THE UTILIZATION OF CNG IN MASS TRANSPORTATION

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1. INTRODUCTION

The natural gas has been used as fuel for transport vehicles for quite some time. Many countries such as Canada, U.S.A., Austria, Italy and New Zealand have been using natural gas as fuel for both stationary and vehicular applications in internal combustion engines. The natural can be considered to be the fourth most common vehicular fuel after gasoline, diesel and liquified petroleum gas (LPG). It is a lighter-than-air gaseous fuel and it can not be liquified in an uncontrolled ambient. It has to be stored in a compressed form so that its volume can be conveniently handled. The storage pressure is normally about 16 MPa (2,400 psi) therefore it is known as "compressed natural gas (CNG)". When CNG is supplied to the engine, its pressure has to be reduced to a suitable level depending on applications.

The utilization of CNG on vehicles operation has many advantages. There are:

1. It burns more efficiently than liquid fuels.
2. It produces less environmental pollutants,
3. It is safer because the lighter-than-air property allows rapid dispersion when leakage occurs.
4. The lower flamability limit of 5% (in comparison to 1.5% for LPG) means that it is less probable for the leaking natural gas to ignite.
5. The engine life is longer since there is no lublicant dilution.

6. The engine operation can be very efficient and smooth when the natural gas is properly used.

7. It costs less than any other vehicular fuels used at present.

However, there still exist some disadvantages in using the natural gas as a vehicular fuel. There are:

1. It is not readily marketed since it is only available in the vicinity of the main gas pipelines.

2. CNG cylinders require suitable location and space for installation. They inevitably reduce the luggage space and also add extra weight to the vehicles.

3. Training programs have to be conducted since such technology is not readily available.

In view of the country economy, the natural gas utilization in vehicles is desirable for the following reasons.

1. There exists a redundant supply of natural gas in Thailand with relatively dim prospect for exporting as liquified natural gas (LNG).

2. There is a need to diversify fuel sources in the transport sector. At present, our national refineries are facing with a problem of excess demand in diesel fuel while gasoline is over-supplied.

3. Thailand will be less dependent on the imported fuels for vehicular use.

4. The low cost of CNG will definitely reduce the operating cost of BMTA and make it to be profitable.

The above benefits were recognized and the feasibility studies on the CNG utilization for BMTA buses have been established under the guidance of Dr. Boontium Khamapirad (Deputy Minister for Communication at the time of this project initiation). This program is now under the management of the Bangkok Community Development Project. The objective of this report is to study the utilization of the natural gas to substitute diesel fuel in the BMTA buses.

2. BACKGROUNDS

CNG has been used as a vehicular fuel in many countries as mentioned above. Many other countries are now trying to substitute CNG for the petroleum-based fuels. For examples, Burma and Bangladesh have also planned to use CNG in public transports.

There are two methods that the natural gas can be utilized in internal combustion engines.

1. Monofuel Engine: The entire fuel supply is natural gas. The combustion is initiated by a spark plug in the same manner as in the spark-ignition engine.

2. Dualfuel Engine: Two different fuels are used at the same time. The engine characteristics can be that of the spark-ignition engine or the compression-ignition engine. In case of Thailand, only compression-ignition engines are used with CNG and diesel. There are two following systems.

a) CNG Assisted Diesel Engine: This type of system uses diesel fuel as the main fuel. CNG is supplemented for a more complete combustion particularly during full-load operation. The combustion characteristic is almost the same as the diesel engine. CNG supply at full load is 40% and less for part load.

b) Pilot Injection Engine: This type of system can result in a more diesel substitution of up to 70%. The natural gas is supplied as the main fuel while the diesel fuel is used as a combustion initiator.

Advantages of the monofuel engine over the dualfuel counterpart are as follow.

1. It operates more quietly since the combustion characteristic is the same as the spark-ignition engine.

2. There is less chance of improper fuel metering and supply.

3. As a result of a more complete combustion, less environmental pollutants are emitted.

4. The diesel fuel is completely substituted by the natural gas.

5. It has longer life since there are less engine stresses, less vibration and no lubricant dilution.

Dualfuel system may be considered to be suitable in a certain application because of the following advantages.

1. It is more flexible in respect to the fuel supply. If there should be an interuption of the natural gas supply, the dualfuel engine can always be switched back to use diesel fuel.

2. The fuel containers are lighter.

3. The conversion of existing diesel engines is simple since it needs no extensive engine modifications.

In spite of the many advantages of the dualfuel engine over the monofuel counterpart, the most suitable engines for the BMTA buses should be monofuel engines. However, it is not possible to convert all BMTA buses to use CNG because of the strategic unsuitability. It is estimated that about 500 buses (out of 5,000 buses) of the BMTA fleet can be converted to use CNG with no appreciable loss of free mileage. The cost of diesel-to-CNG engine conversion is estimated to be about 120,000 Baht depending on the models of the original diesel engines.

Several organizations both in the private and govermental sectors have paid serious attention to the study on the CNG utilization. The Bangkok Community Development Project has done the feasibility studies since 1985. The Petroleum Authority of Thailand (PTT) has also investigated the possibility of using CNG in the transport sector with some success. The National Energy Administration has persued several studies in the natural gas utilization including the possibity of expanding the gas pipelines. All these efforts are aimed at the utilization of CNG in mass transportation.

In view of natural gas refueling stations, a pilot refueling station was successfully established at the Southern Bangkok Power Plant with a technical assistance from the New Zealand goverment in 1985. The purpose of this station was to refuel the experimental fleet of 11 CNG buses. Since 1986, the refueling station has been moved to Teparak Road, Bang Pli, Samut Prakarn.

3. ENGINE CONVERSION

Importing custom-built CNG engines is not economically suitable because they can be locally converted from the existing diesel engine. Therefore, it is not necessary to modify the rest of the bus. We shall discuss only the diesel-to-CNG monofuel engine conversion in this report.

The diesel engine, has high compression ratio. Thus, it can not use CNG as fuel without some internal engine modifications. The fuel supply system is entirely different. The diesel injection system has to be replaced by CNG fuel supply system. Figure 1 shows a schematic diagram of the CNG fuel system of a typical BMTA bus. The engine conversion consists of the following steps.

1. Lowering the Compression Ratio: This is done by increasing the clearance volume of the combustion chamber. In practice, it has been found that it is more convenient to machine off the piston head than to modify or redesign the cylinder head. In doing this, only the pistons are disassembled from the engine while the cylinder block can be left untouched. The compression ratio is reduced from 17:1-25:1 to about 13:1

2. Modification of the Cylinder Head: The fuel injectors must be removed from the cylinder head so that spark plug adaptors can be installed. In the case of the indirect injection diesel engine, the precombustion chambers have to be forced out.

3. Replacing the Fuel Pump with the Distributor: The gasoline engine distributor can be coupled to the fuel pump shaft with an adaptor. This is probably one of the most critical parts of the modification procedure since the diesel engine block has not been designed to accommodate such installation.

