

ESTIMATION OF BI-FUEL VEHICULAR EMISSION BY SYSTEM DYNAMICS APPROACH

by

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ABSTRACT

The growth in the number of vehicles in big cities is around 8-12% annually. In Indonesia the growth during the period of 1990 to 1998 was dominated by motor cycles (72%), passenger cars (15%), cargo cars (9%), buses (4%) the majority of which use oil fuel in the form of premix, gasoline or diesel oil. The contribution of vehicular emission as pollutant is around 60-70%, while industrial emission contributes around 10-15%. Carbon monoxide is the major pollutant, and motor vehicles are the major source of that pollutant.

Generally, the objectives of this study are to anticipate the increase of pollutant from exhaust emission from vehicles by using alternative fuels especially CNG. In particular, this study is to carry out a trial to know the change in CO, HC and CO₂ pollutant from vehicle in the city by simulation. This study is an experimental study which used converted vehicle (bi-fuel) that can use either gasoline or CNG. The experiment was done on chassis dynamometer. Based on the chassis dynamometer testing results, some data will be used for simulation to determine the condition of some parameters such as CO, HC and CO₂. Simulation was conducted by using Powersim version 2.5 d software.

The simulation results show that in the year of 1997 the amount of CO was 614,887 ton, in the year of 2002 was 1,436,002 ton and in the year

of 2008 will be 2,626,647 ton. The amount of HC in the year of 1997 was 25,167.80 ton, in the year of 2002 was 846,171.90 ton and in the year of 2008 will be 2,036,683 ton. The amount of CO₂ in the year of 1997 was 9,702,000 ton, in the year of 2002 was 10,523,330 ton and in 2008 will be 11,714,240 ton. Sensitivity test was conducted with two scenarios. The results are as follows: The first scenario based on the calculation of vehicle growth 2% from total of number of vehicles in 1997, the growth of bi-fuel vehicle 1000 units annually and 90% refill of CNG from tank capacity. The results showed that the amount of CO in the year of 2002 reduced to 57.51%, and the year of 2008 will be reduced to 77.41%. The amount of HC in the year of 2002 reduced 88.65%. And in the year 2008 will be reduced to 91.66%. The amount of CO₂ in the year of 2002 reduced to 17.85%. The amount of CO₂ in 2008 will be reduced to 17.36%. The second scenario based on the calculation of vehicle growth 5% from total of vehicle in 1997, the growth of bi-fuel vehicle 2000 units annually and 90% refill of CNG from tank capacity. The results showed that the amount of CO in the year of 2002 reduced 43.73%, and in the year of 2008 will be reduced to 60.41%. The amount of HC in the year of 2002 reduced to 88.51%. And in the year 2008 will reduced 91.67%. The amount of CO₂ in the year of 2002 reduced to 17.80%. The amount of CO₂ in 2008 will be reduced to 17.18%.

I. INTRODUCTION

A. Background

The Development has resulted in increasing prosperity, and caused industrial and transportation growth. The growth of industrial and transportation causes an

increase in oil fuel utilization which in turn will increase air pollution.

In some big cities air pollution emitted from motor vehicles has caused apprehension. The growth in the number of vehicles in big cities is around 8-12% annu-

ally. In Indonesia the growth during the period of 1990 to 1998 was dominated by motor cycles (72%), passenger cars (15%), cargo cars (9%), buses (4%) the majority of which use oil fuel in the form of premix, gasoline or diesel oil (Abubakar, 2000).

The contribution of vehicular emission as pollutant is around 60-70%, while industrial emission contributes around 10-15%. The remaining percentage comes from household, disposal burning, forest fire Carbon monoxide is the major pollutant, and motor vehicles are the major source of that pollutant (Kusnoputranto, 2000).

Land transportation dominates air pollution. Vehicles are the source of some pollutant such as carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbon (HC) and sulphur oxide (SO₂) and tetraethyl lead (Soedomo, 2001).

One of the efforts for air pollution control involves the use of alternative fuel, Maxwell (1995) mentioned that compared to gasoline or diesel fuel alternative fuels have the following advantages: alternative fuels are more likely to be produced from domestic resources, alternative fuels generally reduce vehicular emission, and some alternative fuels offer the potential to lower operating cost. The types of alternative fuels that can be used for vehicle are Compressed Natural Gas (CNG), and Liquefied Petroleum Gas (LPG). The reserves of natural gas in Indonesia are scattered in Aceh, North Sumatra, South Sumatra, West Java, East Java, East Kalimantan, Natuna and South Sulawesi. In addition to its availability, the advantages of natural gas is that it produces less emission.

