Which Is Greener: Idle, or Stop and Restart? Comparing Fuel Use and Emissions for Short Passenger-Car Stops

November 2012

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4,074 words plus 7 figures (1,750) and 5 tables (1,250) = 7,074

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ABSTRACT

Most advice to the public about idle-reduction lacks scientific basis. And the information in the literature is often inconsistent. Argonne National Laboratory performed some simple experiments to provide a preliminary factual basis for recommendations on when to keep the engine on, and when to turn it off, for the minimum environmental impact.

Our previous work demonstrated that idling is a very inefficient way to warm up your car (your diesel might never warm up if it is very cold [*1*]), and that the catalytic converter cools slowly enough that it will still be working when you return to your car after a short stop. The argument against parking and going into a business, rather than using a drive-through window, has been that the emissions and fuel use associated with restarting your car are greater than those incurred by idling for that time. Argonne undertook a series of measurements to determine whether this was true by comparing actual idling fuel use and emissions with those for restarting. This work seeks to answer the question: Considering both fuel use and emissions, how long can you idle in a queue before impacts from idling are greater than they are for restarting? We determined that fuel use and carbon dioxide emissions are greater for idling over 10 seconds. Other emissions from idling were found to be low, so that much longer idling times were preferable before they exceeded restart emissions; these crossover times were found to vary by pollutant. The restart emissions were found to be much smaller than those from cold starts. Note, however, that these results are very limited and more research is necessary.

BACKGROUND

Idling reduction efforts have focused on heavy-duty diesel vehicles because they are typically idled for extended periods. Long-haul trucks often idle overnight to keep the driver comfortable; our previous work has identified and compared lower-impact alternatives (*2, 3*). We have also identified workday idling by all classes of vehicles as a significant waste of petroleum and source of excess emissions (*4*). And the EPA's large and visible program to reduce emissions from school buses includes a component on idling reduction (*5*). But many people ignore passenger car idling —even at schools — as a source of emissions and wasted fuel. While idling in traffic is necessary for safety, drivers can turn off their vehicles while waiting for passengers or for freight trains to pass. And remote start, although now a popular option, is still idling, and in some jurisdictions, idling an unattended vehicle is illegal. If each of the 250 million cars in the United States idles just 6 minutes per day at 0.3 gal/h, almost 3 billion gallons of fuel are wasted annually, costing drivers $10 billion or more, with no vehicle miles traveled.

Major vehicle manufacturers and suppliers hold the view that idling modern engines is not only unnecessary but undesirable (*6*). Owner's manuals often advise against idling and encourage "ecodriving" as a way to increase fuel economy and reduce emissions. In addition, the U.S. Department of Energy (DOE), U.S. Department of Transportation (DOT), and the U.S. Environmental Protection Agency (EPA) discourage unnecessarily idling, and the Department of Defense (DOD) attempts to reduce idling to limit fuel costs and engine wear (*7, 8, 9, 10*).

We found inconsistent and conflicting recommendations, with minimal scientific data to support them, in anti-idling literature distributed across North America. One fast-food chain claimed that it was "greener" (from an emissions perspective) to use the drive-through than to park and go into the restaurant. The study it cited used actual drive-through vehicle statistics but relied on modeled emission data that are several orders of magnitude higher than what we report here (*11*). One technical paper (*12*) did report hydrocarbon and NO_x emissions from several model-year 2004 passenger vehicles, but it did not measure fuel use or CO_2 emissions.

The U.S. Department of Energy Clean Cities Program uses its national network of almost 100 local coalitions to reduce transportation dependence on petroleum through the use of alternative fuels and efficiency measures, including idling reduction. The program therefore funded Argonne to measure idling fuel use by and emissions from light-duty vehicles and to compare these to start-up emissions to enable data-based decision-making.

EXPERIMENT DESCRIPTION

Vehicle Set-Up

A model year 2011 Ford Fusion was used for the majority of the analysis for this work (Figure 1). This vehicle is a 4-door mid-size sedan with a 2.5-L 4-cylinder engine (175 HP) and 6-speed automatic transmission. Its EPA fuel-efficiency label shows 23 mpg city/33 mpg highway and 26 mpg combined. It was instrumented with equipment to measure numerous engine parameters and temperatures, including catalyst inlet and brick temperatures (see Figure 2) and oil and coolant temperatures. The vehicle was installed in one of Argonne's test cells at the Advanced Powertrain Research Facility (APRF), utilizing a Semtech emissions analyzer for emissions and a direct fuel flow meter for fuel measurement. The APRF has a two-wheel-drive (2WD) chassis dynamometer that is used for simulating road load, monitoring tractive effort, and performing coast-down testing; it is also used for the calibration of 2WD vehicles of up to 12,000 lb. The restart emissions and the idle emissions were measured in real time at a no-load stationary position; one exception is noted below. The vehicle was prepared and run by using approximate Federal Test Procedure (FTP) standard ambient temperature testing criteria.