4. Installation of the Gas Carburetor: The gas carburetor can be installed on the inlet manifold with a suitable adaptor. Custom-made accelerator linkages are needed for the air control

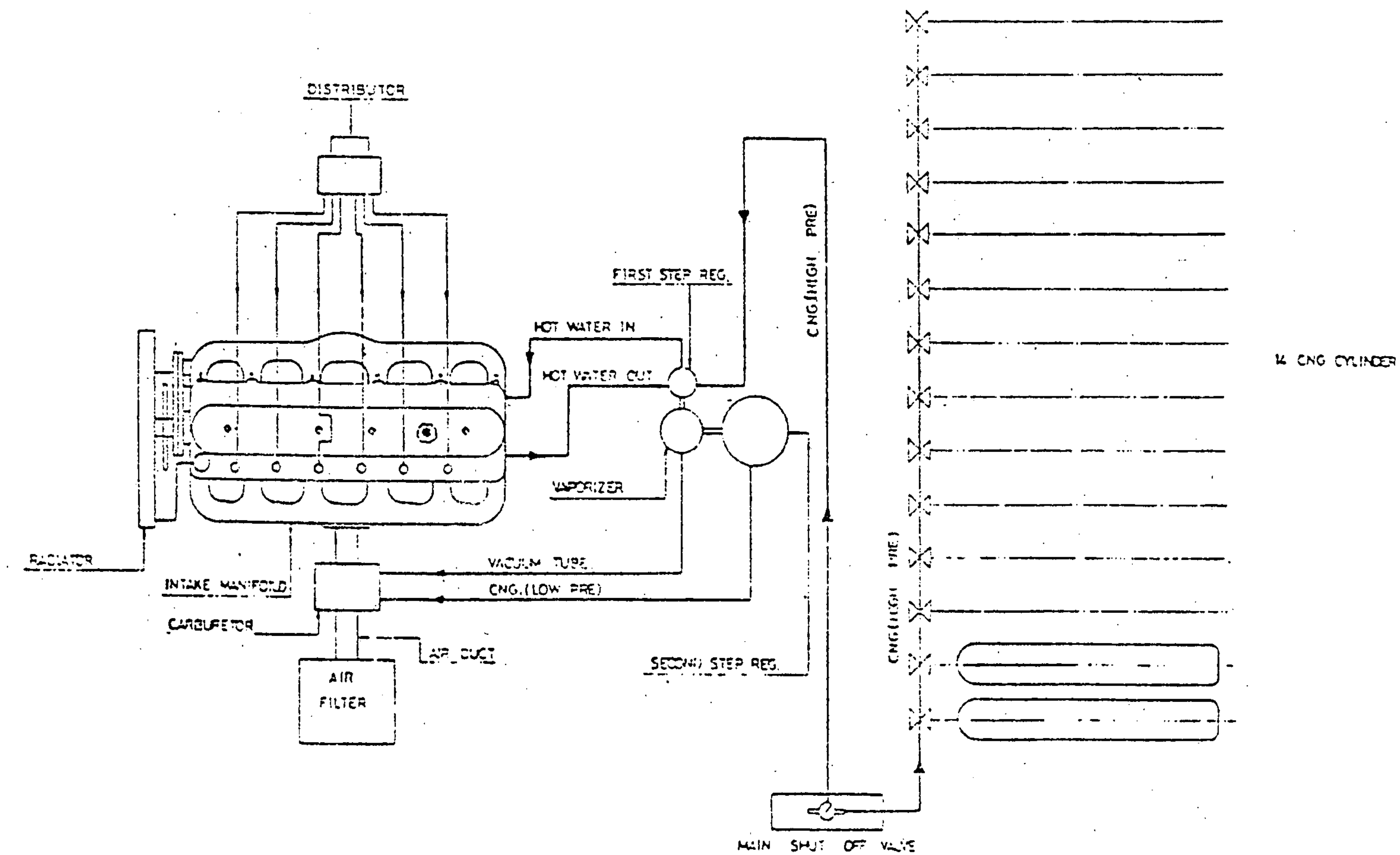


FIGURE 1

NO	ITEM		MATERIAL	SIZE	QN
DRN	PIRAPORN KONKHUM			DATE	DWG. NO
CHK				20/10/85	C0/1
DSN					
APP					
SCALE	CNG fuel system			DIMENSION	

[illegible] COMMUNITY DEVELOPMENT PROJECT.

valve.

5. Installation of the Pressure Regulators: Pressure regulators are needed to reduce the pressure of CNG before it can be supplied to the carburetor. There are two stages of reductions. The first stage reduces the pressure to about 1 MPa (150 psi) and the second stage reduces it further to about 0.1 MPa (15 psi) or a little below depending on the type of carburetor. Heat is required for these pressure reductions. This heat is supplied from the cooling water that circulates through the first-stage pressure regulator while the second-stage pressure regulator can adequately extract heat from the surroundings. These regulators should be installed in the engine compartment so that the cooling water can be conveniently supplied from the engine block.

6. Installation of the CNG Cylinders: The cylinders are installed underneath the bus body. Figure 2 shows a schematic diagram of this installation in which the heavy cylinders must be properly distributed. The imbalance can effect the bus controlability and its pay load distribution characteristic.

7. Piping of the Gas Lines: Gas lines on the high pressure side (see Figure 1) must be seamless and made of stainless steel 316 that can stand a pressure of 22.5 MPa (1.5 times the working pressure or 3,600 psi). The gas lines with diameter of 8 mm is quite adequate for the fuel supply of a 200-HP engine or less. All other fittings must be compatible with these gas lines. The pressure tests of the gas lines are essential to assure safety. They are normally done by applying high pressure kerosene or diesel oil into the system. The oil pressure will drop if there

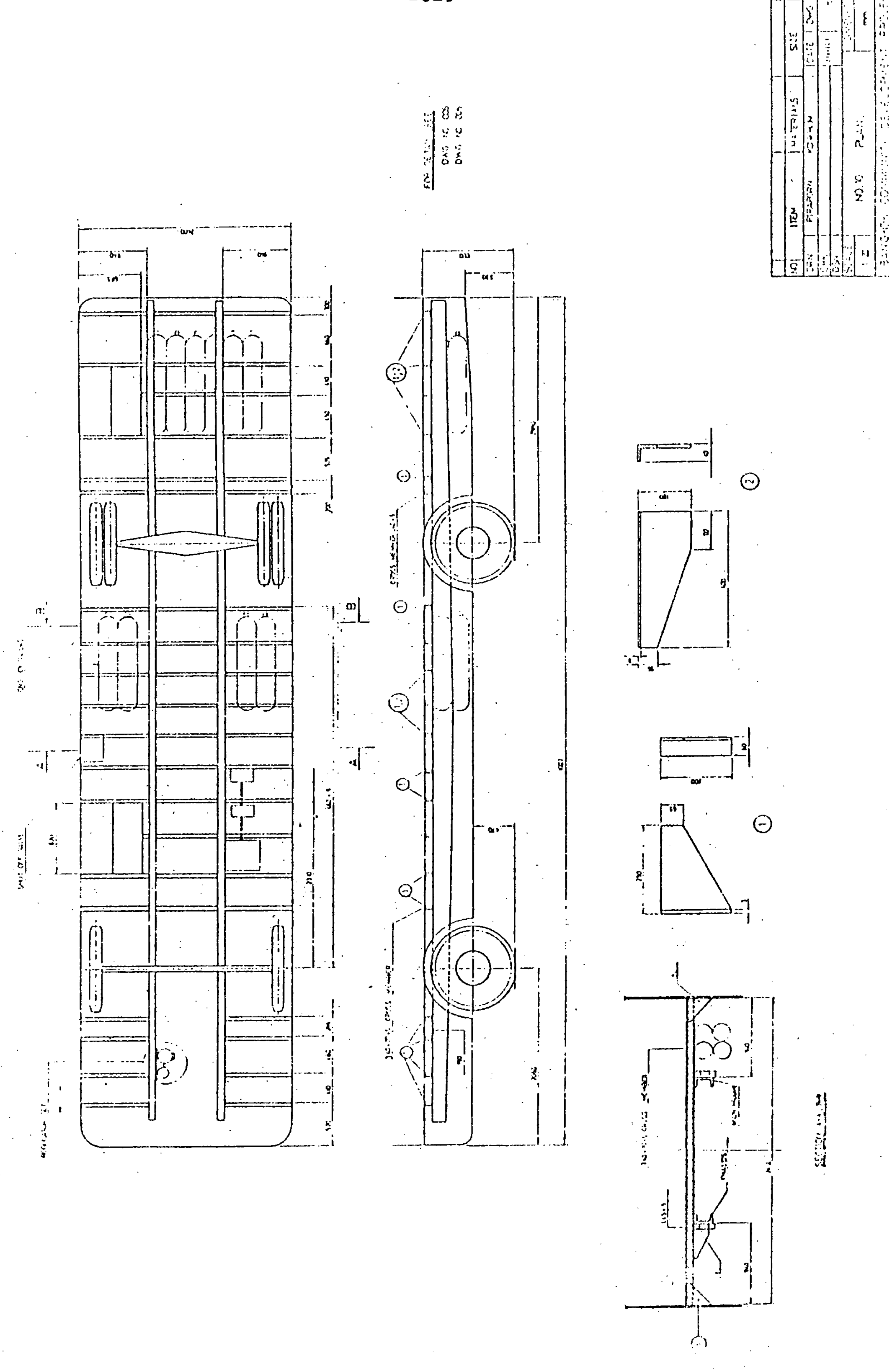


FIGURE 2

are any leakage in the lines. Piping of the low pressure side (see Figure 1) can be done in the same manner but with a lower test pressure.

