Running Vehicle Emission Factors of Passenger Cars in Makassar, Indonesia

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Abstract: The present paper aims to grasp the emission factors of passenger cars under a running vehicle condition in Makassar, Indonesia. Field measurements using a portable combustion gas analyzer on six technology types of cars in the city were conducted. The vehicle exhaust emissions such as CO, NO, NO_x, and CO_2 were measured for various running speeds of the vehicles under hot engine and free flow speed conditions. The vehicle speeds are varied on 0, 20, 40, and 60 km/hr in following a certain driving cycle. The relationships between the exhaust emissions and the vehicle speeds using polynomial model are obtained, as well as the emission factors for average values of the speeds. The results show that the CO_2 emission factors are slightly lower from International Vehicle Emission Model (IVEM) value, as well as the others emission types. These emission factors will be used in predicting running vehicle emission on the city in further study.

Keywords: Running vehicle, emission factors, passenger cars, Makassar

1. INTRODUCTION

The increasing of the motor vehicle on the road leads to the rising of air pollution that exhausted by the vehicles as consequently. Therefore, nowadays the efforts in order to reduce the emission become more and more important issue in many cities in developing countries, including Makassar City in Indonesia, one of the biggest countries in Asian developing countries. In order to mitigate and control the environmental problem, first of all, an effort to develop a prediction method of the quantity of the vehicle emission accurately is needed. In order to calculate the quantity of the vehicle’s pollutant, the base emission or emission factor of the motor vehicle play important role on the estimation. However, the base emission is influenced by many factors (Wang, H. et.al, 2008) regarding the engine technology types or others characteristics and operating (idle or running condition) of the cars.

Regarding Smith et.al, (2010), many emission factor models have been developed by many scholars in the previous studies. Some of them are 1) ‘Average-speed’ models (e.g. COPERT, MOBILE, EMFAC), where emission factors (in g veh km-1) are a function of the mean travelling speed; 2) ‘Traffic-situation’ models (e.g. HBEFA, ARTEMIS), where emission factors (in g veh km-1 are determined by descriptions of a particular traffic situations (e.g. ‘stop-and-go-driving’, ‘freef low motorway driving’); and 3) ‘Cycle-variable’ models (e.g. MEASURE, VERSIT), in which emission factors (in g veh km-1 or g s-1) are a function of various driving cycle variables (e.g. idle time, average speed, positive kinetic energy) at high resolution (seconds to minutes).

However, the emission factors of the vehicles are highly fluctuated due to influenced by many factors particularly by traffic condition and driving cycle of driver behavior. Therefore, the values of the base emission of the motor vehicles will be different from one road, area, city, or region to another.

According to the above background, this paper aims to grasp the emission factors of vehicle fleets in particular the passenger cars type, under a running vehicle condition in Makassar city, Indonesia. The paper develops the emission factors of vehicle fleets under a running vehicle using polynomial model approach.

The rest of this paper is organized as follows. Section 2 describes methodology of the vehicle emission measurement and the selected polynomial model related to vehicle emission factor model of passenger cars. Section 3 demonstrates the result of the measurement and the modeling. The final section, Section 4 provides discussion related to the result of the model implementation and concludes.

2. THE STUDY METHODS

This study consists of three stages activities, firstly identifying passenger car characteristics, secondly measurement for base emission of the fleet, and thirdly development and validation of the emission factor model. The next subsections will explain each stage more detail.

2.1 Passenger Cars Characteristics Survey

In order to identify the characteristics of passenger cars in Makassar city, an interview survey using a questionnaire to drivers of the passenger cars was carried out in the road side of a primary arterial road, Pettarani street, in the city. The questionnaire that using in the survey involved some characteristics of the cars such as engine size or capacity, vehicle age, vehicle engine technology, and vehicle kilometer traveled. The passenger cars were randomly selected to be stopped at the road side for interviewing. In this regards, the surveyors stopped 5 passenger cars each fifteen minutes periodically. During three hours survey on the morning peak hour period, we collected more than five hundred passenger cars.

