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COMPARISON OF THEORETICALLY DETERMINED FUEL ECONOMIC INDICES OF TRACTOR DIESEL AND CNG (Alternative Fuel) ENGINES

D. Adgidzi[1], and F.B .Akande[2],

[1]Department of Agricultural Engineering, Federal University of Technology, Minna, Nigeria.
[2]Department of Agricultural Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo State.

ABSTRACTS

The fuel economic indices of tractor diesel and tractor Compressed Natural Gas (CNG) engines were compared theoretically to determine the economy of using the two fuels (i.e diesel and compressed Natural Gas, (CNG) to power tractor engines under various operating conditions and to determine which of the two tractor fuel engines specified is the most economical. The operating conditions considered are engine rated condition, idle running condition and under maximum torque. The economic indices considered were indicated fuel consumption (g/kWhr), the effective fuel consumption (g/kWhr), the effective indicated efficiency and the hourly fuel consumption (kg/hr). A 47kW Steyr tractor diesel was compared with a 41.7kW tractor CNG engine since the two are in the same tractor classification. The indicated fuel consumption of the tractor diesel engine was determined to be 282.35 g/kWhr, while that of the tractor CNG was 224.22 g/kWhr. The effective fuel consumption of tractor diesel engine under rated condition, idle running and maximum torque were 392.15 g/kWhr, 433.50 g/kWhr and 461 g/kWhr respectively. The corresponding values for the tractor CNG engine under the same conditions were 263.79 g/kWhr, 290.21 g/kWhr and 275 g/kWhr respectively. The hourly fuel consumptions for the two engines were also determined under the specified conditions as 18.43kg/hr, 4.61kg/hr and 18.71kg/hr for tractor diesel engine and 11.00 kg/hrs 2.75 kg/hr and 11.71 kg/hr for tractor CNG engine. The effective indicated efficiencies of the two engines were determined to be 21.6% for tractor diesel engine and 27.2% for tractor CNG engine. The tractor CNG is therefore more economical in terms of fuel consumption compared to the tractor diesel engine.

Key words: Fuel (Diesel, CNG- Alternative fuel), Economic Indices, and Tractor Engines.

INTRODUCTION

The U.S. Department of energy defines Alternative Fuel as fuel that is essentially non-petroleum and yields energy security and environmental benefits. Alternative fuels or alternatives are broadly divided into two categories; those that serves as replacement for conventional fuels such as LPG (Liquefied Petroleum Gas- propane), CNG (compressed Natural Gas-methane), LNG (liquefied Natural Gas) DME (Di-methyl ether), Hydrogen (H_2) and those that are blended with conventional fuels example being Alcohols (E85 & M85) or bio- fuel (Peter, 2001).

The need for replacement of conventional fuels (petrol and diesel) by the alternative fuels is as a result of the environmental friendliness (i.e. from experimentation with alternative fuels, each has some characteristics that give it an environmental advantage over petroleum fuels and most are less damaging to the environment if spilled generally, the emission from alternative fuels are less reactive (Bechtold, 1997). Initial work on alternative fuels focused on which one was best from the viewpoint of technical feasibility, production capability and the cost, technical feasibility is no longer questioned and the focus now has shifted towards which alternative fuel can be produced at a competitive cost. Cost is calculated in terms not only of fuel price but vehicle price and operating characteristics. Countries like Nigeria are seen as ideal for gas-power generating sets as good quality natural gas are readily available cheaper than diesel power (African Review, 2002). Hence, this paper makes a comparison in terms of fuel economic indices (as part of operating characteristics) between tractor diesel engine and tractor CNG Engine.

The Fuel economic indices are used to measure the rate of fuel consumption under different operating conditions of the tractor engines. These conditions include: idle running, rated condition (maximum effective power) of the engines and under maximum torque. The fuel economic indices considered are as follows; the indicated specific fuel consumption, effective fuel consumption, hourly fuel consumption under various specified conditions and effective indicated efficiency

An important criterion of engine performance in use is thermal efficiency, it can be expressed in percentages but it is easier to express the efficiency as the ratio of mass of fuel burned per hour to the Pto power, or as a ratio of the amount of heat actually contained in the fuel. It is usually in the range of 0.26 – 0.37 (Hunt, 1995). About 30% of thermal energy from fuel is converted to effective power, the rest (of thermal energy) is used in overcoming mechanical losses; 10%- heating the cooling liquid, 45%- heating the engine, and 15%- thermal losses through exhaust gases.(source)

In engine tests, the fuel consumption is measured as a flow rate (mass flow per unit time). A more useful parameter is the specific fuel consumption (sfc) – the fuel flow rate per unit power output, it measures how efficiently an engine is using the fuel supplied to produce work (Heywood, 1996).

