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Fuel Consumption, Exhaust Emission and Vehicle Performance Simulations of a Series-Hybrid Electric Non-Automotive Vehicle

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Abstract

In the recent years, the studies on hybrid electric vehicles have increased in automotive industry. Particularly, the studies focused on passenger cars. However the studies conducted on Non-Automotive Vehicle (Vehicles are not suitable for standard driving cycles) are not adequate in literature. Because Non-Automotive vehicles are more complicated in terms of designing and their daily tasks therefore it is difficult to simulate these vehicles by using software. In this work, a series hybrid electric street sweeper is modeled and simulated by using AVL Cruise. The main aim of this study is performing simulations on a hybrid electric street sweeper and presenting its fuel consumption, vehicle performance and exhaust emissions. Driving cycles are used in vehicle simulations in order to determine fuel consumption and exhaust emission. However the current driving cycles are not appropriate to simulate Non-Automotive Vehicles. Additionally, in this study an appropriate driving cycle is constructed by using Random Cycle Generator of AVL Cruise in accordance with the daily tasks of the street sweepers. The simulations are performed depending on this driving cycle. Vehicle block diagrams are also created by AVL Cruise. The mechanical, electrical and informational connections of hybrid electrical street sweeper are demonstrated in this study. Consequently, the fuel consumption, vehicle performance and exhaust emissions are presented depending on driving cycle. With this study, it is presented that a street sweeper can simulated as a series hybrid electric sweeper and its vehicle performance, fuel consumption and exhaust emissions (CO, HC, NO_X and PM) can be determined by using AVL Cruise.

Key words: Series-Hybrid Electric Vehicle, Fuel Consumption, Exhaust Emissions, AVL Cruise, Vehicle Simulation, Driving Cycles

Nomenclature

EM	Electric Motor	HESS	Hybrid Electric Street Sweeper
HEV	Hybrid Electric Vehicle	SHESS	Series Hybrid Electric Street Sweeper
ICE	Internal Combustion Engine		

1. Introduction

Owing to higher efficiency of electric motors, various studies performed on Hybrid Electric Vehicles (HEV). Due to current world order and conditions, automotive industry focused on hybrid electric vehicles before the transition to all-electric vehicle (only powered by electric motors). To sustain development of automotive industry with clean energy, electric driven vehicle have become a national consensus [1].

When the drivetrain of electric vehicles are compared to conventional vehicles, a more complicated structure is encountered. The designing of these vehicles is required more effort and experience. To simulate electric driven systems, simulation softwares such as AVL Cruise, Psat, Amesim, Msc Easy 5, Advisor, Adams , etc. is essential [2]. In this work, the simulations are performed by AVL Cruise because of its suitable structure for Non-Automotive vehicle. AVL Cruise is a simulation package that supports everyday tasks in vehicle systems and driveline analysis, from concept planning to vehicle design. Previous studies show functionality of Cruise [3-6].

In this study, an appropriate driving cycle is developed for series hybrid electric street sweepers and it is constructed as a series-hybrid electric driveline system. The main specification of components such as Internal Combustion Engine (ICE), Electric Motors (EM), generator and transmission are shown in Cruise. As a result, the fuel consumption, exhaust emissions and vehicle performance data are presented according to changing driving cycle conditions.

This study is also a theoretical part of an ongoing project. The project was supported by Scientific and Technological Research Council of Turkey (TUBITAK) and a prototype has been produced by our team. Additionally Research & Development studies on series hybrid electric street sweeper are in progress.

2. Modeling and Simulation

Electric driven vehicles are basically divided into all-electric and hybrid electric vehicles. All-electric vehicle has only EM to drive vehicle. In case of hybrid electric vehicle, more than one power source is found. Two major configurations are used in HEVs and they are series and parallel hybrid cases [7].

