IMPROVEMENT OF LOCALLY PRODUCED GASOLINE AND STUDYING ITS EFFECTS ON BOTH THE PERFORMANCE OF THE ENGINE AND THE ENVIRONMENT

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عميد كلية الدراسات العليا

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To My Parents Brother and Sisters,

With Love and Appreciation.

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NOMENCLATURE

A/F	Air fuel ratio.
F.E.P	Fuel equivalent power.
m_a	Mass flow rate of air.
m_f	Mass flow rate of fuel.
MR	Reading of manometer, (mm H_2O).
N	Engine speed, (rpm).
P_a	Atmospheric pressure, (mbar).
P_B	Brake power.
P_I	Indicated power.
P_L	Loss power.
r	compression ratio.
S.F.C	Specific Fuel Consumption.
sg_f	Specific gravity, (kg/L).
T	Ambient temperature, (K).
t	Time, (second).
V_S	Swept volume.
V/V	Volume by volume.

Greek Symbols

γ	Specific heat ratio, (C_p/C_v).
η_b	Brake thermal efficiency.
η_m	Mechanical efficiency.
η_t	Thermal efficiency.
η_v	Volumetric efficiency
ρ_a	Density of air.
τ	Torque.

ABSTRACT

Improvement of locally produced gasoline and studying its effects on both the performance of the engine and the environment

by
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This study aims at investigating the effect of Methyl-tertiary Butyl Ether (MTBE) addition to gasoline on the performance of engines and its effect on emitted exhaust gases. Also, the effect of MTBE addition on octane number of gasoline is investigated.

Six base fuels were used in a TD110 engine which is coupled with a gas analyzer. Each of these fuels were blended with five different percentages of MTBE namely; 0, 5, 10, 15 and 20%.

It was found that octane number of gasoline increases continuously and linearly with MTBE percentage in gasoline. The rate of this increase depends on the octane number of the gasoline before adding MTBE.

CHAPTER ONE

INTRODUCTION

1.1 General:

Environmental pollution is recognized worldwide as a major problem today, it occurs when the naturally clean atmosphere is contaminated by a concentration of some substance that produces an objectionable, and often harmful, effect .

The human quest for development and use of the earth's atmosphere as a disposal sink for waste gases have resulted in pollution of the air, rivers and seas, destruction of rain forests and the widening hole in the ozone layer .

Automobiles powered by gasoline are a major source of air pollution, because this gasoline contains Tetra-Ethyl Lead (TEL) and Tetra-Methyl Lead (TML). These two lead alkyls are normally added to gasoline fuel in order to increase the octane number which also increases the performance of the engine .

Approximately 90% of lead compounds in urban air comes from gasoline, posing a significant health risk. When lead alkyls are added to gasoline, auto emission make a significant contribution to lead pollution of the soil . Street dust is thus contaminated, affecting the residents in surrounding areas .

Lead compound attacks the blood, kidneys, Central Nervous System (CNS) and reproductive as well as other physiological systems. At high concentrations, it can cause anemic failure, massive and permanent brain damage, and eventually death. Further studies have shown that lead also has its most severe impact on children. At elevated lead levels in their bodies, children experience more behavioral problems, a lower Intelligence Quotient and reduce ability to concentrate .

The intense search for an effective and economical octane-boosting alternative to lead has continued. Oxygenates have emerged as alternatives for improving the octane number and the oxygen content in gasoline. The most important of these oxygenates has been Methyl Tertiary Butyl Ether (MTBE) which will be studied in this work .

1.2 Objectives Of The Present Work :

In this work locally produced gasoline is improved by adding MTBE instead of TEL . Experimental investigations are carried out to determine the fuel octane number. The improved gasoline is used as a fuel in an internal combustion engine to find the engine performance. Further, the effect of burning this improved gasoline on environment is investigated by carrying out exhaust gas analysis.

1.3 Layout Of The Thesis :

This thesis is divided into seven chapters and this introduction is the first. Literature review is presented in chapter two. In chapter three, the background on the MTBE compound and its advantages are presented. Chapter four deals with theoretical analysis for combustion. Chapter five presents the experimental setup and procedure. The results obtained are presented in chapter six and these results are discussed in the same chapter. Finally, conclusions and recommendations of this work are given in chapter seven.

CHAPTER TWO

LITERATURE REVIEW

Nowadays, most of the efforts on research and development in American refineries are concentrated on the improvement of gasoline which contributes to almost 40% of the total refined crude oil. These efforts are concentrated on the utilization of oxygenates as additives to gasoline . Two types of such additives are : alcohols and ethers . (Brockwell *et al.,* 1991)

In the 1970s methanol was used instead of lead compounds in America to increase the octane number . However some studies indicated the possibility of formaldehyde emission upon combustion , while other studies indicated the possibility of an increase in the emission of the Nitrogen oxides . In addition, alcohol dissolves rapidly in water leading to the formation of a water layer in the bottom of the gasoline tank. (Brockwell *et al.,* 1991)

As a result work concentrated on the utilization of ethers in America especially Methyl Tertiary-Butyl Ether (MTBE), which was first added to gasoline with 6-8% during 1970s . In 1985 Shamrock company in Texas installed MTBE plant resulting in the production of super premium unleaded gasoline. (Masters *et al.,* 1988)

Dorn *et al.* (1987) discussed the relationship between the physical and chemical properties and performance of gasolines and diesel fuel . For gasolines, emphasis is placed on the effects of oxygenates when used as gasoline blending components. Emissions, water tolerance and incremental octane gain are also shown for oxygenates blends .

A study was carried out by Stump *et al.* (1990, a) to measure emissions from a 1988 GM Corsica supplied with an adaptive learning closed loop control with 4 fuels at intake air temperature of 4, 24 and 32°C . Evaporative and exhaust emissions were examined from each fuel at each test temperature .

Test fuels used in this study were unleaded summer grade gasoline; unleaded summer gasoline blend containing 8.1 percent ethanol; a refiner's blend stock; and the blend stock containing 16.2 percent MTBE. Regulated emissions, detailed aldehydes, detailed hydrocarbons, ethanol, MTBE, benzene and 1,3-butadiene concentrations were determined. It was found that the MTBE fuel blend offered the most reduction in total hydrocarbon, carbon monoxide, and oxides of nitrogen for the fuels and temperatures tested .

Stump *et al.* (1990, b) measured evaporative and tailpipe emissions from a 1987 GM Corsica with adaptive learning closed loop control with six fuels and four inlet air temperatures . The six fuels were commercial unleaded regular summer grade gasoline, a blend of this fuel containing 8.1% (v/v) ethanol, a second blend of this fuel containing 16.2% MTBE, a commercial ARCO EC-1 fuel containing 4.9% MTBE, a refiner's gasoline blended with 16.2% MTBE , and a second blend of the refiner's gasoline with hydrocarbons . The four temperatures were 4, 24, 32 and 41°C. They found that blending certain oxygenated compounds (alcohols and ethers) at specified levels with gasoline to be used as a vehicle fuel introduces several benefits such as : increasing fuel octane number and reducing tailpipe emissions of total hydrocarbons and carbon monoxide .

Walter *et al.* (1989) provided a technical assessment of using MTBE up to 15 % (v/v) in gasoline. Pertinent properties ,important for proper gasoline blending, were examined . Information with 15% MTBE blends covers vehicle performance and driveability, exhaust and evaporative emissions, 50000 mile durability testing, materials compatibility and over-the-road evaluations. The data from these studies, cost-effectiveness, and benign environmental characteristics, make MTBE a very desirable high octane blending component for gasoline .

William (1990) determined the effect of gasoline/oxygenate blends on exhaust emissions (particularly carbon monoxide) for three types of emission control technologies . Test were performed at sea level and high altitude and at temperatures of 24, 10 and 2 degree C. The primary fuel set consisted of a 896 mbar Reid Vapor Pressure (RVP) hydrocarbon(1)-only gasoline, a hydrocarbon blend containing 11% MTBE, and a hydrocarbon-splash blended with 10% ethanol. Additionally, sea level tests were conducted with a hydrocarbon containing 11% ethanol matched-volatility blend and at limited conditions with a hydrocarbon containing 16% MTBE blend. The cars and emission control technologies tested were six 1986-88 “Adaptive Learning” closed loop three-way catalyst systems, six 1983-86 closed-loop three-way systems without the adaptive learning capability, and four 1979-80 carbureted oxidation catalyst systems. He found that : the Adaptive Learning vehicles exhibited a small CO emissions reduction at high altitude and very little response at sea

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(1) A type of gasoline which contains only hydrogen and carbon.

level, the closed loop 'nonadaptive cars' showed a variable reduction in CO with increasing fuel oxygen at high altitude and diminished response at sea level and the oxidation catalyst cars showed the greatest reduction of CO emissions in response to fuel oxygen content over the range tested .

Baur *et al.* (1990) investigated the performance of an SI engine with Ethyl Tertiary Butyl Ether (ETBE) as a blending component in motor gasoline and to assess its relative performance with other blending components; such as, ethanol and Methyl Tertiary Butyl Ether (MTBE). The result of the experiment and the numerical assessment with a computer simulation program, ZMOTTO, show that ETBE, a new blending component in gasoline fuels, when evaluated based on emission levels and the overall performance in a test engine, can be favorable compared with the performance and emission parameters of the base gasoline, ethanol and MTBE .

Oda *et al.* (1993) clarified the effect of each gasoline component on engine performance during warm up period, changes in the air fuel ratio and quantity of wall flow (liquid gasoline on the induction port) were measured using ordinary gasolines and model gasolines consisting of a blend of several hydrocarbons and MTBE. The unburned air-fuel mixture in combustion chamber was sampled via a solenoid valve and analyzed by gas chromatography to investigate the vaporization rate of each component. The results show that MTBE has an important effect on driveability because it contains oxygen and easily vaporizes, resulting in a lean mixture in the transient state .

Hamid *et al.* (1995) studied the effects of blending gasoline with (MTBE) on the properties of gasoline . They found that MTBE effectively boosts the octane number of gasoline without adversely affecting other properties and MTBE addition lowers the distillation temperature which improves driveability and cold engine operation. They also found that MTBE gasoline blends are free of gums and peroxides after long term storage and pose no phase separation problems in the presence of water .

Here in Jordan there are two types of gasoline namely; regular gasoline and super gasoline and it is believed that no gasoline improving with MTBE has been conducted. In this work locally produced gasoline is improved by adding MTBE instead of TEL. Also different percentages of MTBE will be added to gasoline that contains TEL. Then gasoline blends are used in an internal combustion engine to find MTBE addition effects on both the engine performance and the main emitted pollutants.

CHAPTER THREE

BACKGROUND

3.1 Introduction :

Researches proved that the two kinds of oxygenates 'alcohols and ethers' are useful and safe compared with lead compounds. There are two alcoholic compounds which are characterized by wide use namely; Ethanol and Methanol. Ethers are divided into two groups, the first is butyl ethers which contain MTBE and ETBE and the second group is amyl ethers which contain Tertiary-Amyl Methyl Ether (TAME) and Tertiary-Amyl Ethyl Ether (TAEE).

These two types of oxygenates represent good alternatives for lead additives in gasoline, however, the high volatility of alcohol prevents using them in warm weather. Further, the high solubility of alcohol in water makes gasoline blends unstable because when gasoline touches water in tanks or in pipes, alcohol will transfer to water because it is soluble in it and leaves gasoline 'which is insoluble in water' with low octane number. On the other hand ethers have low solubility in water and they are stored like gasoline. For these reasons ethers are better than alcohols with gasoline, and the most widely used type of ethers is MTBE.

3.2 Properties And Advantages Of MTBE :

3.2.1 What is MTBE?

MTBE is produced by reacting methanol with isobutylene in the presence of an acidic catalyst according to the shown mechanism in figure(3.1). It is an ether compound which contains one oxygen atom embedded in a chain of carbon and hydrogen atoms. Adding oxygen to gasoline through MTBE significantly reduces motor vehicle emissions compared with leaded gasoline.

MTBE can be blended easily and safely with gasoline. It is miscible in all proportions in hydrocarbons and is slightly soluble in water without a phase separation problem. The similarity of MTBE to gasoline hydrocarbons has made MTBE blends suitable for handling in the same manner as conventional gasoline. MTBE is stable during handling and storage, in its pure from as well as after mixing with gasoline.

3.2.2 Storage and handling :

MTBE can be shipped or stored in conventional fuel tanks. Nitrogen purging is strongly recommended in case of loading vessels in hot weather, noting that acid or iron rust contamination should be avoided. MTBE does not form peroxide compounds during long-term storage. MTBE is shipped in fuel tanks (similar to those used for gasoline).

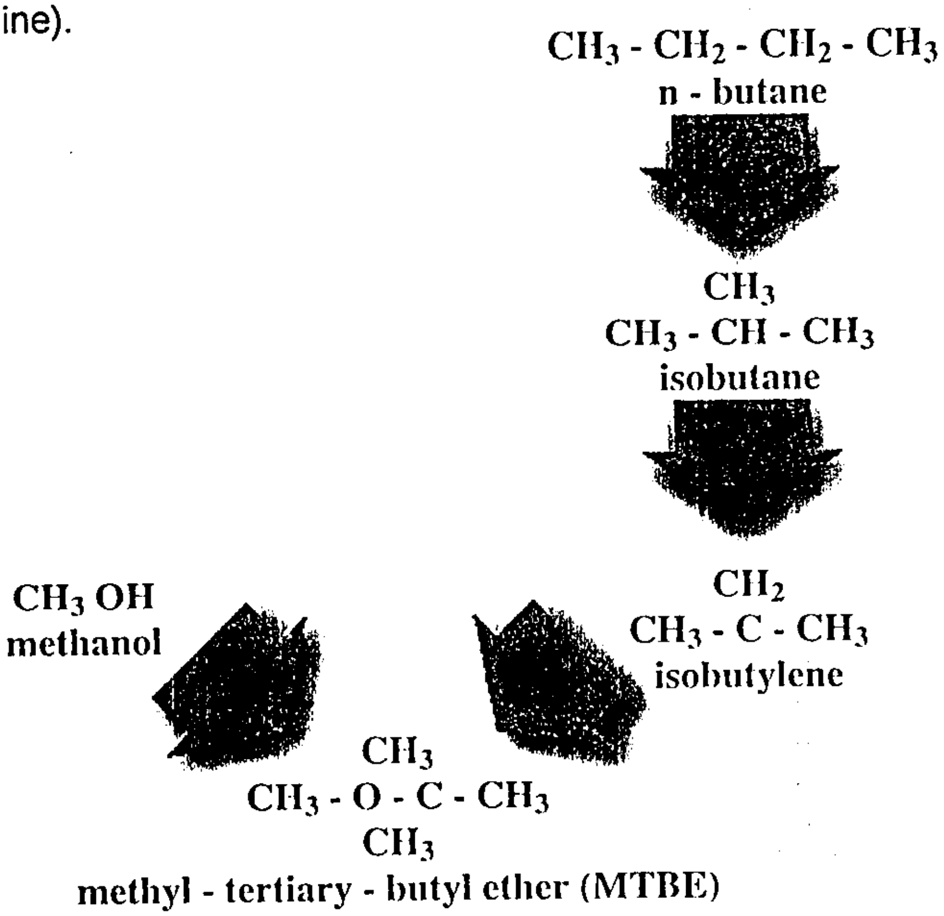


Figure (3.1): The production stages of MTBE manufacturing.

3.3 MTBE's Role In Pollution Control:

MTBE-blended gasoline offers several environmental and health advantages over ordinary and leaded gasoline, mostly in the form of reducing harmful emissions.

When gasoline fuel is burned in an engine, exhaust emissions are produced as a result of fuel combustion. The gases that are emitted include carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x), unburned hydrocarbons (UBHC), lead particulates (in case of leaded gasoline), aldehydes as well as reactive hydrocarbons such as a polyaromatics.

Some of the most harmful gas emissions that can be reduced or eliminated by blending MTBE in gasoline are :

3.3.1 Carbon monoxide (CO) emissions :

Carbon monoxide (CO) is an odorless and colorless gas produced by incomplete combustion of hydrocarbons. CO is a major pollutant and health hazard because it is absorbed into the human blood stream. Its strong affinity for hemoglobin (which is 210 times greater than that for oxygen) poses a series threat to the organism. This phenomenon leads to a decrease in oxygen transported from the blood into tissues, a condition which is particularly dangerous for individuals suffering from cardiovascular diseases. Therefore, more blood must be pumped to deliver the same amount of oxygen, which will cause an increase in the heart pumping rate.

Adding MTBE to gasoline reduces carbon monoxide emissions. This is because that extra oxygen provided by MTBE blended in gasoline will react with CO to convert it into carbon dioxide (CO_2).

3.3.2 Hydrocarbon emissions :

Hydrocarbon emissions from gasoline-powered vehicles are classified into two categories: exhaust and evaporative. Exhaust emissions are products of the combustion of air and gasoline in the engine, and are emitted from the tailpipe. Evaporative emissions are a function of the volatility of liquid gasoline, and its tendency to evaporate from fuel tank, fuel lines, the carburetor, and during refueling.

Motor vehicles account for approximately 50 percent of all toxic air problems. The major toxic pollutants from gasoline are aromatics. Benzene is a toxic compound in air with a relatively long atmospheric lifetime, and is the most hazardous gasoline component. The average benzene content of today's gasoline ranges between 2% and 5% by volume. Studies show that even relatively low benzene exposure levels cause liver cancer and various other cancers in human beings. Also exhaust emissions of unburned aromatic hydrocarbons include benzene even when it is not present in the fuel. These studies determine that other aromatic hydrocarbons are partially converted during the combustion process into benzene emitted through the exhaust. (SABIC, 1996)

Benzene and other aromatics are mainly produced in the refinery by the catalytic reforming of naphtha. They are included in large quantities in the gasoline pool because of their very high octane ratings. The average aromatic content in conventional gasoline is in the range of 35 to 50 percent, which is very high ratio.

Inclusion of MTBE in the gasoline pool helps reduce aromatics content significantly; it also replaces aromatics as the main octane-enhancing element in gasoline. Adding MTBE to gasoline also reduces unburned hydrocarbons (UBHC) because there is extra oxygen to complete the combustion.

3.3.3 Aldehyde emissions :

Aldehydes are a class of organic compounds found at various levels in exhaust gases of all gasoline powered motor vehicles. Aldehydes are formed in engines by the incomplete combustion of the fuel.

Depending on the source, aldehydes can be divided into two categories: primary and secondary aldehydes. The primary are emitted directly from motor vehicles and the secondary are produced by photochemical reactions of various hydrocarbons. The secondary aldehydes now are known to be the major source of aldehyde (45%

to 95% of the total). By using MTBE with gasoline, the primary will increase, while the secondary will decrease due to the reduction of the hydrocarbon emission. Thus a slight reduction in the total of aldehyde emissions will be resulted.

Aldehyde emissions from both MTBE-gasoline blend and other gasolines can be virtually eliminated by using exhaust catalysts. But lead in gasoline is a major impediment to the use of catalytic converters. It poisons the converter and efforts to develop "lead-tolerant" catalysts have not been very successful. Thus only unleaded gasoline which may be containing MTBE can be used by vehicles fitted with catalytic converters.

3.3.4 Nitrogen Oxides emissions :

Of all the oxides of nitrogen (No_x), the two most important are nitric oxide (NO) and nitrogen dioxide (NO_2). Nitric oxide plays an important role in photochemical reactions, which lead to the formation of several products, including NO_2. Nitrogen dioxide is a pulmonary irritant and an edema producer.

The Oxygenated Fuel Association (OFA) of the united states has conducted a supplemental vehicle testing program for different fuels (oxygenated and non-oxygenated). The OFA's test results showed that there is no statistical difference in NO_x emissions between the oxygenated and non-oxygenated fuels.

However, a test conducted by ARCO (a major oxygenate producer) proved that using MTBE with gasoline reduce NO_x emissions. (Arco Chemical Europe, 1988)

In general, the main factors affecting NO_x emission from gasoline vehicles are :

- The gasoline sulfur content: which affects the activity of the vehicle catalytic converter. The lower sulfur content in the gasoline results in increased control of NO_x emissions.
- The gasoline Hydrogen/Carbon (H/C) Ratio: NO_x emissions from high H/C ratio gasoline are lower than from low H/C ratio gasoline.
- The gasoline Motor Octane Number (MON): Higher MON decreases the vehicle's NO_x emissions.

CHAPTER FOUR

THEORETICAL ANALYSIS

4.1 Introduction :

The main internal combustion engines are either spark-ignition engines (or gasoline engines) or compression-ignition (or diesel engines). In this chapter, gasoline engine performance will be analyzed.

4.2 Experimental Air Fuel Ratio:

The mass flow rate of air at standard condition (1013 mbar and 20°C) according to the catalogue of manometer is given by :

$$\dot{m} = 1.02207MR + 1.05263 \qquad (4.1)$$

where MR is the reading of manometer in mm H_2O

Under actual conditions, the flow rate is corrected by the factor:

$$\text{Factor} = 3.564\, P_a \frac{(T+114)}{T^{2.5}} \qquad (4.2)$$

where P_a is atmospheric pressure in (mbar) and T is ambient temperature in (K).

Then mass flow rate of fuel is given by:

$$\dot{m}_f = \frac{8\times10^{-3}}{t} sg_f \qquad (4.3)$$

where sg_f is specific gravity of the fuel in kg/L and t is time in seconds taken for the engine to consume 8ml of fuel.

The mass flow rate of fuel is expressed in kg/s, however it may be expressed in kg/hr for convenience.

Then air fuel ratio is found as:

$$A/F = \frac{\dot{m}_a}{\dot{m}_f} \qquad (4.4)$$

$$A/F = [3.564\, P_a \frac{(T+114)}{T^{2.5}}(1.02207MR + 1.05263)t] \,/\, [8\times10^{-3} \times sg_f] \qquad (4.5)$$

4.3 Theoretical Air Fuel Ratio:

Several methods are available for calculating the air-fuel ratio of the mixture from the exhaust gas analysis: Carbon balance method, Hydrogen balance method, Carbon-hydrogen balance method, and Oxidized exhaust method.

In order to use any method, the chemical composition of fuel must be known, except for carbon-hydrogen balance method which calculates this composition. This method involves the balancing of the chemical reaction equations. Since the gas analysis is reported by volume, the percentage of each component can be considered to be moles. When unburned hydrocarbons are not known, they are taken as an average hydrocarbon with chemical symbol of CH_4 . (Obert, 1973)

The general chemical equation that represents burning of hydrocarbon is:

$$C_xH_y + wO_2 + zN_2 \longrightarrow$$

$$aCO_2 + bCO + YO_2 + XCH_4 + zN_2 + WH_2O(\text{condensed})$$

where a,b,X and Y are known from gas analysis.

Applying nitrogen balance gives:

$z = 100 - [\, a + b + X + Y \,]$

$w = z / 3.764$

Carbon balance gives: $x = a + b + X$

Oxygen balance gives: $W = 2w - [\, 2a + b + 2Y \,]$

Hydrogen balance gives: $y = 4X + 2W$

From knowing the chemical composition of the fuel, the mass of air and fuel may be estimated as:

The mass of air = $29(w + z)$

The mass of fuel = $12(x) + 1(y)$

Then the air fuel ratio A/F = (The mass of air) / (The mass of fuel)

$$A/F = [\, 29(w + z)] \,/\, [\, 12(x) + (y) \,] \qquad (4.6)$$

4.4 Performance Analysis:

Engine torque (τ) is measured directly using a dynamometer coupled to the engine output shaft. Because the dynamometer acts as a brake on the engine, the power at the output shaft is referred to as the brake power.

$$P_B = \frac{2\pi N}{60} \times \tau \qquad (4.7)$$

Assuming complete combustion, the heat generated per unit mass of fuel is equal to the calorific values, *H*. This is typically 42000 kJ/kg for gasoline.

Volumetric efficiency:

Ignoring the volume occupied by the fuel, the volume of air induced into the cylinder during each cycle is ideally equal to the swept volume V_S. If the air is drawn in from atmosphere at a density ρ_a, then:

$$Ideal\, mass\, of\, air\, per\, cycle = \rho_a V_S \qquad (4.8)$$

The actual mass of air drawn in per cycle can be calculated from the consumption rate and the number of cycles completed in unit time. If the consumption rate is m_a kg/h, then for a four stroke engine,

$$Actual\,mass\,of\,air\,per\,cycle = \frac{\dot{m}_a}{60} \times \frac{2}{N} \qquad (4.9)$$

Then the volumetric efficiency which is defined as actual mass of air per cycle divided by ideal mass of air per cycle is given by:

$$\eta_v = \frac{2\dot{m}_a}{60N} \times \frac{1}{\rho_a V_s} \qquad (4.10)$$

The output power depends on the amount of air drawn into the cylinder, therefore any reduction in volumetric efficiency reduces the output power. Volumetric efficiency is therefore an important measure of engine performance.

Thermal efficiency :

The thermal efficiency is defined as the work done in the cycle of combustion divided by the heat input.

The ideal thermal efficiency is given by:

$$\eta_t = 1 - \frac{1}{r^{\gamma - 1}} \qquad (4.11)$$

where r is the compression ratio and γ is the ratio of specific heats. (for air, $\gamma = 1.4$).

But this value of thermal efficiency is higher than the actual thermal efficiency which is given by:

$$\eta_t = \frac{P_I}{F.E.P} \qquad (4.12)$$

where P_I is indicated power which equal to brake power (P_B) plus loss power(P_L) and F.E.P is fuel equivalent power.

Loss power for each speed is estimated from line represents the relation between fuel consumption and power of the engine.

Mechanical efficiency:

The mechanical efficiency is used to determine the amount of useful work available at the output shaft. It is defined as useful work divided by energy available at piston. So it is given by the following relation:

$$\eta_m = \frac{P_B}{P_I} \qquad (4.13)$$

where P_B is brake power and P_I is indicated power.

Brake thermal efficiency:

Brake thermal efficiency (or fuel conversion efficiency) is used for economic reasons, it is important to obtain the useful work from a given amount of fuel. It is expressed as output power divided by rate of input heat, so that it is defined as:

$$\eta_b = \frac{P_B}{F.E.P} \qquad (4.14)$$

From this equation and previous equations, brake thermal efficiency can be expressed as the product of the actual thermal and mechanical efficiencies: $\eta_b = \eta_t \times \eta_m$.

Specific Fuel Consumption:

Another measure of engine efficiency is the specific fuel consumption, defined as the fuel consumption rate divided by the brake power.

$$S.F.C = \frac{\dot{m}_f \times 10^3}{P_B} \qquad (4.15)$$

Specific fuel consumption is a useful measure of engine performance because it relates directly to the economy of an engine. It enables the operator to calculate how much fuel is required to produce a certain output power for a certain length of time.