2.2 Measurement for Base Emission of Passenger Cars

The measurement of passenger car’s emission on running mobile condition was conducted on the road. The measurement used a portable combustion gas analyzer that measure four types of vehicle exhaust emissions such CO, NO, NO_x, and CO_2. Regarding the budget constraint, we measured six technology types of passenger cars that have major composition regarding the result of the passenger car characteristics survey as shown in Table 1 as green colors. The six is representation of dominant variously of the cars characteristics such as exhaust type, engine size, and vehicle age. Regarding the Table 1, the six passenger car types that selected are listed below:

- Vehicle-1: 3-Way/EGR, Light, 0-6 years
- Vehicle-2: 3-Way/EGR, Medium, 0-6 years
- Vehicle-3: 3-Way/EGR Medium, 6-13 years
- Vehicle-4: SULEV, Medium, 0-6 years
- Vehicle-5: ULEV, Light, 0-6 years
- Vehicle-6: ULEV, Medium, 0-6 years

The emission measurement varied running speeds of the vehicles under hot engine and free flow speed conditions. The vehicle speeds were varied on 0, 20, 40, and 60 km/hr in following a certain driving cycle. In this regard, we develop a driving cycle for driving behavior of driver under heterogeneous traffic situation in Makassar, namely 3T-0-60 as shown in Figure 1. The cycle means that the vehicle emissions are measured during three times period for a speed cyclic of 0, 20, 40, and 60 km/hr, where each cyclic needs 300 seconds.

Table 1. Composition (%) of Passenger Cars in Makassar

Exhaust Type	Carburator					Multi Point Fuel Injection					
	Light Size			Medium Size		Light Size			Medium Size		
	0-6	6-13	>13	6-13	>13	0-6	6-13	>13	0-6	6-13	>13
3-way			0.3			1.7	0.5		1.3	0.7	
3-Way/EGR	0.2	0.2	3.2	0.5	6.6	16.0	1.5	0.2	17.0	7.2	0.3
Euro 3						0.5					
Hybrid							0.2		1.0	1.2	
None					0.2						
SULEV						1.0	1.2		7.2	4.0	0.3
ULEV						14.5	1.3		6.7	3.0	
Euro 4						0.2					
Total (%)	0.2	0.2	3.5	0.5	6.7	33.8	4.7	0.2	33.3	16.2	0.7
	11.1					88.9					

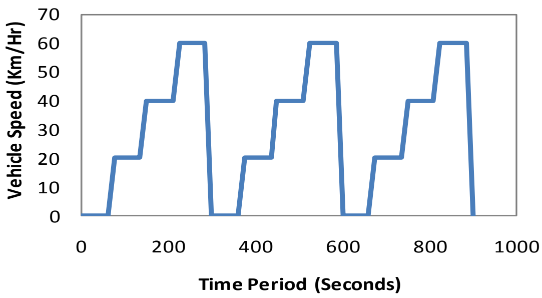


Figure 1. Driving Cycle for Vehicle Emission Test

2.3 The Development of Emission Factor Model

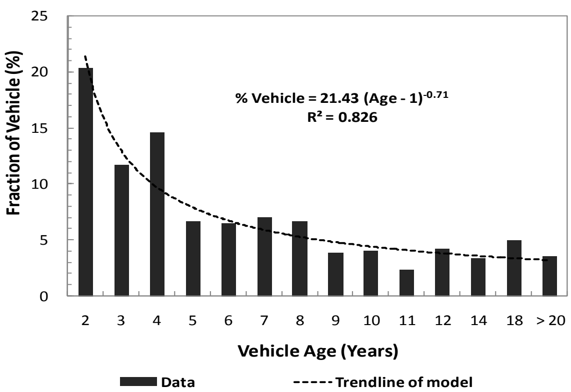
Regarding the measurement results of the vehicle emission, the emission factor model was developed. We adopt polynomial regression model approach using polynomial equation of orde-3.