B. Objectives of the Study

Generally, the objectives of this study are to anticipate the increase of pollutant from exhaust emission from vehicles by using alternative fuels especially CNG, and to support the energy conservation and diversification policy. In particular, this study is to carry out a trial to know the change in CO, HC and CO₂ pollutant from vehicle in the Jakarta city by simulation.

II. SIMULATION OF BI-FUEL VEHICULAR EMISSION

This study is an experimental study which used converted vehicle (bi-fuel) that can use either gasoline or CNG. The experiment was done on the chassis dynamometer to determine the power losses and fuel consumption, and also exhaust emission. Based on the chassis dynamometer testing results, some data will be used for simulation to determine the condition of some param-

eters such as CO, HC and CO₂. Simulation was conducted by using Powersim version 2.5 d software. Simulation was done with the following assumptions: the number of vehicles always increases, vehicle trip is 300 km per day, the number of CNG refuelling station increases annually, service capacity of CNG refuelling station is 2500 lpe (litre premium equivalent), refuelling capacity is 80% from tank capacity, CNG vehicles increase by 1000 units per year.

A. Concept

The simulation was conducted with Fixes That Fail archetype. In fixes that fail situation, a problem symptom cries out for resolution. A solution is quickly implemented, which alleviates the symptom. However, the solution produces unintended consequences that, after a delay, cause the original problem symptom to return to its previous level or get worse.

B. Simulation model

In this case a problem symptom is the increase in CO, HC and CO₂ emission from vehicle based on oil fuel utilisation, the number of vehicles, and vehicles trip. A solution is implemented by using alternative fuel (CNG). Hopefully, this solution will result in dropp of emission, however, limitation and distribution of CNG refuelling stations cause converting the fuel from CNG to oil fuel again, so the problem symptom returns to previous level (see Figure 1)

As shown in Figure 1 CO, HC and CO₂ emission are the problem symptoms because of combustion process in the engines which use oil fuel. The effort to drop that emission is implemented by using CNG. CNG utilisation is expected to drop the emission, however because of

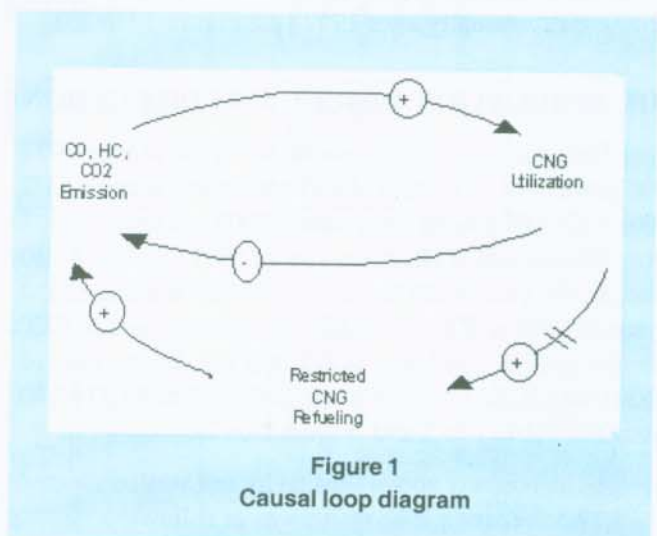


Figure 1
Causal loop diagram

restriction in CNG refuelling, the problem symptoms return to the previous level because fuel changing back to oil fuel

The simulation was based on the following assumptions:

1. The growth of vehicle population
2. Vehicle trip 300 km per day per vehicle
3. CNG refuelling stations increase annually
4. Service capacity of CNG refuelling station 2500 l per day
5. Refuelling capacity 80% from tank capacity
6. CNG vehicles increase of 1000 units annually

See Figure 8 to 10 stock flow diagram for CO, HC and CO₂ pollutant

1. Validity Model

Validity test was conducted to look how far the output of the model suits empirical data. Validity test was done with Absolute Mean Error (AME). The result of validity test shows that AME value for CO pollutant is 1.37%, HC 10.61%, and CO₂ 1.08%.

C. Sensitivity Model

Functional intervention was conducted to examine the response of the model to stimulus. Functional intervention was conducted with two scenarios as follows:

Scenario 1: calculate the increase of vehicles by 2% from the number of vehicles in 1997, CNG refuelling 90% from the tank capacity, increase in CNG vehicles 1000 units annually after 1997.