CHAPTER FIVE

EXPERIMENTAL SETUP AND PROCEDURE

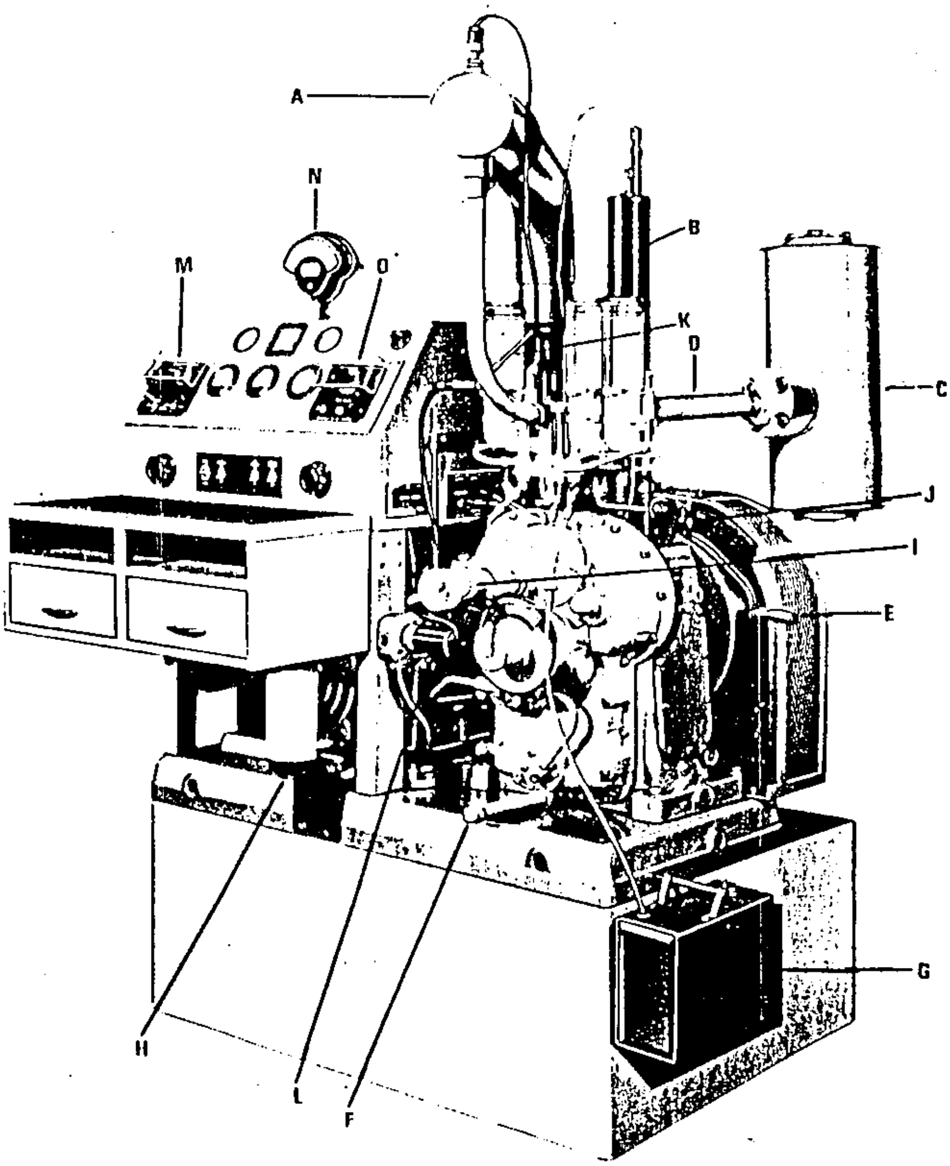
This chapter describes the apparatus used to perform the experiments, preparing gasoline samples with MTBE and the procedure that was followed throughout the experiments.

5.1 Experimental Equipments :

In the present work, the following three different equipments were used.

5.1.1 The knock testing unit:

It is used to determine the octane number of the gasoline. A photograph of the unit is shown in figure (5.1). As shown in this figure the unit consists of a single cylinder engine of continuously variable compression ratio, with suitable loading and accessory equipment and instruments, mounted on a stationary base. The carburetor is connected with four carburetor tanks and its venturi is 14.3 mm diameter at the throat. The engine has constant speed which is 600 rpm with a maximum variation of 6 rpm during a test. The equipment also contains knockmeter which determines the knocking characteristics of the fuel. Intake air humidity must be 0.00356 to 0.00712 kg of water/kg of dry air.



A—Intake Surge Pipe
B—Coolant Condenser
C—Exhaust Surge Tank
D—Exhaust Manifold
E—Crank for Adjusting Compression Ratio
F—Oil Drain Cap
G—Waste Fuel Can, Closed for Safety
H—Oil Filter
I—Ignition Breaker
J—Cylinder Clamp
K—Intake Air Thermometer
L—Ignition Coil
M—Detonation Meter, Model 501-T
N—Knockmeter
O—Temperature Controller

Figure (5.1): The knock testing unit.

5.1.2 The mini-engine test rig:

It is used to study performance of the engine by measuring engine parameters (speed, torque, flow rates etc..).

It consists of an engine (TD110), Hydraulic dynamometer (TD115) and Instrumentation unit (TD114). The complete mini-engine test rig is shown in figure (5.2).

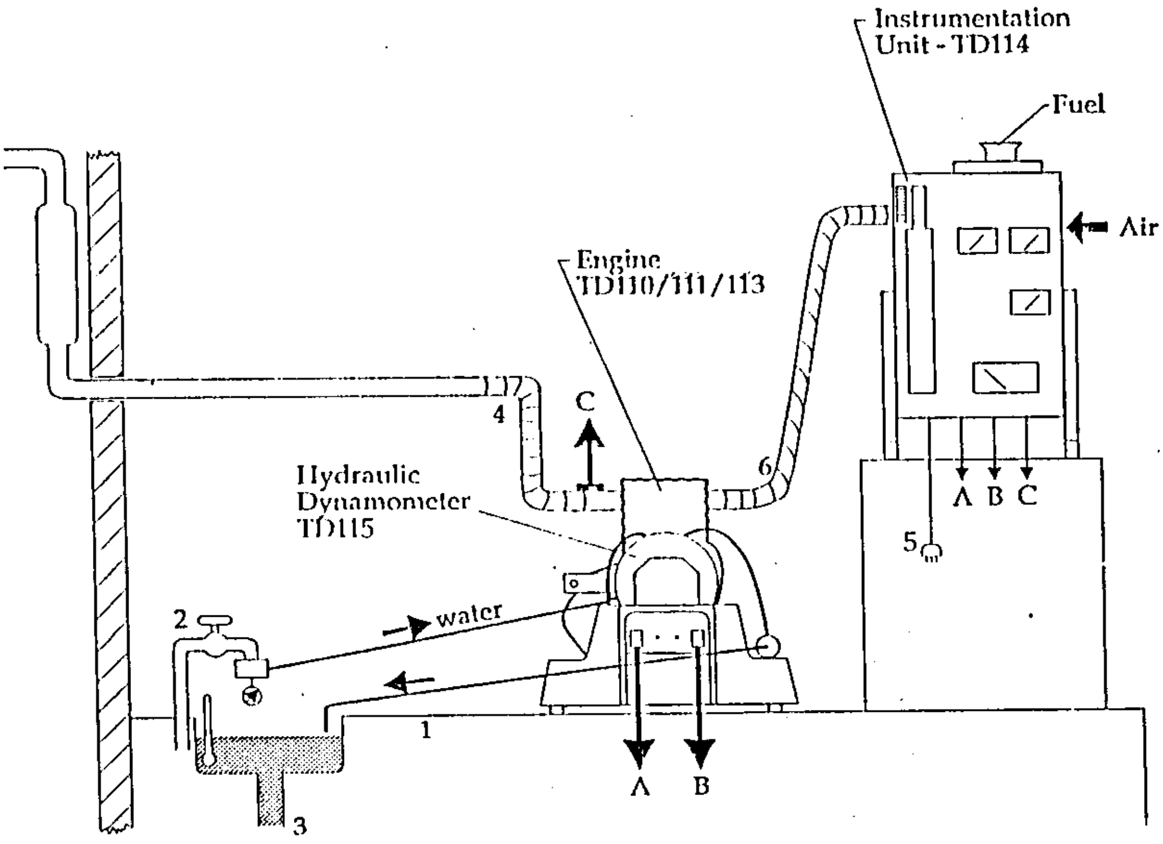


Figure (5.2): The complete mini-engine test rig.

- **TD110 Engine:**

It is a four stroke gasoline engine (spark ignition) with a single cylinder. Some of specifications of this engine are shown in table (5.1)

Table (5.1): Specifications of TD110 Engine.

Manufacturer/Type	TECUMSEH
Valve position	Sidevalve
Swept volume	199.6 cc
Bore	66.69 mm
Stroke	57.15 mm
Compression Ratio	6:1
Recommended maximum speed	3600 rpm

- **TD115 Hydraulic Dynamometer:**

It is connected to the engine shaft to measure the torque. Figure (5.3) shows the principles and layout of the dynamometer. It consists of a paddle (D) inside the vaned casing (B) this paddle is connected with engine shaft. Around the casing, there is a spring loaded nylon cord (E). There is also a damper (g) filled with lubricating oil which is connected to the casing. The two springs (F) have equal stiffness, and are always in tension as the dynamometer casing rotates. On the top of the casing, there is a needle valve (a) which controls the quantity of water in dynamometer and hence the power absorbed from the engine.

The angular position taken up by the casing depends on the torque T and stiffness of the two springs. The peripheral displacement of the casing is proportional to the torque and is measured by a rotary potentiometer (H), the output of which is fed into the input of the TD114 torquemeter.

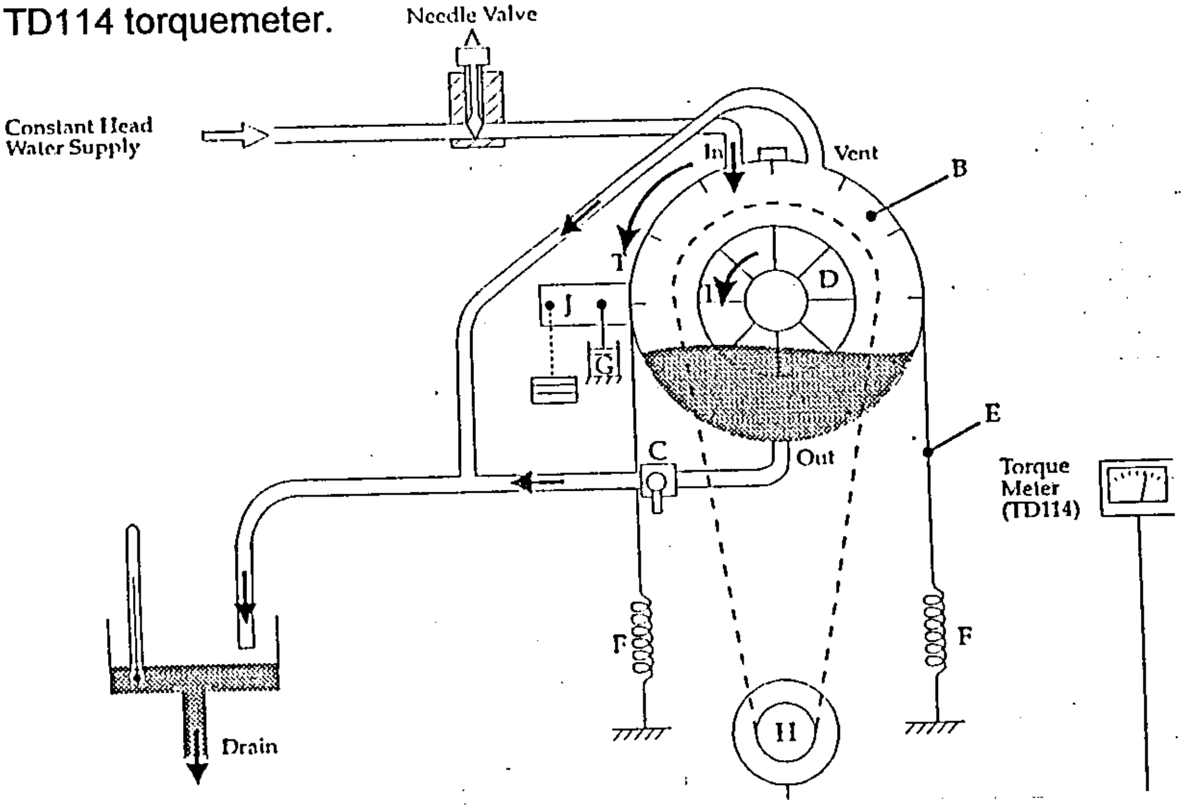


Figure (5.3): Schematic drawing of dynamometer and torque instrumentation.

- **Instrumentation Unit (TD114):**

The instrumentation unit is designed to stand beside the engine under test. In addition to housing the instruments necessary for measuring the engine performance, it contains the fuel system and airbox / viscous flow meter used to measure the consumption of air. A front view of the instrumentation unit is shown in figure (5.4).

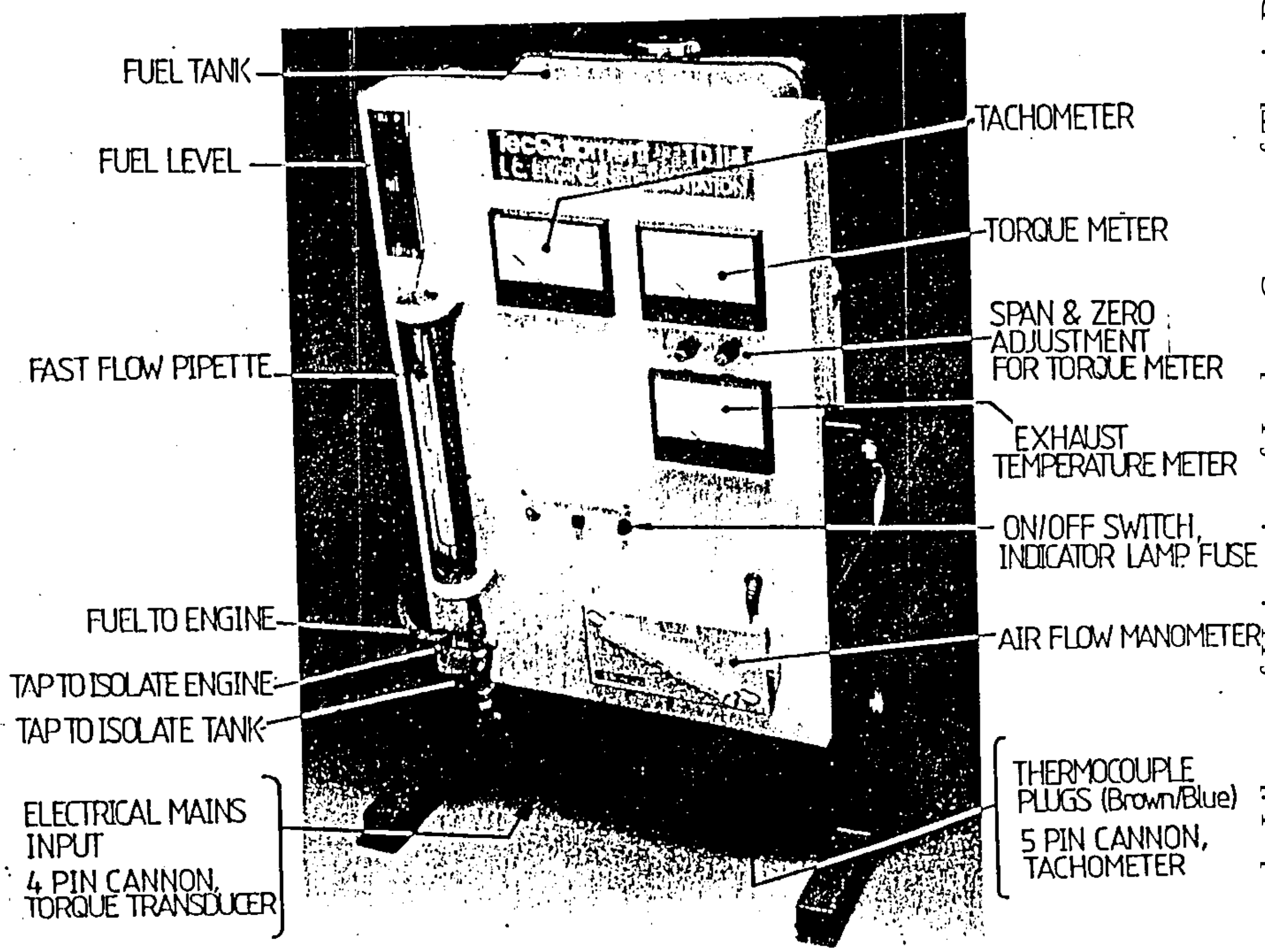


Figure (5.4): TD114 instrumentation unit.

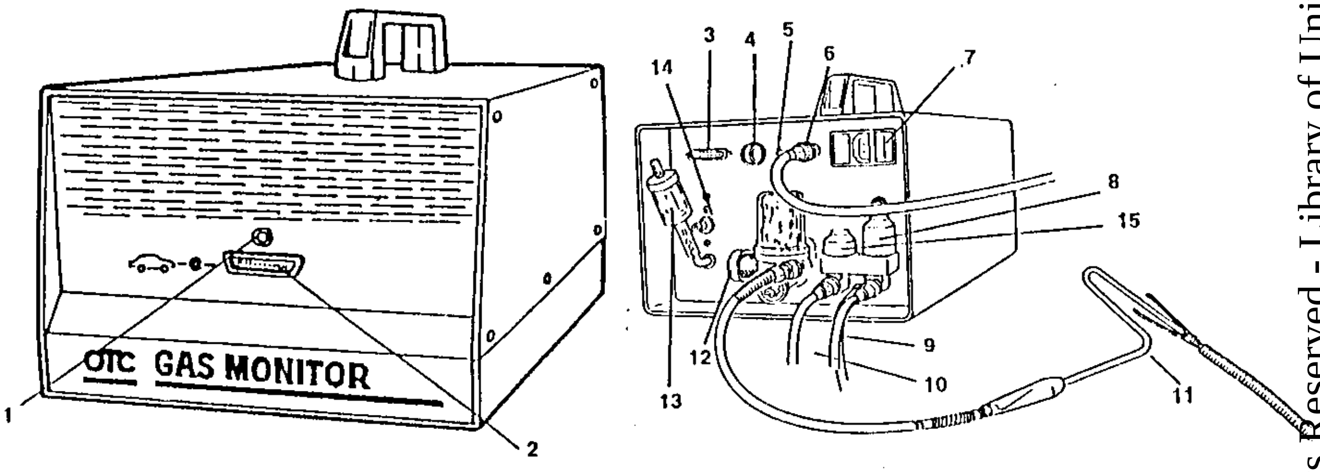
5.1.3 Gas Analyzer Unit:

It consists of keyboard, screen, printer and gas monitor which connected with a probe through hose. The gas monitor is a microprocessor controlled test unit that provides real-time measurement of gases found in gasoline powered vehicle exhaust, engine rpm and engine oil temperature (In this work, the last two parameters were not measured).

Measurement Ranges:

- Hydrocarbons (HC): 0-9,999 ppm.
- Carbon Monoxide (CO): 0-10 %.
- Carbon Dioxide (CO_2): 0-20 %.
- Oxygen (O_2): 0-25 %.

The gas monitor and parts are shown in figure (5.5)



1. ON/Off light.
2. Auxiliary connector.
3. DB25S connection.
4. Power line for printer.
5. 12 volt fuse.
6. Battery jack.
7. 110 volt AC inlet power switch.
8. Oxygen sensor.
9. Drain hose.
10. Waste gas hose.
11. Exhaust Sampling hose and probe.
12. Input sample filter.
13. Air filter.
14. Calibration gas fitting.

Figure (5.5): The gas monitor and its parts.

5.2 Preparing Gasoline Samples:

The Jordanian refinery produces the following three main types of gasoline :

- Platforming unit gasoline with 94 octane number.
- Fluid Catalytic Cracking(F.C.C) unit gasoline with 89 octane number.
- Light Straight Run (L.S.R) gasoline with 70 octane number.

These types are mixed together in different percentages to form two main blends namely; A and B. TEL is then added to each blend in two different quantities. These quantities were for blend A: 0.18 and 0.35 cc/U.S.G of gasoline and for blend B: 0.18 and 0.5 cc/U.S.G of gasoline. Thus with the two main blends, six base fuels ,two of them are regular and super gasoline, are obtained.

Blend A consists of:

- 38 % L.S.R gasoline.
- 44 % Platforming gasoline.
- 18% F.C.C gasoline.

While blend B consists of:

- 5 % L.S.R gasoline.
- 20 % F.C.C gasoline.
- 75 % Platforming gasoline.

The six base fuels are given as follows :

1. Blend A without lead.
2. Blend A with 0.18cc TEL/U.S.G . (Blend AT)
3. Blend A with 0.35cc TEL/U.S.G which is commercially called in Jordan regular gasoline. (Blend AR)
4. Blend B without lead.
5. Blend B with 0.18cc TEL/U.S.G . (Blend BT)
6. Blend B with 0.6cc TEL/U.S.G which is commercially called in Jordan super gasoline. (Blend BS)

Five blends were prepared from each base fuel. The first blend was the base fuel itself and the other four blends were the base fuel containing four percentages of MTBE namely; 5, 10, 15 and 20% v/v. The six base fuels and their properties are shown in Table (5.2).

Table (5.2): The six base fuels and their properties.

Base fuels: Blend	Platforming %	F.C.C %	L.S.R %	TEL cc/U.S.G	Octane Number
A	44	18	38	0	85
AT	44	18	38	0.18	86.3
AR	44	18	38	0.35	87.4
B	75	20	5	0	92.4
BT	75	20	5	0.18	93.3
BS	75	20	5	0.5	95.4

5.3 Experimental Procedure :

The experimental procedure involves measuring the octane number of the gasoline samples, and measuring the engine performance when these samples are used as fuel to run it.

5.3.1 Measuring octane number :

Reference blends of gasoline (having octane number between 80 and 100) were prepared by mixing two standard gasolines with different percentage. The first standard gasoline is iso-octane gasoline with 100 octane number and the other standard is gasoline with 80 octane number. Reference blends of gasoline with octane number larger than 100 are produced by mixing the iso-octane gasoline with TEL according to the certain table.

Based on the knock characteristics of the fuel, there are two methods to determine octane number which are: bracketing method and compression ratio method.

- **Bracketing method:**

This method is based on bracketing the knockmeter reading for the sample at constant compression ratio between knockmeter readings for two reference blends, This is done through the following procedure :

1. After the engine is started, the ignition is turned on.

2. The unknown sample is placed in the first carburetor tank and the carburetor is set to draw fuel from this tank.
3. The compression ratio is varied until the knockmeter points at the middle of the scale.
4. Then two reference blends are prepared such that the knockmeter reading of the sample is bracketed.
5. After that, octane number of the sample is calculated by interpolation with the knockmeter readings of the blends.

- **Compression ratio method:**

In this method, one reference blend of gasoline is used. Octane number of the sample is measured according to the digital counter setting for the reference blend and the sample and by using a table supplied by the manufacturer. The following procedure is followed:

1. A reference blend is prepared such that its octane number is close to the octane number of the sample.
2. Engine is turned on and the blend is placed in the first tank.
3. Then compression ratio is varied until the digital counter setting corresponds to a similar value in the table (C.1) for octane number of the blend.

4.Then the meter read control is set to obtain 50 konckmeter reading.

5.The sample is placed in the second tank and the carburetor is set to draw from this tank.

6.The compression ratio is varied until the knockmeter reads 50 and the new counter digital setting is recorded.

7.By referring to the previous table and using the new counter setting, octane number of the sample is found.

Note : If the difference between the sample and the reference is more than the listed limits in Table (5.3), the steps were repeated with new reference blend such that difference is not more than the listed limits.

Table (5.3): The maximum permissible octane number.

Sample rating range in octane number	Maximum permissible octane number difference between reference fuel and sample
Below 90	2.0
90 to 100	1.0
100 to 102	0.7
102 to 105	1.3
Above 105	2.0

5.3.2 Measuring engine performance:

The following steps were followed during testing the engine :

1. After assembling the parts of the test rig as in Figure(5.1), the throttle is opened at a small amount and the ignition switch is turned on.
2. The starting handle is pulled rapidly outwards. (This step is repeated until the engine is set in operation.
3. During the engine warming up period, the gas analyzer is turned on and it is left to warm up.
4. After the engine become warm, the chock is put into the open position and the throttle is advanced to the maximum position.
5. The probe of the exhaust gas analyzer is placed in the exhaust pipe.
6. The main valve of water is opened and the needle valve is adjusted slowly such that each step corresponds to a speed decrease of 200 rpm.
7. At each speed the manometer reading, torque, exhaust temperature and time needed to consume 8 ml of fuel are recorded. Also The gas analyzer reading is printed each time.
8. The last step is repeated for a speed range of 3600 and 1400 rpm, with speed intervals of 200 rpm.

CHAPTER SIX

RESULTS AND DISCUSSION

6.1 Introduction:

As mentioned previously, MTBE is used to increase octane number of gasoline leading to improvements in the performance of the engine that utilizes this improved fuel. Further this addition of MTBE leads the reduction of some serious pollutants emitted from the engine.

6.2 Effect Of MTBE Addition On The Octane Number Of The Gasoline:

The effect of adding MTBE with different percentages on octane number of gasoline is shown in Figures (6.1) and (6.2). These figures show that octane number increases with the addition of MTBE in a linear fashion. Figure (6.1) shows that octane number of the blends increase continuously and linearly until reaches a maximum value of 118 at 100% MTBE. The rate at which octane number increases for all blends depends on the octane number of the base fuel as shown in Figure (6.2).

Figure (6.3) shows the quantities of both TEL and MTBE that should be added to maintain a constant octane number. As shown, and as expected, the amount of MTBE to be added increases as that of TEL decreases.

6.3 Effect Of MTBE Addition On The Performance Of The Engine:

6.3.1 Group A:

Figures (6.6) through (6.15) show the performance of the engine when fuels of group A were used in the engine.

Figures (6.6) through (6.8) show the effect of MTBE addition on the power output of the engine. As shown in Figure(6.6), the maximum increase in power, compared with that obtained when base fuel is used, occurs when 10% of MTBE was added. This maximum value of increase in the power depend on the speed conditions and it was 8% and 10% under low and high speed condition, respectively.

It is clear from Figures (6.7) and (6.8) that power first increases with MTBE percentage in the blend, and then starts to decrease slightly beyond 10% of MTBE in the blend, however the power output remains higher at any value of MTBE compared with that obtained when base fuel is used.

Figure (6.9) shows the effect of addition of MTBE on the specific fuel consumption. As indicated in the figure the specific fuel consumption has a minimum value when 5% of MTBE was used and then increases when 10% of MTBE was added. This is due to the fact that the measured flow rate of fuel was the smallest when 5% of MTBE was used. So that to produce the same output power from each blend, the consumed fuel was smaller when 5% of MTBE was used.

Figures (6.10) and (6.11) show the effect of MTBE addition on thermal and brake thermal efficiency. As expected, and referring to Figure (6.9), the maximum increase in thermal and brake thermal efficiency occur when 5% MTBE blend is used, and with values of 12% and 17% respectively.

Figure (6.12) shows that the maximum increase in air-fuel ratio was about 25% when 5% MTBE blend is used which corresponds to the maximum thermal and brake thermal efficiency. This is in agreement with thermodynamic fact that when mixture is more lean (air-fuel is large), it will produce high cycle efficiency.

Mechanical efficiency is shown in Figure (6.13). It was maximum when 10% MTBE blend is used. This is due to the fact that the maximum power occurs when 10% MTBE blend is used.

Figure (6.14) shows variation of volumetric efficiency for group A blends with speed. From this figure, it may be noticed that there is no significant improvement in the volumetric efficiency of MTBE blends comparing with clear blend.

Finally, the variation of exhaust temperature with speed is shown in Figure (6.15). The maximum increase in exhaust temperature was about 6% occurs when 5% MTBE blend is used which corresponds the highest thermal efficiency. This is in agreement with the thermodynamic fact that actual cycle efficiency increases with increase in the high temperature limit.

6.3.2 Group AT:

Figures (6.16) through (6.25) show the performance of the engine when fuels of group AT were used in the engine.

Figures (6.16) through (6.18) show the effect of MTBE addition on the power output of the engine. As shown in Figure(6.16), the maximum increase in power, compared with that obtained when base fuel is used, occurs when 15% of MTBE was added. This maximum value of increase in the power depend on the speed conditions and it was 12% and 15% under low and high speed condition, respectively.

It is clear from Figures (6.17) and (6.18) that power first increases with MTBE percentage in the blend, and then starts to decrease slightly beyond 15% of MTBE in the blend, however the power output remains higher at any value of MTBE compared that obtained when base fuel is used.

Figure (6.19) shows the effect of addition of MTBE on the specific fuel consumption. As indicated in the figure, the specific fuel consumption has a minimum value when 15% of MTBE was used for low speed and when 10% of MTBE was added for high speed. This is due to the fact that the measured flow rate of fuel initially was the smallest when 15% of MTBE was used and then becomes smaller when 10% MTBE blend was used.

Figures (6.20) and (6.21) show the effect of MTBE addition on thermal and brake thermal efficiency. As expected, and referring to Figure (6.19), the maximum increase in thermal and brake thermal efficiency occur when 15% MTBE blend was used for low speed and when 10% of MTBE was added for high speed. These increases in thermal and brake thermal efficiency were 8% and 14% respectively.

Figure (6.22) shows that the maximum increase in air-fuel ratio occurs when 10% MTBE blend was used followed by 15% MTBE blend which corresponds to the maximum thermal and brake thermal efficiency. This is in agreement with thermodynamic fact that when mixture is more lean (air-fuel is large), it will produce high cycle efficiency.

Mechanical efficiency is shown in Figure (6.23). It was maximum when 15% MTBE blend is used. This is due to the fact that the maximum power occurs when 15% MTBE blend is used.

Figure (6.24) shows variation of volumetric efficiency for group AT blends with speed. From this figure, it may be noticed that there is small improvement about of 4% in the volumetric efficiency of MTBE blends comparing with clear blend.