FIGURE Ford Fusion Test Vehicle.

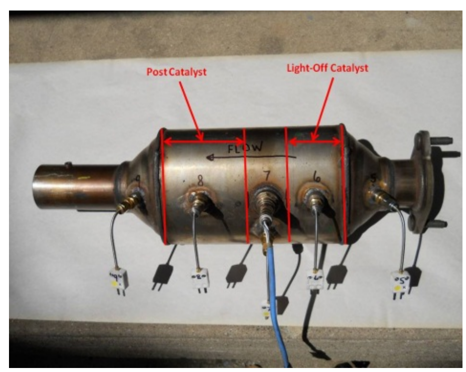

FIGURE 2 Catalyst Temperature Measurement Sites.

The vehicle was connected to a PEMS SemtechD at the tailpipe, which allowed emissions data to be gathered for each species with respect to time. The emissions of interest in this study include total hydrocarbons (THC), nitrogen oxides (NO_x), carbon monoxide (CO), and carbon dioxide (CO_2). The SemtechD is equipped with a heated sample line to minimize the loss of hydrocarbons before they are in range of the sensors. It measures the hydrocarbon emissions by using a Flame Ionization Detector (FID), while the NO_x species are measured by using a Non-Dispersive Ultra Violet (NDUV) method. It measures CO and CO_2 via a Non-Dispersive InfraRed Analyzer (NDIR).

The SemtechD analyzer also accounts for the ambient humidity in the calculation of the emissions. It has been verified to be accurate when testing for these emission species (*7, 8*). The specifications for the analyzer are listed in Table 1. Additionally, the fuel consumption rate was measured directly. For this study, the emission concentrations were measured every 0.1 s, and concentrations were converted to actual masses by using measured air-flow volume. The exhaust measurement was accomplished by using an AVL North America DVE-150 direct vehicle exhaust (DVE) measurement device. This device, when coupled to the SemtechD analyzer, allows the collection and analysis of exhaust mass emissions, particularly in ultra-low- and super ultra-low-emitting vehicles. Flow meter specifications are shown in Table 2.

TABLE 1 PEMS SemtechD Emissions Analyzer Specifications (*1*)

Parameter	NO	NO_2	THC	CO	CO_2
Measurement Range	0–2,500 (ppm)	0–500 (ppm)	0–1,000 (ppm)	0–4 (%)	0–20 (%)
Accuracy (% of Reading)	±3	±3	±2	±3	±3
Resolution	1 ppm	1 ppm	1 ppm C	10 ppm	0.01%
Response Time (T90) (s)	≤2	≤2	≤2	≤3	≤2

TABLE 2 AVL DVE-150 Flow Meter Specifications (*1*)

Exhaust Flow Measurement	8–350 scfm FS
Accuracy (% of Reading)	±1% FS
Resolution	0.1 scfm
Tailpipe Backpressure	±1.5 in. H_2O

Procedure

The intent was to simulate a vehicle idling in queue for the drive-through window at a bank or fast-food restaurant. Fuel use and emissions from an idling hot engine were measured, as were those from a case in which the vehicle was keyed off for 5 minutes following roughly 8 minutes of urban-style driving and then restarted every minute. These cases simulate both a 5-minute visit into the business and turning the vehicle off and on in a queue.

There were two dynamometer runs with the instrumented 2011 Ford Fusion in which emissions were measured as described above and a third without emission measurements. All data were taken at roughly 21°C ambient conditions. Limited funding precluded investigation of additional vehicles or temperatures. To summarize:

1. *20-min idle run:* Turn the cold engine on, idle the vehicle at steady state until the engine temperatures are stabilized. Allow the vehicle to idle in “Drive” with the brake applied. Begin timing 20-min interval and collect emissions data during a 20-min idling interval (initially at higher rpm but then at constant ~750 rpm). Turn the engine off for 30 s, then restart for 30 s, off for 30 s, on for 30 s, and off. No loads are applied.
2. *505 UDDS run + idle:* Turn on the already-warm engine, “drive” for 5 min on the UDDS cycle, turn off the car (soak) for 5 min, then restart 7 times, with 30 s in between. The first five restarts were with no load, 30 s on, and off. The last two on periods are longer (60 s, 90 s) with a load to simulate 3-mph creep or heavy traffic.
3. *50-mph steady speed:* Turn on the cold engine and drive at a steady 50 mph for about 10 minutes.