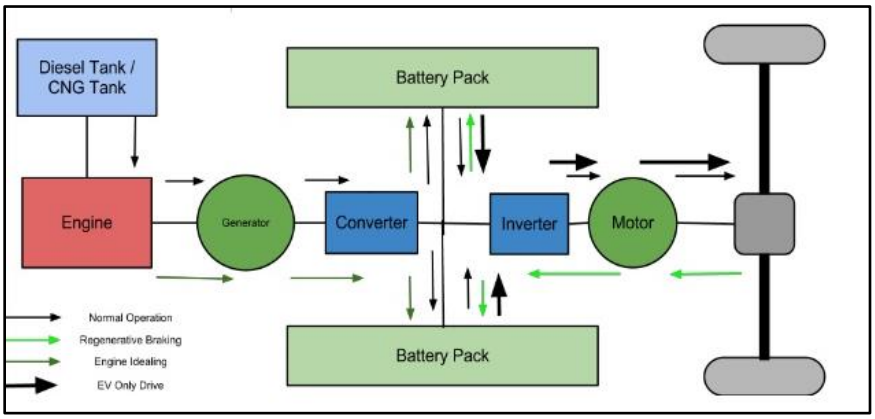

Figure 1. Series Hybrid Electric Vehicle Block Diagram

In this study, only series hybrid electric configuration is modeled and simulated. In this case, vehicle is driven with only EM and the needed power can be supplied by directly generator or batteries. Figure 1. shows a basic block diagram of series hybrid electric vehicle. It is shown in the figure that wheels are driven only by electric motor.

2.1. Modeling the Vehicle

In the recent years, simulation has been a widely used tool in vehicle design. In this work, a series hybrid electric street sweeper is modeled using by AVL Cruise. It is also created as a 3D model via Solidworks. In this section, the block diagram of the street sweeper and its 3D model are presented.

Figure 2. The 3D model of hybrid electric sweeper via Solidworks

Table 1. shows the basic specifications of Hybrid Electric Street Sweeper (HESS) and this parameters are used in AVL Cruise for the simulations.

Table.1. Specifications of HESS

Vehicle Mass (kg)	2500
Frontal Area (m^2)	A_f=2,2
Drag Coefficient	C_D=0,65
Rolling Resistant Coefficient	µr=0,01
Vehicle Width(mm)	1400
Vehicle Length(mm)	3700
Vehicle Height(mm)	1650
Wheel Radius(mm)	320
Air Density (kg/m^3)	1,25
Maximum Speed (km/h)	30

The basic specification of vehicle presented in Table.1. are used in the AVL Cruise simulations in order to reflect the real vehicle performance. As well as these are the actual specifications used during the manufacturing of the series hybrid electric street sweeper.