Finally, the variation of exhaust temperature with speed is shown in Figure (6.25). The maximum increase in exhaust occurs when 15% and 20% MTBE blends were used. This is in agreement with the thermodynamic fact that actual cycle efficiency increases with increase in the high temperature limit.

6.3.3 Group AR:

Figures (6.26) through (6.35) show the performance of the engine when fuels of group AR were used in the engine.

Figures (6.26) through (6.28) show the effect of MTBE addition on the power output of the engine. As shown in Figure(6.26), the maximum increase in power, compared with that obtained when base fuel is used, occurs when 10% of MTBE was added. This maximum value of increase in the power was 10% under both low and high speed condition.

It is clear from Figures (6.27) and (6.28) that power first increases with MTBE percentage in the blend, and then starts to decrease slightly beyond 10% of MTBE in the blend, however the power output remains higher at any value of MTBE compared that obtained when base fuel is used.

Figure (6.29) shows the effect of addition of MTBE on the specific fuel consumption. As indicated in the figure the specific fuel consumption has a minimum value when 10% of MTBE was used. This is due to the fact that the measured flow rate of fuel was the smallest when 10% of MTBE was used. So that to produce the same output power from each blend, the consumed fuel was smaller when 10% of MTBE was used.

Figures (6.30) and (6.31) show the effect of MTBE addition on thermal and brake thermal efficiency. As expected, and referring to Figure (6.29), the maximum increase in thermal and brake thermal efficiency occur when 10% MTBE blend is used, and with values of 15% and 17% respectively.

Figure (6.32) shows that the maximum increase in air-fuel ratio was about 25% when 10% MTBE blend is used which corresponds to the maximum thermal and brake thermal efficiency. This is in agreement with thermodynamic fact that when mixture is more lean (air-fuel is large), it will produce high cycle efficiency.

Mechanical efficiency is shown in Figure (6.33). It was maximum when 10% MTBE blend is used. This is due to the fact that the maximum power occurs when 10% MTBE blend is used.

Figure (6.34) shows variation of volumetric efficiency for group A blends with speed. From this figure, it may be noticed that there is no significant improvement in the volumetric efficiency of 10% MTBE blend comparing with clear blend.

Finally, the variation of exhaust temperature with speed is shown in Figure (6.35). The maximum increase in exhaust temperature was about 5% occurs when 10% MTBE blend is used which corresponds the highest thermal efficiency. This is in agreement with the thermodynamic fact that actual cycle efficiency increases with increase in the high temperature limit.

6.3.4 Group B:

Figures (6.36) through (6.45) show the performance of the engine when fuels of group B were used in the engine.

Figures (6.36) through (6.38) show the effect of MTBE addition on the power output of the engine. As shown in Figure(6.36), the maximum increase in power, compared with that obtained when base fuel is used, occurs when 15% of MTBE was added, followed by 10% MTBE blend. This maximum value of increase in the power was 11% as an average under low and high speed condition.

It is clear from Figures (6.37) and (6.38) that power first increases with MTBE percentage in the blend, and then starts to decrease slightly beyond 15% of MTBE in the blend, however the power output remains higher at any value of MTBE compared that obtained when base fuel is used.

Figure (6.39) shows the effect of addition of MTBE on the specific fuel consumption. As indicated in the figure the specific fuel consumption has a minimum value when 10% of MTBE was used. This is due to the fact that the measured flow rate of fuel was the smallest when 10% of MTBE was used. So that to produce the same output power from each blend, the consumed fuel was smaller when 10% of MTBE was used.

Figures (6.40) and (6.41) show the effect of MTBE addition on thermal and brake thermal efficiency. As expected, and referring to Figure (6.39), the maximum increase in thermal and brake thermal efficiency occur when 10% MTBE blend was used, and with values of 17% and 23% respectively.

Figure (6.42) shows that the maximum increase in air-fuel ratio was about 6% when 10% MTBE blend was used which corresponds to the maximum thermal and brake thermal efficiency. This is in agreement with thermodynamic fact that when mixture is more lean (air-fuel is large), it will produce high cycle efficiency.

Mechanical efficiency is shown in Figure (6.43). It was maximum when 15% MTBE blend is used. This is due to the fact that the maximum power occurs when 15% MTBE blend is used.

Figure (6.44) shows variation of volumetric efficiency for group B blends with speed. From this figure, it may be noticed that there is no any improvement in the volumetric efficiency of MTBE blends comparing with clear blend.

Finally, the variation of exhaust temperature with speed is shown in Figure (6.45). The maximum increase in exhaust occurs when 20% MTBE blend was used and followed by that when 10% of MTBE was added.

6.3.5 Group BT:

Figures (6.46) through (6.55) show the performance of the engine when fuels of group BT were used in the engine.

Figures (6.46) through (6.48) show the effect of MTBE addition on the power output of the engine. As shown in Figure(6.46), the maximum increase in power, compared with that obtained when base fuel is used, occurs when 5% and 10% of MTBE were added. This maximum value of increase in the power depend on the speed conditions and it was 10% and 20% under low and high speed condition, respectively.

It is clear from Figures (6.47) and (6.48) that power first increases with MTBE percentage in the blend, and then starts to decrease slightly beyond 10% of MTBE in the blend, however the power output remains higher at any value of MTBE compared that obtained when base fuel is used. This behavior could be due to the variation of the specific heat ratio of the blend which resulted from the variations of the percentage of MTBE in the blend.

Figure (6.49) shows the effect of addition of MTBE on the specific fuel consumption. As indicated in the figure the specific fuel consumption has a minimum value when 10% of MTBE was used followed by that when 5% of MTBE was added. This is due to the fact that the measured flow rate of fuel was the smallest when 10% of MTBE was used. So that to produce the same output power from each blend, the consumed fuel was smaller when 5% of MTBE was used.

Figures (6.50) and (6.51) show the effect of MTBE addition on thermal and brake thermal efficiency. As expected, and referring to Figure (6.49), the maximum increase in thermal and brake thermal efficiency occur when 10% MTBE blend is used, and with values of 7% and 11% respectively.

Figure (6.52) shows that the maximum increase in air-fuel ratio was about 8% when 10% MTBE blend was used which corresponds to the maximum thermal and brake thermal efficiency. This is in agreement with thermodynamic fact that when mixture is more lean (air-fuel is large), it will produce high cycle efficiency.

Mechanical efficiency is shown in Figure (6.53). It was maximum when 10% MTBE blend was used. This is due to the fact that the maximum power occurs when 10% MTBE blend was used.

Figure (6.54) shows variation of volumetric efficiency for group BT blends with speed. From this figure, it may be noticed that there is no significant improvement in the volumetric efficiency of MTBE blends comparing with clear blend.

Finally, the variation of exhaust temperature with speed is shown in Figure (6.55). The maximum increase in exhaust temperature was about 5% occurs when 20% MTBE blend was used.

6.3.6 Group BS:

Figures (6.56) through (6.65) show the performance of the engine when fuels of group BS were used in the engine.

Figures (6.56) through (6.58) show the effect of MTBE addition on the power output of the engine. As shown in Figure(6.56), the maximum increase in power, compared with that obtained when base fuel was used, occurs when 5% of MTBE was added. This maximum value of increase in the power depend on the speed conditions and it was 11% and 15% under low and high speed condition, respectively. It is clear from Figures (6.57) and (6.58) that power first increases with MTBE percentage in the blend, and then starts to decrease slightly beyond 5% of MTBE in the blend, however the power output remains higher at any value of MTBE compared with that obtained when base fuel is used.

Figure (6.59) shows the effect of addition of MTBE on the specific fuel consumption. As indicated in the figure the specific fuel consumption has a minimum value when 20% of MTBE was used followed by that when 5 and 15% of MTBE were added. This is due to the fact that the measured flow rate of fuel was the smallest when 20% of MTBE was used. So that to produce the same output power from each blend, the consumed fuel was smaller when 20% of MTBE was used.

Figures (6.60) and (6.61) show the effect of MTBE addition on thermal and brake thermal efficiency. As expected, and referring to Figure (6.59), the maximum increase in thermal and brake thermal efficiency occur when 20% MTBE blend was used, and with values of 26% and 35% respectively.

Figure (6.62) shows that the maximum increase in air-fuel ratio was about 21% when 15 and 20% MTBE blend were used which corresponds to the maximum thermal and brake thermal efficiency. This is in agreement with thermodynamic fact that when mixture is more lean (air-fuel is large), it will produce high cycle efficiency.

Mechanical efficiency is shown in Figure (6.63). It was maximum when 5% MTBE blend was used. This is due to the fact that the maximum power occurs when 5% MTBE blend was used.

Figure (6.64) shows variation of volumetric efficiency for group BS blends with speed. From this figure, it may be noticed that there is no significant improvement in the volumetric efficiency of MTBE blends comparing with clear blend except 15% MTBE blend has 7% increase.

Finally, the variation of exhaust temperature with speed is shown in Figure (6.65). The maximum increase in exhaust temperature was about 6% occurs when 20% MTBE blend was used which corresponds the highest thermal efficiency. This is in agreement with the thermodynamic fact that actual cycle efficiency increases with increase in the high temperature limit.

6.4 Effect of MTBE addition on exhaust gases:

Figures (6.66) through (6.89) show the effect of MTBE addition on some of the exhaust gases namely; carbon monoxide (CO), carbon

dioxide (CO_2), unburned hydrocarbons (UBHC) and oxygen (O_2).

6.4.1 Group A:

Figures (6.66) through (6.69) show variation of exhaust gases with speed when group A fuels were used.

Figure (6.66) indicates the variation of the emitted concentration of carbon monoxide. It is clear from this figure that MTBE leads to a reduction in the concentration of CO by provided it with extra oxygen to convert to CO_2. The maximum reduction occurs when 10% of MTBE was added. Beyond this value the amount of CO emitted increases gradually. This is due to the fact the carbon atoms available in the combustion zone increase with the amount of MTBE.

Variation of CO_2 concentration with speed is shown in Figure (6.67). The minimum values of emitted CO_2 were obtained when clear blend of MTBE was used, while the maximum values were obtained when 10% of MTBE was added to the base fuel. This corresponds to Figure (6.66) such that reduction in CO concentration leads to increase in CO_2 concentration. Further, the amount of emitted CO_2 initially decrease with speed up to a minimum values, beyond which they increase.

Figure (6.68) shows the concentration of UBHC in exhaust gases as speed varies. It is obvious from this figure that MTBE also leads to a reduction in the concentration of UBHC, with maximum reduction about 33% when 10% of MTBE was added. Beyond this value the amount of UBHC increases gradually. This is due to the fact the carbon and hydrogen atoms available in the combustion zone increase with the amount of MTBE.

Concentration of O_2 in exhaust gases is shown in Figure (6.69). The amounts of O_2 initially increase with speed up to a maximum value, beyond which they decrease.

6.4.2 Group AT:

Figures (6.70) through (6.73) show variation of exhaust gases with speed when group AT fuels were used.

Figure (6.70) indicates the variation of the emitted concentration of carbon monoxide. It is clear from this figure that MTBE leads to a reduction in the concentration of CO by provided it with extra oxygen to convert to CO_2. The maximum reduction occurs when 5% of MTBE was added. Beyond this value the amount of CO emitted increases gradually. This is due to the fact the carbon atoms available in the combustion zone increase with the amount of MTBE.

Variation of CO_2 concentration with speed is shown in Figure (6.71). The minimum values of emitted CO_2 were obtained when 5% of MTBE was added to the base fuel. Further, the amount of emitted CO_2 initially decrease with speed up to a minimum values, beyond which they increase.

Figure (6.72) shows the concentration of UBHC in exhaust gases as speed varies. It is obvious from this figure that MTBE also leads to a reduction in the concentration of UBHC when 5% of MTBE was added. Beyond this value the amount of UBHC increases gradually. This is due to the fact the carbon and hydrogen atoms available in the combustion zone increase with the amount of MTBE.

Concentration of O_2 in exhaust gases is shown in Figure (6.73). The amounts of O_2 initially increase with speed up to a maximum value, beyond which they decrease.

6.4.3 Group AR:

Figures (6.74) through (6.77) show variation of exhaust gases with speed when group AR fuels were used.

Figure (6.74) indicates the variation of the emitted concentration of carbon monoxide. It is clear from this figure that MTBE leads to a reduction in the concentration of CO by provided it with extra oxygen to convert to CO_2. The maximum reduction occurs when 10% of MTBE was added. Beyond this value the amount of CO emitted increases gradually. This is due to the fact the carbon atoms available in the combustion zone increase with the amount of MTBE.

Variation of CO_2 concentration with speed is shown in Figure (6.75). The minimum values of emitted CO_2 were obtained when 5% of MTBE was used, while the maximum values were obtained when 20% of MTBE was added to the base fuel. This corresponds to Figure (6.74) such that reduction in CO concentration leads to increase in CO_2 concentration. Further, the amount of emitted CO_2 initially decrease with speed up to a minimum values, beyond which they increase.

Figure (6.76) shows the concentration of UBHC in exhaust gases as speed varies. It is obvious from this figure that MTBE also leads to a reduction in the concentration of UBHC, with maximum reduction when 10% of MTBE was added. Beyond this value the amount of UBHC increases gradually. This is due to the fact the carbon and hydrogen atoms available in the combustion zone increase with the amount of MTBE.

Concentration of O_2 in exhaust gases is shown in Figure (6.77). The amounts of O_2 initially increase with speed up to a maximum value, beyond which they decrease. The maximum concentration of O_2 was obtained when 20% of MTBE was added.

6.4.4 Group B:

Figures (6.78) through (6.81) show variation of exhaust gases with speed when group B fuels were used.

Figure (6.78) indicates the variation of the emitted concentration of carbon monoxide. It is clear from this figure that MTBE leads to maximum reduction when 10% of MTBE was added. Beyond this value the amount of CO emitted increases gradually. This is due to the fact the carbon atoms available in the combustion zone increase with the amount of MTBE.

Variation of CO_2 concentration with speed is shown in Figure (6.79). The minimum values of emitted CO_2 were obtained when clear blend of MTBE was used, while the maximum values were obtained when 10% of MTBE was added to the base fuel. This corresponds to Figure (6.78) such that reduction in CO concentration leads to increase in CO_2 concentration. Further, the amount of emitted CO_2 initially decrease with speed up to a minimum values, beyond which they increase.

Figure (6.80) shows the concentration of UBHC in exhaust gases as speed varies. It is obvious from this figure that MTBE also leads to a reduction in the concentration of UBHC, the maximum reduction occur when 10% of MTBE was added. Beyond this value the amount of UBHC increases gradually. This is due to the fact the carbon and hydrogen atoms available in the combustion zone increase with the amount of MTBE.

Concentration of O_2 in exhaust gases is shown in Figure (6.81). The amounts of O_2 initially increase with speed up to a maximum value, beyond which they decrease. The maximum concentration occurs when 10% MTBE was used.

6.4.5 Group BT:

Figures (6.82) through (6.85) show variation of exhaust gases with speed when group BT fuels were used.

Figure (6.82) indicates the variation of the emitted concentration of carbon monoxide. It is clear from this figure that MTBE leads to a reduction in the concentration of CO by provided it with extra oxygen to convert to CO_2. The maximum reduction occurs when 10% of MTBE was added. Beyond this value the amount of CO emitted increases gradually. This is due to the fact the carbon atoms available in the combustion zone increase with the amount of MTBE.

Variation of CO_2 concentration with speed is shown in Figure (6.83). The minimum values of emitted CO_2 were obtained when clear blend of MTBE was used, while the maximum values were obtained when 20% of MTBE was added to the base fuel. Further, the amount of emitted CO_2 initially decrease with speed up to a minimum values, beyond which they increase.

Figure (6.84) shows the concentration of UBHC in exhaust gases as speed varies. It is obvious from this figure that MTBE also leads to a reduction in the concentration of UBHC, the maximum reduction also occurs when 10% of MTBE was added. Beyond this value the amount of UBHC increases gradually. This is due to the fact the carbon and hydrogen atoms available in the combustion zone increase with the amount of MTBE.

Concentration of O_2 in exhaust gases is shown in Figure (6.85). The amounts of O_2 initially increase with speed up to a maximum value, beyond which they decrease. Also the maximum increase occurs when 10% of MTBE was added.

6.4.6 Group BS:

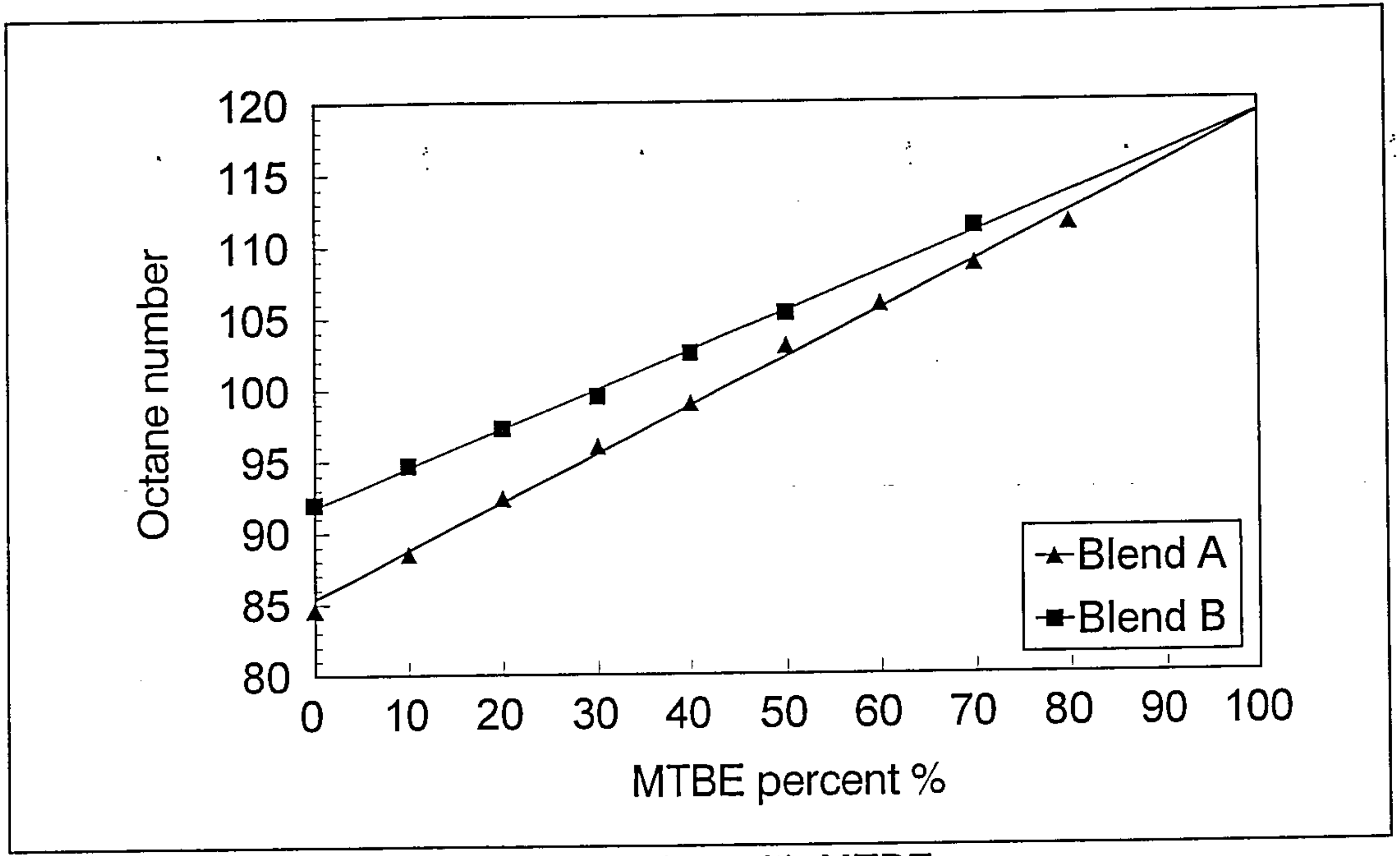
Figures (6.86) through (6.89) show variation of exhaust gases with speed when group BS fuels were used.

Figure (6.86) indicates the variation of the emitted concentration of carbon monoxide. It is clear from this figure that MTBE leads to a reduction in the concentration of CO by provided it with extra oxygen to convert to CO_2. The maximum reduction occurs when 20% of MTBE was added.

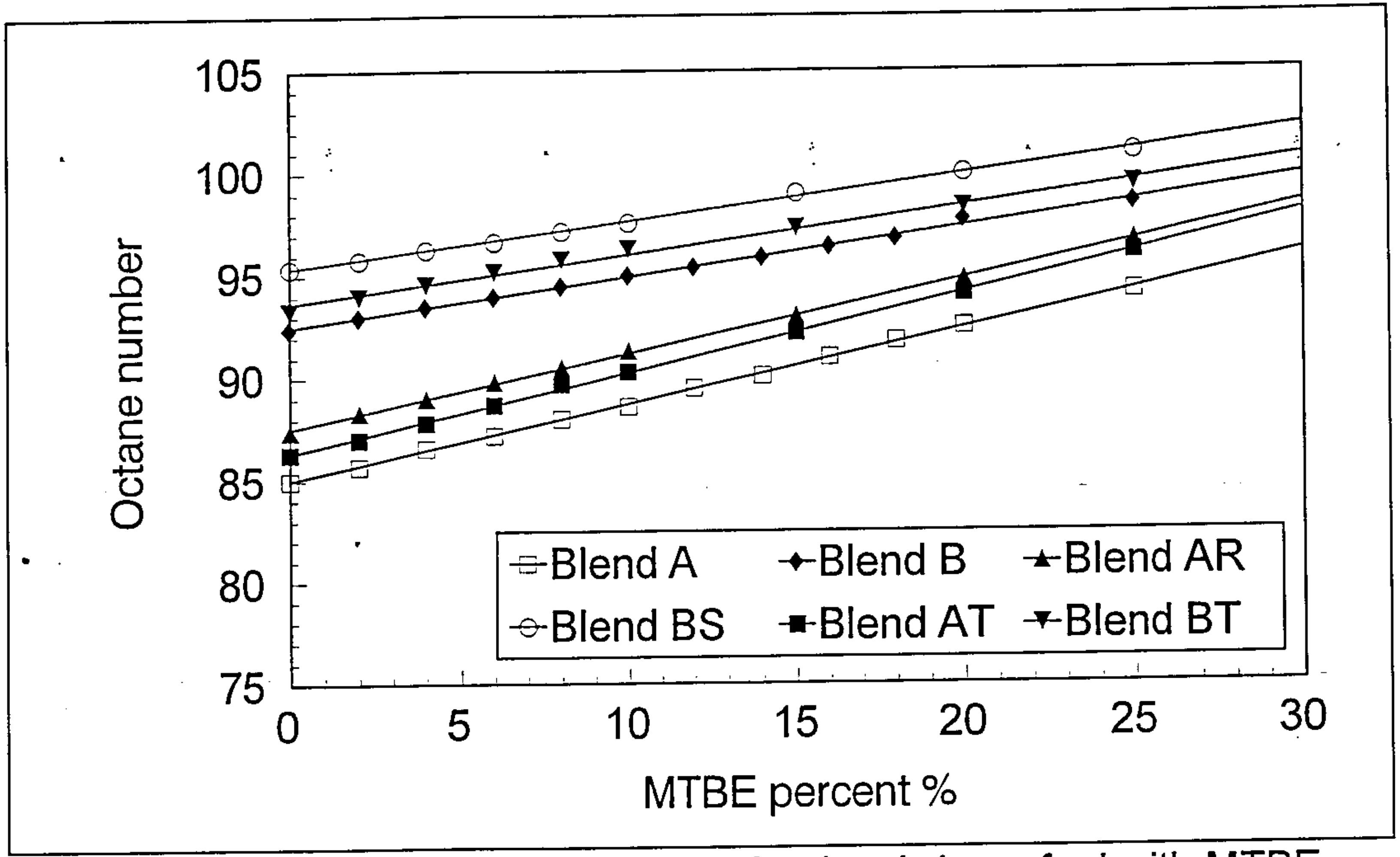
Variation of CO_2 concentration with speed is shown in Figure (6.87). The minimum values of emitted CO_2 were obtained when 15% of MTBE was added, while the maximum values were obtained when 20% of MTBE was added to the base fuel. This corresponds to Figure (6.86) such that reduction in CO concentration leads to increase in CO_2 concentration. Further, the amount of emitted CO_2 initially decrease with speed up to a minimum values, beyond which they increase.

Figure (6.88) shows the concentration of UBHC in exhaust gases as speed varies. It is obvious from this figure that MTBE also leads to a reduction in the concentration of UBHC, the maximum reduction occur when 20% of MTBE was added.

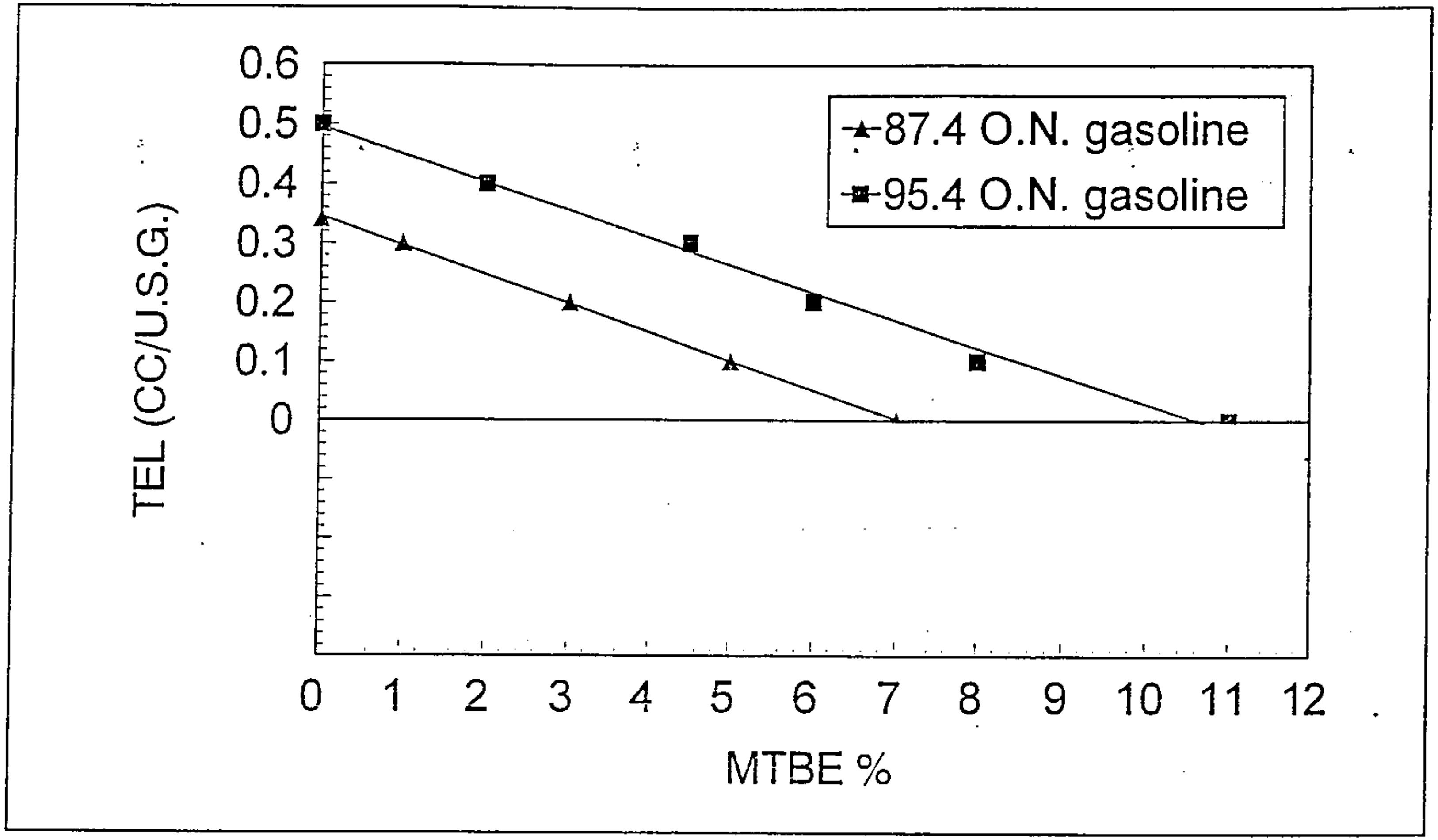
Concentration of O_2 in exhaust gases is shown in Figure (6.89). The amounts of O_2 initially increase with speed up to a maximum value, beyond which they decrease.