Scenario 2: calculate the increase of vehicles by 5% from the number of vehicles in 1997, CNG refuelling 90% from the tank capacity, increase of CNG vehicles 2000 units annually after 1997. (see Figure 10 to 13)

III. SIMULATION RESULT AND DISCUSSION

The simulation results show that in the year of 1997 the amount of CO was 614,887 ton, in the year of 2002 was 1,436,002 ton and in the year of 2008 will be 2,626,647 ton. The amount of HC in the year of 1997 was 25,167.80 ton, in the year of 2002 was 846,171.90 ton and in the year of 2008 will be 2,036,683 ton. The amount of CO₂ in the year of 1997 was 9,702,000 ton, in the year of 2002 was 10,523,330 ton and in 2008 will be 11,714,240 ton. (see Table 1 to 3 and Figure 2 to 7).

As mentioned above sensitivity test was conducted with two scenarios. The result was as follows:

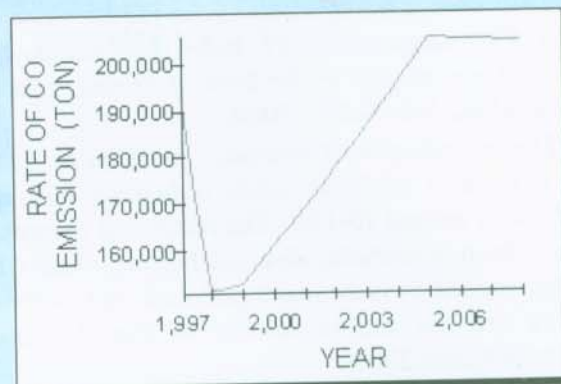


Figure 2
Rate of CO emission

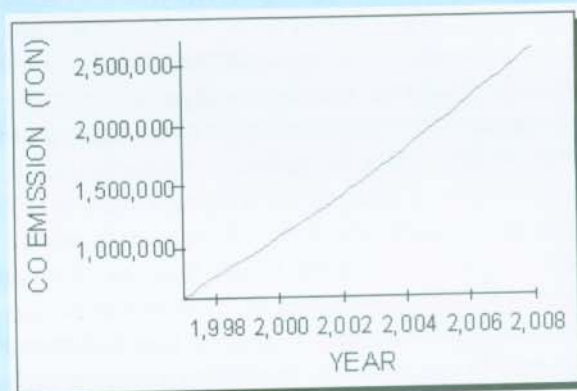


Figure 3
Increasing CO emission during 1997-2008

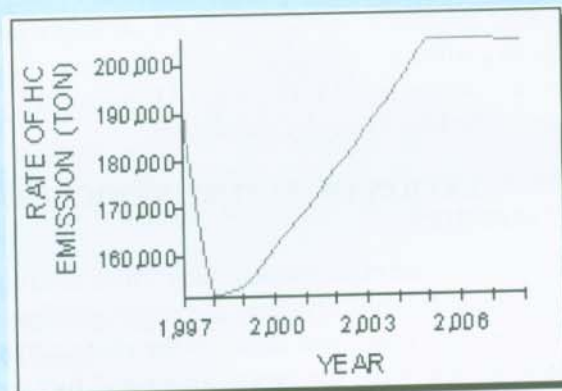


Figure 4
Rate of HC emission

Table 1
Simulation result of CO emission 1997 -2008

YEAR	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Rate of CO Emission (ton)	191.636	151.945	153.115	161.657	169.602	177.965	186.767	196.031	205.779	205.477	205.176	204.874
CO Emission (ton)	614.887	786.677	939.206	1.097.000	1.262.000	1.438.000	1.618.000	1.810.000	2.010.668	2.216.295	2.421.622	2.626.646
CMG Sales (LPE)	2.299.000	8.257.000	14.210.000	20.170.000	26.130.000	32.080.000	38.040.000	44.000.000	499.538.960	559.106.961	618.674.961	678.242.962
Rate of CMG sales (LPE)	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000
Fuel Utilization (litre)	3.790.000.000	3.000.000.000	3.020.000.000	3.190.000.000	3.350.000.000	3.520.000.000	3.690.000.000	3.870.000.000	4.064.560.800	4.058.605.600	4.052.650.300	4.046.694.800
CMG Refueling station	16,00	16,02	16,10	16,18	16,25	16,32	16,37	16,43	16,48	16,52	16,57	16,60

