CHAPTER III

RESEARCH METHODOLOGY

The research methodology in this project involves selection of correct materials, choosing correct testing equipment, data collection and data analysis. The complete overview of the system and wiring diagram as well as ECU connection diagram are shown in figure 24, figure 25, figure 26 and figure 27 in the appendix section of this dissertation. The complete processes of possible results are coming from many insight thoughts and lessons learned from the literature reviews.

Materials for the experiment

Correct materials on this research project included many major equipment and many minor parts to comply with the design of HCNG DDF system (figure 25) that could possibly provide positive satisfy results. Below is the list of materials for this experiment and their technical specification details are shown in the table next to them.

1. Common-rail direct injection vehicle

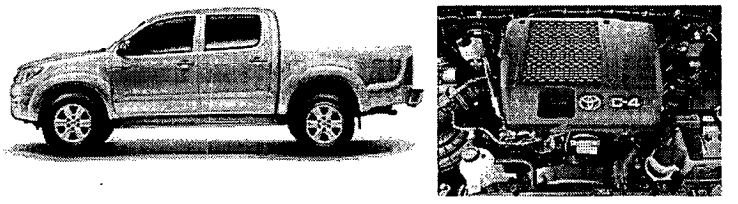

Figure 3 Vehicle with Commonrail D4D engine for this experiment

Table 5 Specification of the vehicle for this experiment

Manufacture	Toyota
Vehicle Model	2.5 J (VNT)
Outside Dimension (Length x Width x Height) mm.	5135 x 1750 x 1560
Height above ground mm	151
Inside Dimension (Length x Width x Height) mm.	1340 x 1475 x 1190
Weight	1460

2. CNG Automotive cylinder

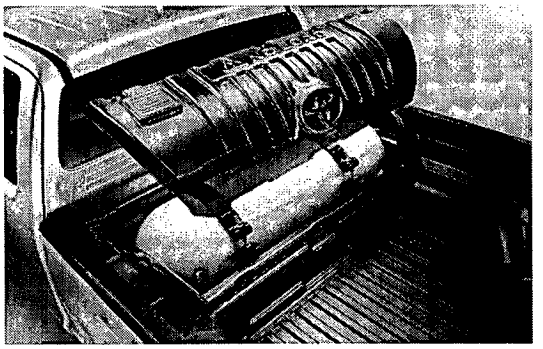

Figure 4 CNG cylinder ISO11439 standard for CNG storage

Table 6 Specification of CNG automotive cylinder

Manufacture	Zhejiang Jindun Pressure Vessel Co., Ltd.
Size	100 Liters
Material	Steel 34CrMo4
Model Number	ISO 11439
Outside Diameter	406mm
Standard	ISO11439-2000

3. CNG filling valve NGV1 profile

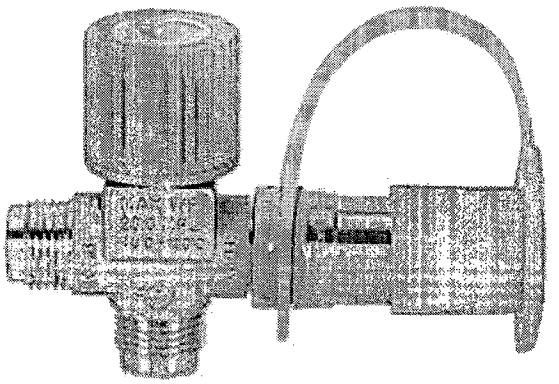

Figure 5 CNG filling valve with NGV1 profile

Table 7 Technical specifications of CNG filling valve

Manufacture	OMB
Model	APUS 1
Maximum working pressure	260 Bar
Maximum working temperature	-40 C - 120 C
Supply System	CNG
Standard	ISO 15500
	ECE R110
Power Supply	12 Volt
In Connection	M12 x 1