Fuel economy of a tractor engine is characterized by the specific fuel consumption determined by dividing Indicated specific fuel consumption, denoted by g_i is expressed as:

$$g_i = \frac{10^3 G_T}{N_i}(g / kWhr) - - - - - 1 \, (Adgidzi, 1988)$$

$$G_T = \frac{3600 N_i}{\eta_i . Hu} - - - - - - - - - - 2 \, (Adgidzi, 1988)$$

Where g_i - Indicated specific fuel consumption

G_T - Hourly fuel consumption, kg/hr.

η_i = Indicated efficiency, N_i – indicated power of the engine (kW)

H_u = Specific heat of the fuel engines (kJ/kg)

g_i = 170 – 200g/kWhr for diesel engines

g_i = 240 – 340g/kWhr for petrol engines (Steyr, 1985)

Effective specific fuel consumption, ge is calculated from the relationship below as:

$$g_e = \frac{10^3 G_T}{N_e} g / kWhr \text{ -------------- } 3$$

g_e = 200 -250g/kWhr for 4 stroke diesel engine

g_e = 250 – 320g/kWhr for 4 stroke petrol engine (Steyr, 1985)

Methodology.

The effective power of a tractor using compressed Natural Gas as alternative fuel was determined theoretically to be 41.70kW (Akande, 2004). This is done by substituting the calculated mean effective pressure P_e of 0.695mPa from the constructed indicated diagram and the engine displacement capacity, V_l of 3 litres into equation 4. And the fuel economic indices of this tractor engine were compared to that of 8075a Steyr tractor diesel engine with effective power of 47kW.

$$N_e = \frac{P_e n V_l}{60\tau}, kW - - - - - - - - (4) \text{ (Adgidzi, 1988)}$$

where n=2400rpm and τ=2 for 4-stroke engines

The theoretically regulated characteristics of these two engines were calculated and the summary is as presented in Tables 1 and 2 for tractor diesel engine and tractor CNG engines respectively, which were used in the construction of control characteristics graphs. (Figs1.-4)

Using these power rating for the two engines (i.e 47kW for tractor diesel engine and 41.7kW for tractor CNG engine) and substituting these values into the fuel economic indices models (equations) where applicable, the fuel economic indices of both tractor diesel engines and tractor CNG engine were determined and a comparison made.

Indicated specific fuel consumption for both engines is determined from the relation as:

the hourly fuel consumption of the engine by its effective power (Liljedahl et al, 1989).

$$g_i = \frac{3600}{\eta_i H_u} . 10^3 g / kWhr - - - - - - - - - - 5$$

Where η_i = (0.28-0.33); indicated efficiency, (Adgidzi, 1988) for a diesel engine, η_i = 0.30 H_u for diesel = 42,500kj/kg therefore,

For a tractor CNG Engine,

η_i = 0.32, H_u = 50,175kj/kg

The effective fuel consumption was determined for both engines using the relationship below

$$g_e = \frac{g_i}{\eta_m} - - - - - - - - - - - - .6$$

η_m for diesel was taken to be 0.72 and for CNG, η_m = 0.85

Hourly fuel consumption: The hourly fuel consumption was determined from the relationship:

$$G_T{}^r = \frac{ge Ne^r}{10^3} kg / hr - - - - - - - - - - 7$$

and to construct the graph of hourly fuel consumption upon rotational speed, 3 values of G_T were determined. Under rated condition, $G_T{}^r$ is calculated as:

$$G_T{}^r{}_{diesel} = \frac{g_{e\,diesel} \times N^r_{e\,diesel}}{10^3}$$

$$G_T{}^r{}_{CNG} = \frac{g_{e\,CNG} \times N_e{}^r{}_{CNG}}{10^3}$$

In operating maximum condition, (n^{max}_{idle})