Table 2
Simulation result of HC emission 1997 -2008

YEAR	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Rate of HC Emission (ton)	191.613	151.922	153.092	161.634	169.579	177.942	186.744	196.007	205.756	205.455	205.153	204.851
HC Emission (ton)	25.168	196.905	349.442	506.805	672.412	846.172	1.028.515	1.219.890	1.420.772	1.626.377	1.831.681	2.036.683
CMG Sales (LPE)	2.299.000	8.257.000	14.210.000	20.170.000	26.130.000	32.080.000	38.040.000	44.000.000	499.538.960	559.106.961	618.674.961	678.242.962
Rate of CMG sales (LPE)	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000
Fuel Utilization (litre)	3.790.000.000	3.000.000.000	3.020.000.000	3.190.000.000	3.350.000.000	3.520.000.000	3.690.000.000	3.870.000.000	4.064.560.800	4.058.605.600	4.052.650.300	4.046.694.800
CMG Refueling station	16,00	16,02	16,10	16,18	16,25	16,32	16,37	16,43	16,48	16,52	16,57	16,60

Table 3
Simulation result of CO2 emission 1997 -2008

YEAR	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Rate of CO2 Emission (ton)	191.678	151.987	153.157	161.699	169.644	178.008	186.810	196.074	205.823	205.521	205.220	204.919
CO2 Emission (ton)	9.702.000	9.873.833	10.026.405	10.183.833	10.349.505	10.523.330	10.705.739	10.897.181	11.096.129	11.303.801	11.509.171	11.714.240
CMG Sales (LPE)	2.299.000	8.257.000	14.210.000	20.170.000	26.130.000	32.080.000	38.040.000	44.000.000	499.538.960	559.106.961	618.674.961	678.242.962
Rate of CMG sales (LPE)	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000	5.957.000
Fuel Utilization (litre)	3.790.000.000	3.000.000.000	3.020.000.000	3.190.000.000	3.350.000.000	3.520.000.000	3.690.000.000	3.870.000.000	4.064.560.800	4.058.605.600	4.052.650.300	4.046.694.800
CMG Refueling station	16,00	16,02	16,10	16,18	16,25	16,32	16,37	16,43	16,48	16,52	16,57	16,60

Table 4
Comparison between *simulation* and *scenario 1* result for CO,HC and CO₂

Pollutant	In tons			
	Simulation result 2002	Scenario 1 2002	Simulation result 2008	Scenario 1 2008
CO	1,436,002	610,150.93 (reduce to 57.51%)	2,626,647	593,271.25 (reduce to 77.41%)
HC	846,171.90	96,051.88 (reduce to 88.65%)	2,036,683	169,916.67 (reduce to 91.66%)
CO ₂	10,523,330	9,697,264 (reduce to 7.85%)	11,714,240	9,680,384 (reduce to 17.36%)

Table 5
Comparison between *simulation* and *scenario 2* result for CO,HC and CO₂

Pollutant	In tons			
	Simulation result 2002	Scenario 2 2002	Simulation result 2008	Scenario 2 2008
CO	1,436,002	808,039.03 (reduce to 43.73%)	2,626,647	1,039,825 (reduce to 60.41%)
HC	846,171.90	97,271.56 (reduce to 88.51%)	2,036,683	169,682.13 (reduce to 91.67%)
CO ₂	10,523,330	9,702,090 (reduce to 7.80%)	11,714,240	9,702,197 (reduce to 17.18%)