4. CNG Reducer

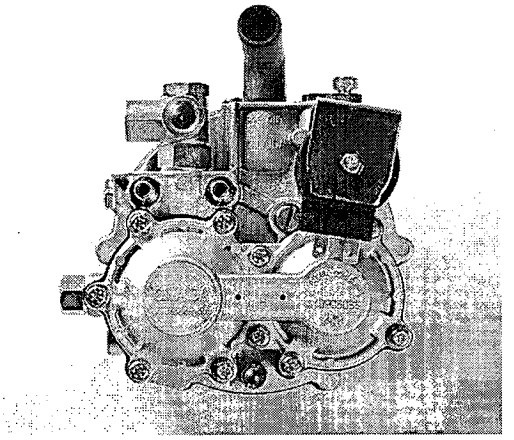

Figure 6 Three stages CNG reducer for this project

Table 8 Technical specification for CNG reducer

Manufacture	Tomasetto Achille
Model number	AT04
Dimension	154.5 x 190 x 110 mm
Material	Die-cast aluminium body, CNC machined
Type of product	CNG traditional reducer
Max. inlet pressure	26 Mpa
Coil voltage	12 V DC
Coil Power	15 W
Inlet Connection	OD 6mm M12x1
Outlet Connection	Swivel plastic pipe OD 19mm

5. CNG pressure sensor

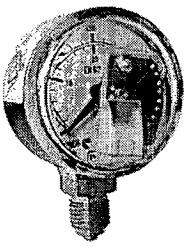

Figure 7 CNG pressure sensor

Table 9 Technical specifications of CNG pressure sensor

Manufacture	AEB
Model	806
Maximum Pressure	250 Bar
Standard	UN ECE R110
	ISO 15500
Power Supply	+12 Volts

6. CNG LED indicator

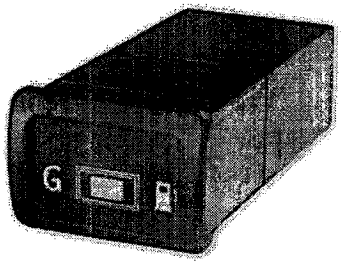

Figure 8 CNG LED level indicator in the CNG cylinder

Table 10 Technical specification of the CNG LED indicator

Manufacture	AEB
Model	706
Operating Power	DC 12V
Standard	UN ECE R110
	ISO 15500

7. CNG high pressure tube

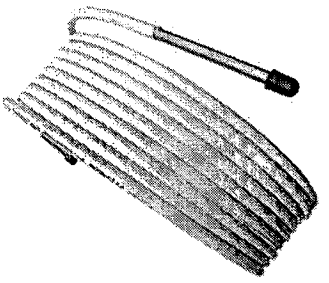

Figure 9 CNG high pressure tube for this experiment

Table 11 CNG high pressure tube technical specifications

Manufacture	OMB
Maximum working pressure	260 Bar
Maximum working temperature	-40 C - 120 C
Supply System	CNG
Standard	ISO 15500
	ECE R110
In Connection	M12 x 1

8. CNG stepping motor

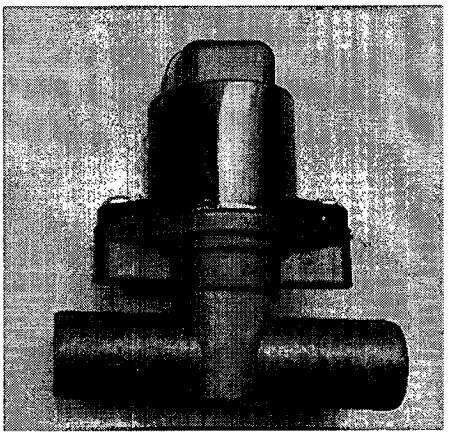

Figure 10 CNG stepping motor

Table 12 CNG stepping motor technical details

Manufacture	LAE
Model	D2
Maximum Pressure	3 Bar
Standard	UN ECE R110
	ISO 15500
Power Supply	+12 Volts

9. Electronic controlled unit for this project

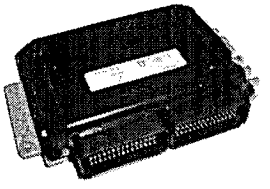

Figure 11 Electronic controlled unit for this project

Table 13 Technical details of the electronic controlled unit

Manufacture	ECOMAX
Engine Configuration	4-6 Cylinder Diesel Engine
Fueling Adjustment	Up to 440 Zone table with configurable load and RPM, TPS, MAP, MAF and options
Limits	Vehicle speed limit, Engine Temp. Limit System Voltage Limit
Processing	40 MHz Automotive Processor Ignition Control to 0.1 degree, Fuel to 0.01 ms, 32 Bit Calculation, Max 6000 RPM 10 Bit ADC Resolution
Inputs / Outputs	2 High current injector drives 4 ignition channels, 2 + 5 Volts 8 Fuel Reduction output, 8 sensor inputs
Communication	On Board USB (Tuning Port), Serial, CAN BUS
Analog Inputs	Display LCD, Wideband O2 Voltage Signal (0-5)
Idle Control	Closed Loop System Solenoid and Stepper Motor Electronic Valve