G_T idle = (0.22 – 0.27) $G_T{}^r$ (Adgidzi, 1988)

Taking G_T idle = 0.25$G_T{}^r$ for this analysis

=> G_T idle (diesel) = 0.25 $G_T{}^r$ diesel

G_T idle $_{(CNG)}$ = 0.25 $G_T{}^r{}_{CNG}$

At maximum torque (i.e. where $n_{tk}{}^{max}$)

$$G_{Ttk}{}^{max} = \frac{1.1 G_T^r}{K_{o\sigma}} - - - - - - - - 8$$

where $K_{o\sigma}$ is engine fixture co-efficient, taking to be 1.3 for both engine.

$$\Rightarrow G_{T\,tk}{}^{max}{}_{(diesel)} = \frac{1.1 G_T{}^r diesel}{K_{o\sigma}}$$

$$\text{And } G_{Ttu}{}^{max}{}_{(CNG)} = \frac{1.1 G_T{}^r CNG}{K_{o\sigma}}$$

Effective Fuel Consumption

To construct the graph (Fig. 1) of effective fuel consumption against rotational speed, 3 values of g_e were determined using the relationship below:

$$g_e = \frac{G_T}{N_e} \times 10^3 g / kWhr. - - - - - - - 9$$

Further values of G_T and N_e were taken from the graph

(Fig. 4) and calculated as;

$$g_e{}^r{}_{diesel} = \frac{G_T{}^r{}_{diesel}}{N_e{}^r{}_{diesel}} =$$

$$g_{e\max.tk}\left(_{diesel}\right) = \frac{G_{Ttk}{}^{\max}}{N_{e\max diesel}}$$

$$N_{e\max(diesel)} = \frac{tk^{\max} n_{tk}{}^{\max}}{9500}$$

$$= 43.16 \text{ kW}$$

g_e idle for diesel $= \frac{G_{T\,idle(diesel)}}{N_{e\,idle}} \times 10^3 g/kWhr$.

From the graph (Fig. 4)

let N_e = 10 kW for idle running for both engines

For tractor CNG engine

$$g_e{}^r = \frac{G_{TCNG}}{N_e{}^r{}_{CNG}} \times 10^3$$

$$g_{etk}{}^{\max}{}_{CNG} = \frac{G^{\max} \times 10^3}{N_{etk}{}^{\max}{}_{CNG}}$$

Where $N_{e\,tk}{}^{\max}{}_{CNG} = \frac{t_k{}^{\max} n_{tk}{}^{\max}}{9500}$ =38.49 kW

$$g_{eidle} = \frac{G_{T\,idleCNG}}{N_{eidleCNG}} \times 10^3$$

Economic effectiveness of tractor engine.

This is achieved or determined through the analysis of the cost of fuel consumption per hour or litres per kilometer under various conditions. The hourly fuel consumption is measured in kg/hr for Tractor Diesel Engine, but diesel is sold in litres hence the hourly fuel consumption is converted to litres per hour by dividing the hourly fuel consumption by the density of diesel (kg/litres) (Technocarb, 2003).

At idle running G_T = 5.7625litres/hr, 1 litre of diesel cost ₦60, therefore, at idle running G_T in Naira/hr was ₦345.75/hr. At rated condition, G_T is 23.037 litres/hr (₦1382.22/litres) and under maximum torque, G_T is 23.357 litre/hr (₦1401.42/hr). At maximum torque, during a ploughing operation (the speed of ploughing operation in Nigeria is 5.3km/hr (Hunt, 1995), therefore, the fuel consumption in litres per km was determined as follow

Fuel consumption in litres/km

$$= \frac{G_T \text{ at max torque}}{speed of operations} = 4.413 litres/km$$

4.413 litres/km = ₦264.78/km.

