25	80	6.5	OSA	3 / 10
I25a	25	900	25	1.5	25	80	6.5	OSA	3 / 10
L25a	25	1800	25	2.0	25	80	6.5	OSA	3 / 10
M25a	25	2500	25	3.0	25	80	6.5	OSA	3 / 10
H25a	25	4000	25	4.0	25	80	6.5	OSA	3 / 10
I40c	25	900	40	1.5	25	50	6.5	OSA	3 / 10
I25c	25	900	25	1.5	25	50	6.5	OSA	3 / 10
L25c	25	1800	25	2.0	25	50	6.5	OSA	3 / 10
M25c	25	2500	25	3.0	25	50	6.5	OSA	3 / 10
H25c	25	4000	25	4.0	25	50	6.5	OSA	3 / 10
I30	15	900	30	1.5	15	80	6.5	OSA	3 / 10
I15	15	900	15	1.5	15	80	6.5	OSA	3 / 10
L15	15	1800	15	2.0	15	80	6.5	OSA	3 / 10
M15	15	2500	15	3.0	15	80	6.5	OSA	3 / 10
H15	15	4000	15	4.0	15	80	6.5	OSA	3 / 10

Six compressors were tested following the SAE J2765 standard – three compressors (HV14, HV16, and HV17) without the variable orifice valve to serve as a baseline, and three compressors (HV14i, HV16i and HV17i) with the variable orifice valve technology to quantify the new technology's benefit. HV14i, HV16i and HV17i compressors have same variable orifice valve technology with different capacity (145cc, 164cc, and 175cc respectively). The results are displayed below.







② LCCP analysis (SAE J2766)

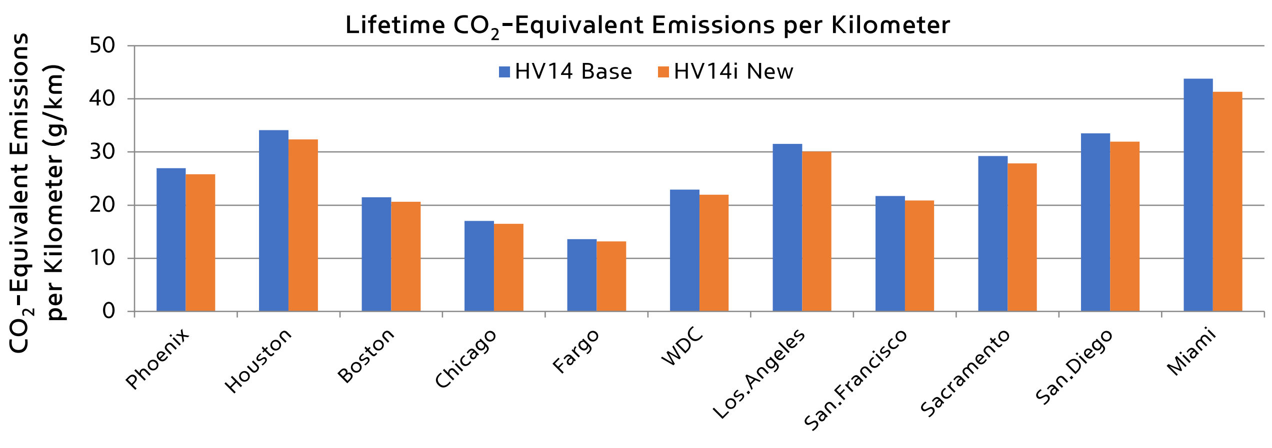
Following bench testing, the COP results and other system specifications are fed into the IMAC-GHG-LCCP model (Improved Mobile Air Conditioning related to Green-House-Gas Life-Cycle Climate Performance) version 1.1 (IMAC-GHG-LCCP-1_1_0_5-20190905). This model, developed by Optimized