8. Laboratory Engine Tests: The engine should be tested on a dynamometer before it is installed on the vehicle. Firstly, the distributor advance curve must be adjusted to give the optimum timing at all speeds. This is where a serious mistake can be made. An improper spark advance can decrease the engine performance significantly and cause serious engine damages from detonation and overheating. In the past, the improper ignition timing has been overlooked resulting in burnt piston, cracked cylinder head, engine overheating and piston seizures. The optimum timing at different speeds and loads can be determined on the dynamometer by varying the timing while keeping all other parameters constant. A typical spark advance timing curve for a converted Hino EH100 engine is shown in Figure 3. Secondly, the fuel-air mixture must be adjusted on the dynamometer. A rich mixture results in an incomplete combustion and a high exhaust temperature while a lean mixture leads to misfiring and engine overheating. The mixture should be adjusted so that the engine performance is equal to that of the original diesel engine. Unless a better cooling system is provided, the engine should not be adjusted to produce more power than the original diesel engine. Figure 3 also shows performance curves of a converted EH100 engine. They are similar to those of the original EH100 diesel engine as shown in Figure 4. Figure 5 shows carbon monoxide and hydrocarbon concentrations in the exhaust of the same converted engine which are low in comparison to the gasoline

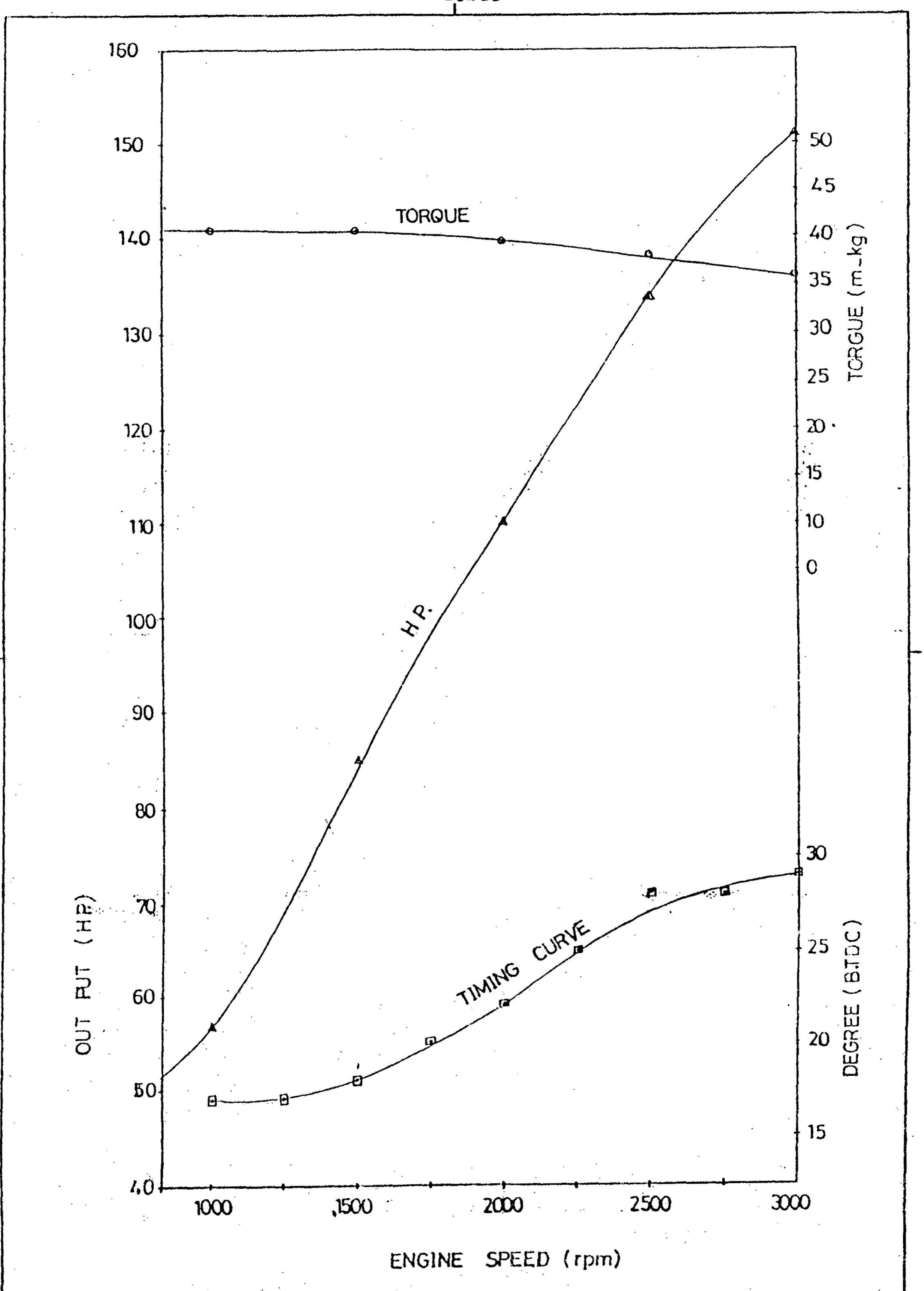

160
150
140
130
120
110
100
90
80
70
60
50
40
TORQUE
H.P.
TIMING CURVE
50
45
40
35
30
25
20
15
10
0
TORGUE (m-kg)
30
25
20
15
DEGREE (B.T.D.C)
OUT PUT (H.P)
1000
1500
2000
2500
3000
ENGINE SPEED (rpm)