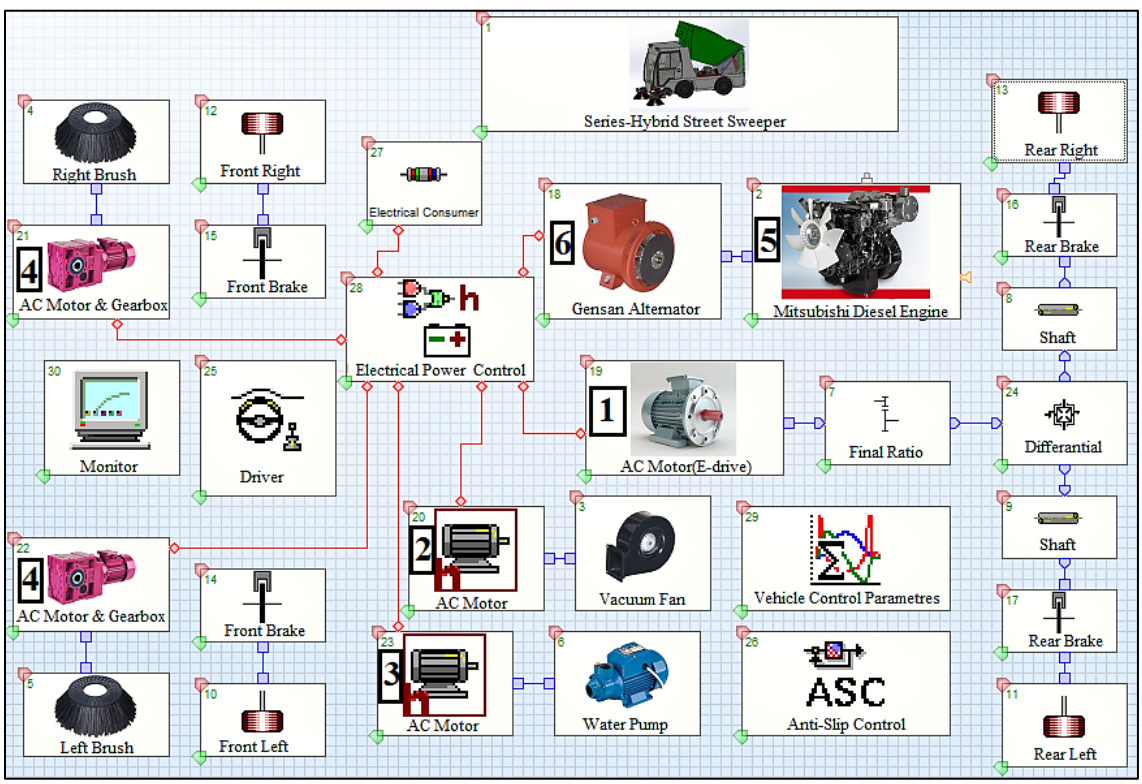

Figure 3. Block diagram of series hybrid electric street sweeper

It is shown in Figure 2. that blue and red lines connect components to each other. They represent mechanical and electrical connections respectively. The components such as ICE, generator, EM and auxiliary electric motors are configured in AVL Cruise in accordance with the test reports of manufacturers. It is seen in the Figure 3. that there are five AC (Alternating current) motors used in vehicle (numbered as 1,2,3 and 4.). The EM (numbered as 1) drives the vehicle, EM (2) is used for vacuum fan, EM (3) is used for water pump and EMs (4) are used for sweeping. Their powers are 15 kW, 7.5 kW, 1 kW and 0.75 kW respectively. The component (numbered as 5) is ICE and it is combined with the generator (numbered as 6). ICE used in this project runs at a constant speed (1500rpm) and its power is 36.8 kW/1500rpm. ICE is used in electricity generation with the aid of generator (6).

2.2. Generating an Appropriate Driving Cycle

Driving cycles are used in investigating the fuel consumption, exhaust emissions and vehicle performance. Many countries have developed a variety of urban driving cycles, such as Federal Test Procedure-72 (FTP-72), New European Driving Cycle (NEDC), Highway Fuel Economy Test (HWFET), Japan 10-15 Mode and highway driving cycles like US 06, etc. [8].