10. Electrolyzer for H2 generation and its accessories

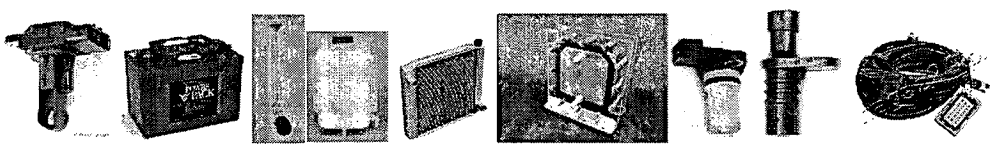

Figure 12 Various parts and sensor for the hydrogen generator for this project

Table 14 Electrolyzer and its accessories details

Manufacture	Custom made only for this project
Materials	SS 316L
Capacity	at least 0.5 liter per minute
Cooling Method	Incinerator and water membrane
Weight	5 Kg
Dimension	4 inches x 4 inches
Working sensor	Camshaft for RPM
	TPS sensor
	Acceleration Sensor
Battery	12 Volts DC
Flow rate	Measure up to 2.5 liter per minute

Testing Equipment

Testing Equipment has been chosen to meet the desire expected results in this experiment with accuracy and repeatability of at least three tests at each time. Pre-selected destination on each test are chosen to meet the require results.

1. Chassis Dynamometer

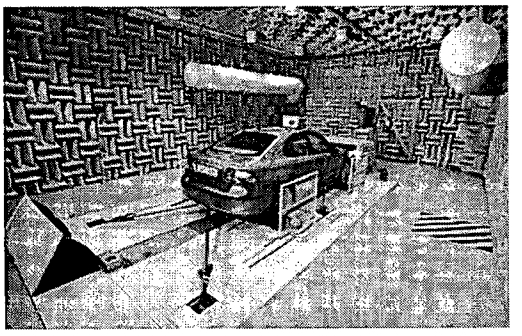

Figure 13 Chassis dynamometer

Table 15 Chassis dynamometer specifications

Manufacture	MAHA
Model	LPS 3000
Measurement Program	Display of Speed
	RPM, and oil Temperature
	Project of engine power
Standard	DIN 70020, EEC 80/1269
	ISO 1585, JIS D 1001
	SAE J 1349
Load Simulation	Constant RPM, Speed
	Tractive Force
Evaluation	Visual Display of limit value deviation
	Selection of measurement units
	(Kw/Ps/ Brake Horse power/Torque)
Printout	Clear Color printout (graphics printout)
	Performance diagrams of continuous
	and discrete measurements printable
	in tabular form, maximum values highlighted,
	selection of tabular values
Database	Storage and loading of performance diagrams
	Data import and Export
	Freely programmable load simulation profiles
	Determination of data according to vehicle type

2. Smoke meter

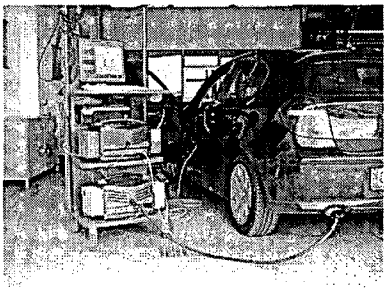

Figure 14 Smoke detector and the measuring equipment

Table 16 Technical specification of the smoke meter unit

Manufacture	MAHA
Model	MGT 5
Weight	24 kg
Test Method	Light extinction detection
Standard	SAE J 1667

3. Gas Analyzer

Figure 15 Gas analyzer stationary unit for this experiment

Table 17 Stationary automotive gas analyzer for this experiment

Manufacture	Naptune
Model	HG 540
Measuring item	HC, CO, CO2, O2, Nox
Measuring Method	HC, CO, CO2,Nox (non-disersive infrared)
	O2 (Electro Chemical)
HC	0-10000 ppm
CO	0.000-9.999%
CO_2	0-20%
O2	0-25%
NO_x	0-10000 ppm
Repeatability	Less than +/- 2% FS
Response Time	Within 10 Seconds
Warming Up time	about 5-10 Minutes

Table 17 (Cont.)