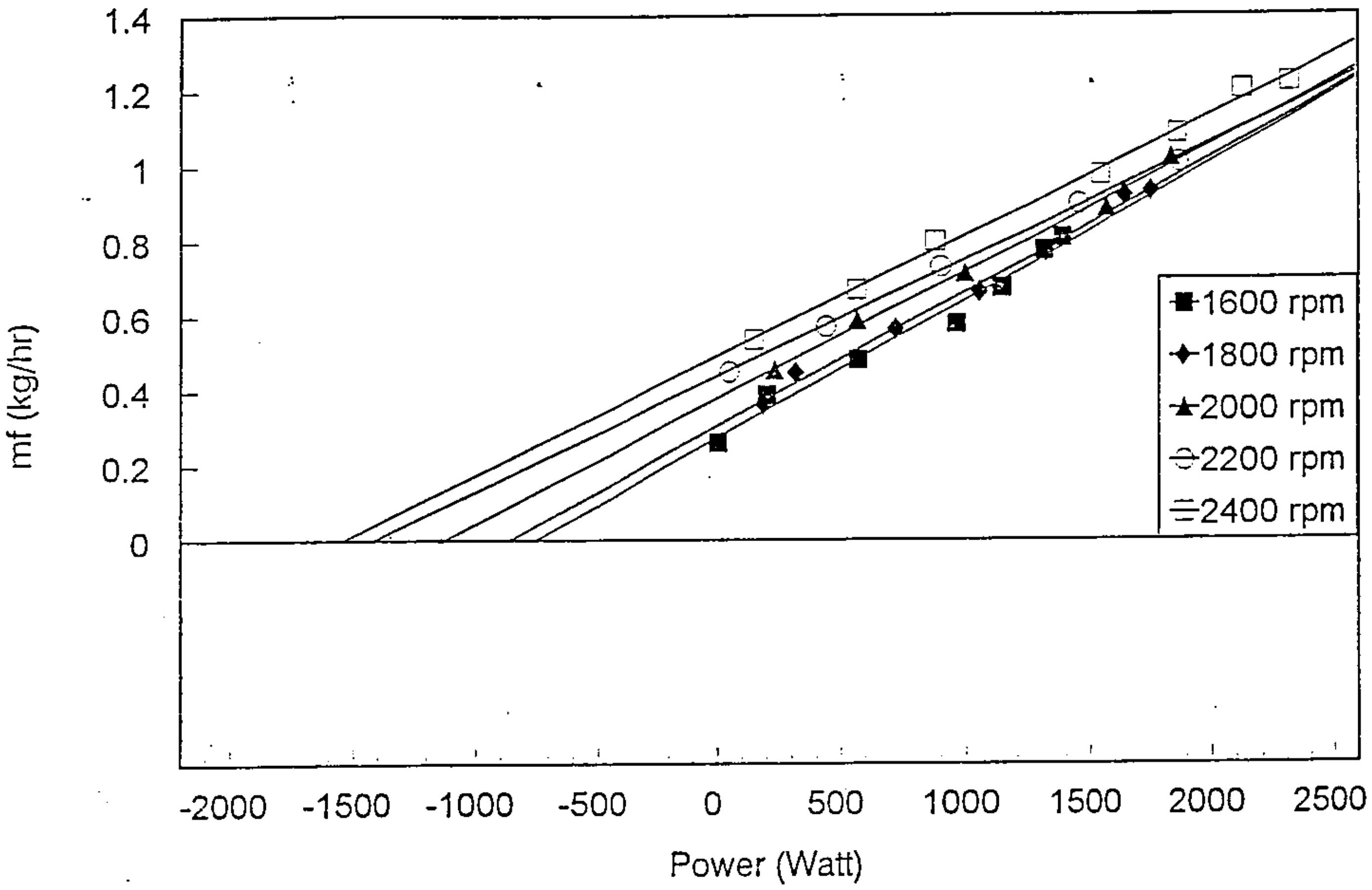
Figure(6.1):Variation of octane number with MTBE



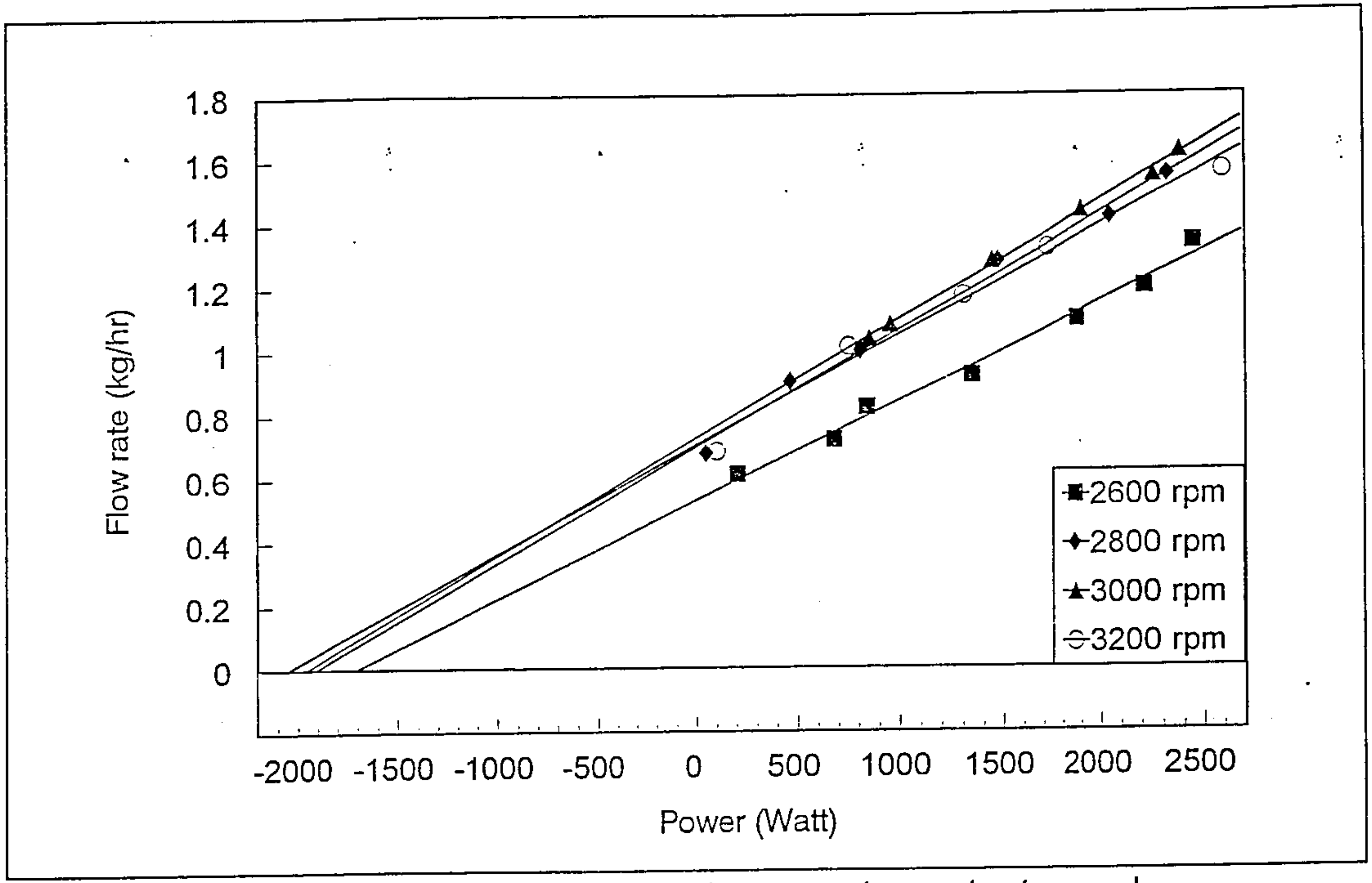
Figure(6.2): Variation of octane number for the six base fuel with MTBE percentage



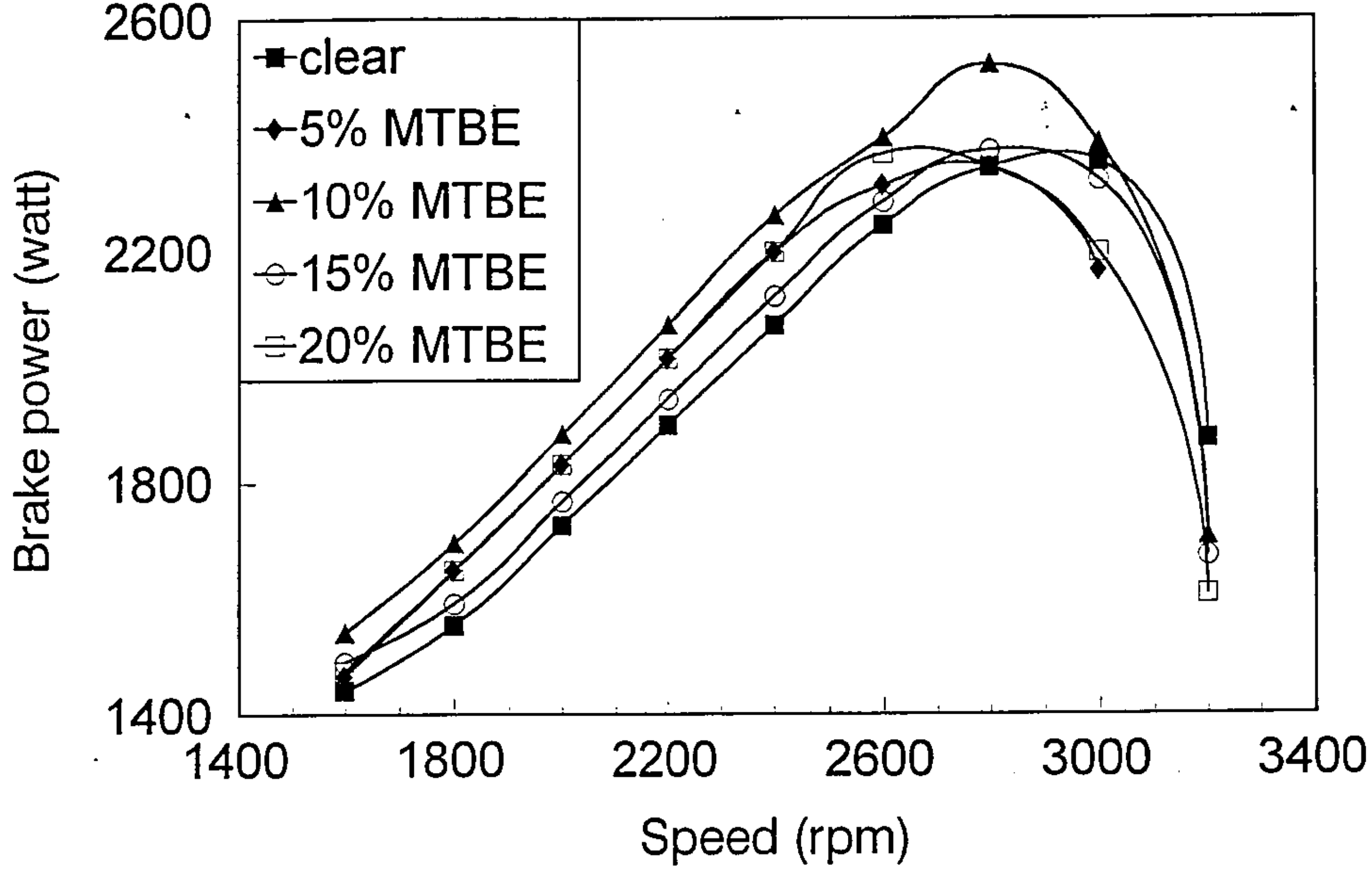
Figure(6.3): Relation between TEL and MTBE quantities for two octane number gasolines



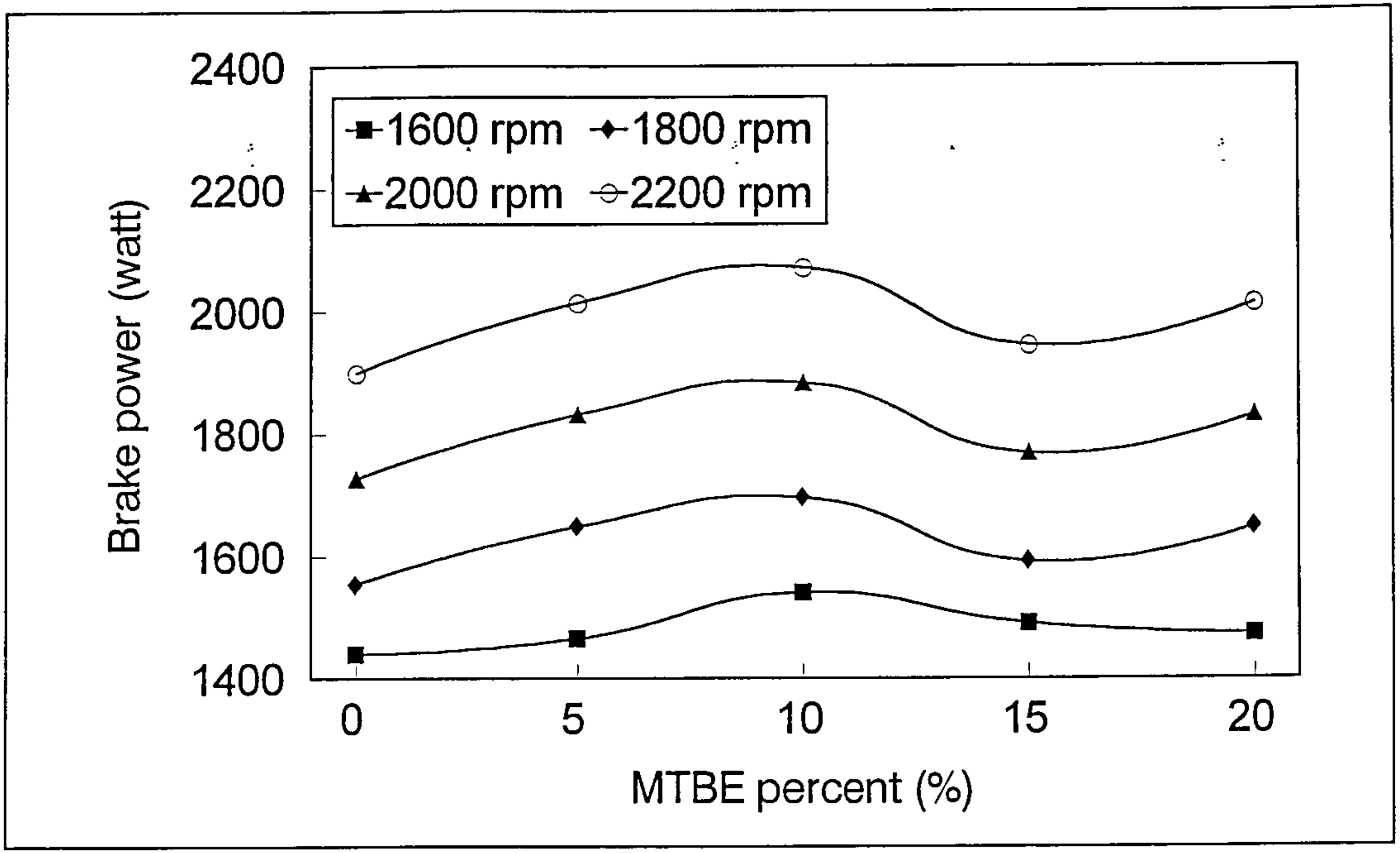
Figure(6.4): Flow rate of fuel versus output power at constant speeds.



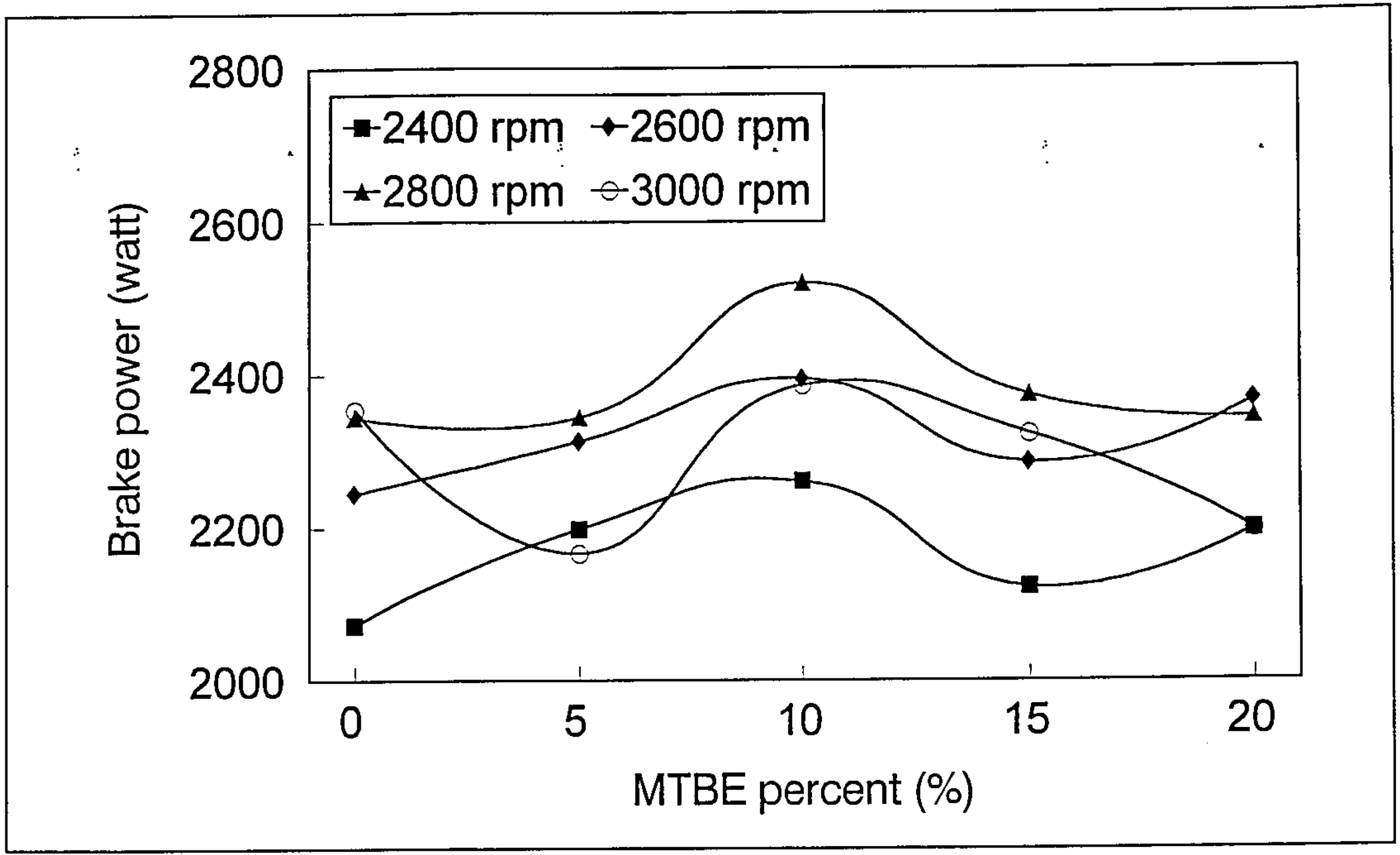
Figure(6.5): Flow rate of fuel versus output power at constant speeds



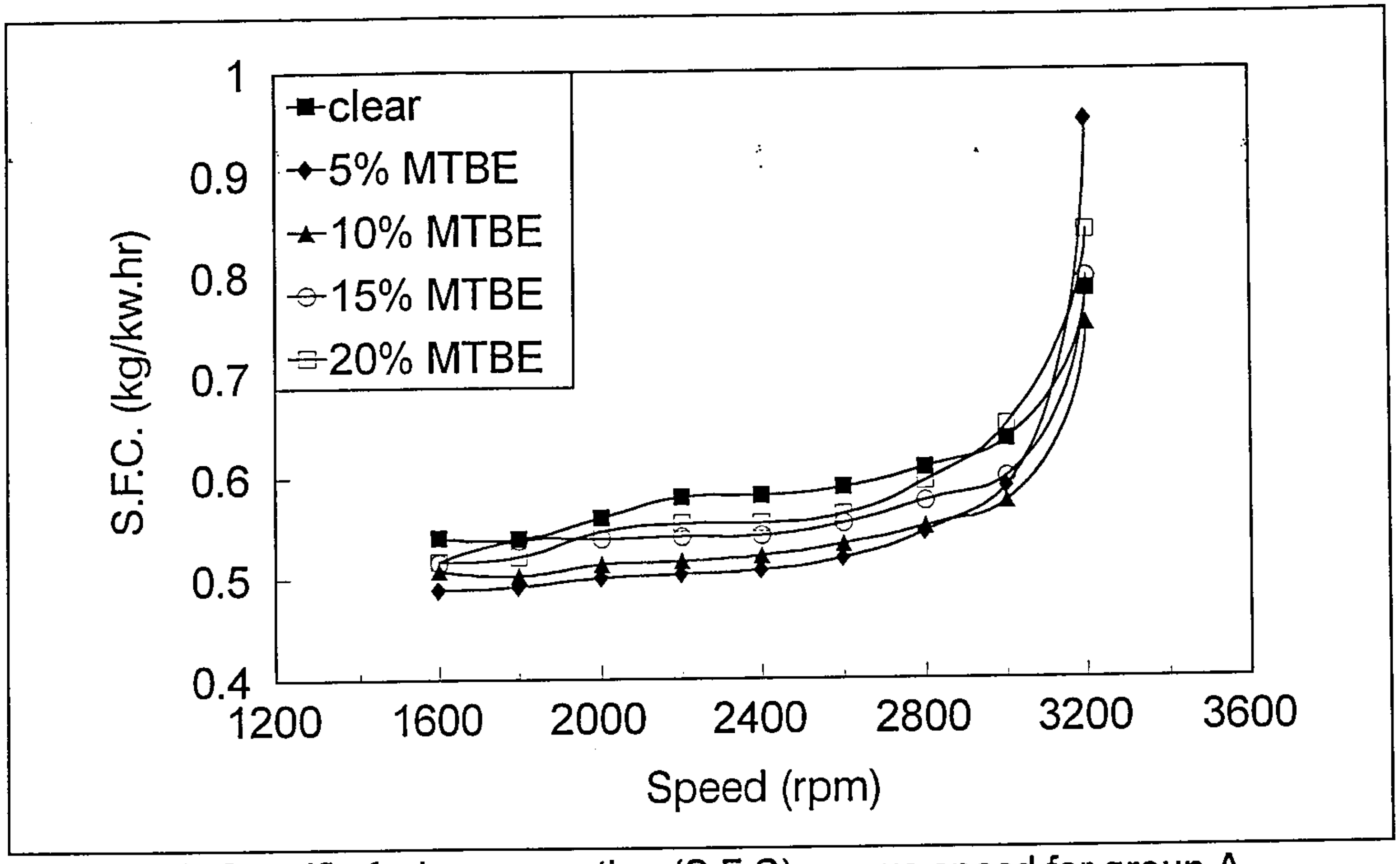
Figure(6.6) : Brake power versus speed for group A



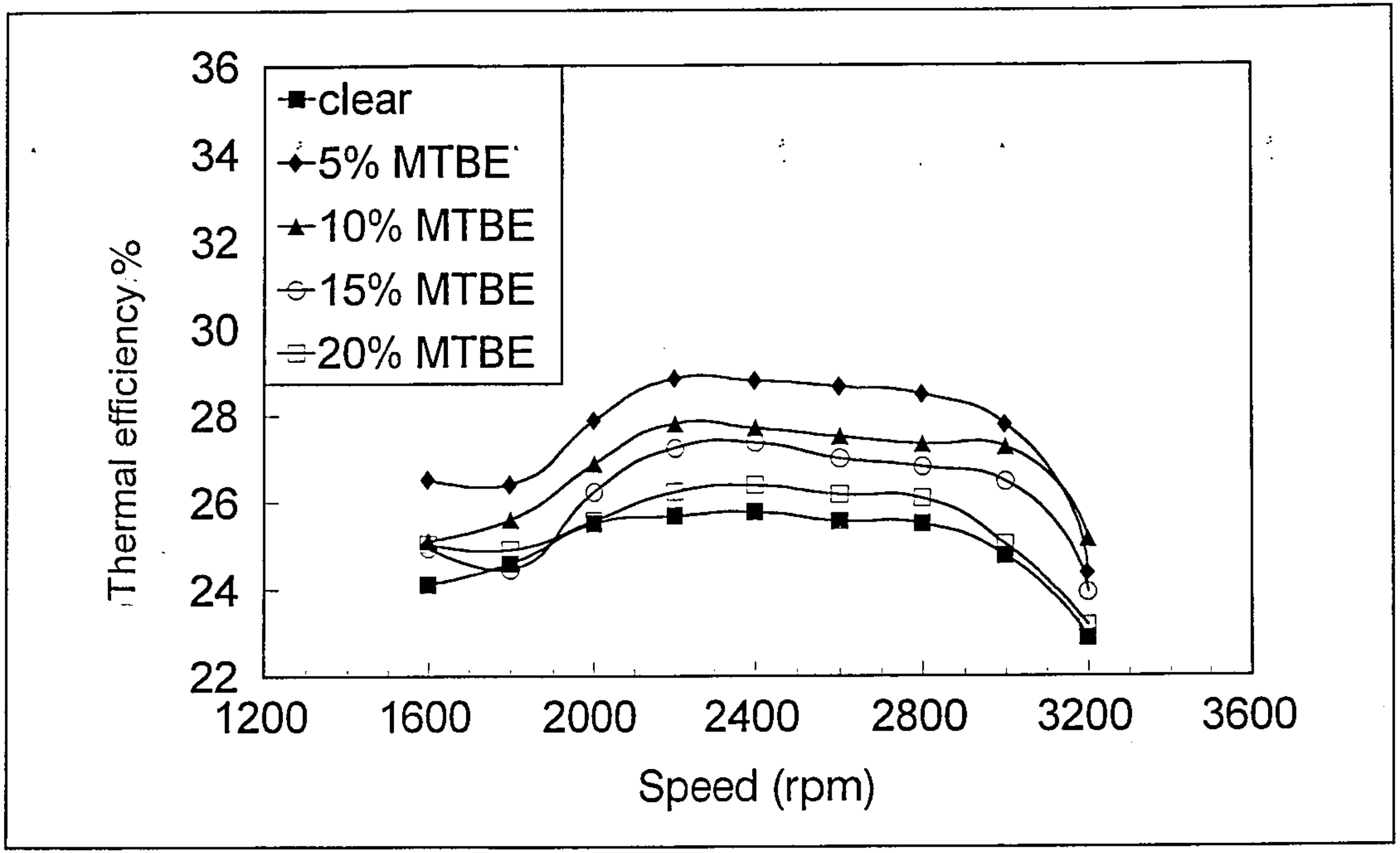
Figure(6.7) : Brake power versus MTBE percentage at constant speeds for group A



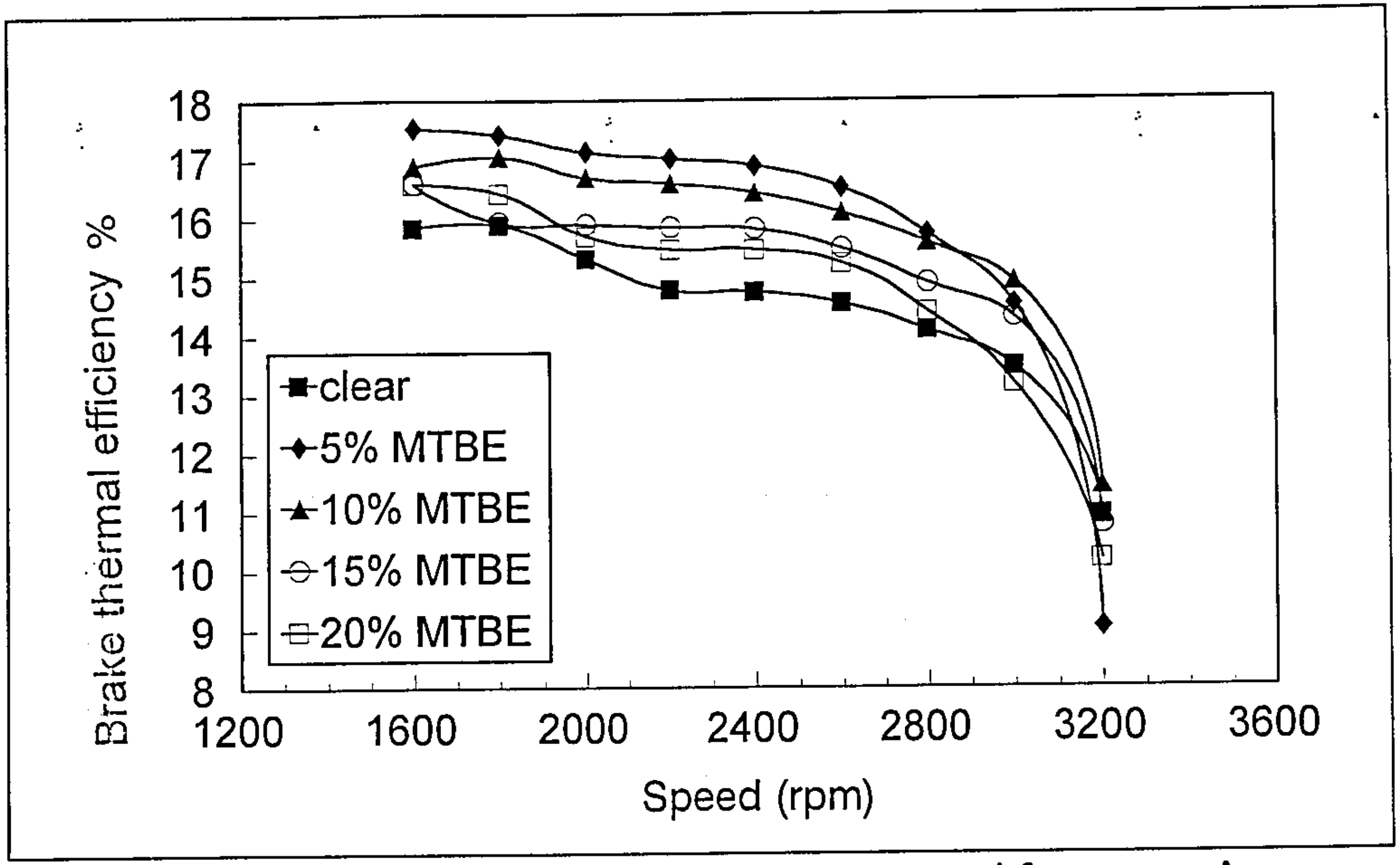
Figure(6.8): Brake power versus MTBE percentage at constant speeds for group A.