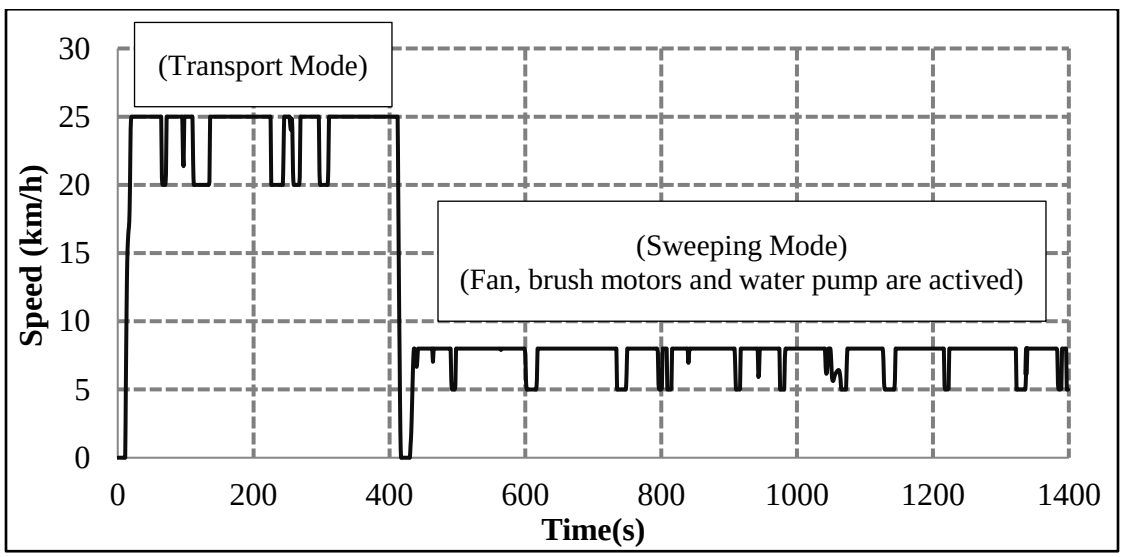

Figure 4. Street sweeper driving cycle depending on vehicle speed

Figure 4. represents the driving cycle generated by using Random Cycle Generator of AVL Cruise. During generating this driving cycle, especially the daily tasks, operating conditions and speed range of street sweepers were taken into consideration. It is shown in the Figure 4. that driving cycle consists of two driving mode (Transport and Sweeping) and it is 1400 seconds. During transport mode, vehicle moves from one location to another location and the components used in sweeping are deactivate. In the following case, the vehicle speed decreases and the sweeping components (Fan, brush motors and water pump) are activated. As a result, the fuel consumption and exhaust emissions change during driving cycle according to driving modes (Transport and Sweeping).

3. Results

Simulations were performed to analyze the vehicle performance, fuel consumption and exhaust emissions of series hybrid electric street sweeper. When the sweeping motors are active (during sweeping mode), the changes in fuel consumption and exhaust emissions are investigated. Additionally, the vehicle performance was also investigated according to changing driving conditions.

Fuel Consumption

file edit view

	Time [s]	Fuel_Consumption (Mass Flow) [kg/h]	Fuel_Consumption (Volume flow) [l/h]
14.257	808,81770833329	5,0875366054904	6,1295621752897
14.258	808,91770833329	5,0874538727478	6,1294624972865
14.259	809,01770833329	5,087529466483	6,1295535740759
14.260	809,11770833329	5,0874603957298	6,1294703563009
14.261	809,21770833329	5,0875235063692	6,1295463932159
14.262	809,31770833329	5,087465841545	6,1294769175241
14.263	809,41770833329	5,0875185304738	6,1295403981612
14.264	809,51770833329	5,0874703880707	6,1294823952659
14.265	809,61770833329	5,0875143762673	6,1295353930931
14.266	809,71770833329	5,0874741838107	6,1294869684467
14.267	809,81770833329	5,0875109080614	6,1295312145319
14.268	809,91770833329	5,0874773527459	6,1294907864409
14.269	810,01770833329	5,087508012573	6,1295277259916
14.270	810,11770833329	5,0874799983821	6,1294939739543
14.271	810,21770833329	5,0875055952293	6,1295248135293
14.272	810,29270833329	5,0874892818486	6,1295051588538
14.273	810,34270833329	5,087491400767	6,1295077117675
14.274	810,39270833329	5,0874924224794	6,1295089427463
14.275	810,44270833329	5,0874929151337	6,1295095363057
14.276	810,49270833329	5,0874931526854	6,1295098225125
14.277	810,54270833329	5,0874932672295	6,1295099605175
14.278	810,59270833329	5,087493322461	6,1295100270614
14.279	810,64270833329	5,0874933490928	6,129510059148
14.280	810,69270833329	5,087493361934	6,1295100746192
14.281	810,74270833329	5,0874933681258	6,1295100820793
14.282	810,79270833329	5,0874933711114	6,1295100856764
14.283	810,84270833329	5,0874933738935	6,1295100890283
14.284	810,89270833329	2,49196235354	3,0023642813735
14.285	810,90833333329	3,1612013671814	3,8086763460016

- row selector
- Time [s]
- Fuel_Consumption (Mass Flow) [kg/h]
- Fuel_Consumption (Volume flow) [l/h]
- Cumulated_Fuel_Consumption (Mass
- Cumulated_Fuel_Consumption (Volum

Figure 5. An example of simulation results obtained from AVL Cruise

Figure 5. shows the fuel consumption results depending on driving cycle. These results were obtained from AVL Cruise simulations and presented with graphics. The graphics in this section are fully created from Cruise data.