EXPERIMENTAL RESULTS

Idling

The first run enabled estimation of long-duration idling emissions and fuel use, from 700 s in the flat part of the 20-min run at 750 RPM (after an initial period of higher RPM). For each parameter of interest, cumulative readings were calculated, and the difference between the total at the selected end-point (1200 s) and the start point selected during stable 750-RPM idling (500 s) was obtained. This difference represents the emissions during 700 s of stable idling and was used to estimate the emission and fuel use rates for idling at 750 RPM. Table 3 summarizes the calculation and the results. Emissions of criteria pollutants are extremely low.

TABLE 3 Calculation of Idling Emissions and Fuel Use

Time (s)	NO_x (mg)	THC (mg)	CO (mg)	CO_2 (g)	Fuel (cc)
500.1	70.27	159.2	549.5	430.0	135.22
1200.1	77.04	177.8	625.3	1053.0	331.15
Difference	6.77	18.64	75.8	623.0	195.93
Per hour	34.8	95.9	389.8	3204.2	1007.6
Per second	0.0097[a]	0.266	0.108	0.588	0.279

[a] Emissions are nominally zero

The fuel consumption can be converted to a rate of 0.265 gal/h (1 gal = 3785.41 cc). Fuel consumption at idle varies with engine size; other ongoing work on similarly instrumented vehicles at Argonne has estimated fuel consumption at idle of about 0.2 gal/h for a 2004 Ford Focus (2.0-L I4) and 0.5 gal/h for a late-model Crown Victoria Police Cruiser (4.6-L V8).

Fuel consumption at idle also depends on engine speed. The higher RPM period at the start of the long idling period allowed us to verify that fuel use increases with idling speed (see Figure 3).

Restarts

As can be seen in Figure 4, when the engine was restarted, there was an initial sharp rise in fuel use. There were also peaks of THC and sometimes NO_x and/or CO (Figure 5). The fuel use settled back close to the idling rate within about 15 s, but the THC and CO declined more slowly after the spike, remaining elevated for the entire 30-s restart period. Both test scenarios showed emissions spikes during the subsequent engine starts — NO_x spikes appear sporadically, and THC and CO spikes occur consistently, but are variable in size. Both effects are worth additional investigation.

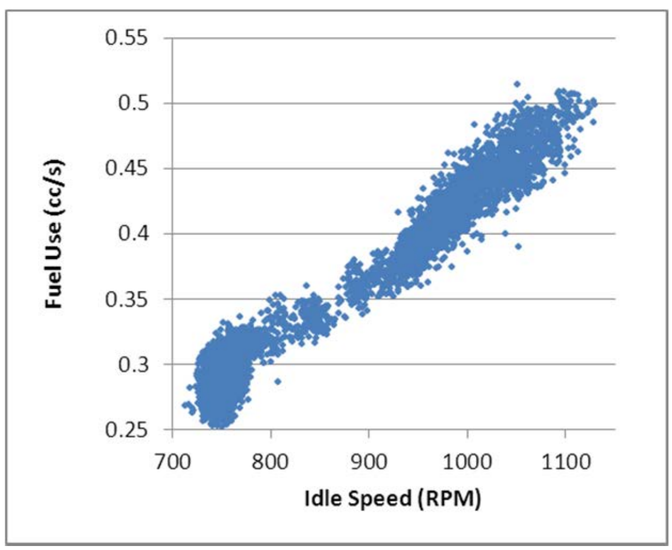

FIGURE 3 Increase of Fuel Use with Idling Speed.