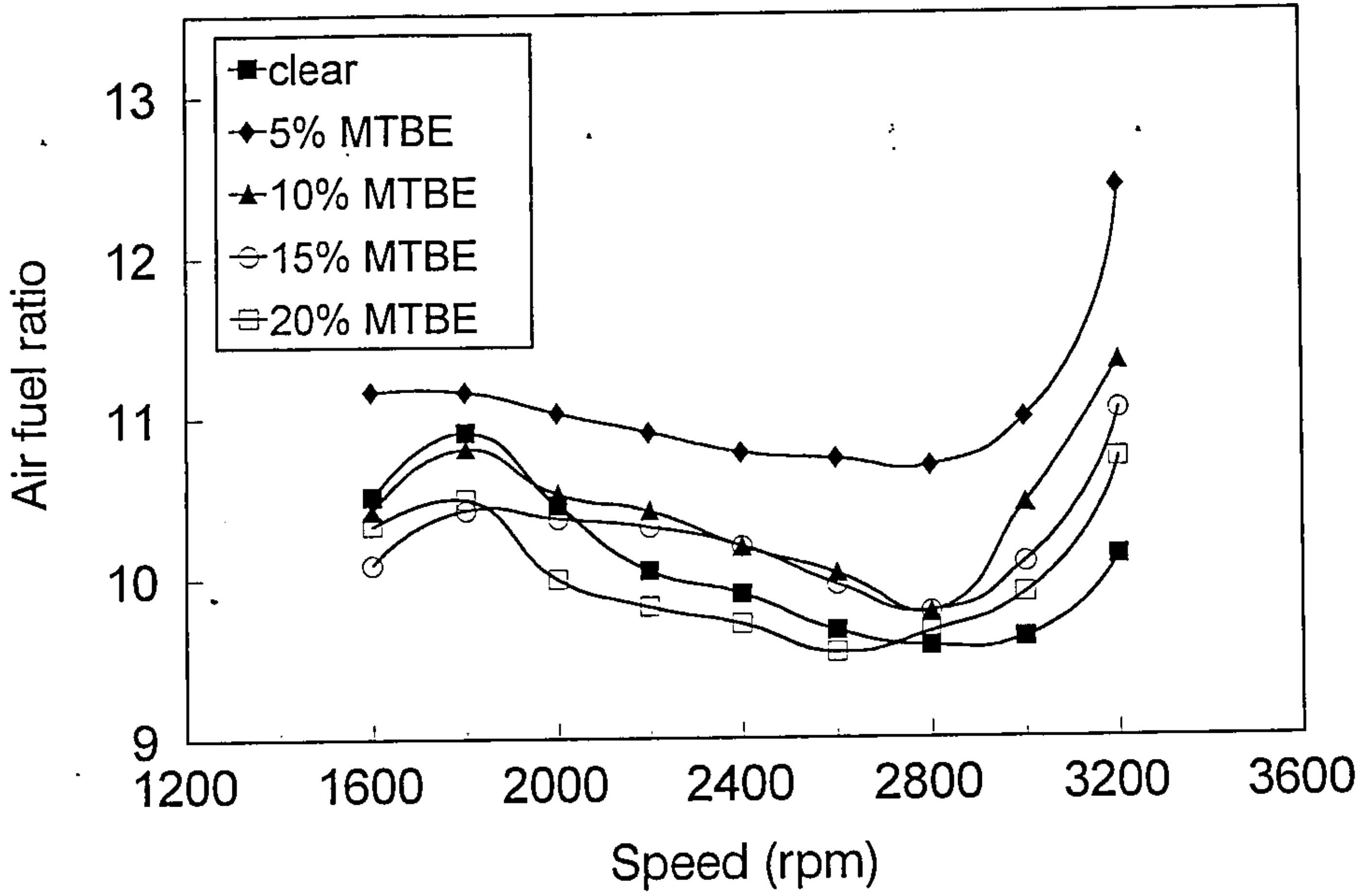
Figure(6.9): Specific fuel consumption (S.F.C) versus speed for group A.



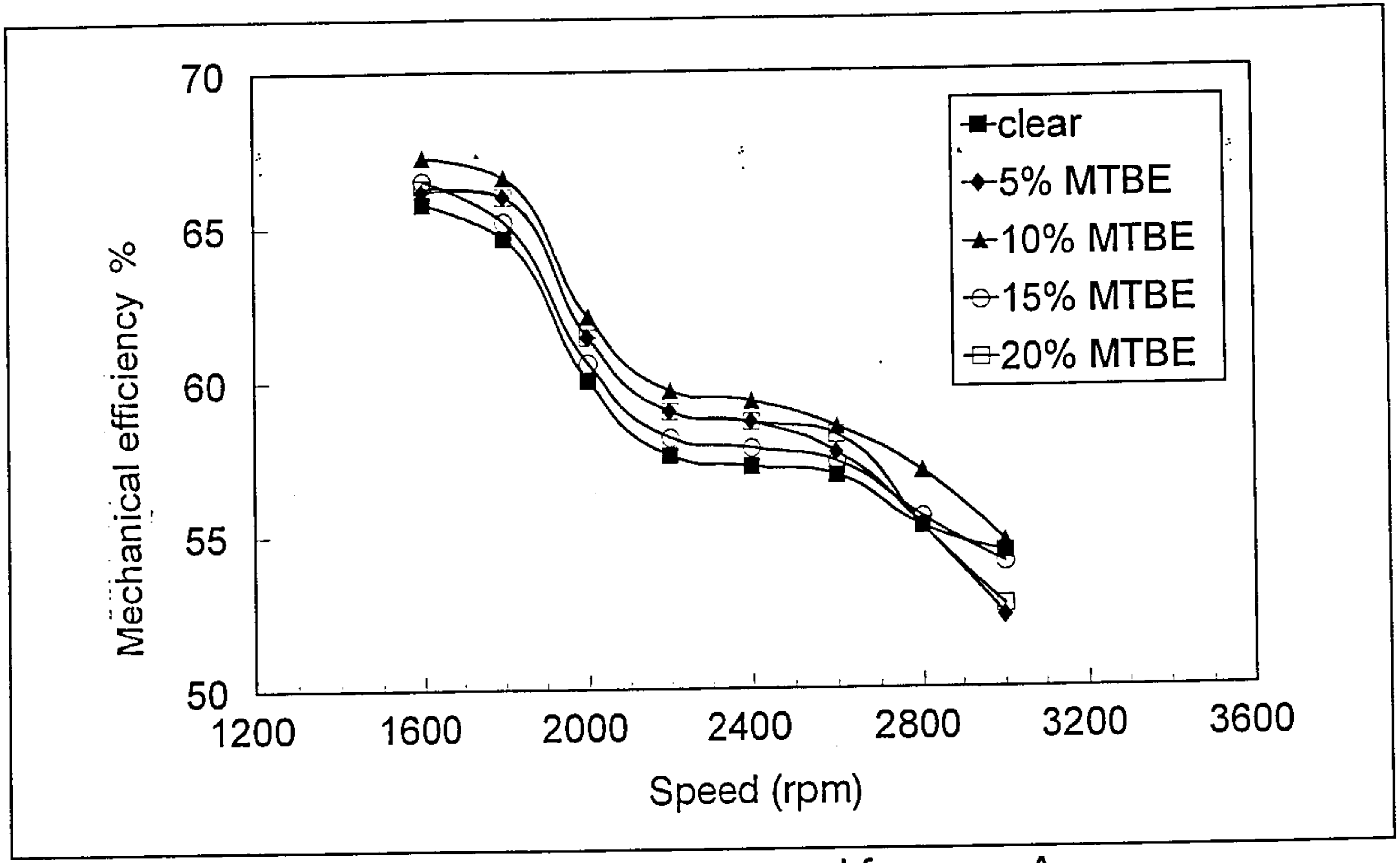
Figure(6.10): Thermal efficiency versus speed for group A.



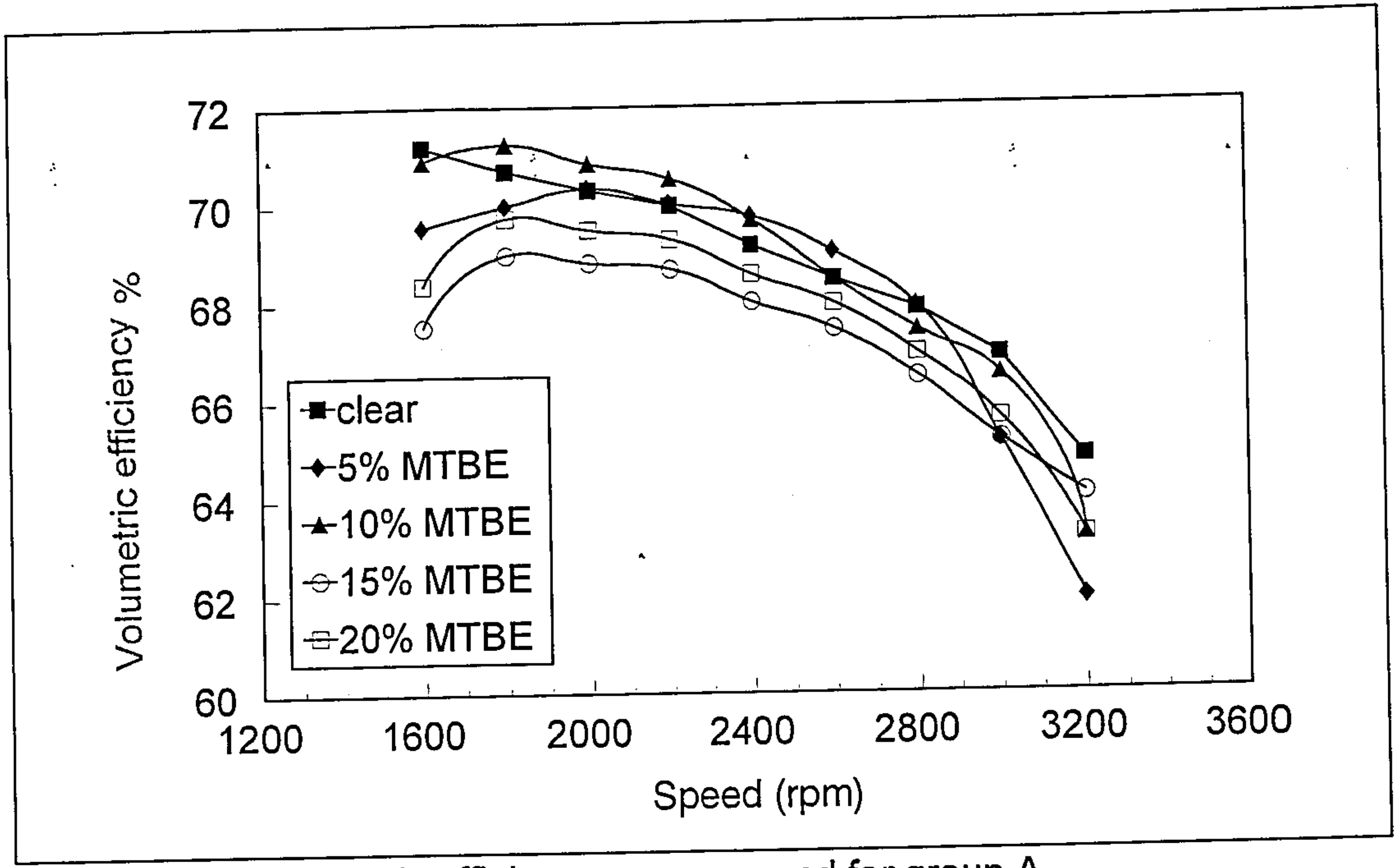
Figure(6.11):Brake thermal efficiency versus speed for group A.



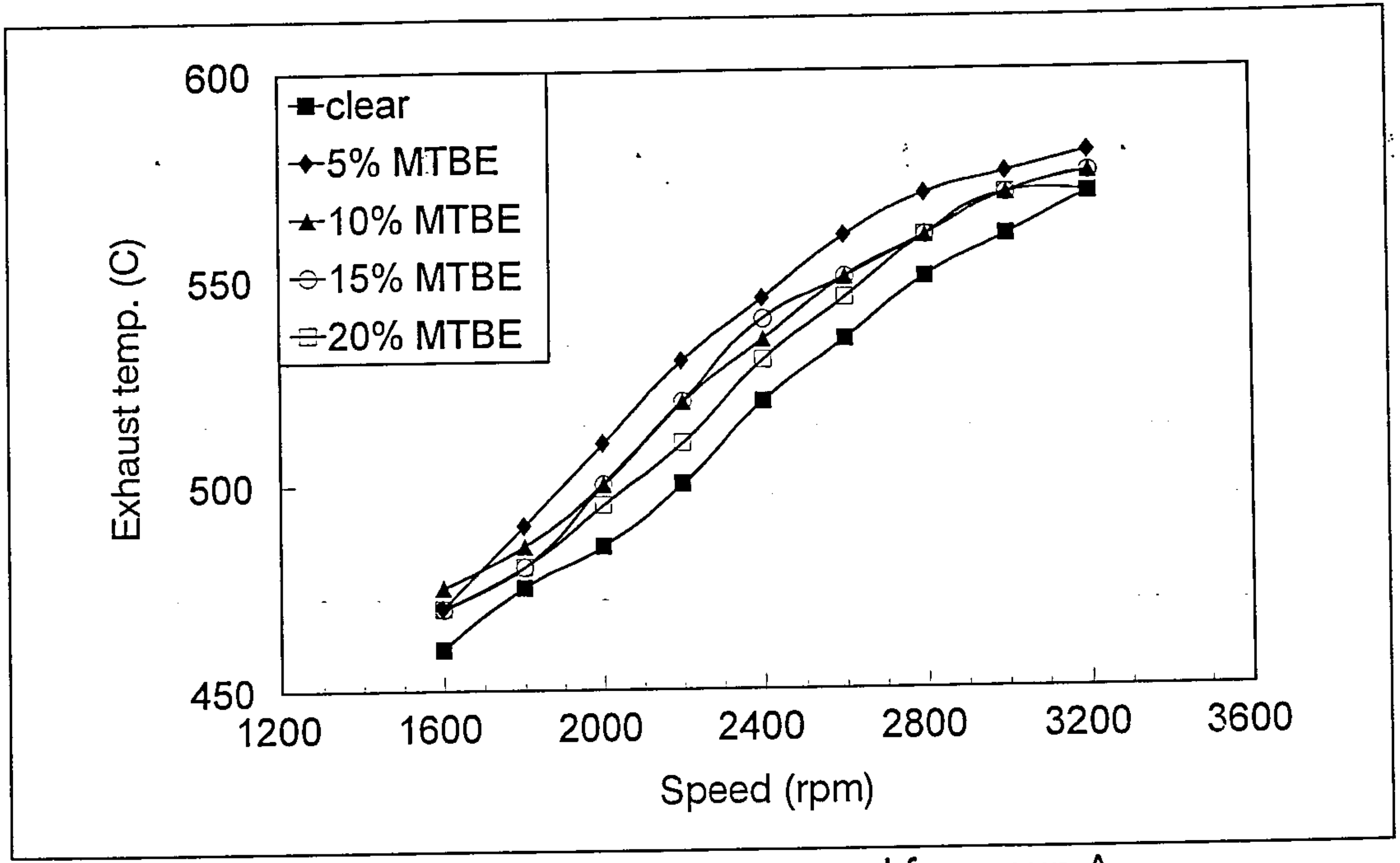
Figure(6.12) : Air fuel ratio versus speed for group A.



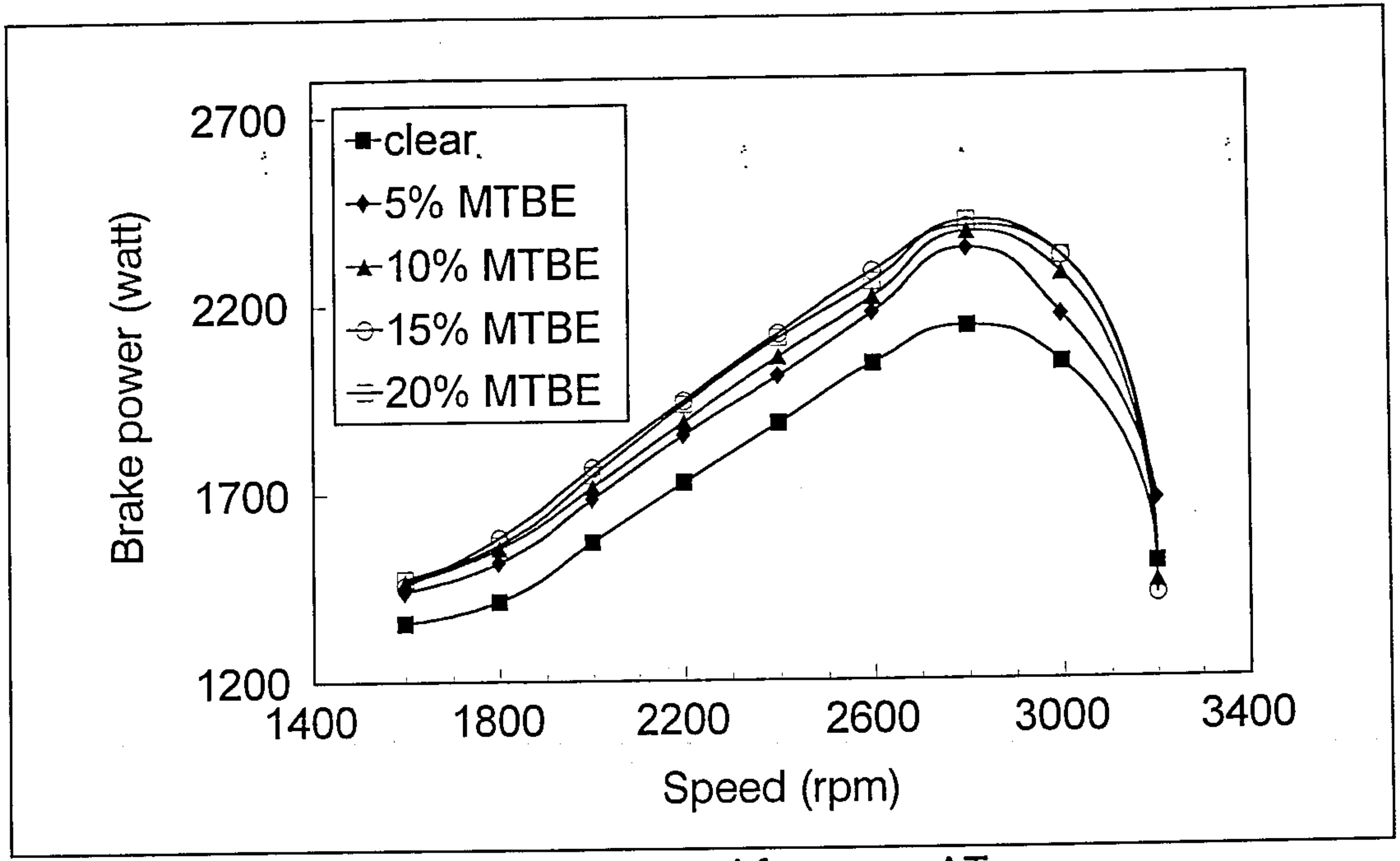
Figure(6.13): Mechanical efficiency versus speed for group A.



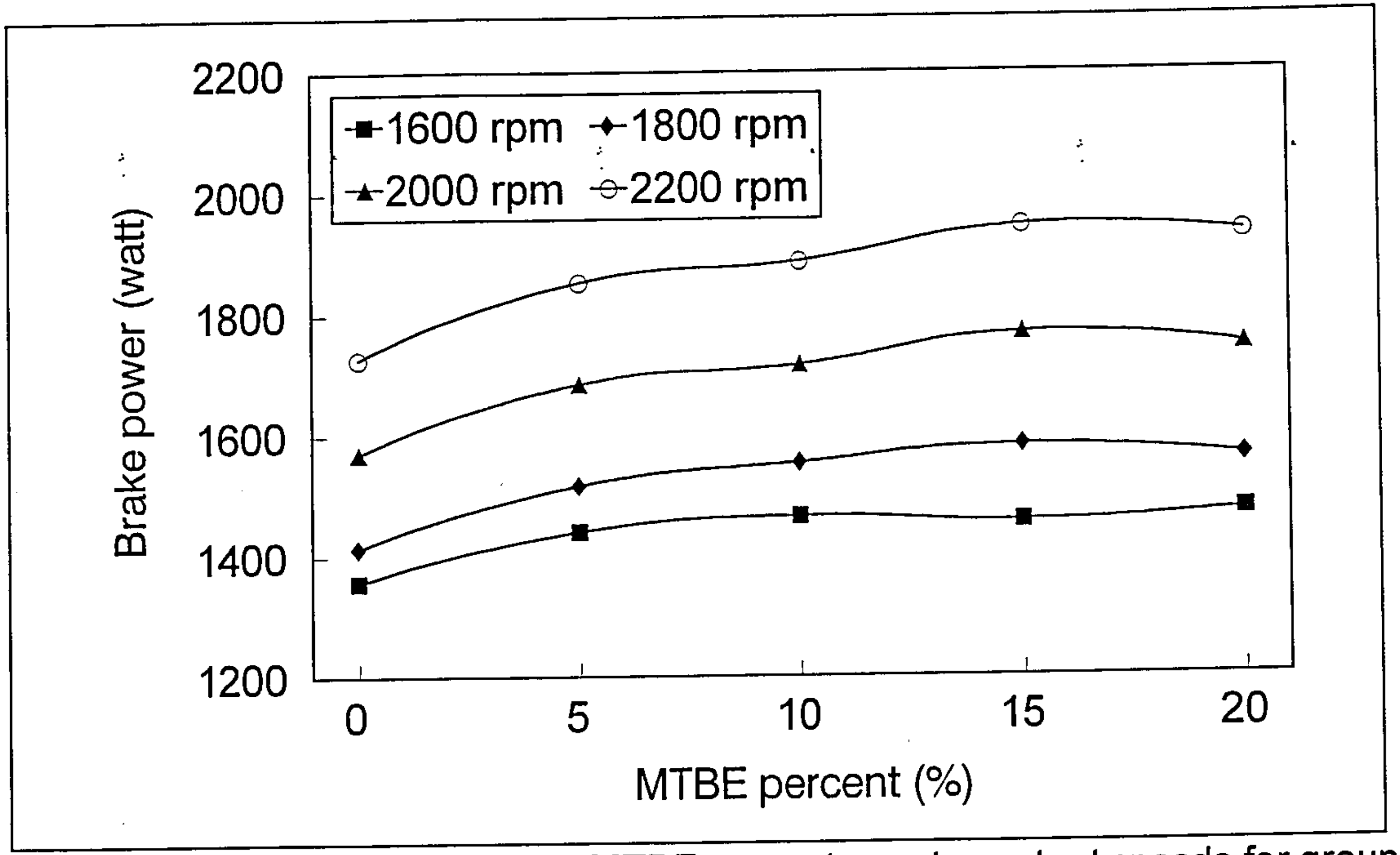
Figure(6.14): Volumetric efficiency versus speed for group A.



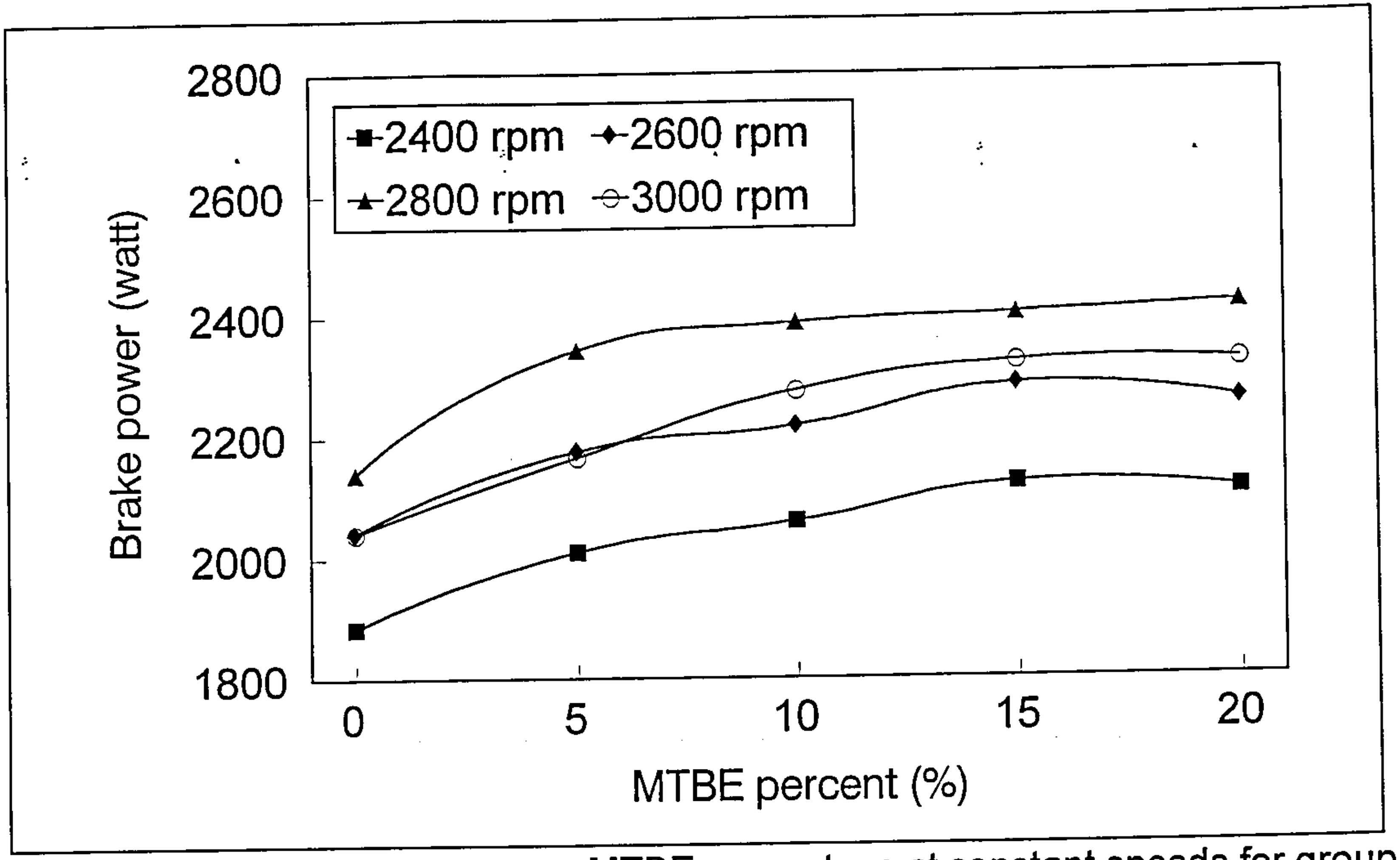
Figure(6.15): Exhaust temperature versus speed for group A.