3. RESULTS

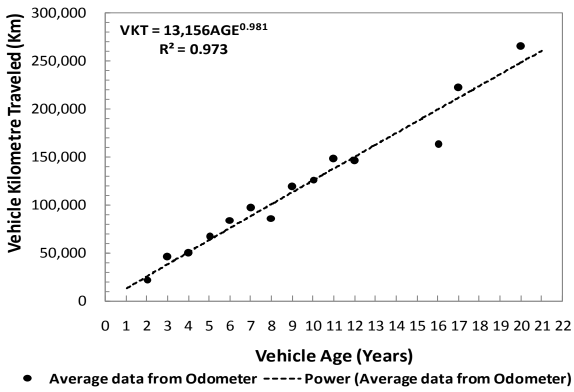
3.1 The Characteristics of Passenger Cars

The results of the car characteristics surveys are shown in Figure 2. Figure 2a shows the fraction of passenger cars based on vehicle age characteristic. The figure shows that the cars having less than or equal 4 years old are dominant cars, more than 10% for each age category, in Makassar. Meanwhile, each category of more than 4 years old has 5% - 7%. The figure also shows that the trend of the vehicle fraction against its vehicle age increasing is following negative power regression. Regarding the vehicle kilometer traveled (VKT), mostly passenger cars have linear relationship trend to the increasing of their age as shown in Figure 2b.

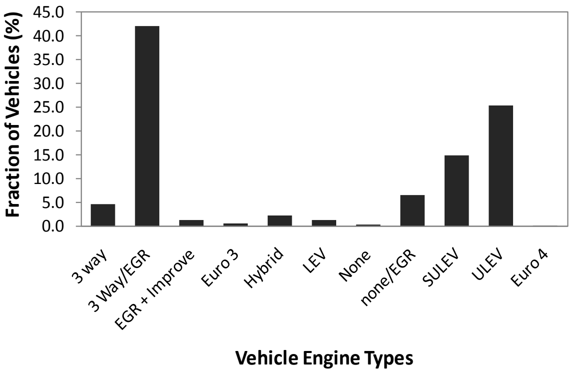
Figure 2c shows that only there are two types of vehicle engine size based on IVEM's category available in Makassar, both are small and medium engine capacity. However, the medium engine capacity is slightly superior to the other one. It has population more than 50%, and the other one only achieves 40% population.



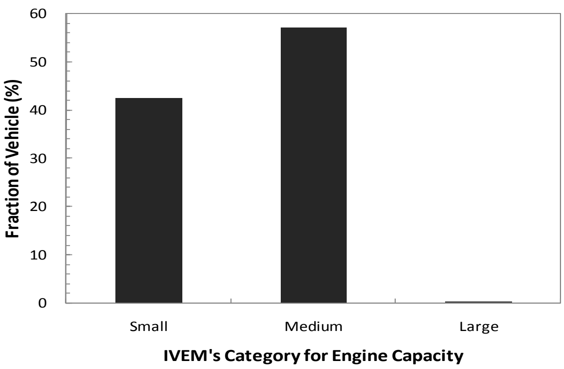
a. Fraction of vehicle age



b. Vehicle kilometer traveled



c. Fraction of IVEM's engine capacity



d. Fraction of vehicle engine type

Figure 2 Characteristics of Vehicle

Figure 2d shows that there are four major vehicle types regarding the vehicle engine type in the city, i.e. 3way/EGR, ULEV, SULEV, and none/EGR. The 3way/EGR vehicle type is superior to the others, while none/EGR vehicle type is inferior to the three vehicle types.

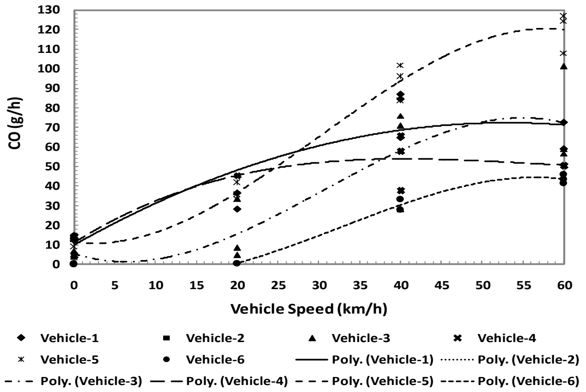
3.2 The Base Emission of the Passenger Cars

The running emissions of the six vehicle types based on the measurement in this study are shown in Figure 3. The figure shows emission types of CO, CO_2, NO, and NO_x in Figure 3a, Figure 3b, Figure 3c, and Figure 3d, respectively. Generally, all of the vehicle emission types show increasing trend in following the increasing of the vehicle speed.