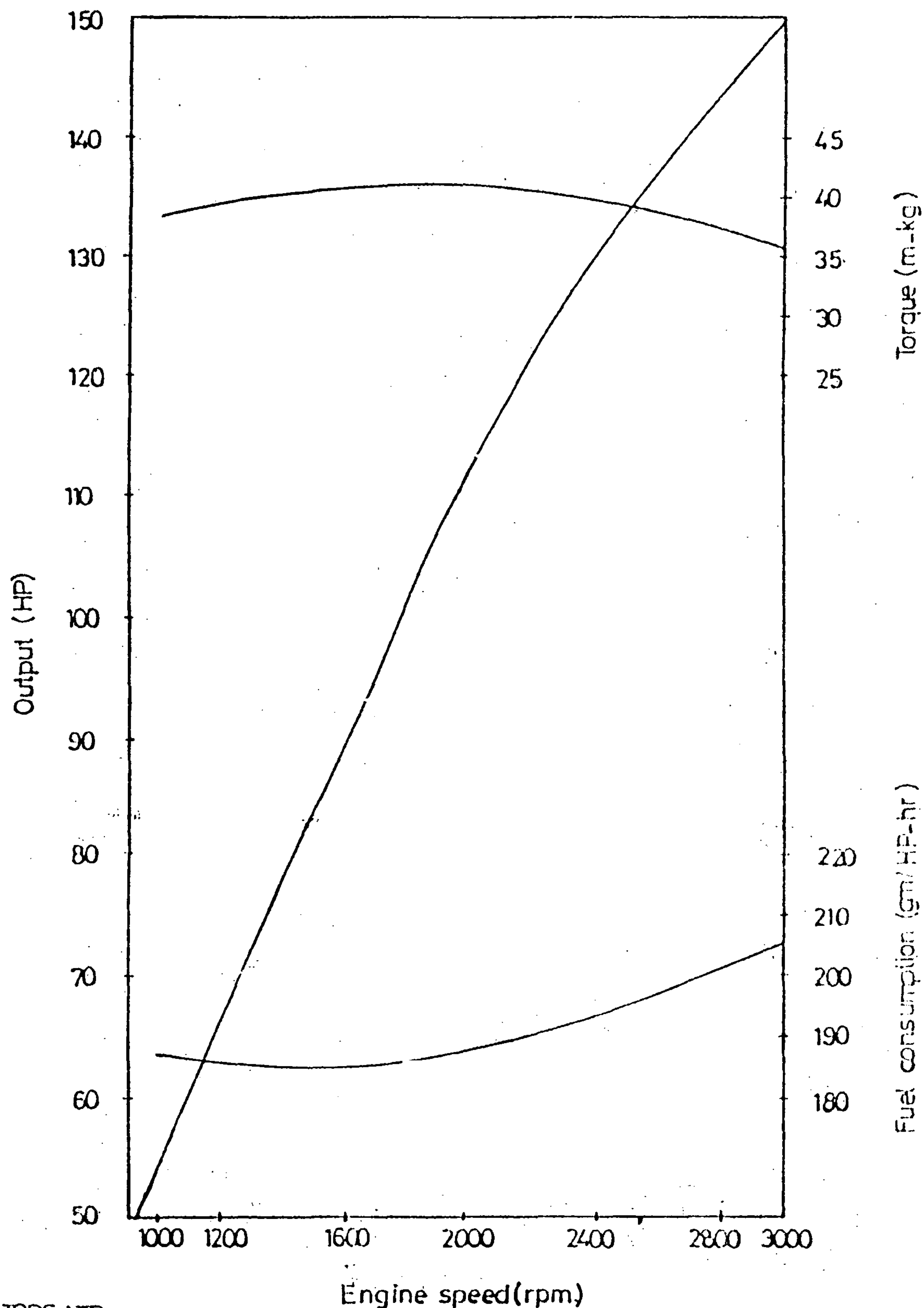
FIGURE 4

PERFORMANCE CURVE OF EH 100 ENGINE

DATA SHEET
NO. TEP-044

ACCORDING TO S.A.E

Max output 150 HP/ 3000 rpm.
Max torque 41 m-kg/2000 rpm.
Min fuel consumption 185gm/HP-hr/1400 rpm.



HINO MOTORS.LTD.

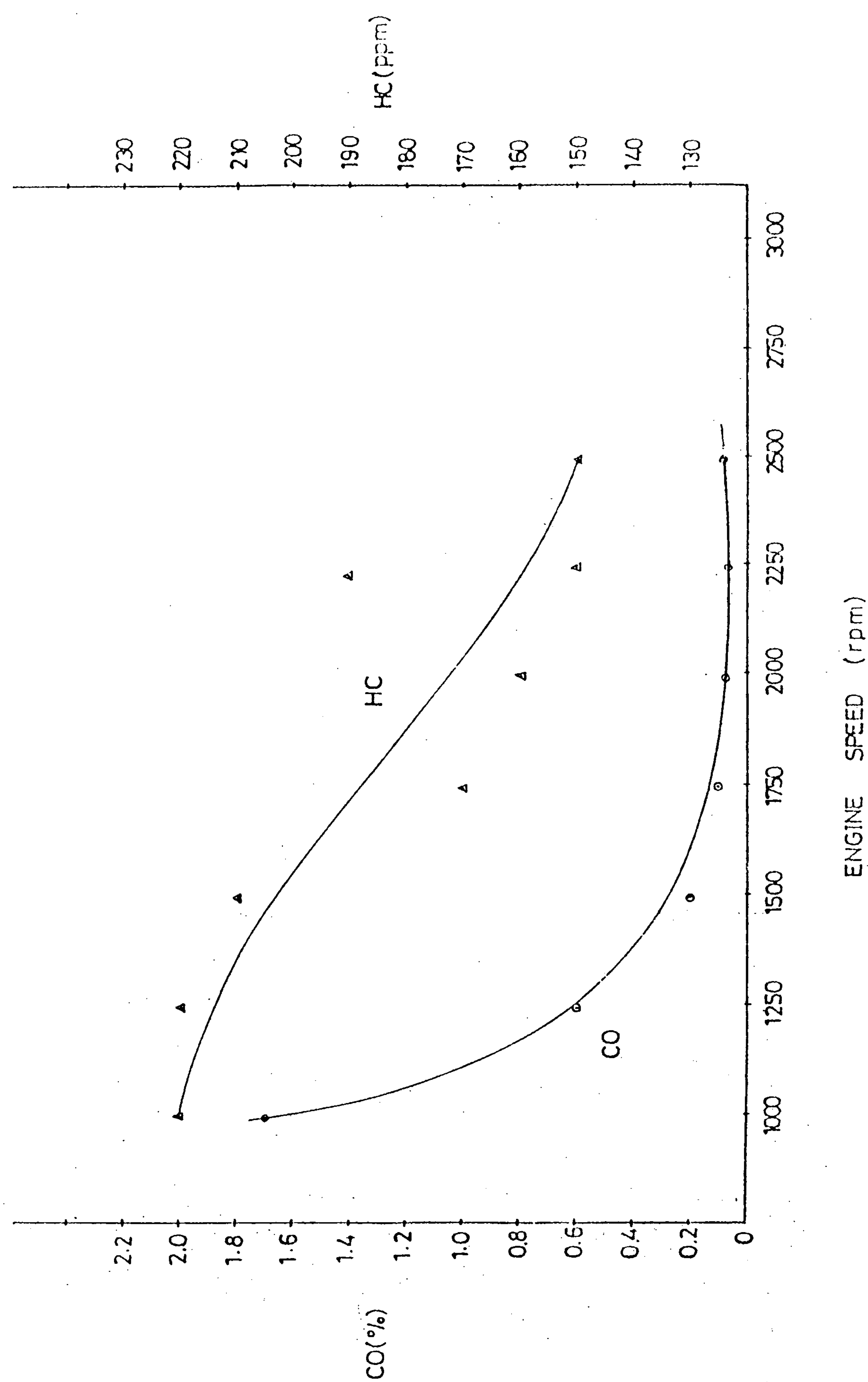

HC (ppm)
230
220
210
200
190
180
170
160
150
140
130
3000
2750
2500
2250
2000
1750
1500
1250
1000
HC
CO
ENGINE SPEED (rpm)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
CO(%)

FIGURE 5

and diesel engines. However, the concentration of nitrogen oxides is expected to be high but a nitrogen oxide gas analyser was not available at the time of these tests.

9. Road Tests: After all the installations and modifications are complete, the vehicle should be road tested to see if there are any unforseen problem.

4. EXPERIMENTAL CNG BUS FLEET

In 1985, the first five BMTA buses were converted to use CNG with financial and technical assistances of the New Zealand government. Six additional buses were thereafter converted locally by Thai engineers. These buses were test run on regular BMTA bus routes for about four months in 1985. It was initially concluded that no major technical problems were detected. By the end of 1985, many unexpected engine damages were observed. The engineering team of the Department of Mechanical Engineering, Kasetsart University, was consulted and invited to investigate the case. It was found that all unexpected damages were caused by detonation due to an improper ignition timing and a mechanical defect in the distributor drive train. These problems were finally solved and the buses were road tested again on both regular BMTA bus and long-distance routes for 10,000 km. It was concluded in March, 1986, that the CNG bus fleet can be operated without CNG-related problems.

In June, 1986, a fleet of only four buses was again put into regular services. The buses were powered by converted Hino EH100 engines with the output of 150 HP at 3,000 rpm. During the test run in normal Bangkok traffic conditions both mileage and amount of fuel were monitored. After two months, the average fuel consumption of the fleet was calculated to be 2.5 km per cubic metre of natural gas at standard condition (25 deg. C and 0.1 MPa).

According to BMTA figures collected at various bus depots, the average fuel consumption of the diesel buses is, surprisingly, 2.5 km per litre of diesel fuel. In term of energy contents, one litre of diesel fuel contains about the same amount of energy as one cubic metre of natural gas at standard condition (35,186 BTU per litre in comparison to 37,700 BTU per cubic metre). Therefore, the thermal efficiency of the CNG engine is apparently higher than that of the diesel counterpart since each CNG bus has to carry approximately 600-800 kg of extra weight.