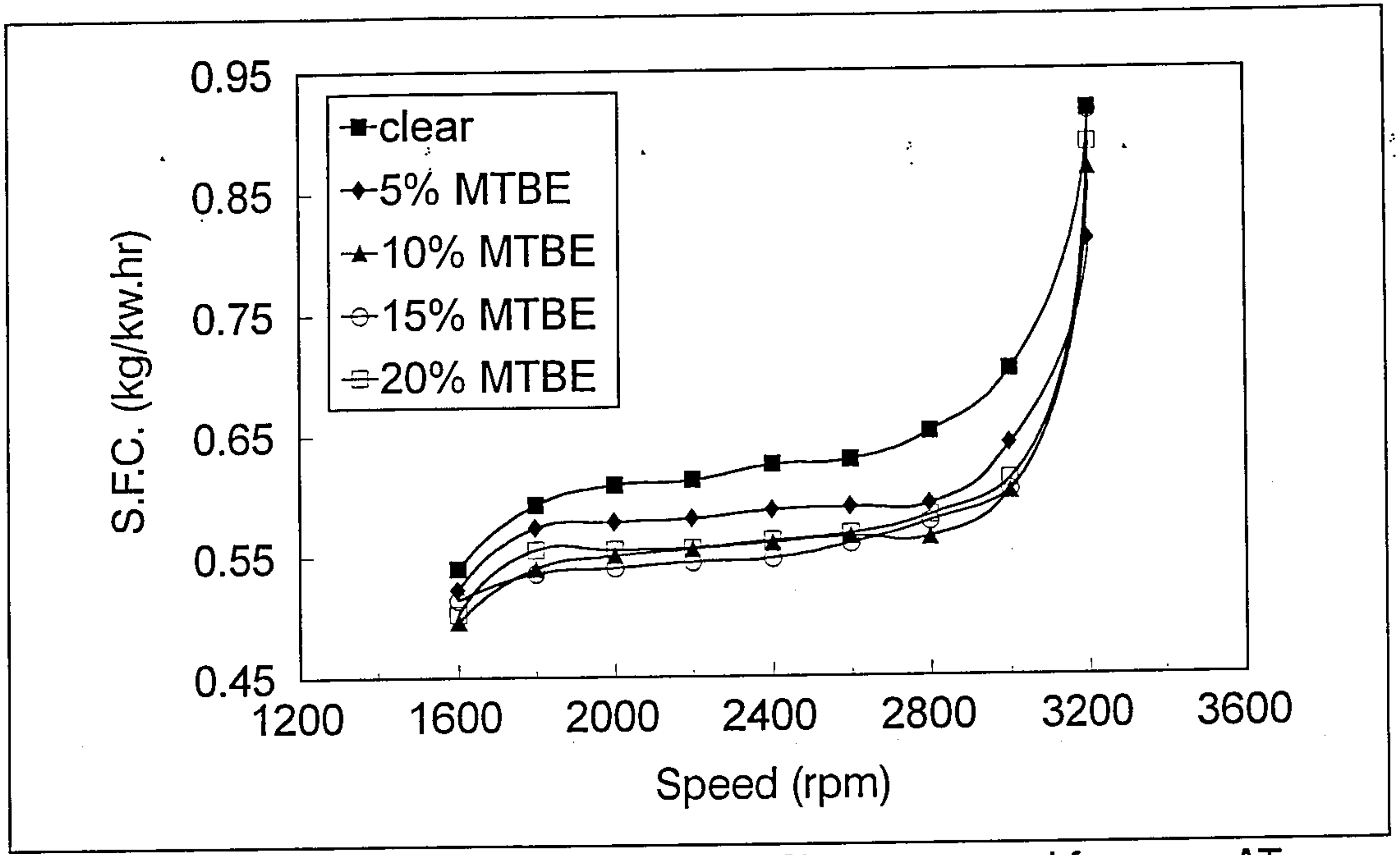
Figure(6.16): Brake power versus speed for group AT.



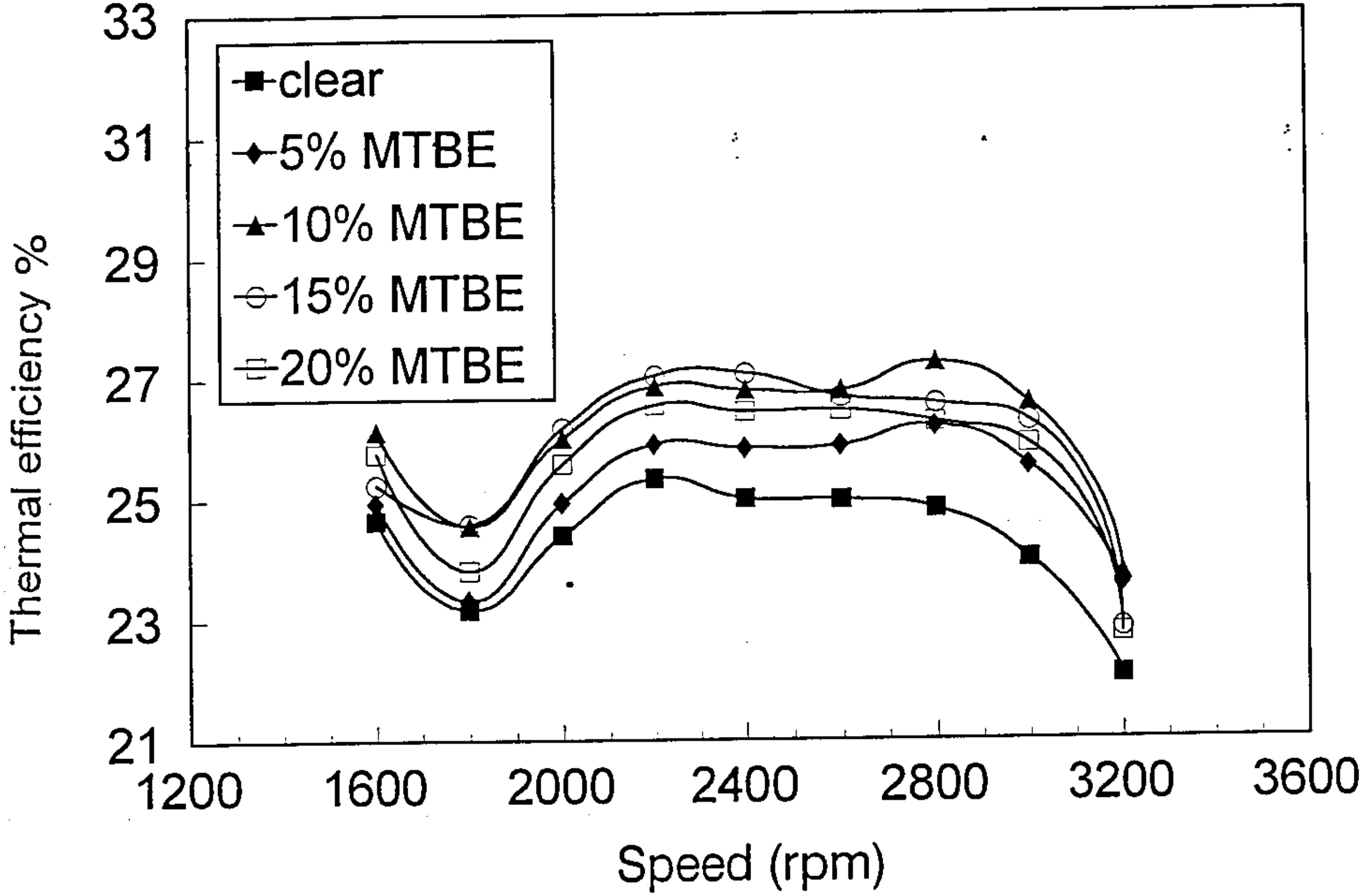
Figure(6.17): Brake power versus MTBE percentage at constant speeds for group AT.



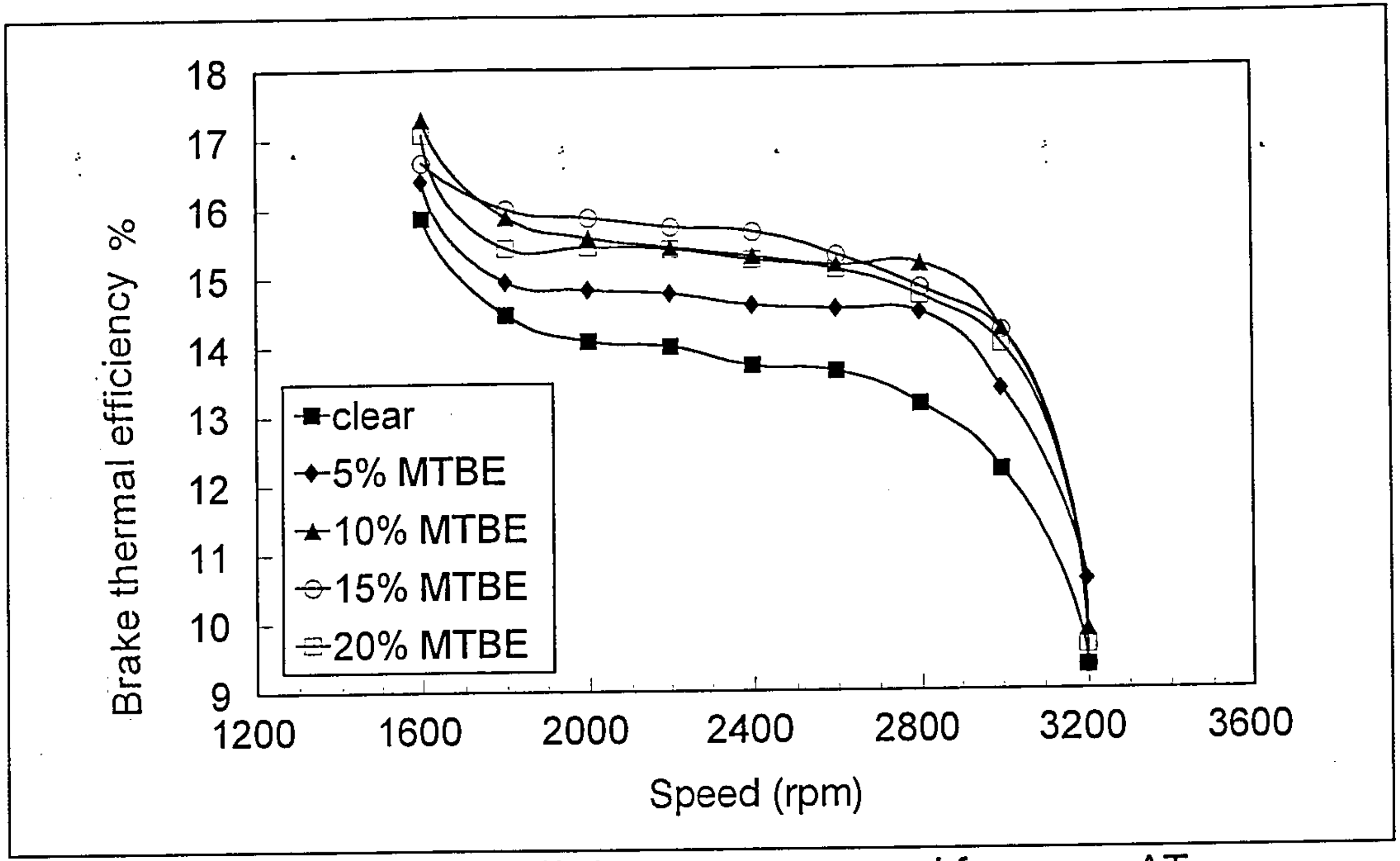
Figure(6.18): Brake power versus MTBE percentage at constant speeds for group AT.



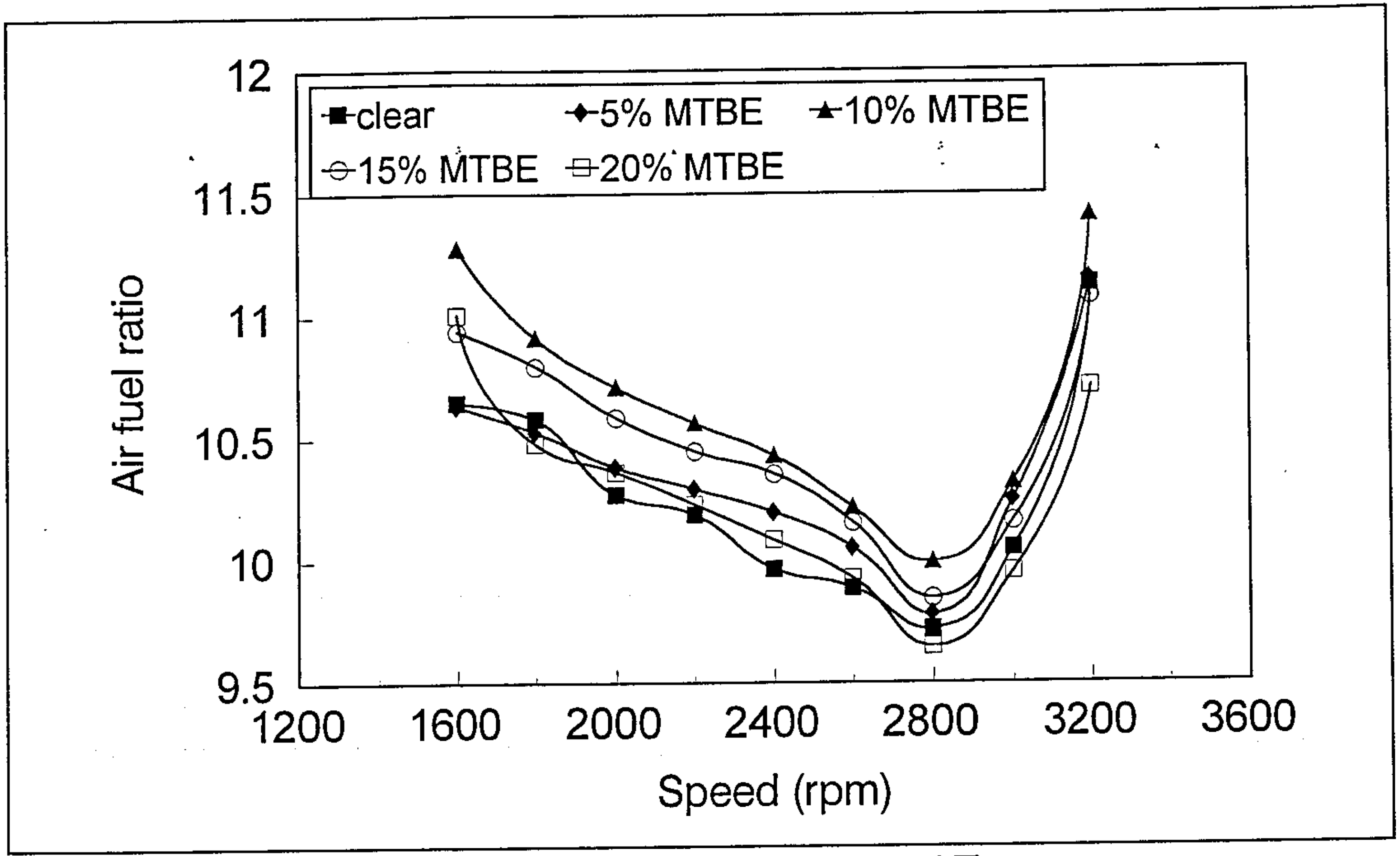
Figure(6.19): Specific fuel consumption (S.F.C) versus speed for group AT.



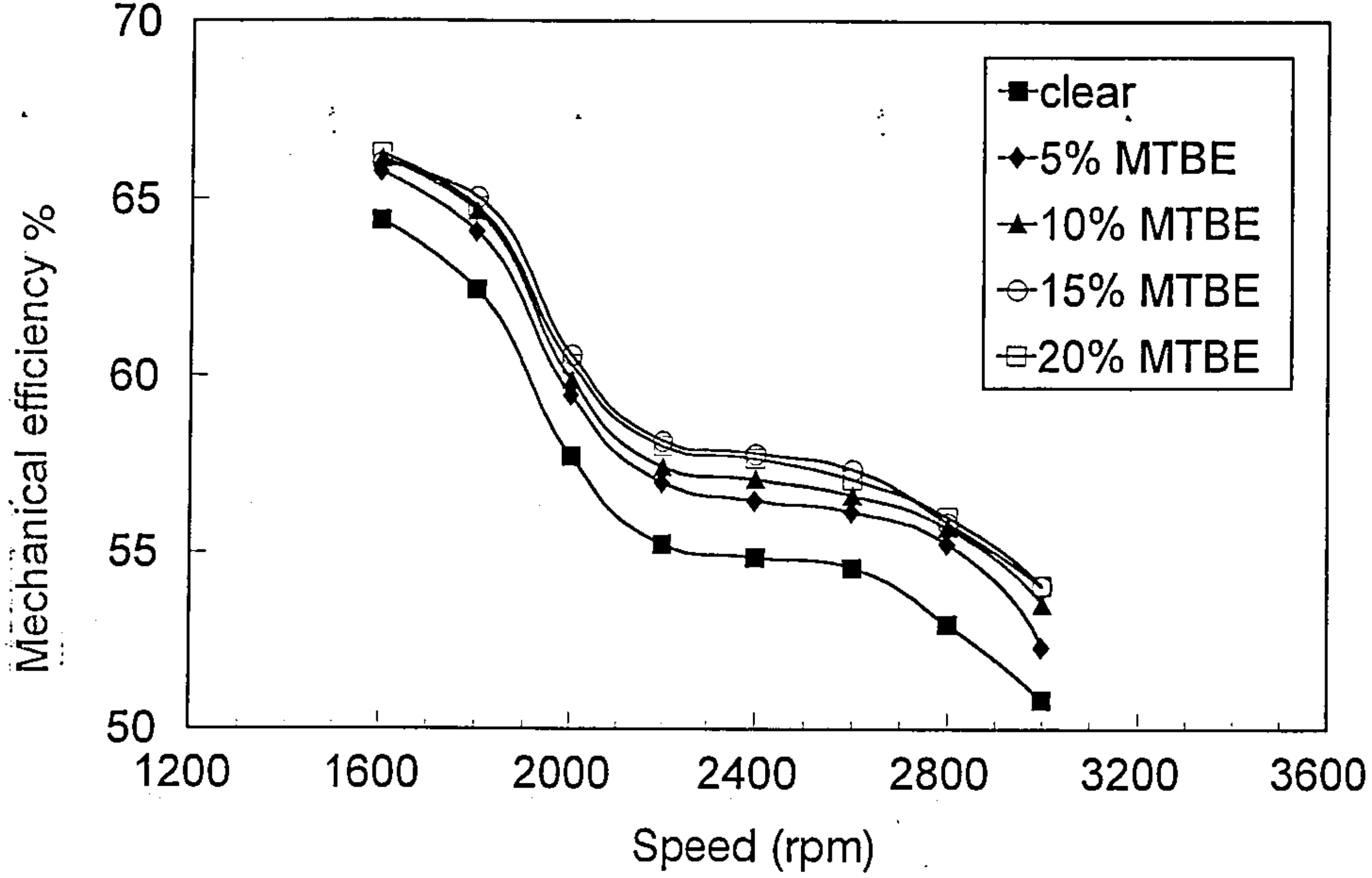
Figure(6.20): Thermal efficiency versus speed for group AT.



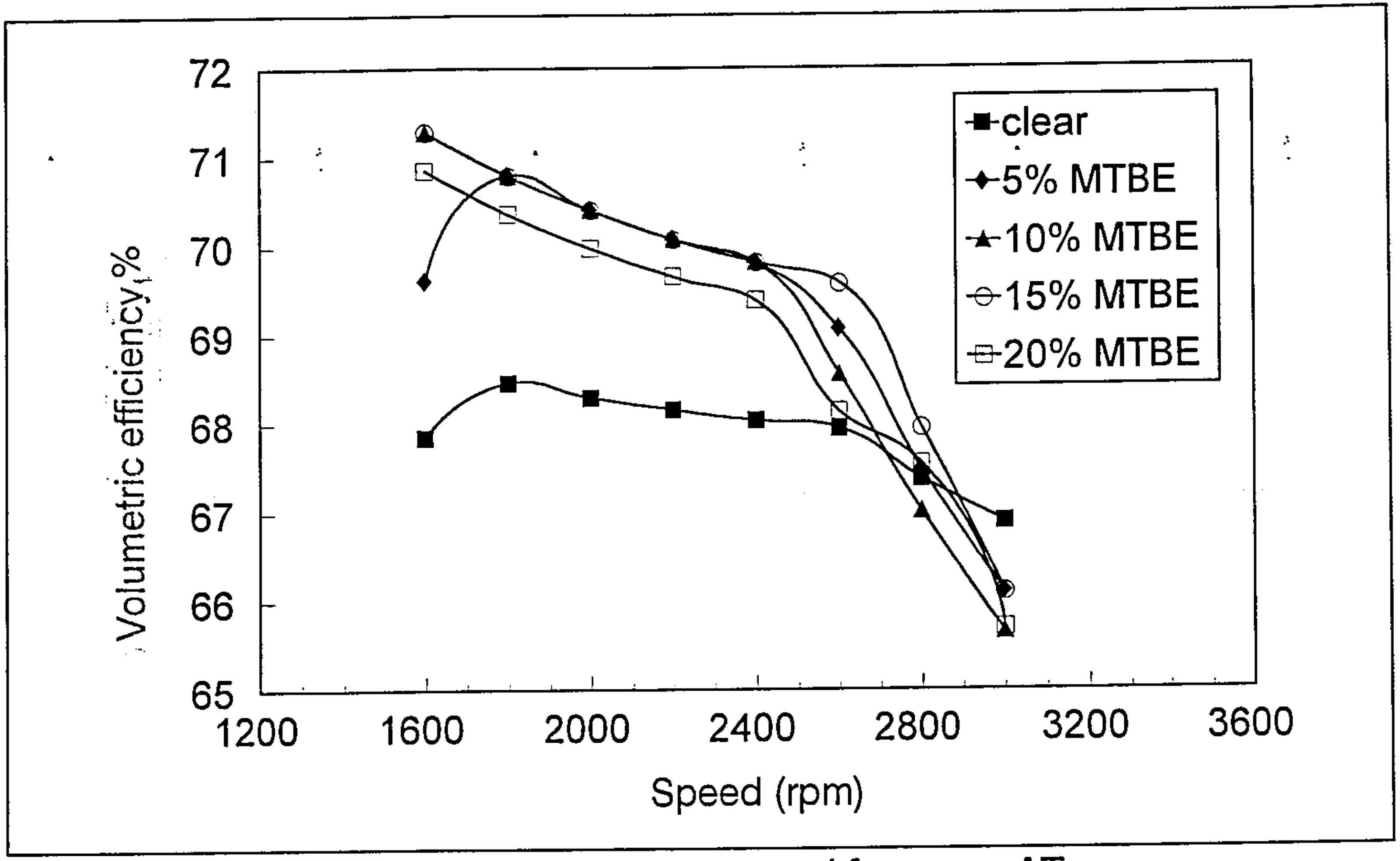
Figure(6.21):Brake thermal efficiency versus speed for group AT.



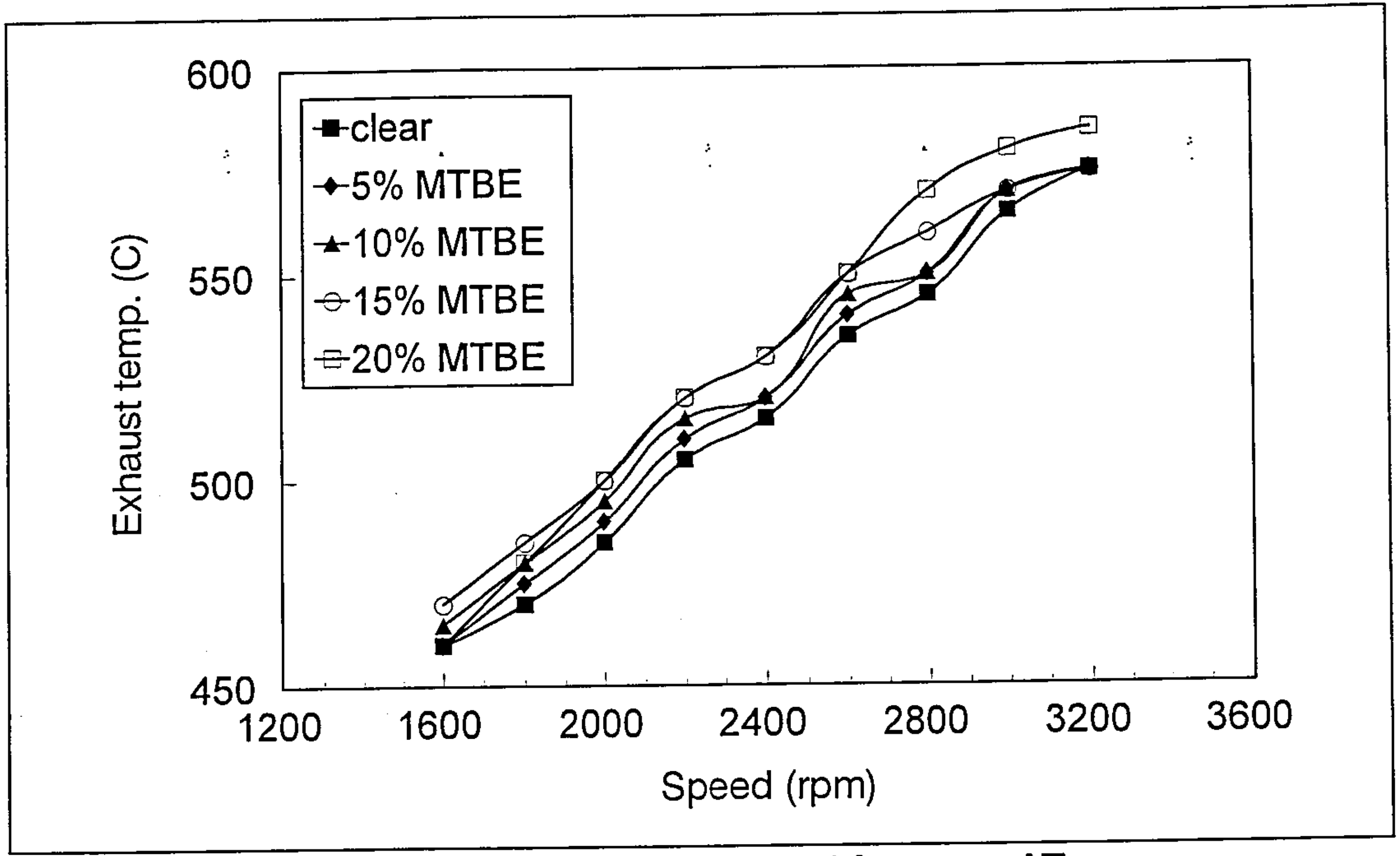
Figure(6.22): Air fuel ratio versus speed for group AT.