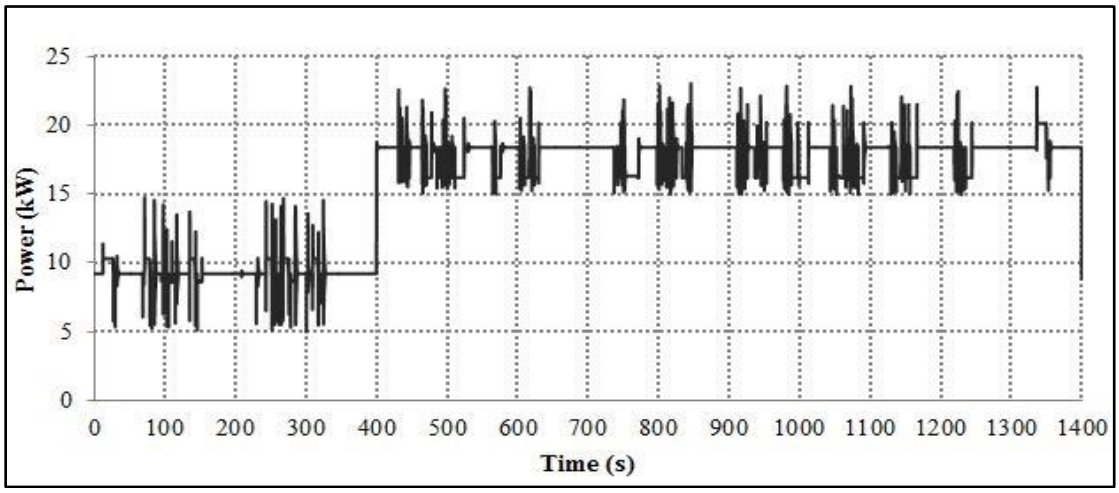

Figure 6. Variation of vehicle power for series hybrid electric street sweeper during driving cycle

Figure 6. shows the needed power of street sweeper during driving cycle. During transport mode (0-400s) and sweeping mode (400-1400s), the average power requirements of vehicle are 10 kW and 18 kW respectively. During transport mode, the needed power is less than sweeping mode (400-1400s) because of the sweeping components are deactivate.

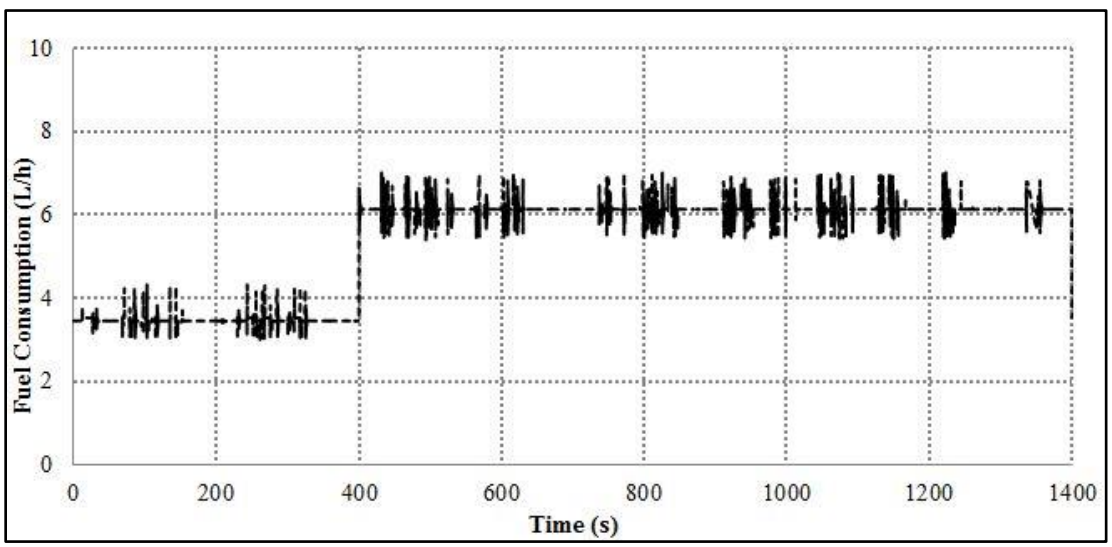

Figure 7. The variation of fuel consumption for SHESS during driving cycle

Figure 7. presents the variation of fuel consumption for series hybrid electric street sweeper. During the transport mode (0-400s), the average fuel consumption is seen approximately 3.8 Lt/h. Due to the series hybrid electric configuration, internal combustion engine runs at a constant speed (1500 rpm). ICE is used in driving generator. During the sweeping mode (400-1400s), the sweeping components are active and the fuel consumption increases to approximately 6 Lt/h. With the sweeping motors are active, the needed power from generator increases and the ICE starts to load therefore the fuel consumption during sweeping mode is higher than transport mode.