The inferior efficiency of the diesel engine can be explained by the fact that most BMTA buses are overloaded. When the diesel engine has to work harder than what it was designed for, an extra amount of fuel has to be injected. This additional fuel can not be completely burnt with a limited amount of air in the combustion chamber since there is not enough time for the fuel to mix with the air. Consequently, there are some diesel fuel droplets that are not oxidized but they are heated to form fine carbon particulates called "smoke". Unlike the diesel engine, The CNG engine makes use of almost all air available since the fuel has more time to form a homogeneous mixture before entering the combustion chamber. Therefore, the CNG engine of the same volumetric capacity as that of its diesel counterpart can produce more power without impairing the fuel consumption. It should be noted that if the BMTA buses used larger diesel engines, the fuel consumption would probably decrease because the engines would work at full load less often.

5. ENGINE PERFORMAMCE AND MAINTAINANCE

During the test run, only buses with HINO EH100 engine blocks were used because they represented typical buses that are owned by BMTA itself. Two of the converted EH100 engines were adjusted optimally on the dynamometer. The CNG engine performance was adjusted to be slightly higher than the diesel engine to compensate for the extra weight of the CNG bus. However, the CNG engine could be tuned to give more power than the diesel engine if the natural gas supply to the engine was not limited by a mixture control valve of the carburator. The CNG engine performance would reach its peak with an elevated exhaust temperature of about 720 deg. C which is quite high but toleratable. When the CNG engine was operated at its peak, the cooling system proved to be inadequate since it was not designed to accomodate such a high output and a larger radiator was needed. At maximum output operation, the engine life would probably be significantly shortened. Considering all these problems that may follow, it was decided to adjust the CNG engine performance to be compatible with the diesel counterpart.

Since CNG and gasoline engines are the same type of internal combustion engines, maintainances are quite similar. The CNG engine needs to be tuned up periodically although less frequently than the gasoline engine. During the 10,000-km test run, the CNG engines proved to be reliable and needed less attentions than the gasoline counterparts. The tune up procedure for the CNG engine is not different from the gasoline engine. In general, the following important parts need to be periodically replaced and/or adjusted.

1. The contact point of the distributor needs to be replaced every 20,000 km. Its gap must be adjusted every 5,000 km.

2. The spark plug gaps need to be readjusted every 5,000 km and replaced every 20,000 km.

3. The oil level should be checked every 1,000 km or less. The oil and filter change of every 10,000 km is generally longer than the gasoline and diesel engines because there are less lubricant dilution and less impurities to washed out by the lubricating oil. After 10,000-km use, the lubricating oil was analyzed by PTT and found to be in a useable condition.

4. In moderately dusty atmosphere, the air filter needs to be replaced every 5,000 km.

5. The rotor, cap and high tension wire of the distributor need to be replaced only when they are damaged.

At the end of the 10,000-km test run, the four engines were disassembled to be examined for possible damages and the levels of wears. It was found that, in general, wears were smaller than those in the gasoline and diesel engines. The general conditions of the CNG engines after the 10,000-km test run are described in Table I. Wears of the journals and bearings were almost undetectable. The piston ring gaps were widened on an average of 0.15 mm due to the wears of the pistons and the rings themselves. In contrast, the valves wore out about twice as much as those in

Table I Summary of the Engine [a] Conditions After the 10,000-km Test Run

Parts	Conditions
Pistons	Clean due to complete combustion, no scrapes, some scalings on the piston heads due to burnt oil from valve guide leakages.
Piston rings	No appreciable wears, the ring gaps widened by by an average of 0.15 mm and no apparent ring groove wears.
Valves	No sign of burns, breaking or sticking but pitted due to excessive heat especially the exhaust valves.
Valve guides	No abnormal wears.
Spark plugs	Clean, no sign of abnormal wears, burns or preignitions.
Cylinder heads	No cracks due to unusual heat concentrations except for a Hino EH 100 engine [b].
Cylinders and cylinder blocks	No abnormal scratches or scrapes on cylinder walls due to efficient lubrication, no appreciable bore wears and no apparent warping.
Journals and Bearings	Practically the same as before.
Engine oil [c]	In useable condition with no apparent diluents [d].

[a] Isuzu GBD1, Isuzu DA640 and Hino EH100.
[b] During the test run, the engine was overheated due to radiator hose leakages. The cracks appeared around valve seats and spark plug holes where heat concentrations occured.
[c] SAE 40
[d] The analysis was done by PTT.

Table II Results of Interviews

Prefer CNG over diesel	63
No preferences	31
Prefer diesel over CNG	6

the diesel counterparts. This is due to the fact that the valve temperature of the CNG engine is generally higher than that in the diesel engine. The natural gas enters the engine through the inlet valves in a gaseous form therefore it has a small cooling effect to the cylinder head and the valves. Unlike the natural gas, the diesel fuel is injected into the combustion chamber as liquid droplets and they have to absorb heat from the combustion chamber wall and valves to evaporate. Thus, the temperature of the diesel engine valves is lower than those in the CNG engine. It is concluded that the CNG engine life can be at least 100,000 km more after conversion without a major breakdown or maintainance except for the cylinder head.

6. SAFETY

The CNG buses were test run on regular BMTA bus and long-distance routes and no CNG-related accidents were reported. Installations of all gas equipments have been conformed to the New Zealand Standards. Accidents that can possibly occur are:

1. Gas Leakage: The natural gas is nontoxic but one can suffer from suffocation if it replaces air. A fire hazard may occur if the concentration of the natural gas is more than 5% by weight. However, in the case of the BMTA buses, accumulation of the natural gas is quite unlikely since it is a lighter-than-air gas. Thus, it should not accumulate in an open-type bus.

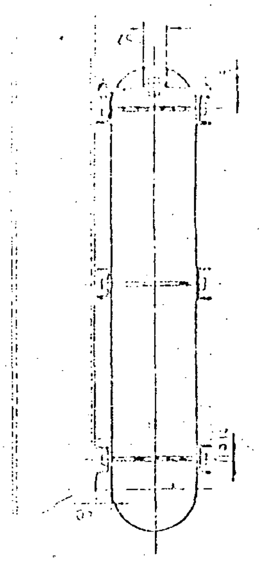
2. Explosion: An explosion can occur as the consequence of mechanical failures. Since the natural gas has to be stored at a very high pressure, the explosion may cause considerable damages.

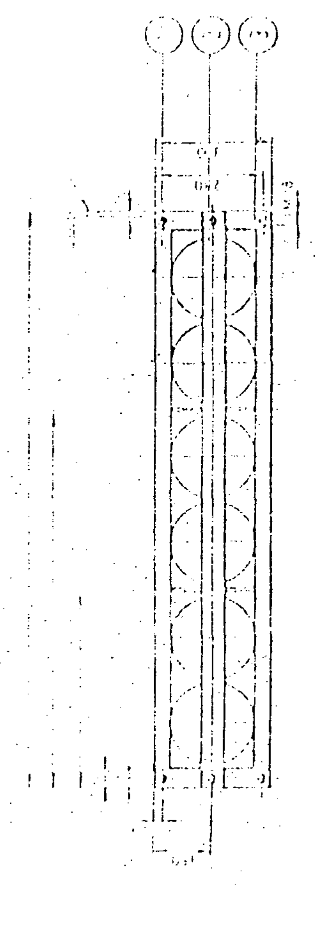
The safty measure in this respect has been assured by the pressure vessel test code. All CNG cylinders have to be hydrotested at 1.5 times the working pressure (22.5 MPa). General inspection and hydrotesting of the cylinders are normally done in five years following the initial service date and every three years thereafter. An explosion protection is also assured by a "burst disc" which is installed at the cylinder inlet valve. If there should be an accidental pressure rise, such as in the case of fire, the burst disc would rupture to relieve the pressure. During such accident, there may be a fire hazard but it should be less damaging than the explosion.