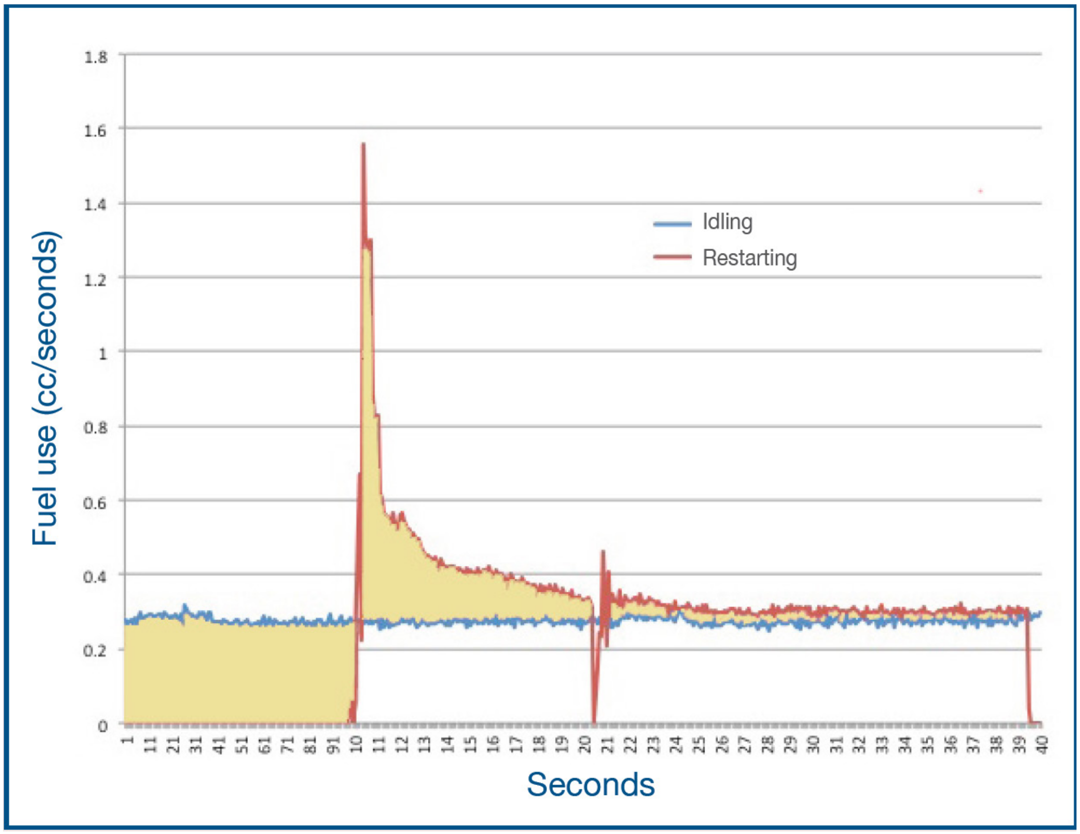

FIGURE 4 Fuel Use for Idling and Restarting.