Flow Rate	2-4 L / Min
Power Supply	AC 110 / 220V, 50/60Hz
Operating Temperature	-10 Celsius to 40 Celsius
Dimension	270 (W) x 340 (D) x 165 (H) mm
Weight	5 Kg
Printer Type	Built-in Thermal Printer
Basic Accessories	Probe, Probe hose, spare fuse, Leak test cap, Dust Filter carbon filter, Operation Manual, Power cord, Printer Paper
PRM / OIL TEMP	Measurable with HRT-300

Testing Procedures

After gathering all of the chosen equipment and arrange the testing devices for data logging and measurement following the connection diagram in figure 26, the experiment would be following the procedures below under each different testing standards require in each testing programs which are the minimum requirement by the ministry of transportation in Thailand. The procedures are separated into three different parts.

Part 1 Performance test

Under this performance test, the purpose is to investigate the horsepower, fuel consumption, flow rate, torques and thermal efficiency of the engine during normal operation and HCNG operation following the connection diagram in figure 26.

The first set up is to test from idle normal diesel operation alone and speed up to the maximum rpm of the engine (approximately from 1400 rpm to 4500 rpm according to the chassis dynamometer standard) which will provide desired details for the calculation of final expected performance parameters. The expected result will provide accurate data of fuel consumption, horsepower, and torque, flow rate of diesel, brake power, air-fuel ratio and thermal efficiency of the vehicle.

The second procedure starts with running in HCNG operation with minimum pilot diesel injection in the engine controlled by the software of the electronic controlled unit by turning on the HCNG mode. The speed on the chassis dynamometer would start the test from running at the idle speed up to the maximum rpm or from 1400 rpm to 4500 rpm during the test. Once the vehicle has been accelerated, the chassis dynamometer computer system will print out both normal diesel operation and HCNG operation for future references. The test will be repeated three consecutive times for more accurate results.

Part 2 Emission Test

The emission test aims to examine the emission level from operating the vehicle under normal diesel operation and HCNG diesel dual fuel operation. The first procedure under this part is to test the vehicle with normal factory standard or under EURO IV standard which advices details require for new vehicle under category M that the chosen experimental vehicle has been classified with particular values in each emission category. The test begins with starting the vehicle under normal operation and speed the engine from idle rpm to the maximum rpm or from 800 rpm to 4,500 rpm. Once the test is done with accuracy, the computerized system will print out the results of both normal diesel operation and HCNG operation for further evaluation. The test will be repeated for 3 consecutive times for more accuracy on the expected results.

Part 3 Real road testing for fuel saving

The procedure starts from filling up full tank of normal diesel into the vehicle and drive at least 20 kilometer in distance with constant speed of 80 kilometer per hour. The purpose of this test is to determine real mass fuel consumption of the diesel engine with the chosen vehicle and compare the result with HCNG operational mode. Data recording starts with recording total kilometer, total diesel in full diesel tank and actual distance of travelling per trip in three consecutive times. And afterward, during HCNG mode; the vehicle will be filled up with CNG and H_2 will be generated while minimum pilot diesel injection will be used to start the engine. Expected results will be recorded in terms of how much diesel and CNG were consumed per trip and the data will be compared against the data from operating diesel alone.

Data collection

1. Performance parameters

The data collection of this experiment consists of 3 main parts. The first part is the performance testing which will incorporate collecting data for further analysis of the engine performance. Performance parameters such as brake horsepower, brake torque, fuel consumption, original diesel substitution, sensor values and brake thermal efficiency were designed to be measured in the most accurate manner and collect all related data for further mechanical analysis on MAHA LPS 3000 chassis dynamometer.