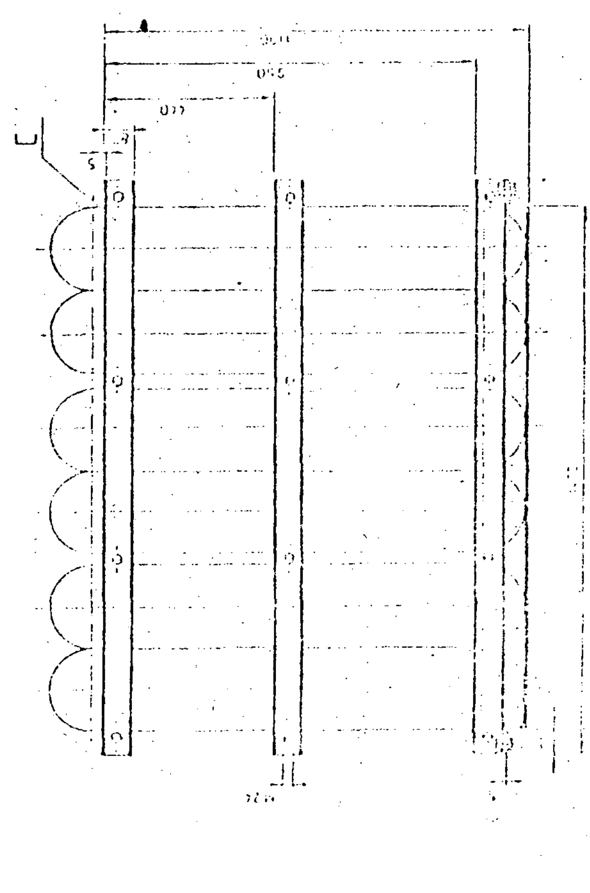
3. Handling Deterioration: One possible danger of the CNG bus is the handling deterioration of the vehicle due to the extra weight of the fuel cylinders and their distributions. It has been experienced during almost one year of experiments that there was no problem in vehicle handling. In fact, the bus operators feel that they actually can handle the CNG buses better than the diesel counterparts. This is probably due to the smoothness of the engine operation.

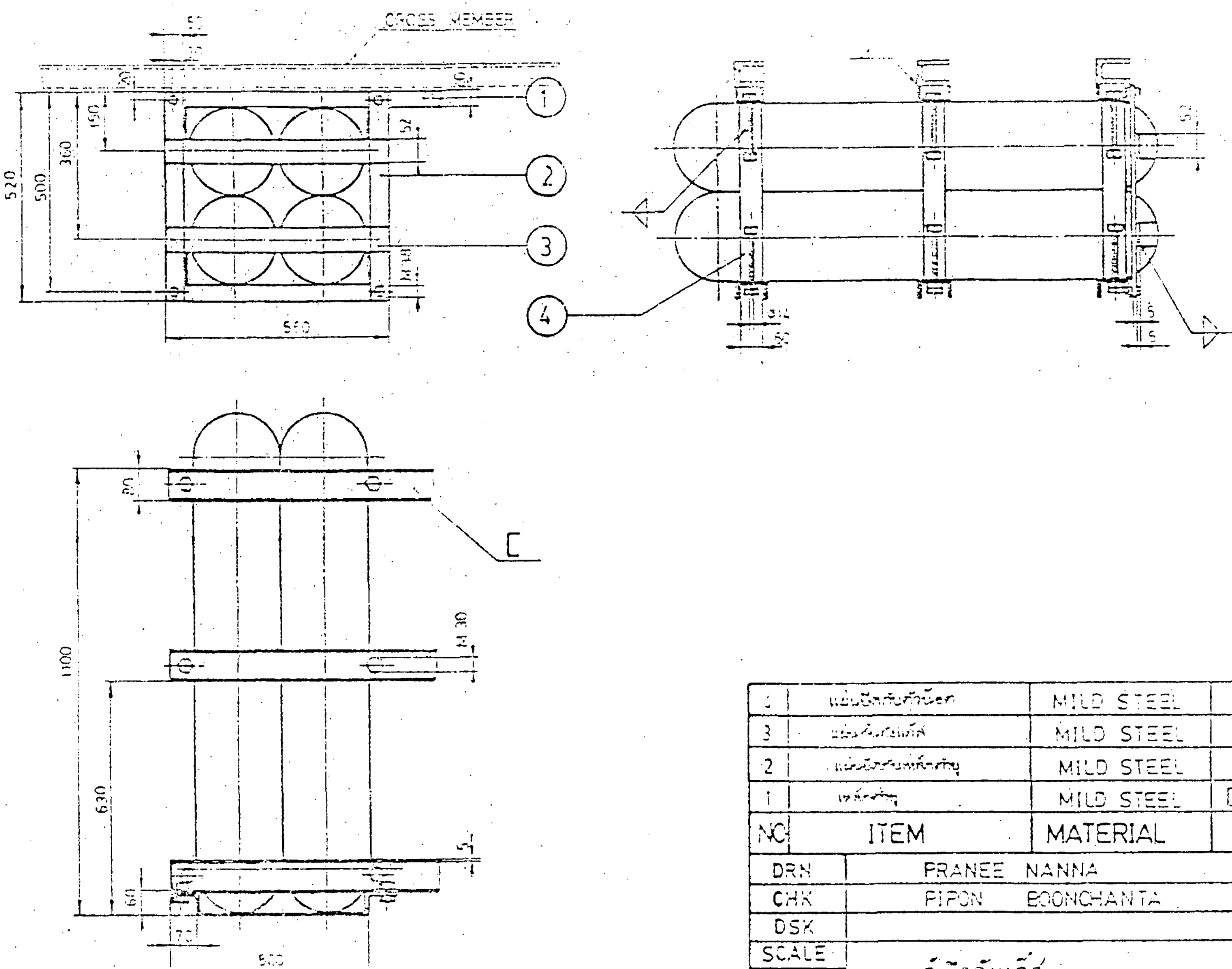
The CNG cylinders are mounted underneath the bus by strapping them to the chassis as shown in Figures 5 and 6. Straps were designed such that they are as strong as the substructure. The cylinders are seamless and probably the strongest components of the bus. They should stay intact in a series of collisions. Valves and gas lines as well as other high pressure components were installed where they can be protected from the possible impact. The high pressure lines were strapped to the chassis at every 0.5 m. Out of the eleven experimental buses, six buses were

3	[illegible]	MILD STEEL	5.350.5	2
2	[illegible]	MILD STEEL	[illegible]	1
1	[illegible]	MILD STEEL	[illegible]	[illegible]
NO	ITEM	MATERIAL	SIZE	QTY









NO	ITEM	MATERIAL	SIZE	QNT
4	แผ่นยึดกันหัวน็อต	MILD STEEL	60.560.5	6
3	แผ่นกั้นถังแก๊ส	MILD STEEL	55.700.5	2
2	แผ่นยึดกับเหล็กฉาก	MILD STEEL	5.560.5	7
1	เหล็กฉาก	MILD STEEL	[50.40.40	6

DRN	PRANEE NANNA	DATE	DWG NO
CHK	PIPON BOONCHANTA	27/5/95	005
DSK			
SCALE	ที่ยึดถังแก๊ส	DIMENSION	
1:10		mm	

BANGKOK COMMUNITY DEVELOPMENT PROJECT.

FIGURE 7

equipped with high pressure oxygen cylinders as fuel storage cylinders. In spite of their high weight-to-capacity ratio (130% of the specially-built CNG cylinders), they have shown to be more reliable than the special CNG cylinders. They can be purchased locally at a low cost of about 1,800 Baht per unit of 40 litre capacity which is less than half of the special CNG cylinders with the same capacity. Their total weight including relevant structural parts is about 800 kg in comparison to 600 kg for the special CNG cylinders.

The 1-1/2-year experience on the CNG bus fleet operation has proved that safety measures have been quite adequate. During the period, the buses were used both on the regular BMTA bus routes and on the rugged conditions of rural roads. No mechanical failures that threatened the safety of human lives occured. Small gas leakages at the gas line fittings due to unskillful maintainances were detected a few times but they were not harzardous. These leakages at the fittings were due to an unskillful use of fittings during the course of maintainance. Fuel cylinder valves also failed after repeated use because they were designed to be use for servicing only.

Interviews of 100 CNG bus passengers with respect to CNG safety have been in the positive direction as shown in Table II. There were few objections to the CNG buses, in fact, many people prefered CNG buses to diesel buses due to the quietness and the comfort of the CNG buses. Those who paid little attention felt no difference. A few prefered the diesel buses over the CNG buses for reasons that there was less chance of fire hazard.