But in Nigeria, the sale of CNG has not been commercialized, but it is known to be 50 – 60% less than the cost of per litre of traditional fuels (NGC release). From above analysis 1 litre of CNG will costs N30

Therefore for a tractor CNG engine

G_T at idle running = 5 litres/hr = ₦150/hr

G_T at rated condition = 20 litres/hr =₦600/hr

G_T at under maximum torque = 20.31 litres/hr =. ₦609.30/hr

And fuel consumption in litres/km under maximum torque was $\frac{20.31 \text{ litres/hr}}{5.31 km/hr}$ = 3.83 litres/km. = ₦114.90/km

Results and Discussion

Tables 1-3 show the values of control characteristics parameters used in the construction of control characteristics graphs for tractor diesel engine and tractor CNG engine under various specified conditions.

Table 1: Control characteristics parameters under idle running condition

Engine Type	Engine speed, n (rpm)	Torque, t_k Nm	Engine effective Power, N_e kW	Hourly fuel Consumption, G_T, kg/hr	Effective fuel Consumption g_e, g/kWhr
Diesel Engine	2554.00	0.00	0.00, 10.00	4.61	∞, 461.00
CNG Engine	2554.00	0.00	0.00, 10.00	2.75	∞, 275.00

Table 2: Control characteristics parameters under engine rated condition

Engine Type	Engine speed, n (rpm)	Torque, t_k Nm	Engine effective power, N_e kW	Hourly fuel Consumption, G_T, kg/hr	Effective fuel Consumption g_e, g/kWhr	Indicated fuel Consumption g_i, g/kWhr
Diesel Engine	2400.00	186.04	47.00	18.43	392.15	282.35
CNG Engine	2400.00	165.93	41.70	11.00	263.89	224.22

Table 3: Control characteristics parameters under maximum torque condition

Engine Type	Engine speed, n (rpm)	Torque, t_k Nm	Engine effective power, N_e kW	Hourly fuel Consumption, G_T, kg/hr	Effective fuel Consumption g_e, g/kWhr
Diesel Engine	1864.15	223.25	43.16	18.71	433.50
CNG Engine	1864.15	199.12	38.49	11.17	290.21

Indicated fuel consumption

For diesel engine, the indicated fuel consumption was determined to be 282.35g/kWhr at an indicated efficiency of 0.30 while the tractor CNG engine has fuel consumption of 224.22g/kWhr at an indicated efficiency of 0.32, the heat of combustion of the CNG is greater than that of the diesel and the indicated efficiency is also greater than then of the diesel. Hence, the indicated fuel consumption of CNG engine is lower than that of the diesel engine, the tractor CNG engine is more economical.

Hourly fuel consumption

The hourly fuel consumption under various operating c onditions were determined, i.e. (idle running, under rated condition and under maximum torque). The hourly fuel consumption for tractor diesel engine under the stated conditions are 4.61kg/hr, 18.43kg/hr and 18.71kg/hr respectively, similarly, the traction CNG engine has an hourly fuel consumption of 2.75kg/hr, 11.00kg/hr and 11.19kg/hr under idle running, rated condition and under maximum torque respectively. This implies that the tractor CNG engines more economical in terms of fuel consumption than the tractor diesel engine. Considering also the fuel consumption in litres per hour and the economic implication i.e the cost per hour for a specific farm operation say ploughing, where the engines are under maximum torque, the fuel consumed per km by CNG engine (3.832 litres/km= ₦114.90/km) is less than that of the tractor diesel engine (4.413 litres/km = ₦264.78/km).

From the graphs the hourly fuel consumption is maximum under maximum torque for both engines (Fig.2), this implies that more fuel is consumed per hour under maximum torque. Fig. 1 shows hourly fuel consumption as a function of rotational speed. And Fig. 4 shows hourly fuel consumption as a function of effective power.

Effective fuel consumption

The effective fuel consumptions under various conditions of idle running rated condition and under maximum torque were determined for both engines. The tractor diesel engine has an effective fuel consumption of 382.15g/kWhr under rated condition, 433.950g/kwhr under maximum torque and 461g/kWhr under idle running at engine power of 10kW. The tractor CNG engine has an effective fuel consumption of 263.79g/kWhr at rated condition, 290.21g/kWhr under maximum torque and 275g/kWhr under idle running. This implies that the tractor CNG engine is more economical then the tractor diesel engine.