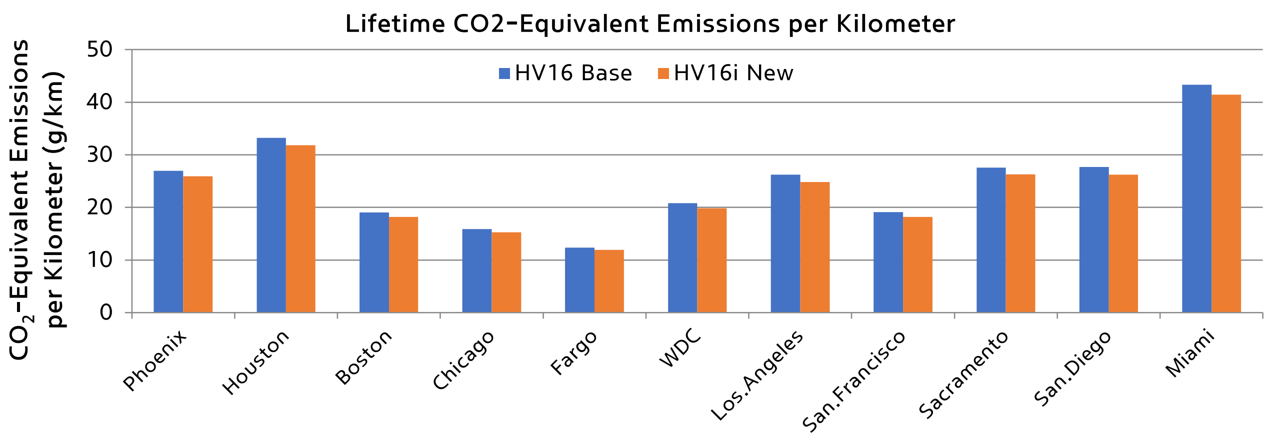
Thermal System, is the 'next generation' of the GREEN MAC LCCP software and estimates the total lifetime direct and indirect CO_2 emissions for mobile air conditioning systems for a given vehicle in each city selected by the user like GREEN-MAC-LCCP (Global Refrigerants Energy & Environmental Mobile Air Condition Life-Cycle Climate Performance). Direct emissions result from direct leaks of the refrigerant into the atmosphere, and are primarily evaluated based on the global warming potential of the refrigerant and the mass emitted. Indirect emissions result from the energy consumption associated with manufacturing, operation, and disposal of the A/C system.

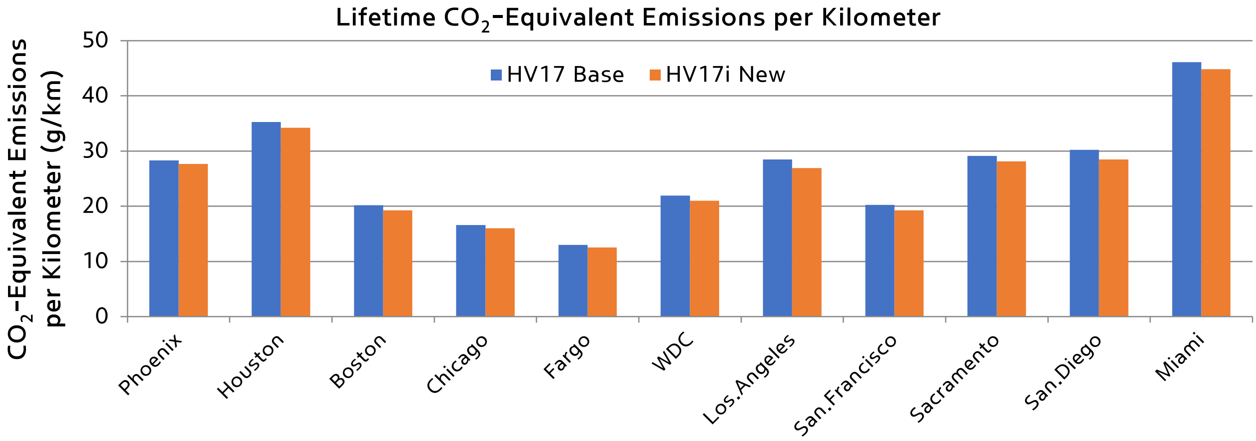
Improvements of IMAC-GHG-LCCP developed by the SAE Cooperative Research Program (CRP) team include the followings:

- Weather dataset updated from TMY2 (Typical Meteorological Year 2) to TMY3 (Typical Meteorological Year 3)
  - TMY3 data comes from the National Solar Radiation Database (NSRDB), covering time periods 1961-1990 and 1991-2005, across 1020 weather stations
  - TMY2 data only covers 1961-1990 NSRDB data, across 239 weather stations
- Added electric compressor support (bench test inputs organized by ambient temperature and vehicle speed)
- Added support for multiple power consumption sources (compressors, evaporators, chillers, etc.)
- Improved UI/UX: uses custom GUI screens instead of multi-tab excel sheet, allows 'project' saving

Combining the J2765 bench test COP data with J2766 model data provides a simulation of average GHG emissions due to usage of an air conditioning system across several US cities. This model, therefore, can be used to quantify and compare indirect CO_2 emissions based on bench test data.
The full analysis was completed with all six compressors (baseline and Hanon VO valve) to quantify the benefit of the Hanon compressor with variable orifice valve technology.