At the time of this project initiation, many people had negative impression on the gaseous fuel because they consider it to be too flamable. This impression was confirmed by a series of LPG accidents due to improper handlings. It has been one of the objectives of this project to show the general public that the gaseous fuel can be handled with a high degree of safety. These interviews indicate that the attitude of the public has leaned toward the positive side of CNG use in vehicles.

7. PRIMARY ECONOMIC STUDIES

Although using CNG is primarily intended for solving the air pollution problems in Bangkok metropolitan area, economy is the consequence. Whether using CNG has the cost benefit over diesel is still widely debated. Careful investigations and considerations are needed before any conclusion can be made in this matter. At the time of writing this report, the prices of the natural gas and diesel fuel are 70 Baht per million BTU and 6.30 Baht per litre respectively. The energy content of diesel fuel is approximately 35,186 BTU per litre. Therefore, the cost of energy per million BTU for diesel can be calculated to be 179 Baht. The cost advantage factor of the natural over diesel fuel is 2.56.

The natural gas for vehicular use has to be compressed to reduce its storage volume. The level of compression depends on the practical limitations of storage cylinders and compressors. In practice, storage pressure of 16 MPa (2,400 psi) is used. The two natural gas compressors used for the purpose of this evaluation have the rated capacity of 350 cubic metre per hour each. This capacity is achieved only when the outlet pressure is 0.1 MPa. Since the outlet pressure varies with the storage cylinder pressure from 0.1 MPa to 16 MPa, the capacity of the compressor decreases to 160 cubic metre per hour on average. For the power consumption of 45 KW, the electricity cost is about 0.80 Baht per cubic metre of natural gas at standard condition.

The production cost of CNG is the combination of fixed and variable costs. The cost of the natural gas as well as its compression cost are considered to be variable costs. The variable costs are those that depend on the volume of sale and can not be determined without a definite plan. It is likely that the number of CNG buses will increase anually for 5 years as shown in Table III. The daily average driving distance of each bus is 200 km. The CNG consumption is 2.5 km per cubic metre. Therefore, the volume of sale of the natural gas may be estimated as shown in Table III based on 320 working days per year. The fixed costs of personel, maintainance, utilities and supplies for the refueling station may also be estimated. It should be noted that the initial cost of the refueling station itself has not been included in this calculation. The total fixed cost is estimated in Table IV whereas the total cost is shown in Table V. Table VI shows production cost calculation using an annual discount rate of 12%. It was found that the production cost of the natural gas is 22,151/5,300 = 4.18 Baht per cubic metre.

Regardless of the advantages of CNG over diesel in performances and environmental impacts, payback period of the diesel-to-CNG conversion cost may be calculated if we are only concerned with the cost advantage of a CNG bus over a diesel bus.

Table III Variable Costs

Year	No. of CNG Buses	Volume of of CNG Sale (1,000 m)	Cost of NG (Baht/m)	Compression Energy Cost (Baht/m)	Total Variable Cost (1,000 Baht)
1987	25	640	2.6	0.8	2,760
1988	36	926	2.7	0.9	3,332
1989	50	1,280	2.8	0.9	4,864
1990	100	2,560	2.9	1.0	9,984
1991	100	2,560	3.0	1.0	10,240

Table IV Fixed Costs

Year	(1,000 Baht)				
	Salary	Maintainance	Utilities	Supplies	Total Fixed Cost
1987	144	60	36	10	250
1988	192	72	48	15	375
1989	240	84	60	20	404
1990	288	110	72	30	500
1991	288	110	72	30	500

Table V Total Cost

Year	(1,000 Baht)		
	Variable Cost	Fixed Cost	Total Cost
1987	2,760	250	3,010
1988	3,332	375	3,707
1989	4,864	404	5,268
1990	9,984	500	10,484
1991	10,240	500	10,740

Table VI Production Cost Calculation

Year	Present Worth of a Discount Rate 12%	Present Value of Total Cost (1,000 Baht)	Present Value of NG Volume Sale (m)
1987	0.893	2,688	572
1988	0.797	2,954	737
1989	0.712	3,751	911
1990	0.636	6,668	1,628
1991	0.567	6,090	1,452
	Total	22,151	5,300

Table VII Payback Period Calculation

Year	Present Worth of a Discount Rate 12%	(1,000 Baht)			
		Conversion Cost	Adjusted Conversion Cost	Annual Saving	Adjusted Annual Saving
1987	0.893	120.0	107.2	33.3	29.7
1988	0.797	-	-	33.3	26.5
1989	0.712	-	-	33.3	23.7
1990	0.636	-	-	33.3	21.2
1991	0.567	-	-	33.3	18.9
	Total		107.2		120.0

The fuel cost advantage depends on the selling price of CNG. Although the production cost of CNG is 4.18 Baht per cubic metre, the selling price is most likely to be 5.00 Baht per cubic metre. Therefore, the annual cost saving for BMTA is (6.30-5.00)x200x320/2.5 = 33,280 Baht per year. Table VII shows the payback period calculation of a converted CNG bus using an annual discount rate of 12%. Based on the conversion cost of 120,000 Baht, the payback period is about 5 years. Therefore, a diesel bus that has less than 5 years of service left should not be converted.

8. ENVIRONMENTAL IMPACTS

The primary objective of the CNG bus conversion program is to improve the city life quality with respect to environmental pollution. Noise and air pollutions are two main parameters affecting the city life quality. The people living in Bangkok metropolitan and surrounding areas have to travel by BMTA buses to and from their work places on the daily average of 20 km or about one hour of travel. During this one hour, a person is subjected to both noise and air pollutions of the city traffic. These pollutions do not only affect one's well being but also his usefulness to the society. The situation can be improved significantly if the diesel engines are substituted by the CNG engines. The CNG engines run smoother thus they produce less vibration and noise than the diesel engines. There is practically no smoke emission from the CNG engines. The black smoke often causes serious accidents due to visibility impairmrnt. It also causes lung cancer.

9. CONCLUSIONS

1. The CNG bus fleet can be operated without any serious CNG-related problem.

2. The thermal efficiency of the CNG engine is higher than the diesel engine.

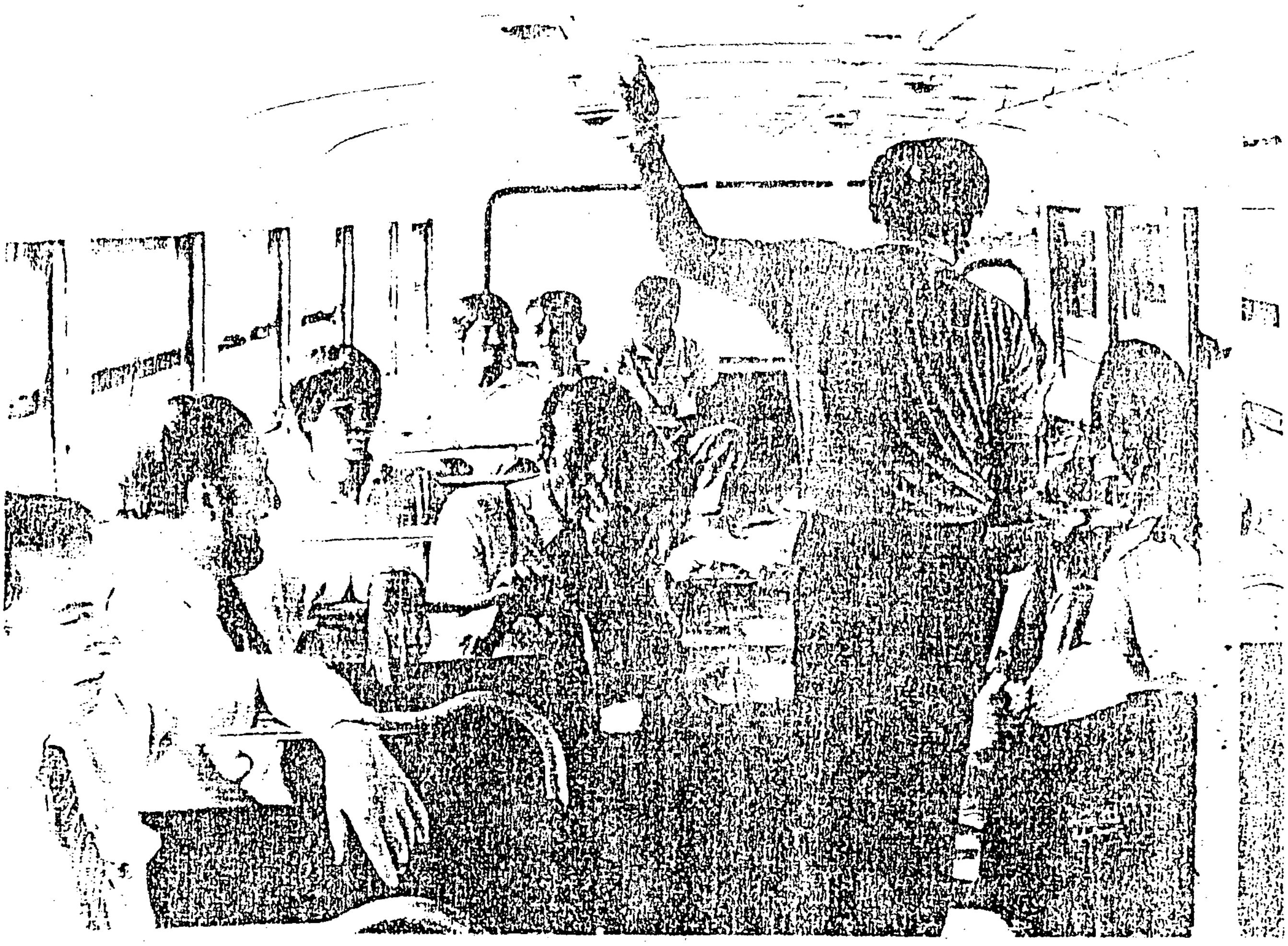
3. The natural gas produces less environmental pollutants since it burns more efficiently than liquid fuels.