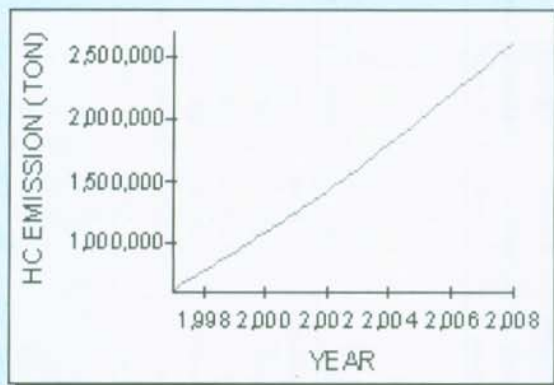


Figure 5
Increasing HC emission during 1997-2008

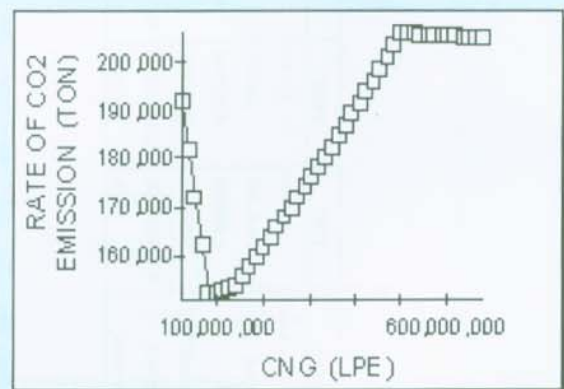


Figure 6
Rate of CO₂ emission

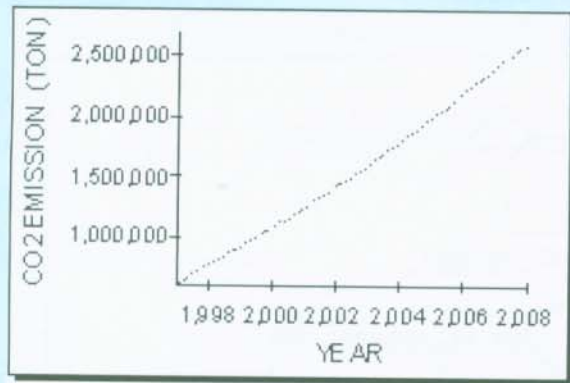


Figure 7
Increasing CO₂ emission during 1997-2008

The first scenario was based on vehicle growth of 2% from the total of number of vehicles in 1997, the growth of bi-fuel vehicle of 1000 units annually and 90% refill of CNG from the tank capacity. The results show that the amount of CO in the year of 2002 was 1,436,002 ton and will be reduced to 610,150.93 ton (57.51%), and 2,626,647 ton in the year of 2008 will be reduced to 593,271.25 ton (77.41%). The amount of HC in the year of 2002 was 846,171.90 ton will be reduced to 96,051.88 ton (88.65%). And 2,036,683 ton in the year 2008 will be reduced to 169,916.67 ton (91.66%). The amount of CO₂ in the year of 2002 was 10,523,330 will be reduced to 9,697,264 ton (17.85%). The amount of CO₂ in 2008 will be 11,714,240 ton will be reduced to 9,680,384 ton (17.36%).