③ *LCCP weighted average*

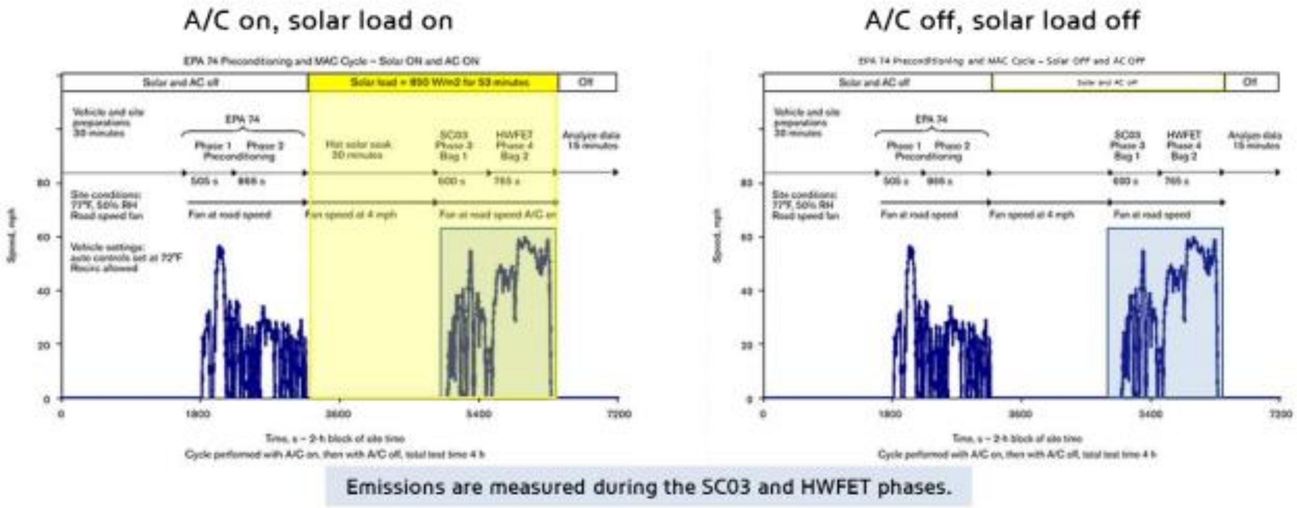
The output of indirect CO_2 emissions due to A/C use in individual cities from the LCCP model can then be weighted to a single gCO_2/mile value for each technology, which represents the US average GHG emissions. The weighting is based on vehicle registration in each city.

Performing the weighted average analysis of the Hanon compressor without VO valve technology resulted in a US average of 27.08 g CO_2/mile, 25.94 g CO_2/mile and 28.18 g CO_2/mile indirect emissions for HV14, HV16, and HV17, respectively. The compressors with VO valve technology resulted in 25.33 g CO_2/mile, 24.29 g CO_2/mile and 26.70 g CO_2/mile for HV14i, HV16i, and HV17i, respectively. From this analysis, vehicles equipped with the Hanon compressor with VO valve technology compressor should receive an off-cycle GHG credit of 1.8 g CO_2/mile for HV14i, 1.7 g CO_2/mile for HV16i, and 1.5 g CO_2/mile for HV17i.

Indirect Contribution, Weighted			Phoenix	Houston	Boston	Chicago	Fargo	WDC	Los Angeles	San Francisco	Sacramento	San Diego	Miami	Sum / Weighted Average
% of total vehicles in the cities			4.5%	16.3%	13.2%	22.5%	4.5%	12.4%	5.0%	5.7%	5.0%	5.0%	5.8%	100%
Driving Distance (km)			20,050	19,635	19,665	19,635	20,050	20,050	20,050	20,050	20,050	20,050	19,832	-
HV14 vs HV14i	Annual MAC Operation Contribution (kg CO_2/year)	HV14 Base	380.3	501.3	249.9	174.3	144.3	288.6	427.6	260.1	415.4	461.9	696.5	-
		HV14i New	357.2	467.6	234.1	163.5	135.5	270.6	400.0	243.7	388.6	432.1	648.9	-
	Weighted MAC Operation Contribution/mi (g CO_2/mi)	HV14 Base	1.37	6.70	2.70	3.21	0.52	2.87	1.72	1.19	1.67	1.85	3.28	27.08
		HV14i New	1.29	6.25	2.53	3.02	0.49	2.69	1.61	1.11	1.56	1.73	3.05	25.33
	GHG Off-Cycle Benefit [g/mile]													1.8
HV16 vs HV16i	Annual MAC Operation Contribution (kg CO_2/year)	HV16 Base	388.2	503.1	227.8	164.5	132.7	269.6	376.8	234.8	404.4	405.9	707.8	-
		HV16i New	368.1	475.0	210.7	153.5	123.7	250.4	349.4	216.1	378.7	376.8	670.0	-
	Weighted MAC Operation Contribution/mi (g CO_2/mi)	HV16 Base	1.40	6.72	2.46	3.03	0.48	2.68	1.51	1.07	1.62	1.63	3.33	25.94
		HV16i New	1.33	6.34	2.28	2.83	0.45	2.49	1.40	0.99	1.52	1.51	3.15	24.29
	GHG Off-Cycle Benefit [g/mile]													1.7
HV17 vs HV17i	Annual MAC Operation Contribution (kg CO_2/year)	HV17 Base	415.8	542.3	249.4	178.0	145.4	291.9	422.0	257.0	434.9	455.8	762.5	-
		HV17i New	402.5	522.0	232.0	167.4	135.6	273.0	390.0	237.7	415.5	421.3	737.4	-
	Weighted MAC Operation Contribution/mi (g CO_2/mi)	HV17 Base	1.50	7.24	2.69	3.28	0.52	2.91	1.69	1.18	1.74	1.83	3.59	28.18
		HV17i New	1.45	6.97	2.51	3.09	0.49	2.72	1.57	1.09	1.67	1.69	3.47	26.70
	GHG Off-Cycle Benefit [g/mile]													1.5