The effective fuel consumption of diesel engine is at maximum under idle running when the effective power equals 10kW and at rated condition. It was at minimum, under maximum torque, the effective fuel consumption increase to 433g/kWhr. But the CNG engine, the effective fuel consumption followed a different pattern, the effective fuel consumption was maximum under maximum torque, while at rated condition, it has a minimum of 263.79g/kWhr under maximum torque, the effective power of both engines (i.e tractor diesel and CNG engine) dropped from 47kW to 43.11 kW and 41.7kW to 33.49kW respectively. Hence, the increase in the effective fuel consumption. (Fig. 3). Figs. 1&2 show the effective fuel consumption as a function rotational speed and torque respectively.

Conclusions

Having determined the fuel economic indices under various operating conditions for both the tractor diesel engine and tractor CNG engine, the tractor CNG engine has lower values of fuel consumption in kg/hr, litres/hr, g/kWhr and even litres/km therefore, the tractor CNG engine is more economical than the tractor diesel engine, couple with its environmental friendliness.

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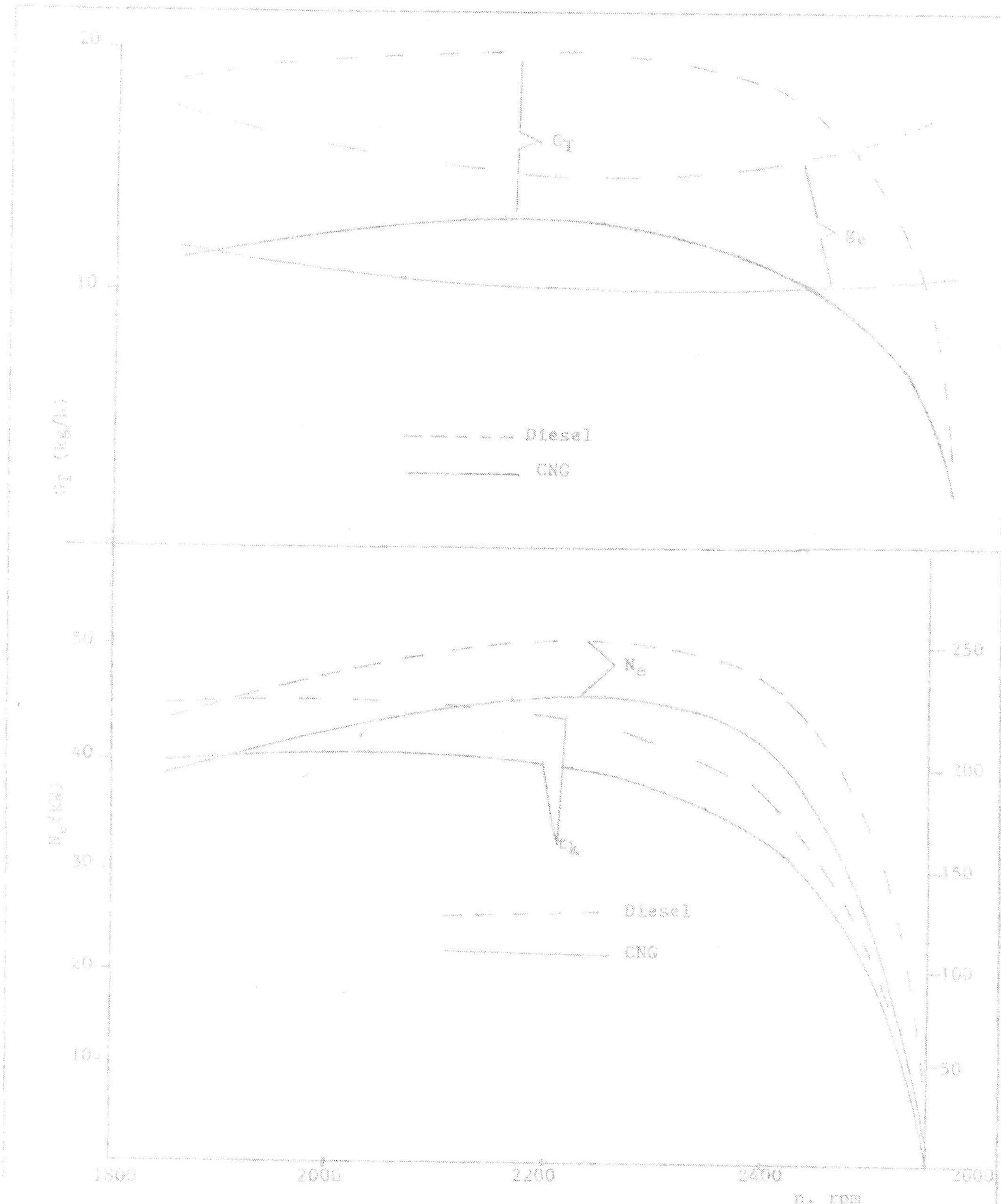