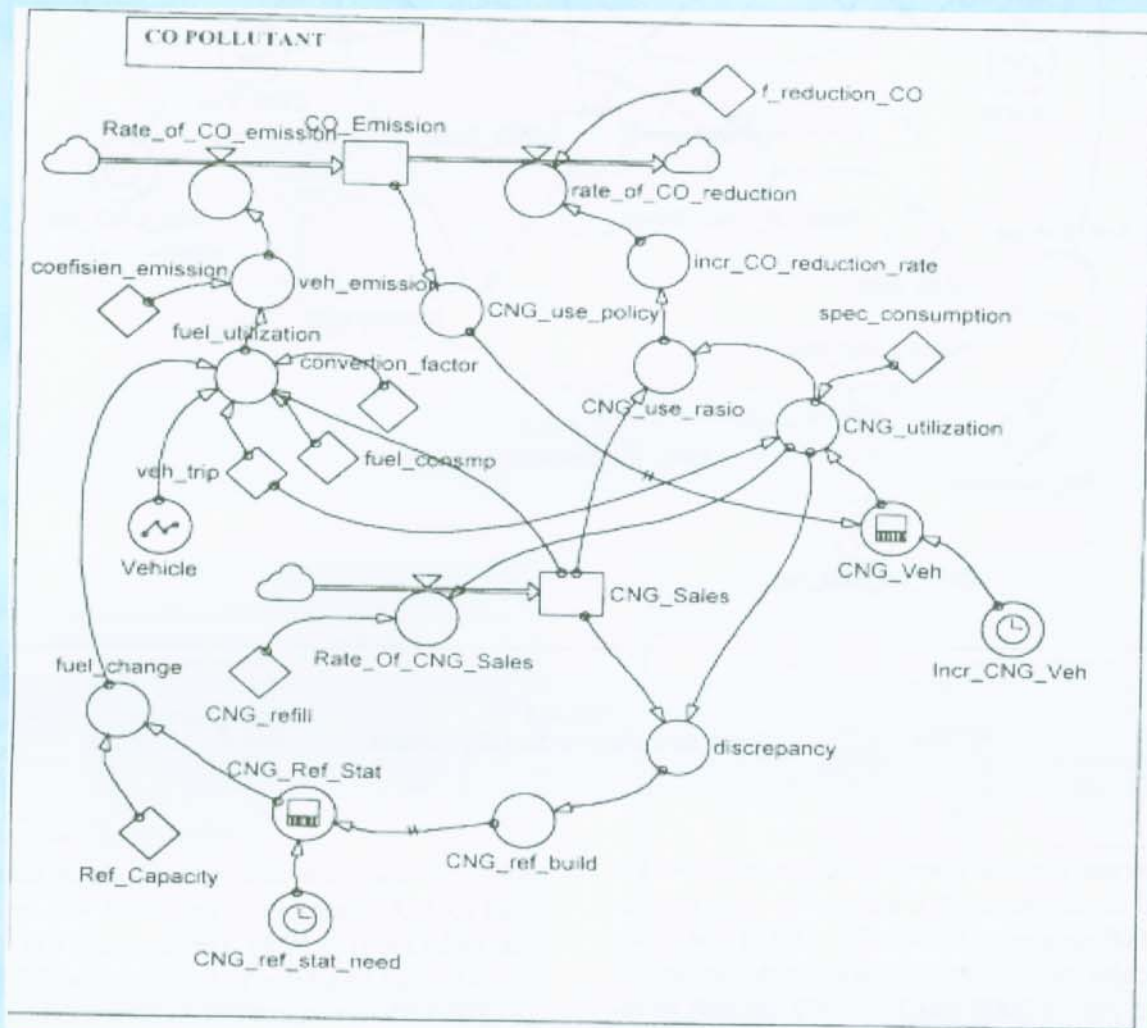


Figure 8
Stock flow diagram for CO pollutant

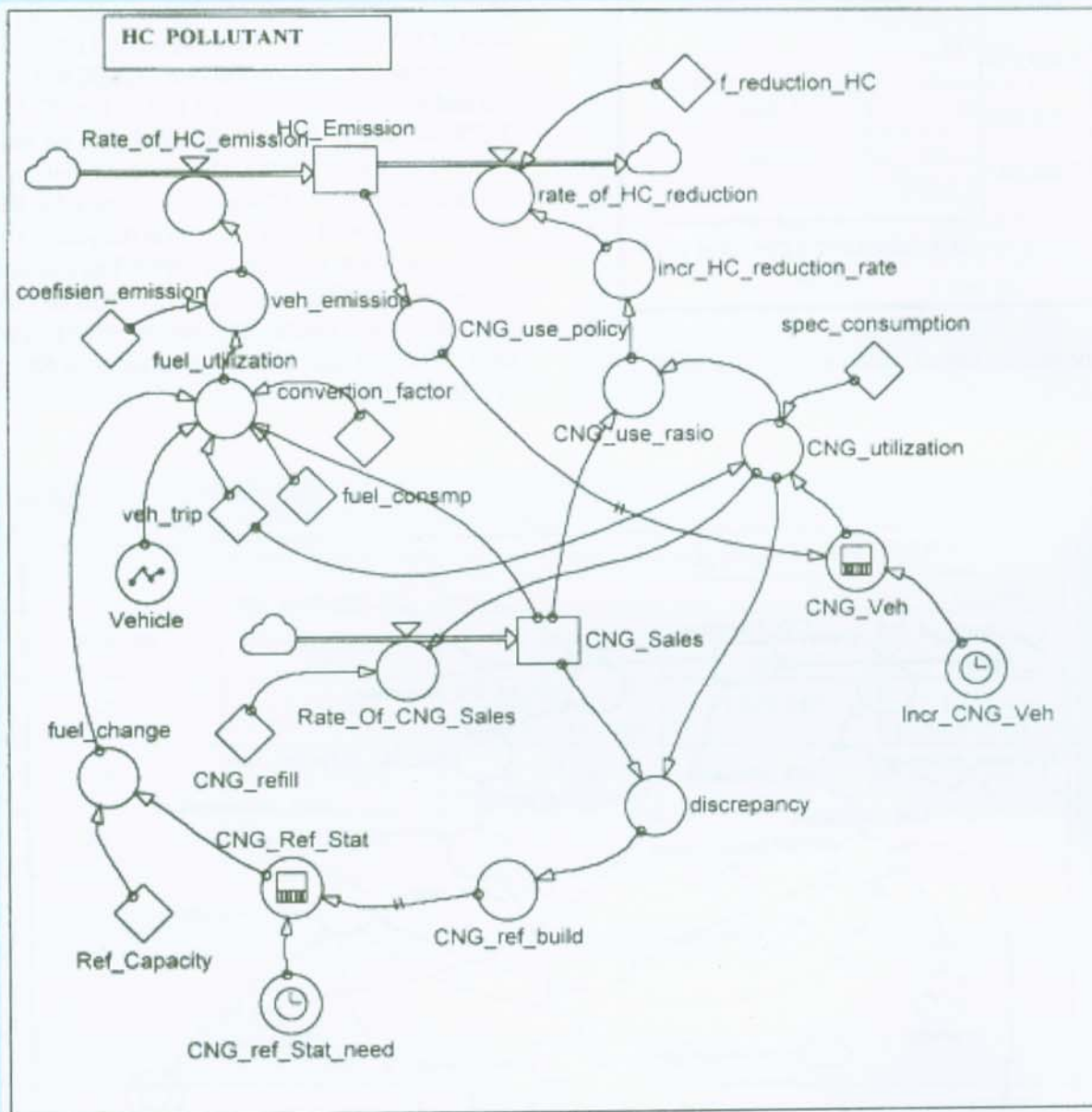


Figure 9
Stock flow diagram for HC pollutant

The second scenario based on vehicle growth of 5% from total of vehicle in 1997, the growth of bi-fuel vehicle of 2000 units annually and 90% refill of CNG from the tank capacity. The result shows that the amount of CO in the year of 2002 was 1,436,002 ton will be reduced to 808,039.03 ton (43.73%), and 2,626,647 ton in the year of 2008 will be reduced to 1,039,825 ton (60.41%). The amount of HC in the year of 2002 was

846,171.90 ton will be reduced to 97,217.56 ton (88.51%). And 2,036,683 ton in the year 2008 will be reduced to 169,682.13 ton (91.67%). The amount of CO₂ in the year of 2002 is 10,523,330 will be reduced to 9,702,090 ton (17.80%). The amount of CO₂ in 2008 will be 11,714,240 ton will be reduced to 9,702,197 ton (17.18%). (see Figure 11 to 13).