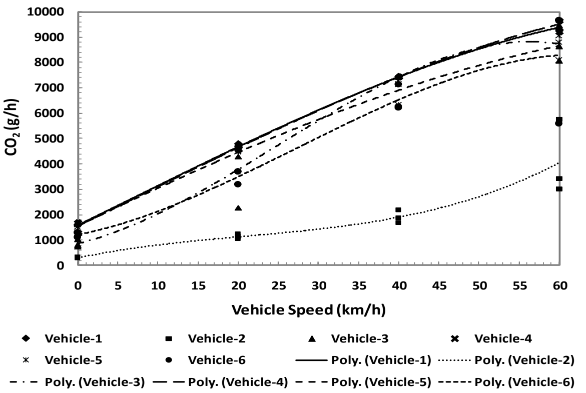
Figure 3a shows that the values of CO emission type are around 10 – 20 g/h in idle condition (vehicle speed is zero). Then, the values increase until 40 – 130 g/h under the vehicle speed at 60 km/h. In this regard, the test vehicle-5, ULEV-Light type has the largest CO emission.

Figure 3b shows that CO_2 emission of the six vehicle types have similar trend against their vehicle speed. The values of this emission increase to the rising of the vehicle speed. Mostly the vehicle types have CO_2 values near each others, except ULEV type that is the lower than the others. In this regard, most of them have CO_2 values in range 1000 – 2000 g/h at zero speed condition until 8000 – 10000 g/h at speed 60 km/h.

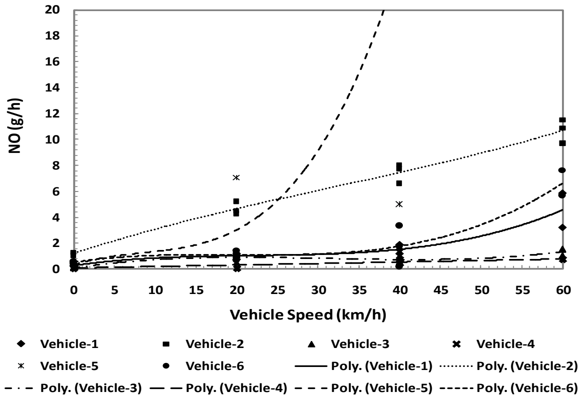
Figure 3c and Figure 3d show the similar phenomenon between NO and NO_x emission types of the all test vehicle. The test vehicle-3 and test vehicle-4 have base emission values for both emission types near each other, as well as the test vehicle-1 to the test vehicle-6. While the base emission of the others two test vehicles are different from all vehicle types. Mostly the vehicles have emission values of NO and NO_x around 0 – 20 g/h.



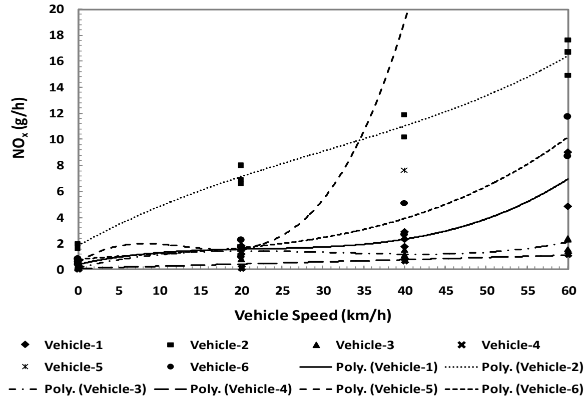
a. CO Emission type



b. CO_2 Emission type



c. NO Emission type



d. NO_x Emission type

Figure 3. Base Emission Measurements of the Cars

3.3 The Base Emission Model of the Passenger Cars

The model of emission factors of each passenger cars type that measured in this study was developed by using the polynomial regression approach, in particular using polynomial equation of orde-3. The parameters values of the models is presented on Table 2, Table 3, Table 4, and Table 5 for the base emission CO, CO_2, NO, and NO_x, respectively. Those tables show that all of the model have very good determinant coefficient, R^2. Their values are mostly more than 0.9, the value that show the high acceptability of the models.