The fuel consumption flow rates are measuring accordingly from two flow meters and also from the chassis dynamometer in advance mode. Brake specific thermal efficiency could be calculated from fuel consumption, times, power input and power output of different fuels for further mechanical analysis of the real engine performance parameter. For the performance test, the experiment begins with mainly double checking on safety practices of both diesel operation and HCNG DDF operation ensuring no leakages of any sort of hazard and dangerous fuels were leaking during the test and afterward. Then run only in diesel mode on chassis dynamometer to collect initial data for diesel operation three consecutive times. Horsepower, torque, fuel consumption and etc. were measured in three consecutive events on pure diesel operation to ensure accuracy of correct results in this experiment. The computerize system of chassis dynamometer will print out reports on each desire performance parameter against different RPM from the lowest to the highest possible for review and references. Afterward, the vehicle will be entered into HCNG diesel dual fuel mode and will run on the same test three consecutive times while performance data were collecting for further analysis of performance between pure diesel operation and HCNG diesel dual fuel operation. The printed reports of HCNG DDF operation were collected after three consecutive tests had been done with accuracy.

2. Emission parameters

The emission test for this experiment was separated into two parts. The first part was tested with gas analyzer, Naptune HG 540, to collect all of important data of the automotive emission according to the requirement under EURO IV standard, and to examine the vehicle appropriateness for this experiment. The

computerize gas analyzer will print out reports of each emission after each test. Emission of pure diesel operation was tested three consecutive times starting from running at the lowest rpm (idle), approximately 800 rpm to the highest rpm of 4000 rpm. Printed out of the results were collected after each test had been done with accuracy. After that, emission of HCNG Diesel dual fuel operation was also tested three consecutive times from the same conditions which starting from at the lowest rpm to the highest rpm. Printed out results were collected after the all three tests had been conducted with gas analyzer with accuracy.

The second part of the emission test was smoke opacity test. Three tests were conducted with pure diesel operation and data of how much smoke in each test were recorded. Following with three more tests conducted through a smoke opacity computerized system, results of both pure diesel and HCNG diesel dual fuel were recorded and printed out for further data analysis.

3. Fuel saving parameters

Fuel saving is the key area in this research study. Accurate data collection was designed to ensure positive results and high accuracy. Data collecting started from running the vehicle with constant speed of 80 kilometer per hour on the road while collecting real mass fuel consumption during the test. Distance and actual mass fuel consumptions were measured and collected with printed out receipts from the filling stations of both diesel and CNG, while for the electrolyzer; purified water was added only 600 ml. at the beginning and it lasted until the end of the test.

The test began with running the chosen vehicle on pure diesel operation in three different distances and measured real mass diesel consumption in each diesel filling station for further data analysis on fuel saving. Afterward, with double checking on the HCNG diesel dual fuel operation; the same tests were done three consecutive times. Mass fuel consumptions were collected again at both filling stations for diesel and CNG real mass consumption for further fuel saving analysis. Once the results were satisfied and assured of accuracy, the fuel savings would then be ended with highest accuracy and great results for further analysis.

Data Analysis

The data analysis of this experiment consists of three parts. The first part is analyzing performance characteristics of using HCNG in diesel engine or turning normal diesel engine into HCNG diesel dual fuel. The second part is analyzing HCNG effects on emission level whether it will be within the require standard of EURO IV or it will produce undesirable results to the environment. The third part is the on-road experiment which was conducted in real situation with actual results that could later be developed into a newer version of fuel at the filling stations or new development in aftermarket devices option which could then be an option for automobile owners to operate their vehicle in the most affordable fuel saving manner in the near future.

The first part is to analyze data of the performance tests in both diesel and HCNG diesel dual fuel against the tested chassis dynamometer RPM. The printed out reports from the computerized chassis dynamometer were examined to provide indicators on the performance aspects of this experiment. Measurements of horsepower, torque, diesel substitution, sensor values and brake thermal efficiency were used to analyze the results. The average result will be an indicator which can be summarized into performance indicator for further suggestions, recommendation and conclusion.

The second part is to analyze emission levels and smoke opacity. Printed reports from gas analyzer and smoke opacity meter provided values of emission levels. These values showed emission levels accurately because both tests were conducted in three consecutive times. An average of all three tests was concluded in each emission parameters for further suggestion, review and recommendation.

Lastly, fuel saving analysis shows exactly the values of how much mass fuel consumption in each three tests was used during the test. It could be a real indicator whether HCNG diesel dual fuel would be appropriated for the new generation of dual fuel system for diesel engine. Results recorded from the test would show exactly the distance travelled by the vehicle and how much diesel had been consumed in each given time frame at the same speed, loads and distances.