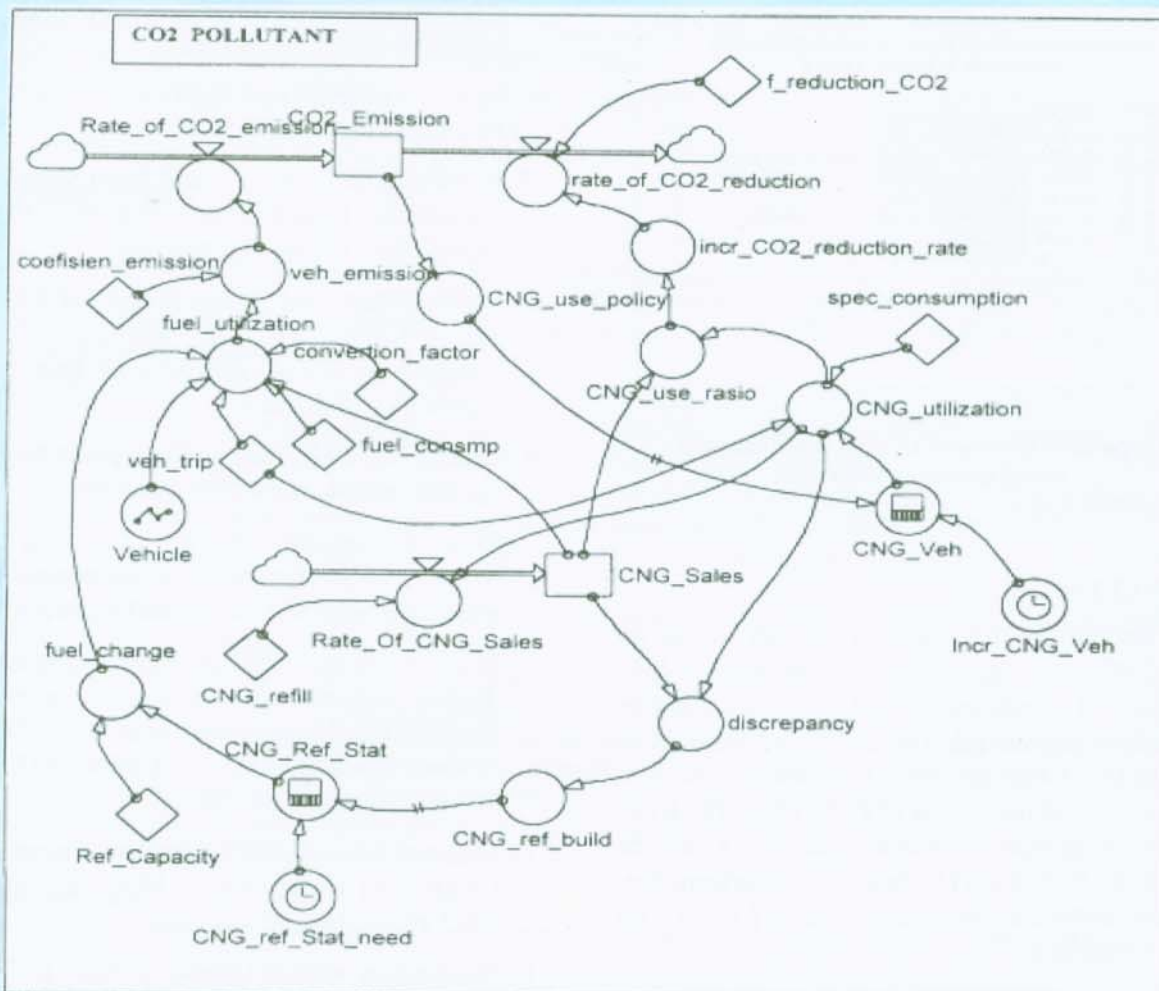


Figure 10
Stock flow diagram for CO₂ pollutant

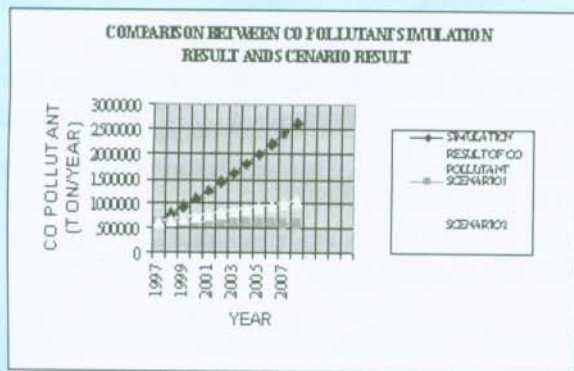


Figure 11
Comparison between CO pollutant simulation result and scenario result

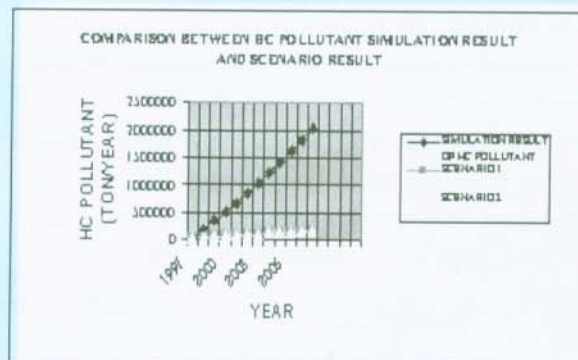


Figure 12
Comparison between HC pollutant simulation result and scenario result

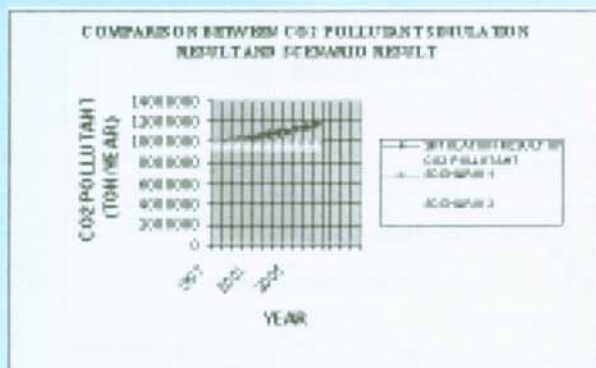


Figure 13
Comparison between CO₂ pollutant simulation result and scenario result

IV. CONCLUSION

The amount of CO in the year of 2008 will be reduced to 593,271.5 ton (77.41%) if we perform Scenario 1, and will be reduced to 1,039,825.67 ton (60.41%) if we perform Scenario 2. The amount of HC will be reduced to 169,916.67 ton (91.66%) if we perform Scenario 1 and will be reduced to 169,682.13 ton (91.67%) if we perform Scenario 2. The amount of CO₂ will be reduced to 9,680,384 ton (17.36%) if we perform Scenario 1 and will reduce to 9,702,197 ton (17.18%) if we perform Scenario 2.

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