Fig 1: Control Characteristics as a Function Of Rotational Speed

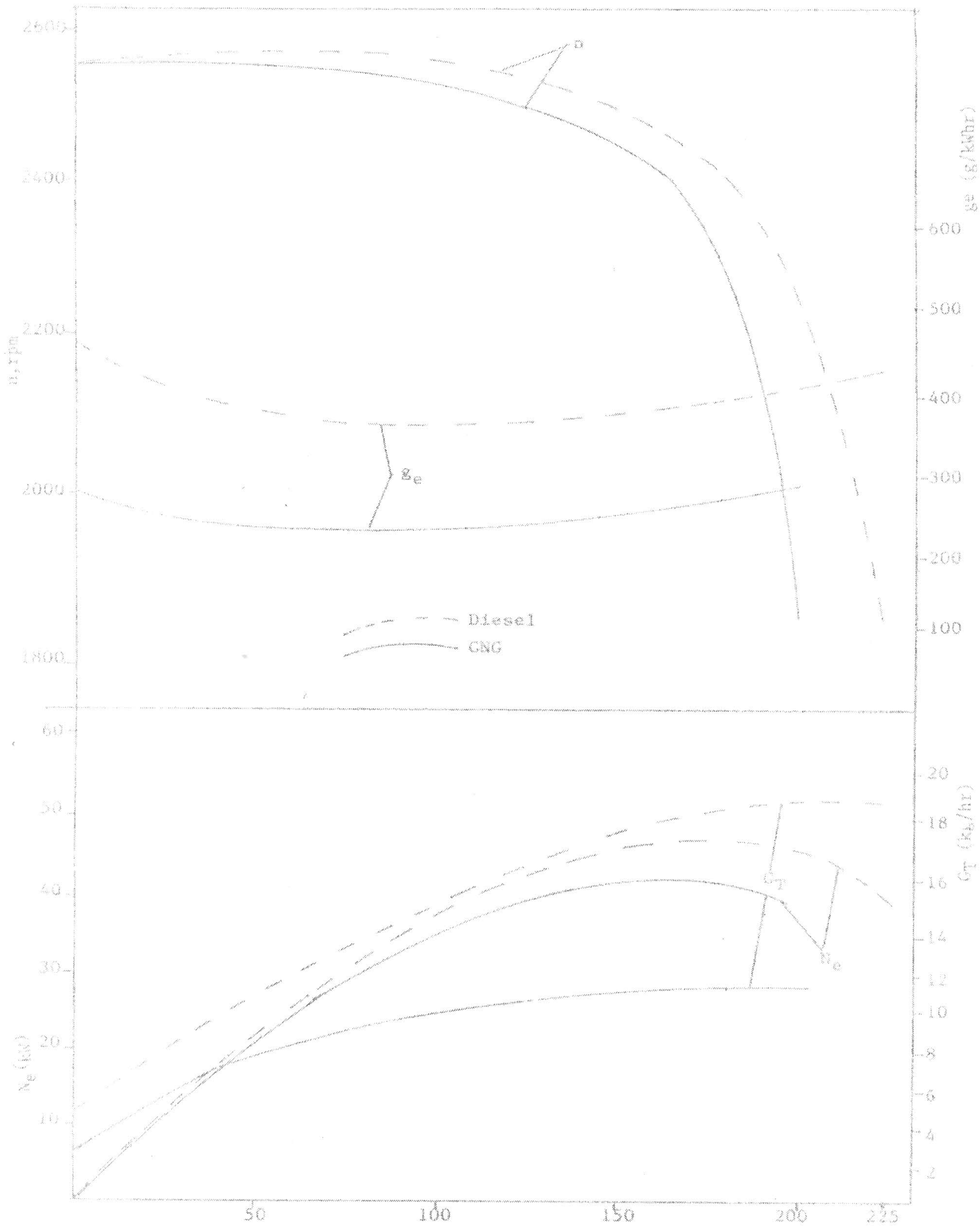

Fig 2: Control Characteristics as Function of Torque t_k (Nm)