In order to examine the emission factor models of the passenger cars in Makassar, the parameters values of the models were used to calculate the averagely base emission factor of each the five vehicle types. Then, the results are compared to the emission factors that given by International Vehicle Emission Model (IVEM). The comparing results are shown in Figure 4a, Figure 4b, and Figure 4c for CO, CO_2 and NO_x emission types, respectively.

Figure 4a shows that mostly of CO base emission values of passenger car in Makassar are larger than base emission of emission factor provided by IVEM, particularly in SULEV and ULEV vehicle types. As well as 3-way/EGR for medium and large engine size are also slightly superior to the IVEM's value. However, one other of 3-way/GER for large size of engine is slightly smaller than the emission factor of IVEM. Figure 4b shows that CO_2 base emission values of the five test vehicles are mostly similar to IVEM's emission factor. Only the 3-way/EGR of large engine size vehicle type is smaller than the IVEM's value. Figure 4c shows that NO_x emission factors of each the five vehicle types fluctuate in comparing to the IVEM's factors. SULEV, ULEV, and 3-way/EGR of medium engine size are larger than emission factor values of IVEM. Meanwhile, the others vehicles are smaller than IVEM's .

Table 2. Parameters values of base emission CO model

Variables	Codes	Parameters of CO Emission Models					
		Veh.-1	Veh.-2	Veh.-3	Veh.-4	Veh.-5	Veh.-6
Orde-3 (X^3)	β_3	-	-	-0.001	0	-0.001	-0.001
Orde-2 (X^2)	β_2	-0.022	-	0.117	-0.05	0.117	0.094
Orde-1 (X^1)	β_1	2.355	-	-1.319	2.605	0.561	-1.494
Constant	β_0	9.797	-	5.369	11.15	11.450	0.240
Determinant	R^2	0.834	-	0.751	0.873	0.981	0.993

Table 3. Parameters values of base emission CO_2 model

Variables	Codes	Parameters of CO_2 Emission Models					
		Veh.-1	Veh.-2	Veh.-3	Veh.-4	Veh.-5	Veh.-6
Orde-3 (X^3)	β_3	-0.009	0.029	-0.064	-0.009	-0.005	-0.042
Orde-2 (X^2)	β_2	0.142	-1.845	4.77	0.176	-0.265	3.452
Orde-1 (X^1)	β_1	156	66.34	76.68	154.8	152.3	62.44
Constant	β_0	1586	304.6	864.6	1552	1567	1223
Determinant	R^2	0.998	0.836	0.961	0.997	0.988	0.883

Table 4. Parameters values of base emission NO model

Variables	Codes	Parameters of CO Emission Models					
		Veh.-1	Veh.-2	Veh.-3	Veh.-4	Veh.-5	Veh.-6
Orde-3 (X^3)	β_3	0.00006	0.00002	0.00004	-	0.00000	0.00009
Orde-2 (X^2)	β_2	-0.003	-0.002	-0.003	-	-0.015	-0.005
Orde-1 (X^1)	β_1	0.090	0.206	0.095	0.011	0.197	0.095
Constant	β_0	0.265	1.202	0.099	0.066	0.362	0.496
Determinant	R^2	0.856	0.977	0.837	0.806	0.928	0.878

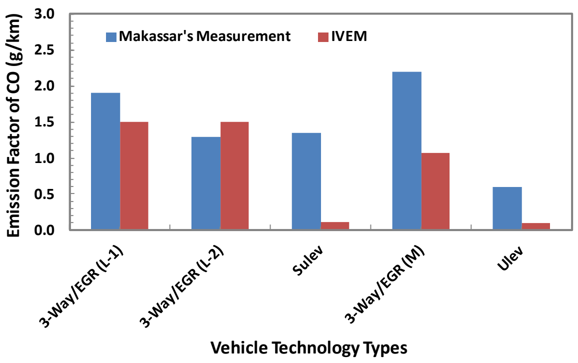
Table 5. Parameters values of base emission NO_x model