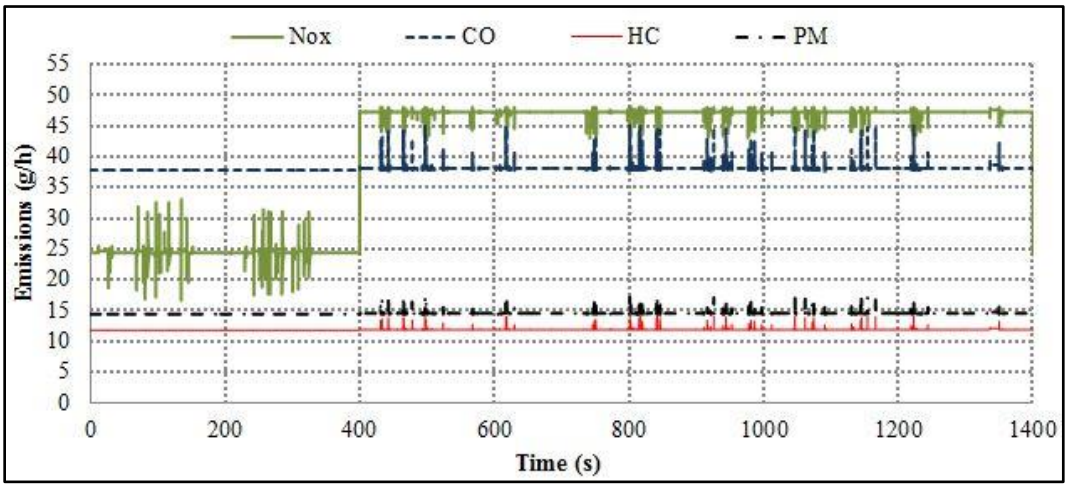

Figure 8. The variation of fuel consumption for SHESS during driving cycle

Figure 8. shows the variation of exhaust emissions (NO_x, CO, HC and PM). It is seen in the figure that especially there is a significant increase in the NO_x emission. The average NO_x emission is 25 g/h during transport mode and it is 48 g/h in the sweeping mode. On the other hand, the average emission values for CO, HC and PM are 38 g/h, 12 g/h and 14 g/h respectively. During sweeping mode, a fluctuation is seen in figure. Because during the sweeping mode, ICE is loaded with the sweeping motor so it gives rise to fluctuation in emissions values.

4. Discussion and Conclusion

In the literature, hybrid electric vehicle conversion studies on non-automotive are not enough. This study presents a simulation of hybrid electric non-automotive vehicle with AVL Cruise. Mechanical and electrical connections of vehicle are shown in software. In this work, a street sweeper is simulated as a series-hybrid electric vehicle and its components regarding sweeping function are also modelled in the software.

Non-automotive vehicles are difficult to simulate by using software. Because these vehicles include different components from standard drivetrains such as lifting, sweeping, carrying etc.. On the contrary, it is easy to simulate passenger cars therefore studies are focused on in this area. Additionally an appropriate driving cycle is needed to obtain reasonable results. Therefore we created an appropriate driving cycle according to velocity, daily tasks and driving conditions of street sweepers. Simulations are performed with this driving cycle in order to reflect the real situations.

Simulations show that series hybrid electric street sweeper consumes approximately 3.8 Lt/h during transport mode (moves one location to another location without sweeping) and it consumes approximately 6 Lt/h during sweeping mode (sweeping motors, fan motor and water pump are activated). When the results are analysed, it is seen that the simulation results matches with the technical values of the ICE.

Acknowledgements

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