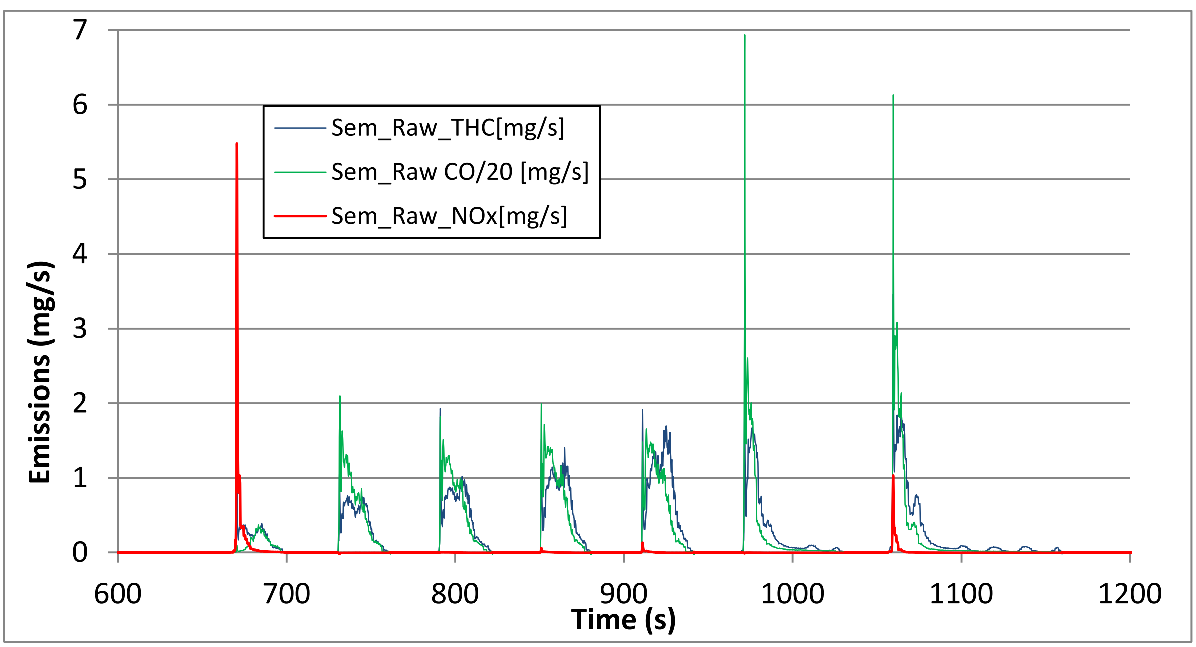

FIGURE 5 Emissions for 7 Restarts.

NO_x emissions were essentially zero, actually at the limit of instrument resolution. The two longer restarts in the run with seven restarts included a dynamometer load to simulate 3-mph creeping. In those two cases, the THC dropped quickly back to near the idling levels after about 30 s. Therefore, the 30-s starts captured most of the excess (compared to idling) THC emissions from restart. Emissions of CO on restart were similar to those during vehicle operation and over two orders of magnitude larger than those during idling. For both CO and THC, emissions during restart were over a factor of 2 larger during the restarts after a long idling period than after a 5-min soak. This difference has not been explained and will likely be investigated in future work. Emissions during restarts while the catalyst is still hot are likely due primarily to engine start calibrations for consistent engine start, as well as additional issues related to stopping/starting the engine.

To estimate additional impacts caused by the restarts, we compared the fuel use and emissions from the restarts with those from an equivalent period (30 s) of idling at 750 RPM. Figure 4 includes a graphical representation for this comparison. In the graph, the shaded area under the blue line (idling fuel rate) and the red line (restart) before the engine is restarted (at 10.1 s) represents the quantity of fuel that the engine would have burned if it were idling instead of being off, and the area between the red and blue lines after the engine is restarted represents the excess on restart. All of the impacts and calculated excesses (over idling levels) for the restarts are shown in Table 4, along with equivalent idling times for that excess impact. *Our key conclusion: To minimize fuel use (and CO_2 emissions) under nominal test conditions (25°C ambient temperature), the engine should be turned off if idling is to be over 10 s in duration.* The appropriate "crossover" (maximum idling duration) is longer if the objective is to minimize criteria pollutant emissions, and that duration depends on the pollutant. The maximum idling duration is for CO, which is emitted in significant quantities during restarts.

TABLE 4 Emissions and Fuel Use for Restarts and Equivalent Idling Times

Parameter	Average (per second)	Average per start	Equivalent idling time
NO_x after soak	0.043 mg	1.3 mg	1.7 min
NO_x after idle	0.050 mg	1.6 mg	2.3 min
THC after soak	0.53 mg	16.0 mg	10 min
THC after idle	1.34 mg	40.4 mg	25 min
CO after soak	10.5 mg	315 mg	48 min
CO after idle	35.0 mg	1050 mg	2.7 h
Fuel after soak	0.34 cc	10.2 cc	6 s
Fuel after idle	0.38 cc	11.3 cc	10 s

Thus, we can see that, on the basis of fuel use, idling should be minimized. In terms of criteria pollutant emissions, frequent restarts do have some negative impacts. However, to put these into perspective, it is necessary to compare them to emissions from cold-starting the vehicle.

Comparison to Cold Start

While the criteria emissions related to vehicle restarting with a hot catalyst are, on a percentage basis, relatively large compared to the extremely low emissions during warm vehicle idling, it is important to understand these emissions in the context of overall allowable vehicle emissions. Although this work did not include measurements of cold start, data were available from other experiments performed with the same instrumented 2011 Ford Fusion. Emissions from restarts and idling are compared with those from initial engine cold-start and with regulated emission levels for the vehicle class in Table 5. For comparison with the collected data, the Tier 2-Bin 5 CO criteria emissions limit is 3.4 g/mi for the first 50,000 mi (*14*). So even with the higher restart emissions described above, the engine must be restarted three times to equal the emissions from just one mile of driving, and so CO emissions from restarts are a less-serious concern.