④ AC17 confirmatory testing

The combination bench test and national simulation of the technology using LCCP provides an accurate measurement of the expected benefits, however, documenting the benefits at a vehicle level is also important for the off-cycle credit application. To quantify benefits at the vehicle-level, the AC17 test was conducted. AC17 is test used by OEMs and the EPA to confirm the GHG reduction benefit of other A/C efficiency technologies; relative to SC03, this test has more moderate load conditions.



Compared to other standard chassis dynamometer tests, the AC17 test is quite complex. It involves the use of a special environmental chamber to create the necessary test conditions including solar load, road speed fan, temperature and humidity specifications, etc. Also, this test takes approximately 4 hours to complete. This environmental chamber is under very high demand given its 5-cycle certification and range of capabilities, even beyond AC17 testing. For these reasons, only a limited number of AC17 tests were run to confirm the benefit of the technology. AC17 testing result shows the same directional benefit of the VO valve technology. This testing is for confirmatory purpose only, and the result is not used to determine GHG off-cycle credit amount per vehicle.

Date	Test	Test vehicle	Condition	AC on average	AC off average	Δ CO_2
5/25/2018	AC17	K900/Cadenza	HV14 (base, w/o VO Valve)	340.1	301.0	39.1
			HV14i (new, w VO Valve)	326.4	295.0	31.4
					A/B Δ	7.7 g/mile

Durability

Durability of the Hanon compressor has been thoroughly tested by Hanon System to meet Kia Motor Company specifications. This durability bench test procedure includes fundamental performance test, operational noise test, clutch noise test, pulsation pressure test, high pressure test, high speed continuous test, high speed cycling test, high pressure low charge test, program durability test, gas shortage test, vibration test, low oil charger condition test, cleanness test, refrigerant leakage test, burst test, temperature cycling test, clutch characteristic test, clutch minimum engagement test, corrosion test, and EMC test.

The Hanon compressors with VO technology will be applied on HMC vehicles from 2021 model year and are expected to meet all the durability requirements of 40 CFR §86.1869-12(d). The durability evaluation does not predict any expected in-use emission deterioration rate over the full useful life of the vehicle. Durability test results are included in Attachment D.

Conclusion

Based on the bench and vehicle test data presented in this application, combined with the Life-cycle Climate Change Performance model, Kia Motor Company, represented by HATCI, hereby requests that the EPA approve an off-cycle GHG credit of 1.8 grams CO_2 per mile for HV14i, 1.7 grams CO_2 per mile for HV16i, and 1.5 grams CO_2 per mile for HV17i compressors for 2021 and later model year vehicles equipped with the Hanon compressors with variable orifice valve technology.
These 1.8 grams CO_2 per mile, 1.7 grams CO_2 per mile and 1.5 grams CO_2 per mile credits have been estimated to be representative of the indirect fuel savings and subsequent GHG emissions that can be expected from this technology in real-world usage in U.S. national average climate conditions.

Thank you for your consideration of this application for off-cycle GHG credits.

Justin Fink
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Jinho Ha
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Hyundai America Technical Center, Inc.

Byungho Lee
Senior Manager, Powertrain Product Development
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Richard Willard
Senior Manager, Certification and Compliance Department
Hyundai America Technical Center, Inc.

Attachments:

Attachment A: Confidential listing of 2021 and later KMC Vehicles with Hanon compressors with variable orifice valve technology, Sales Volumes and Credits

Attachment B: Bench testing results [CBI]

Attachment C: LCCP analysis projects and results files [CBI]

Attachment D: Durability test results [CBI]