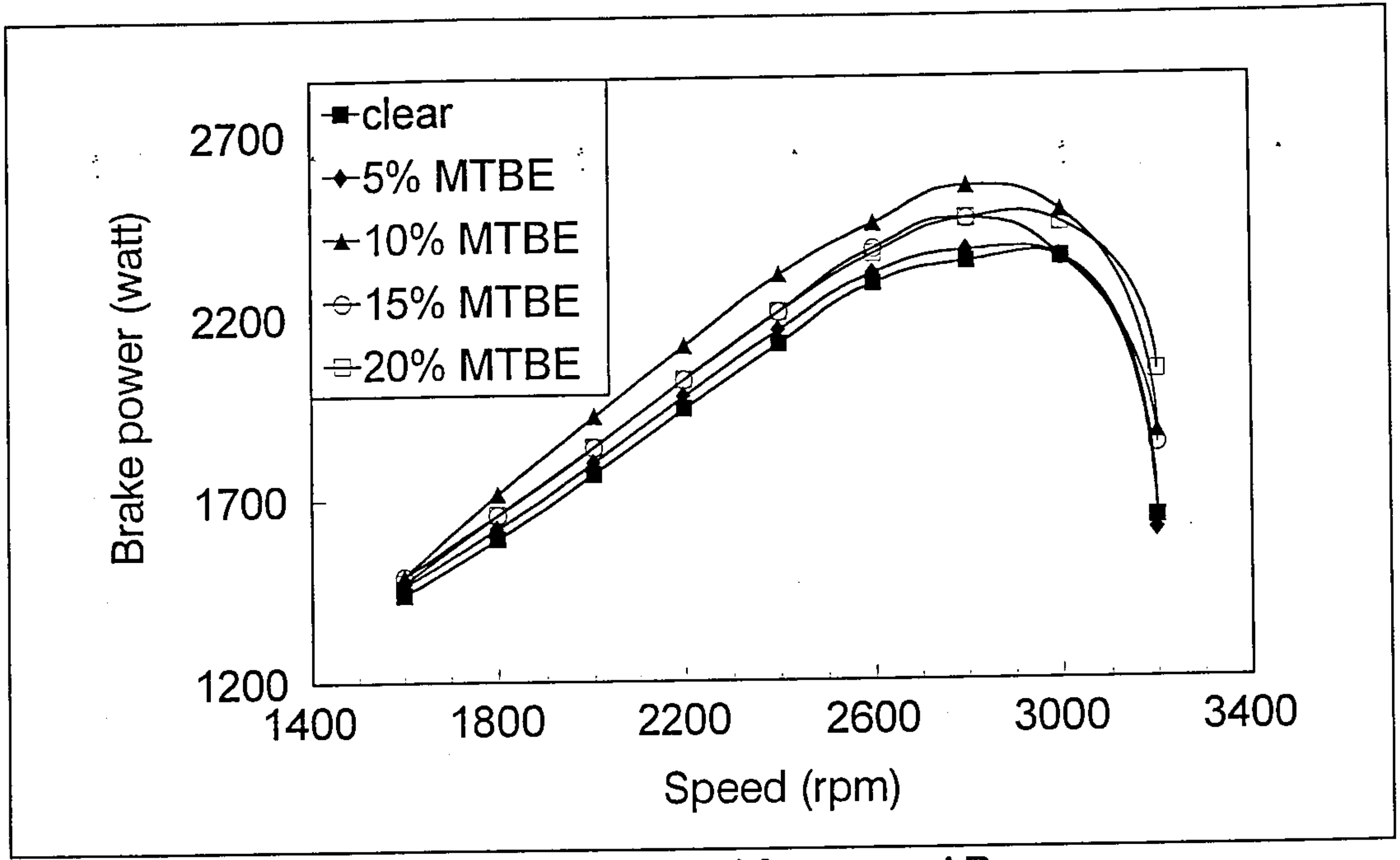
Figure(6.23): Mechanical efficiency versus speed for group AT.



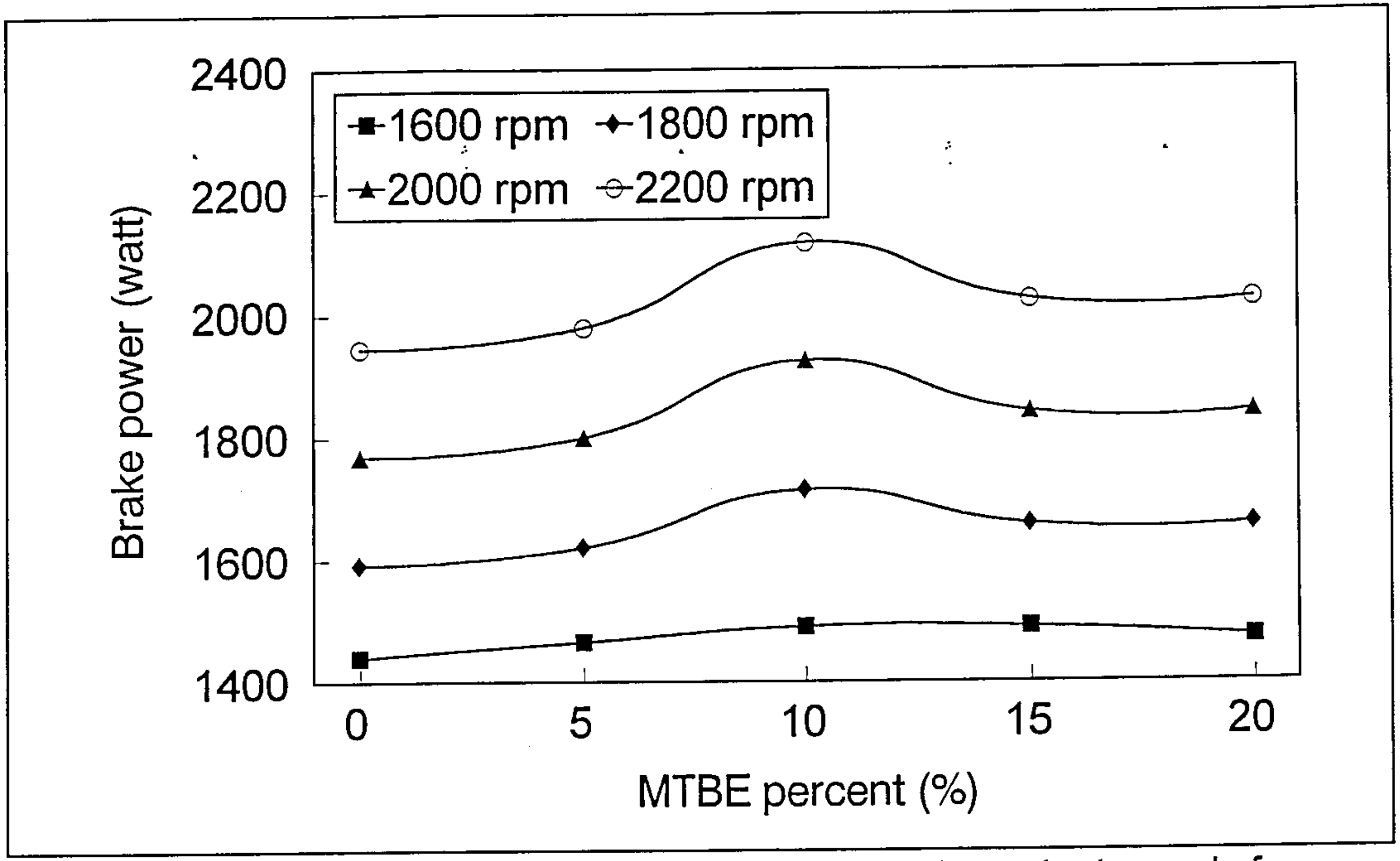
Figure(6.24): Volumetric efficiency versus speed for group AT.



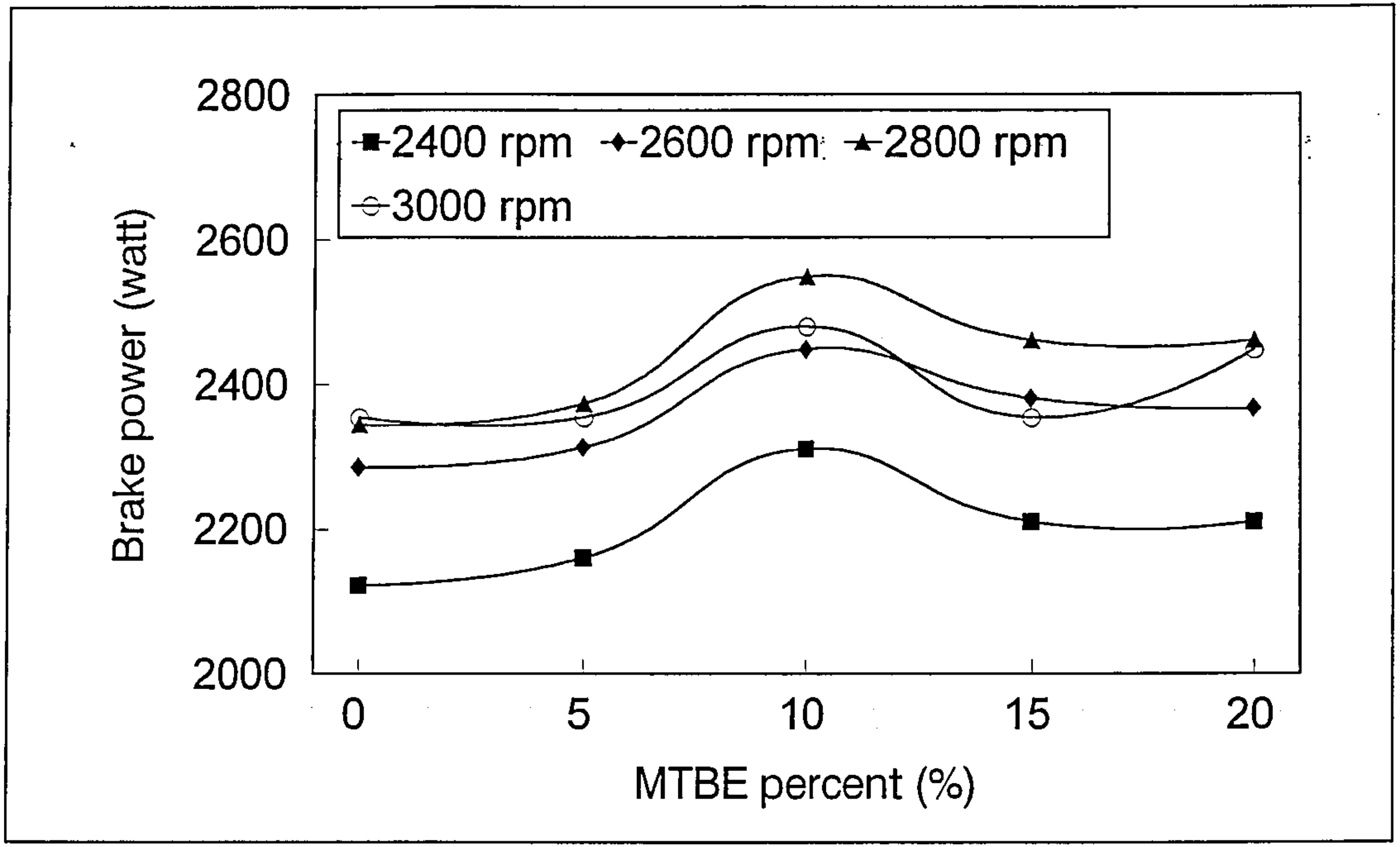
Figure(6.25): Exhaust temperature versus speed for group AT.



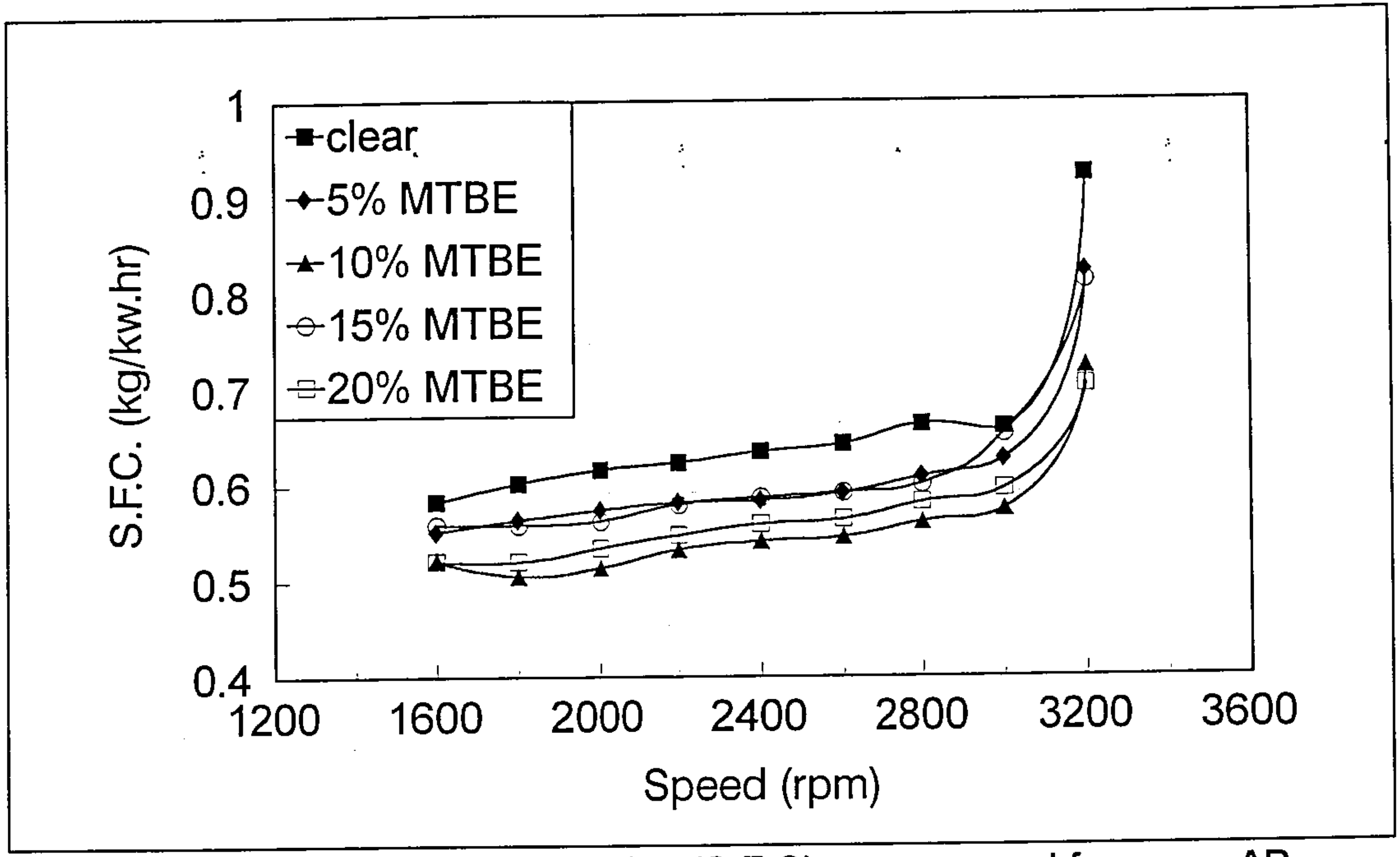
Figure(6.26): Brake power versus speed for group AR.



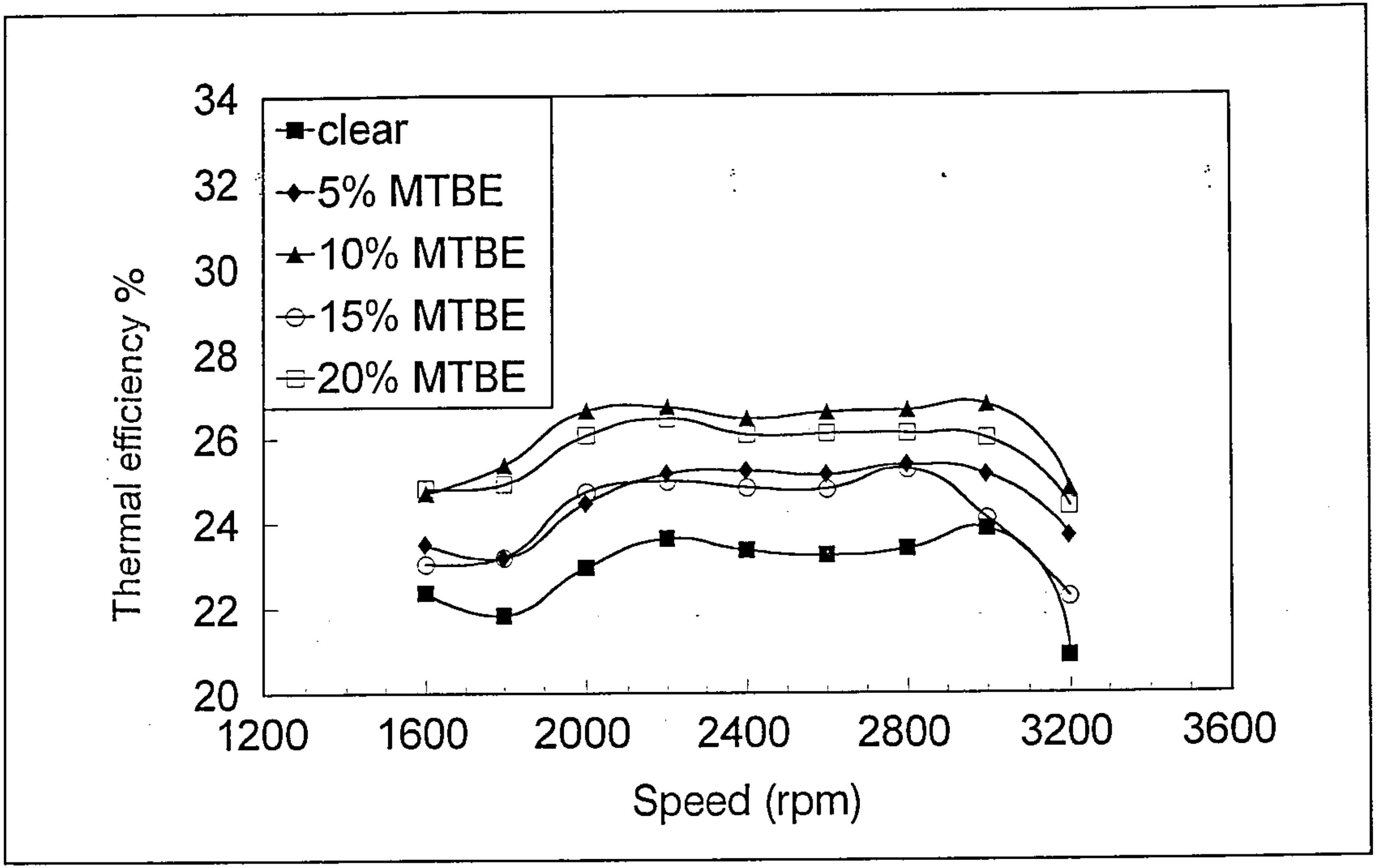
Figure(6.27): Brake power versus MTBE percentage at constant speeds for group AR.



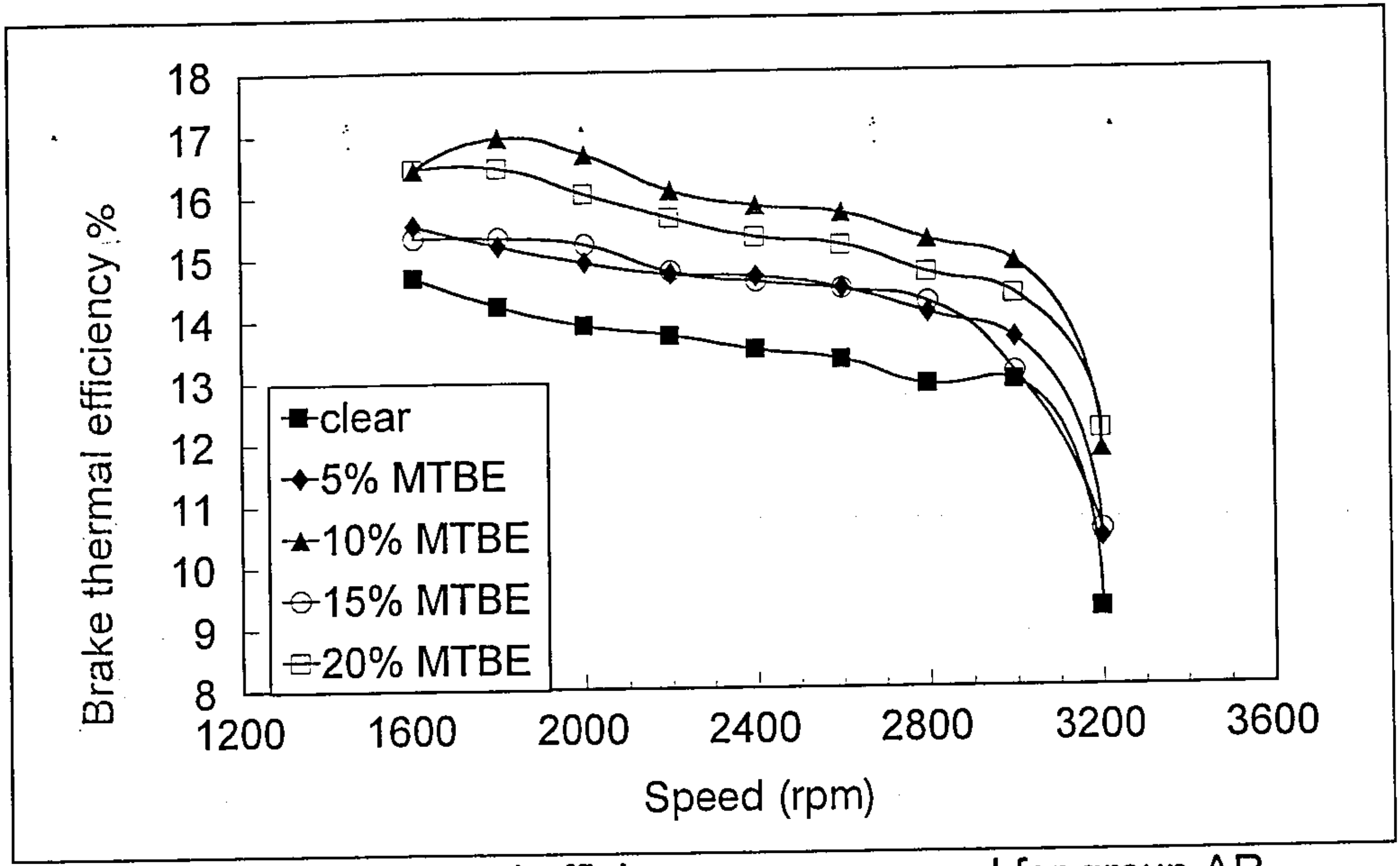
Figure(6.28): Brake power versus MTBE percentage at constant speeds for group AR.



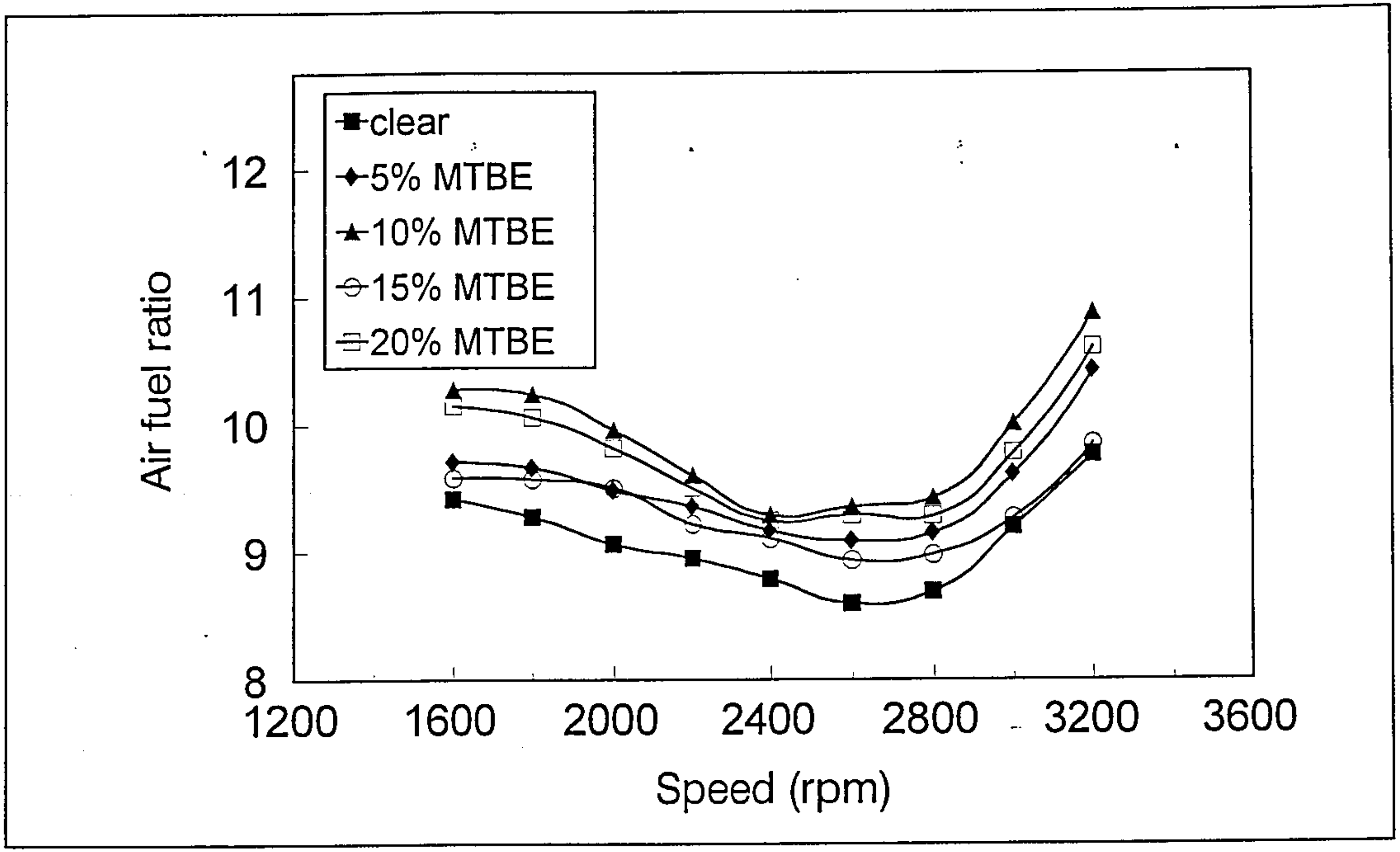
Figure(6.29): Specific fuel consumption (S.F.C) versus speed for group AR.



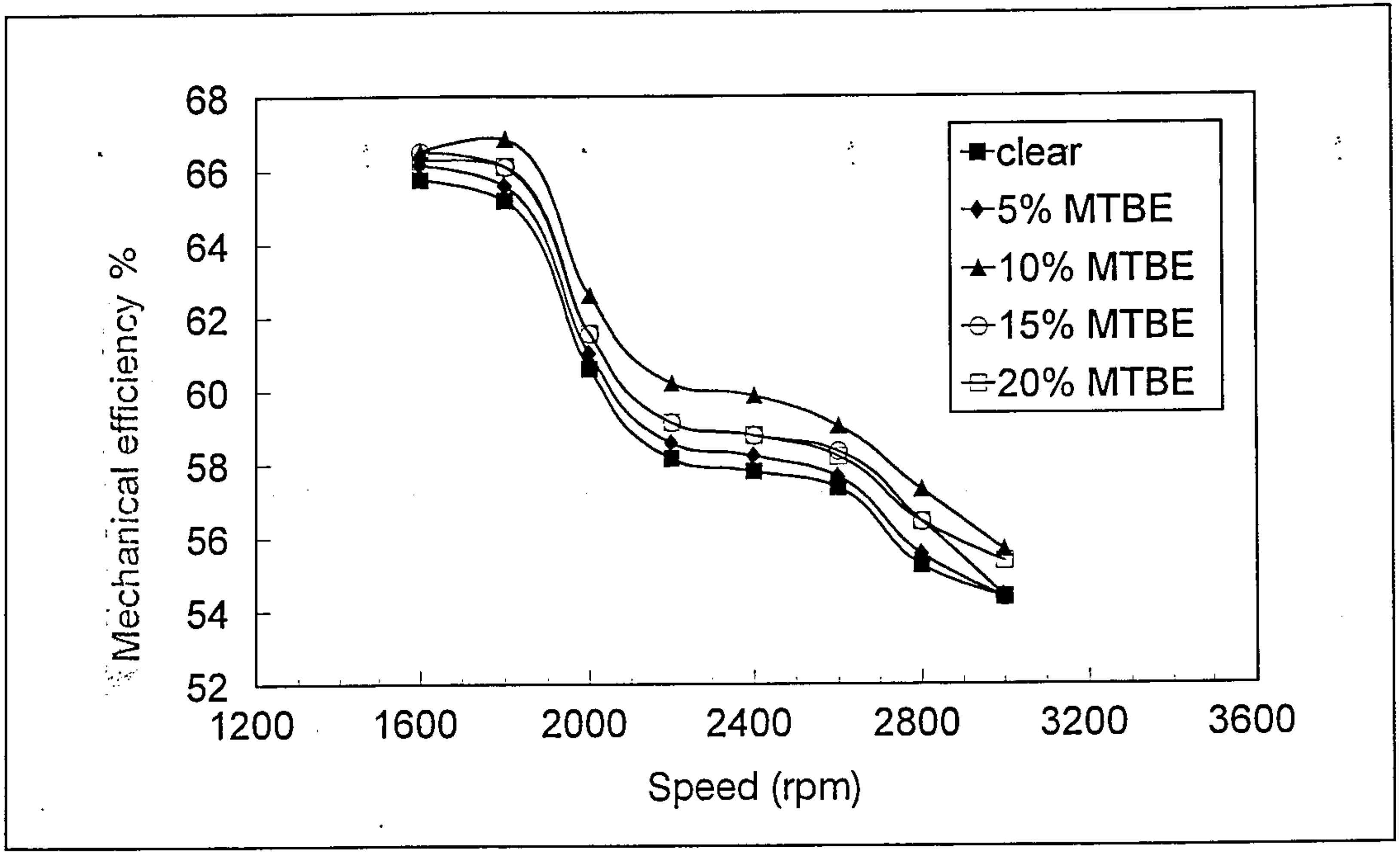
Figure(6.30): Thermal efficiency versus speed for group AR.