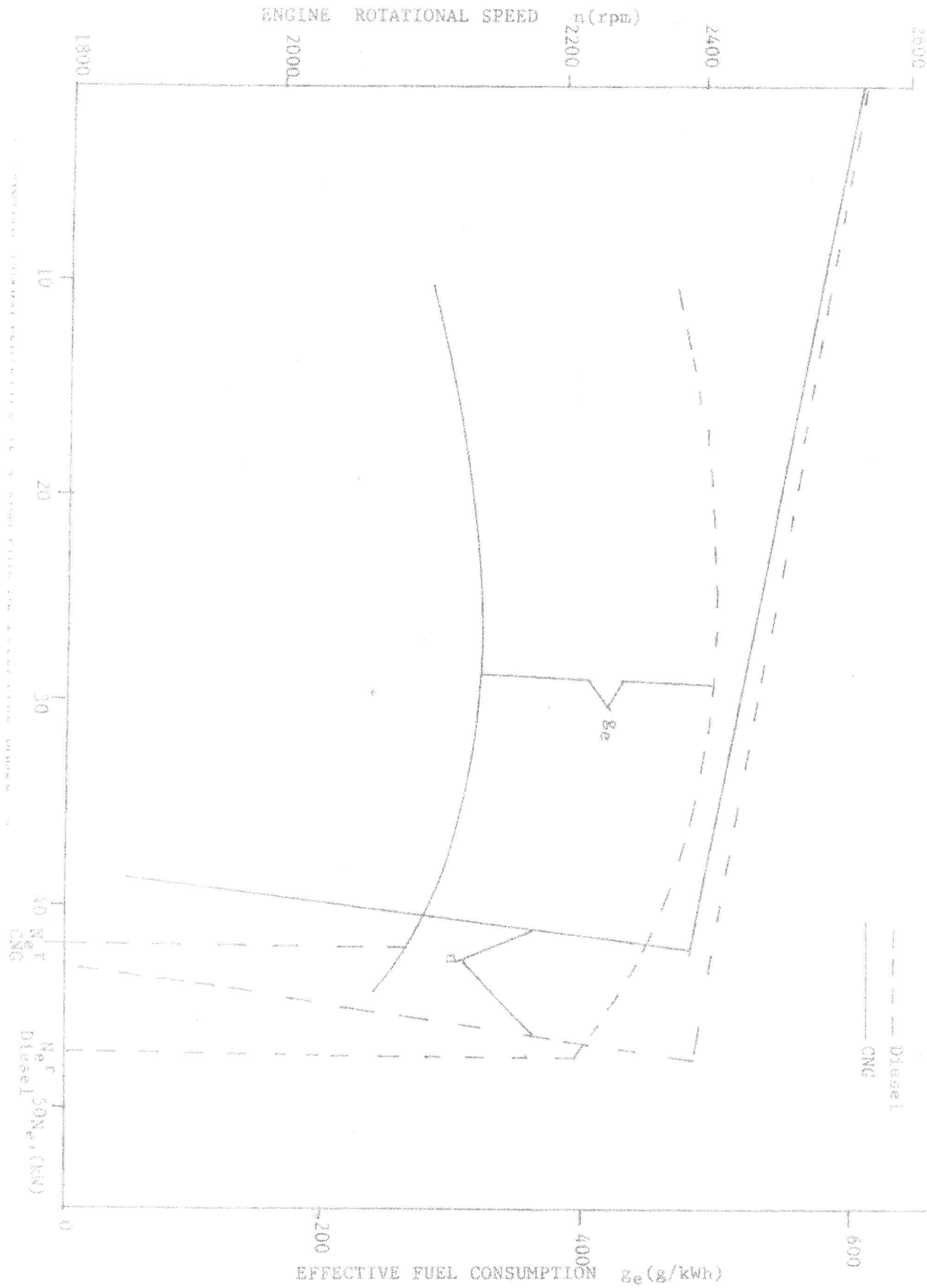

Fig 3: Control Characteristics as a Function of Effective Power, N_e