Variables	Codes	Parameters of NO_x Emission Models					
		Veh.-1	Veh.-2	Veh.-3	Veh.-4	Veh.-5	Veh.-6
Orde-3 (X^3)	β_3	0.00009	0.00006	0.00006	-	0.001	0.00005
Orde-2 (X^2)	β_2	-0.005	-0.005	-0.005	-	-0.038	-0.001
Orde-1 (X^1)	β_1	0.138	0.349	0.146	0.016	0.423	0.053
Constant	β_0	0.409	1.847	0.148	0.087	0.553	0.758
Determinant	R^2	0.853	0.980	0.832	0.877	0.848	0.937

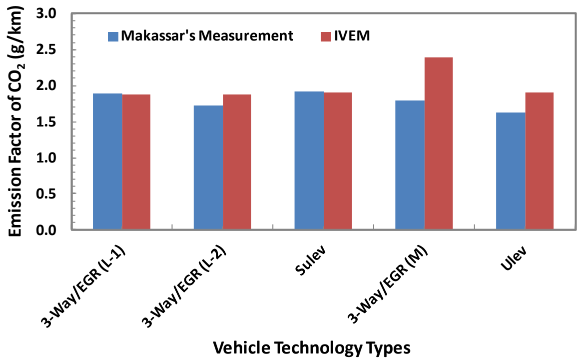
4. DISCUSSION AND CONCLUSSION

This paper presents the running vehicle emission factors of the vehicle fleet particularly the passenger car types in Makassar, Indonesia. The study conducted a field measurement using a portable combustion gas analyzer of the base emission types that exhausted by the six test vehicles of passenger car type. The measurement was carried out for four various running speed condition of the vehicles, i.e. 0, 20, 40, and 60 km/hour regarding a certain driving cycle, namely 3T-0-60. The measurement measured four types of the vehicle exhaust emissions such CO, CO_2, NO, and NO_x. In order to develop the vehicle emission factor model, we adopted a polynomial model approach.

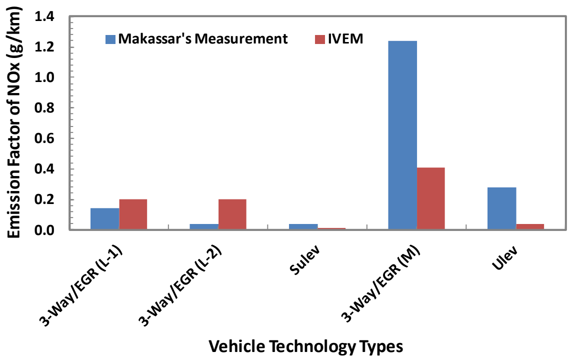
The measurement results showed that the base emission of each test vehicle type is highly fluctuated, even at same vehicle speed condition. This phenomenon conform the various behavior of the vehicle's driver on operating the cars such various on engine stress etc. However, generally the emission factors values are increasing according to the rising of the vehicle speed. The result is in-line to some previous researches, such IVEM and MOBILE.



a. CO Emission type



b. CO_2 Emission type



c. NO_x Emission type

Figure 4. Comparison results of Makassar's car & IVEM

Furthermore, a verification of the emission factor model was conducted to the IVEM's base emission factors. The comparing results show that mostly CO_2 emission type of the vehicles from the model is slightly lower than the IVEM's values. In contrary, mostly Co emission type is upper than the values of IVEM. This phenomenon indicates that the passenger car in Makassar exhaust CO emission in larger portion than the CO_2 emission in comparing to the international experience. It means that the cars are lower sensitive to the environmental health.

Briefly, the factor emission models that developed in this study are acceptable in significant level. Then, we expect that these emission factors will be used in predicting running vehicle emission on the city in further study.

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User`s Manual IVEM