TABLE 5 Comparison of Emissions from Initial Engine Start and Restart

	Tier 2-Bin 5 (*15*)[a]	Initial Engine Start	Engine Restart
THC (mg)	878	191	44
NO_x (mg)	552	228	6
CO (mg)	31290	2970	1253

[a] Tier 2-Bin 5 g/mi converted to FTP-75 mg

These results clearly imply that emissions from starting an engine cold are by far the largest environmental risk. Therefore, we also considered how quickly the catalyst cooled when the vehicle was turned off.

Rate of Catalyst Cooling

The catalyst brick temperature was monitored for both runs and can be seen in Figure 6. In the long-idle run, the catalyst temperature remained stable around 375°C after the initial warm-up. In the other run, the catalyst temperature reached over 550°C during the period in which a “driving” load was applied and cooled down slowly, falling to about 460°C after 5 min with the engine off and stabilizing around 350°C (above the catalyst activation temperature) after three restarts. The engine dipstick oil temperature was also measured, and it did not decrease significantly during the 5-min soak (see Figure 7). This cooldown was slow because the vehicle was not moving and therefore experienced little airflow and resultant heat transfer.

We estimate from the cooling results that the catalyst remained above the light-off temperature for at least 5 min after the engine was turned off, at 21°C. The catalyst would not cool any faster at higher (*4*) temperatures, but it would certainly cool faster at lower ambient temperatures. Funding constraints prevented us from repeating these experiments at lower temperatures. However, other work done at Argonne confirmed this (*1*). Measurements during a Chicago winter of the external temperature of the catalytic converter of a 2009 Volkswagen Jetta after the vehicle was shut down showed that the time it took to cool down decreased slowly, from about 3 min to just under 2 min when the temperature dropped from 1°C to -17°C.

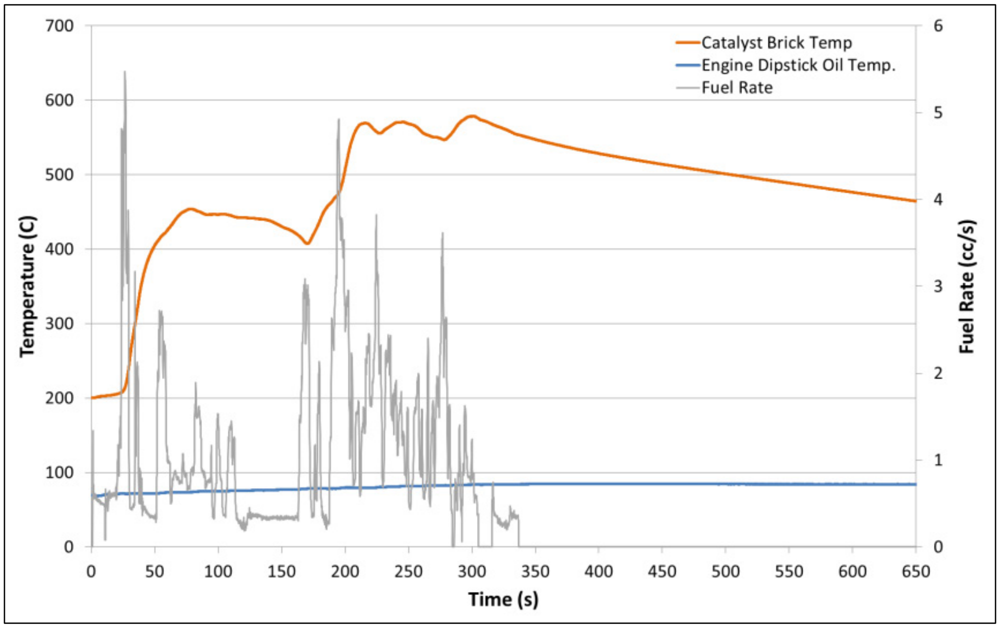

FIGURE 6 Catalyst and Dipstick Temperature Behavior when Engine Is Shut Off (at ~340 s).

Engine Warm-Up

The conventional wisdom has always been that it is necessary to idle for some period to warm up the engine before driving the car. This strategy might actually be appropriate in some circumstances, such as in extremely cold temperatures. Hard acceleration is also not recommended with a cold engine and catalyst. However, under normal conditions, the engine warms up much faster when driven than when idled. Figure 7 compares engine oil temperature for the case where the engine is started and then idled for 20 min with the case when the engine was started and then run at a constant 50 mph (and then restarted several times). As a point of comparison, note that the engine oil reaches 60°C (a nominal comparison point) roughly 4 min faster when driving versus at idle. There is no need to consume fuel in idle if the intent is to warm the engine.