4. Wears in the CNG engine are generally smaller than those in the diesel engines.

5. Periodical maintainances of the CNG engine are similar to the gasoline engine.

6. The CNG bus operation has proved that the safety measures taken are quite adequate.

7. Primary economic studies show that the selling price of the natural gas should be about 5.00 Baht per cubic metre at standard condition. At this price, pay back period for diesel-to-CNG-bus conversion is 5 years.




ลองใช้ก๊าซธรรมชาติ (CNG)
1085

อุปกรณ์ซ่อม
และตรวจสภาพรถยนต์ล้ำยุค
BISHAMON
AUTOLIFT
"บิชามอน" เครื่องยกรถแบบเสาเดียว สองเสา และสี่เสาระบบไฮโดรลิค ลิฟท์กระดก
SUN
"ซัน" เครื่องตรวจสภาพเครื่องยนต์ จากขนาดกระเป๋าหิ้วถึงคอมพิวเตอร์โปรแกรม
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"แอมโก้" เครื่องเจียรเบรคชุดใหญ่ ทั้งแบบดรัมและดิสค์ พร้อมเครื่องปาดผ้าเบรค
Clayton
เครื่องทดสอบกำลังม้ารถยนต์
SUN
"ซัน" เครื่องถ่วงล้อระบบคอมพิวเตอร์ ถ่วงล้อได้เร็ว และแม่นยำที่สุด
EIWA
เครื่องเชื่อมจุดตัวถัง (SPOT WELDER) แบบอัตโนมัติ
NISSALCO
เครื่องล้างรถยนต์ทั้งคันแบบอัตโนมัติ
RUARO
เครื่องเจียร, กลึง, ไส, ขัดคว้าน มีทุกขนาด
ARO
"แอโร่" ถังอัดจารบี เติมน้ำมันเกียร์ เฟืองท้าย และปั๊มพ่นน้ำยากันสนิม
สินค้าดี คุ้มราคา อะไหล่พร้อม บริการฉับพลันทันใจ
บทพ
บริษัท ยูไนเต็ดมอเตอร์เวิกส์ (สยาม) จำกัด
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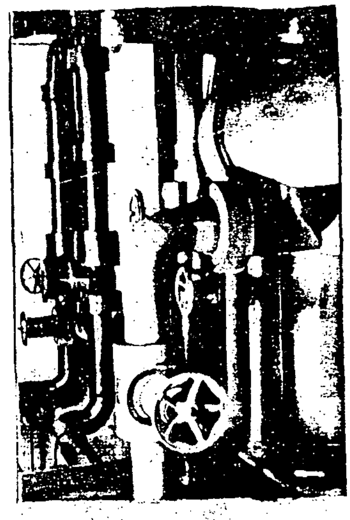
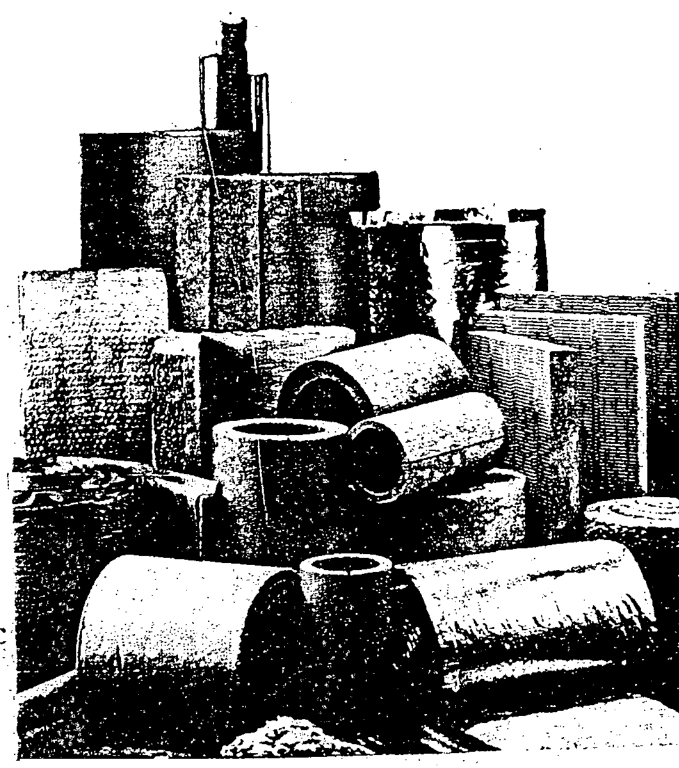
ศูนย์บริการ 342/1 ถ.วิภาวดี รังสิต อ. ธัญญบุรี จ. ปทุมธานี โทร.(02) 523-9275, 531-1036



ทนทานสูงต่อสารเคมีชนิดมีขั้วและไม่มีขั้ว

Thermaflex

- ฉนวนกันความร้อนสมบูรณ์แบบ เพื่อการประหยัดพลังงานอย่างคุ้มค่า มีทุกขนาดทั้งชนิดท่อและชนิดแผ่น สำหรับหุ้มท่อน้ำเย็น ท่อน้ำยา ท่อลม ท่อน้ำร้อน และอื่น ๆ
  - Thermaflex มีลักษณะเป็นเซลปิดสนิท มีความเป็นกลางทั้งทางกายภาพ และทางเคมี ต้านทานการแทรกซึมความชื้นได้ดีเยี่ยม ค่าสัมประสิทธิ์การนำความร้อนต่ำ และคงที่ตลอดเวลา ไม่เป็นเชื้อเพลิง มีปริมาณควันน้อยมากเมื่อเผาไหม้ และควันไม่เป็นพิษ น้ำหนักเบา คงสภาพ สวยงาม และทนทาน อุณหภูมิใช้งานตั้งแต่ -80°C ถึง + 95°C



ROCKWOOL LAPINUS

- ทำหน้าที่เป็นฉนวนกันความร้อน วัสดุกันไฟ วัสดุเก็บเสียง สำหรับงานก่อสร้างและอุตสาหกรรม

- เหมาะกับงานทุกลักษณะ ทั้งงานท่อ แท้งค์ ผนัง ปล่อง ท่อลม โครงเหล็ก เครื่องจักร-อุปกรณ์ การต่อเรือ และอื่น ๆ อุณหภูมิใช้งานสูงสุด1,000°C

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