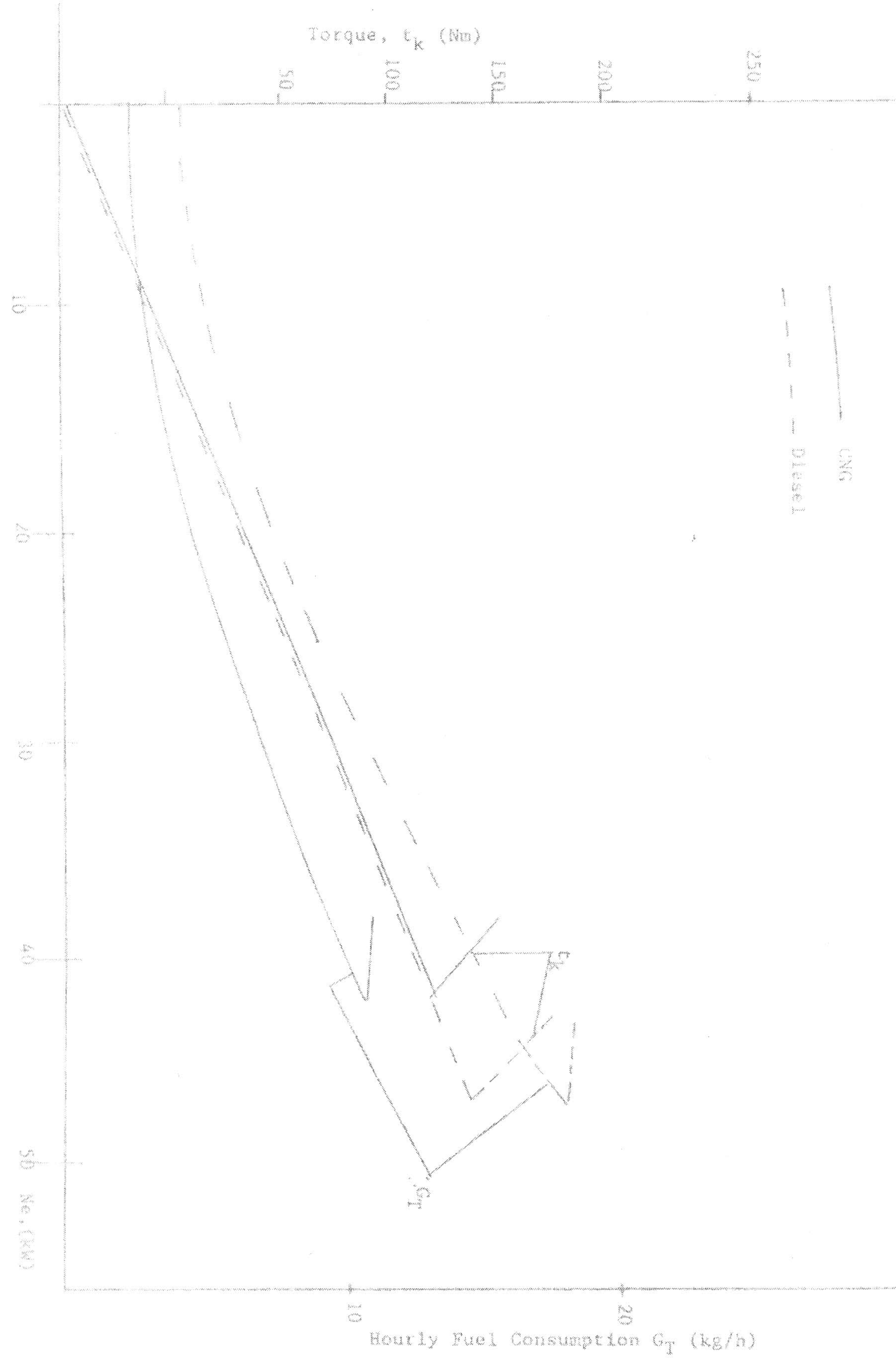

Fig 4: Con Trol Characteristics as a Function of Effective Power, Ne