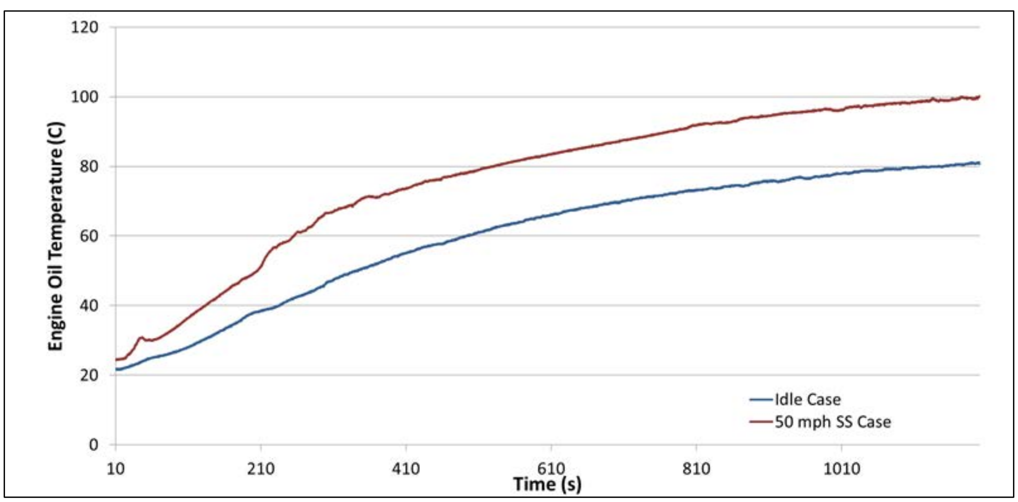

FIGURE 7 Coolant Temperature for 50-mph Drive on Start-Up vs. Idle on Start.

EXPERIMENT LIMITATIONS

Data presented here are extremely limited, based on one vehicle at one temperature, with a small number of runs. Therefore, although several conclusions are appropriate as a result of this work, generalizations are unwarranted without additional work to confirm the extent to which the results apply. Hot and cold ambient conditions are likely to impact results, as are the loads required to supply passenger comfort at those temperatures. Older vehicles and diesels are both likely to behave differently. And no simulation of driving away immediately on restart was done, and so this work does not compare warming up the vehicle during idling with warming up the vehicle as it is being driven. In addition, more research would be required to explain differences in THC emissions between the runs, as well as to make more generalizations regarding the impacts of different restart/soak times on emissions. Additional research to fill in all these gaps would enable more conclusive statements concerning the differences in emissions between idling and restarts.

CONCLUSIONS

Argonne testing at 21°C ambient conditions on a late-model mid-sized American car (2011 Ford Fusion) shows that idling for more than 10 s uses more fuel and emits more CO_2 than restarting the engine. Idling fuel usage was shown to vary from 0.2 to 0.5 gal/h for passenger vehicles across a range of sizes. Criteria pollutant emissions were determined to be relatively low for idling following catalyst activation. Emissions from restarting were larger, but at least an order of magnitude lower than those from starting a cold engine, as shown in Table 5. The catalyst was found to cool down slowly so that restarts after times equivalent to a short transaction at a bank or restaurant are unlikely to allow the temperature to drop below light-off and result in high cold-start emissions. Therefore, for short stops, it makes sense to turn the vehicle off in order to minimize fuel use and CO_2 emissions.

Unpublished results of recent tests at Argonne that involve auto-stopping/starting a vehicle are similar to those of Fusion testing conducted here; clearly, stop/start decreases fuel consumption, but engine re-starts result in increased emissions (16). The degree of increased emissions has differed among vehicles, as well as between engine technologies (diesel versus gasoline).

At least for the conditions evaluated in this work, a penalty in terms of criteria pollutant emissions is very small compared to cold-start emissions. Idling was also shown to be a very slow way to warm up your car.

ACKNOWLEDGMENTS

This work was sponsored primarily by the Clean Cities Program U.S. Department of Energy's Office of Vehicle Technologies, to which we offer our thanks. We also thank Steven McConnell, Christopher Saricks, Michael Duoba, and Terry Levinson of the Center for Transportation Research for extremely helpful discussions and insights.

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