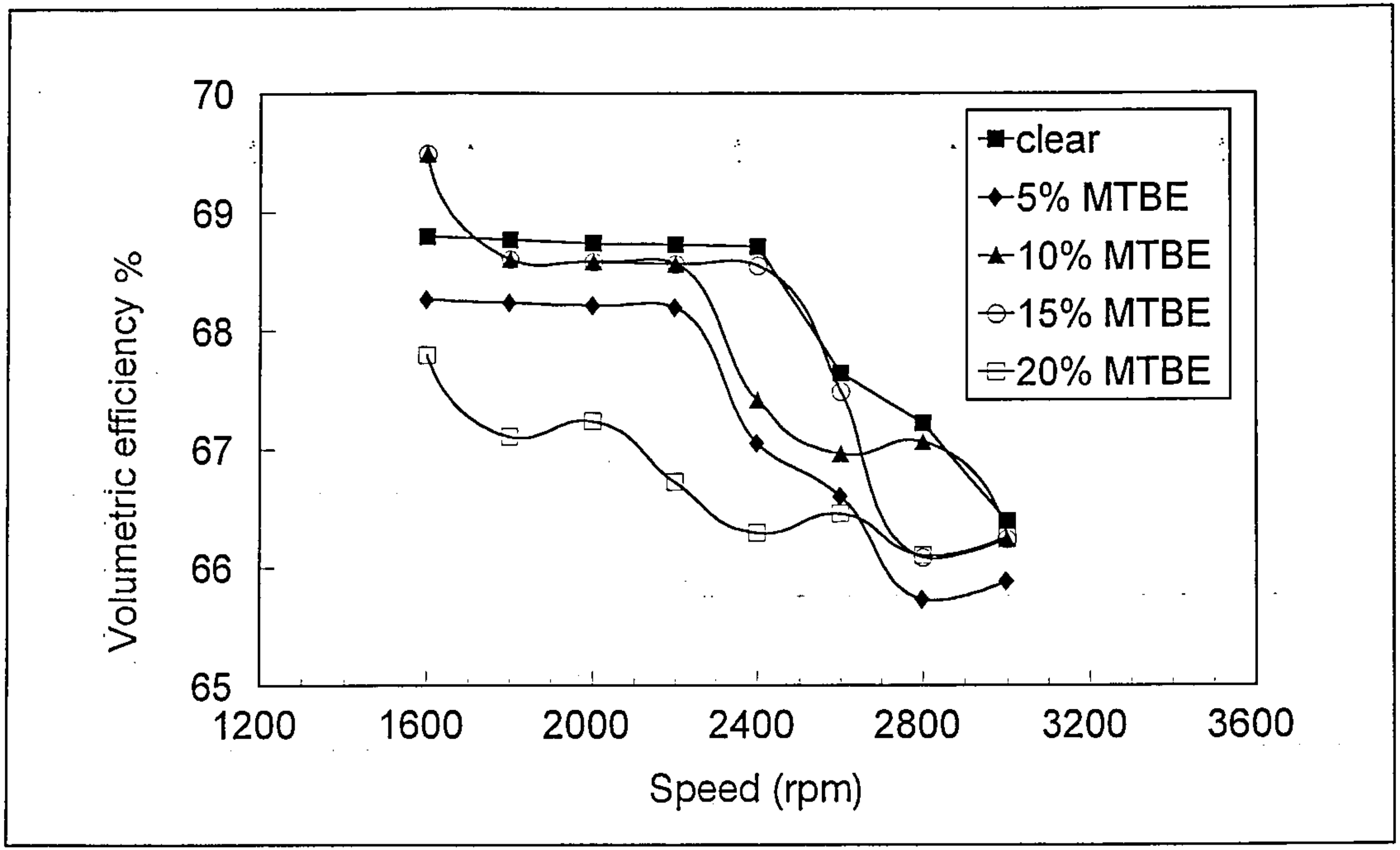
Figure(6.31): Brake thermal efficiency versus speed for group AR.



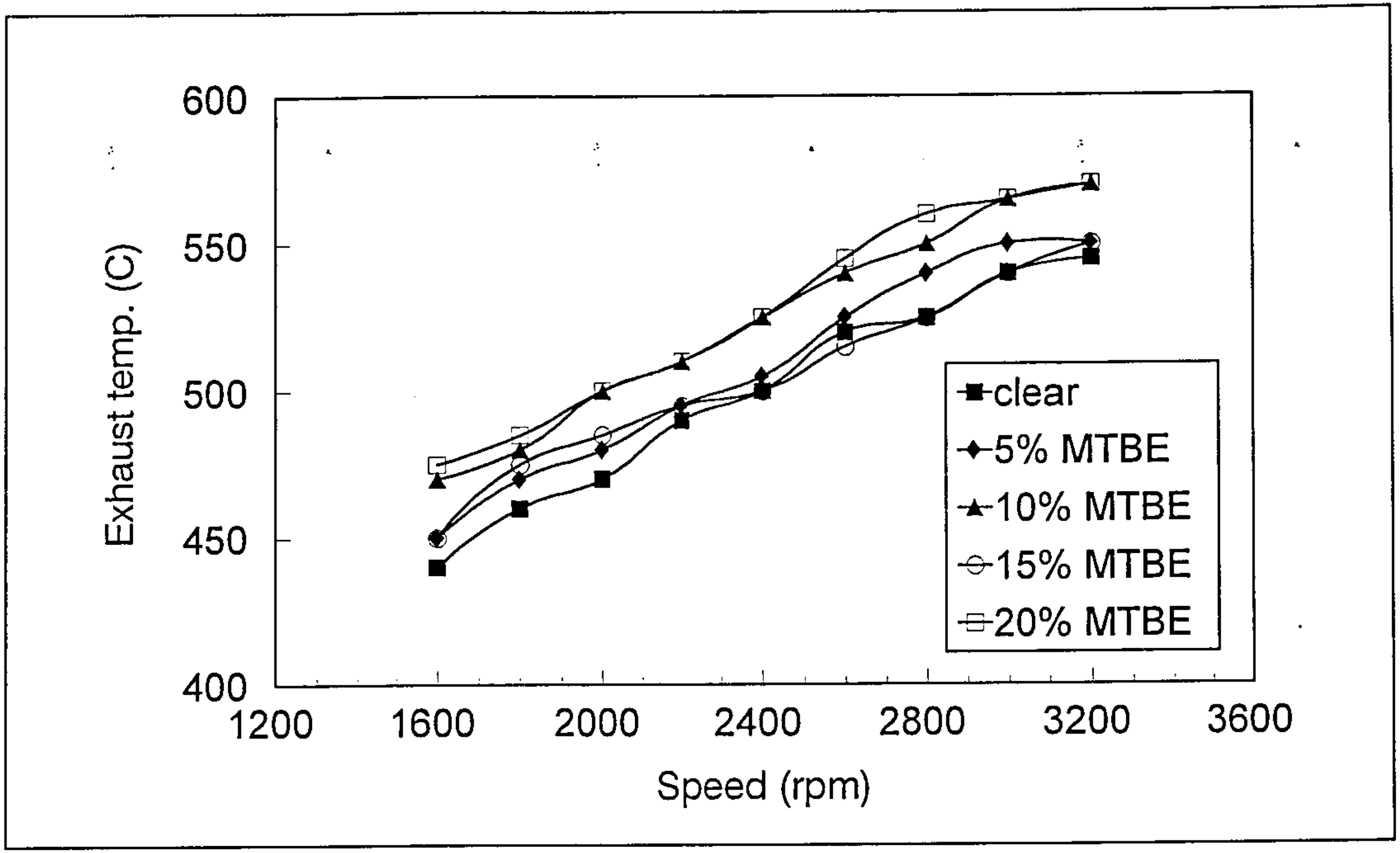
Figure(6.32): Air fuel ratio versus speed for group AR.



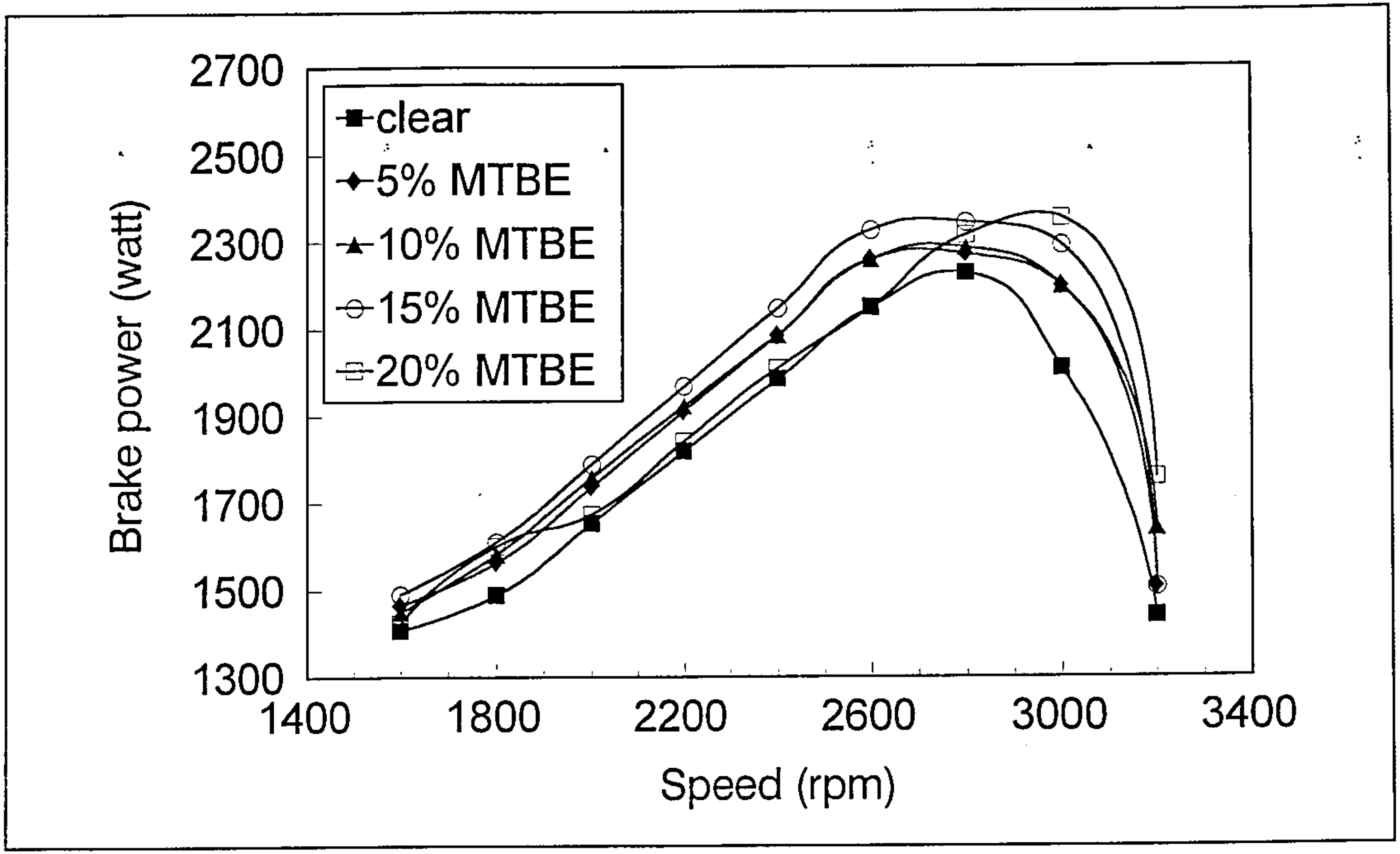
Figure(6.33): Mechanical efficiency versus speed for group AR.



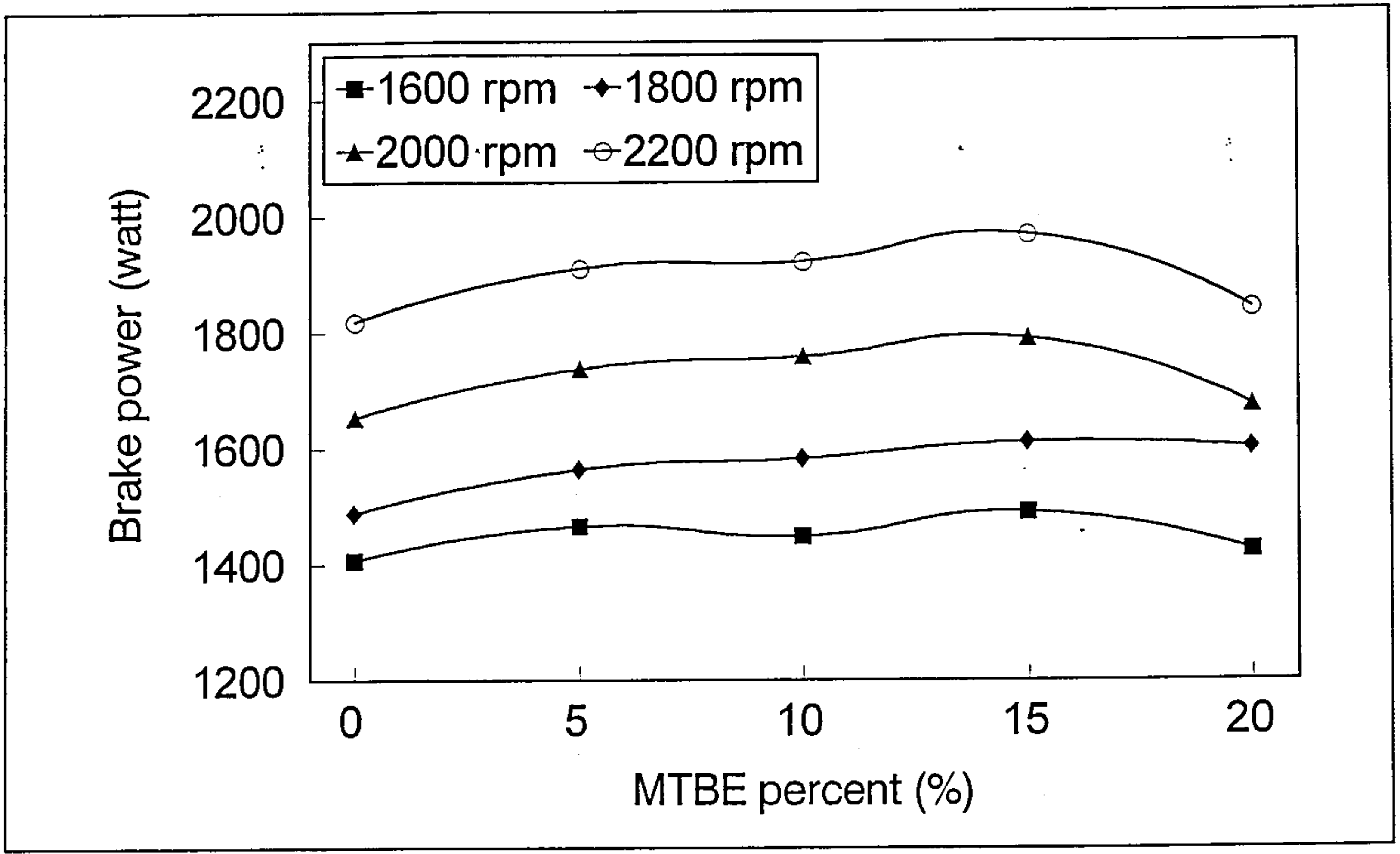
Figure(6.34): Volumetric efficiency versus speed for group AR.



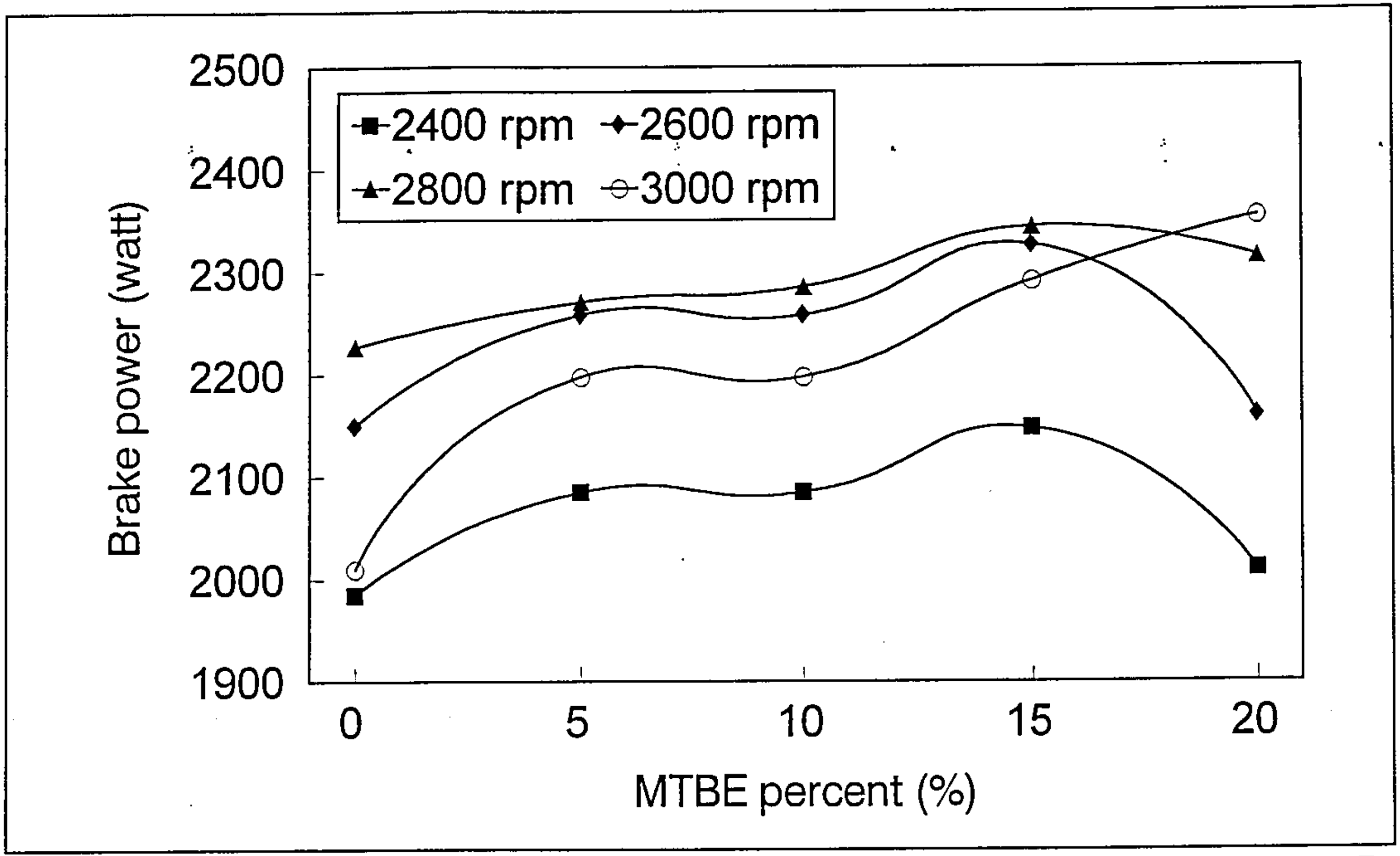
Figure(6.35): Exhaust temperature versus speed for group AR.



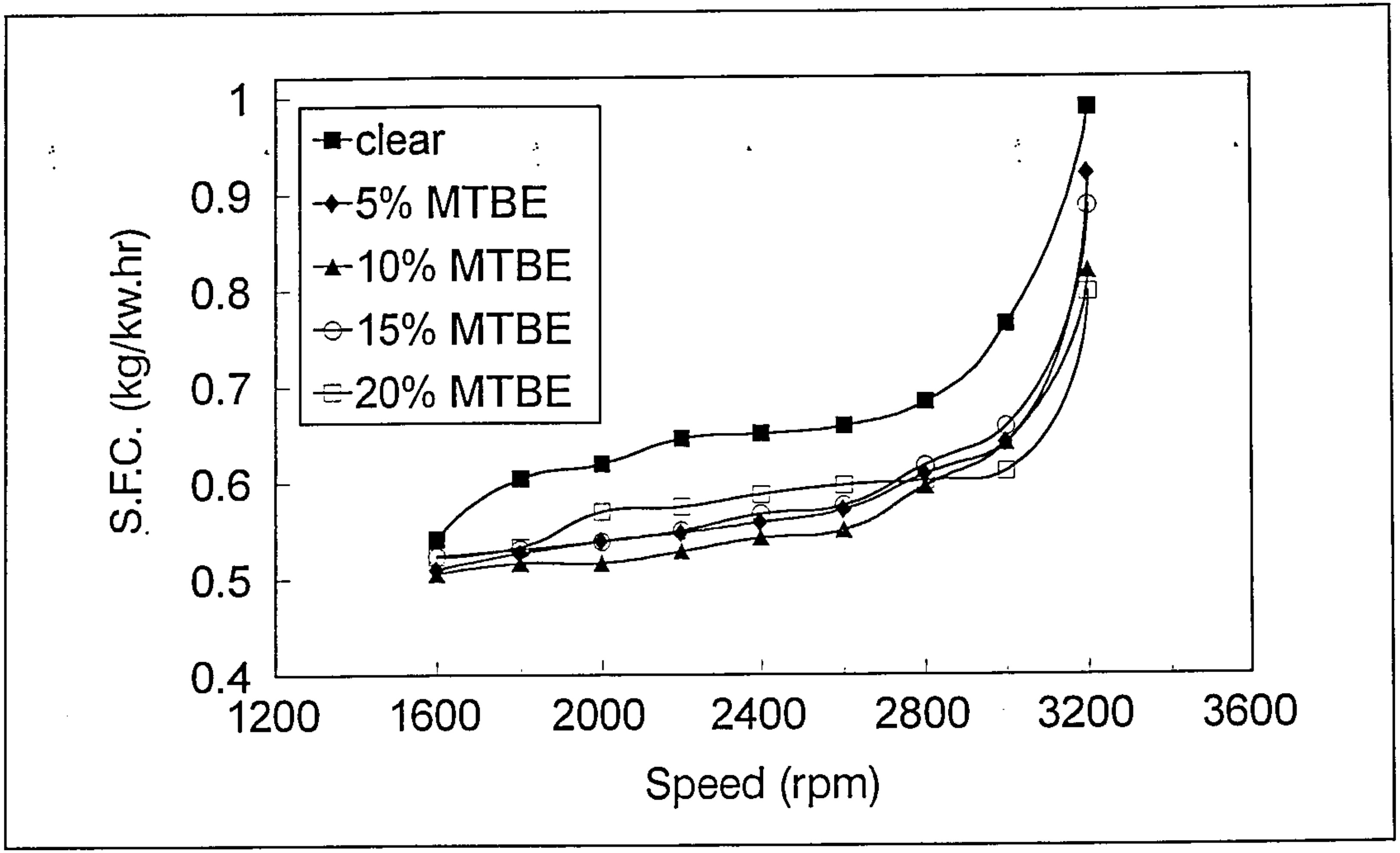
Figure(6.36): Brake power versus speed for group B.



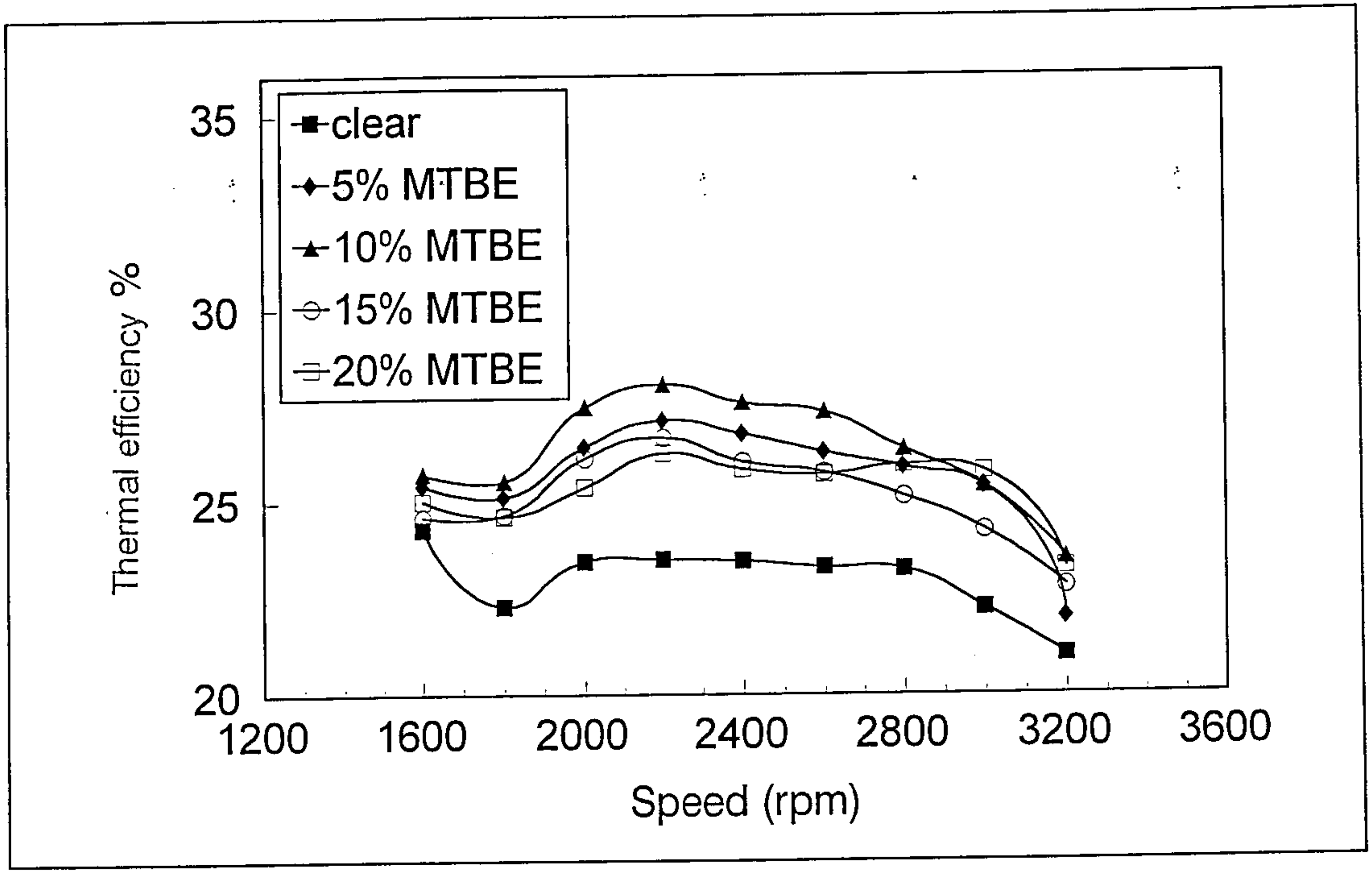
Figure(6.37) : Brak power versus MTBE percent at constant speeds for group B.



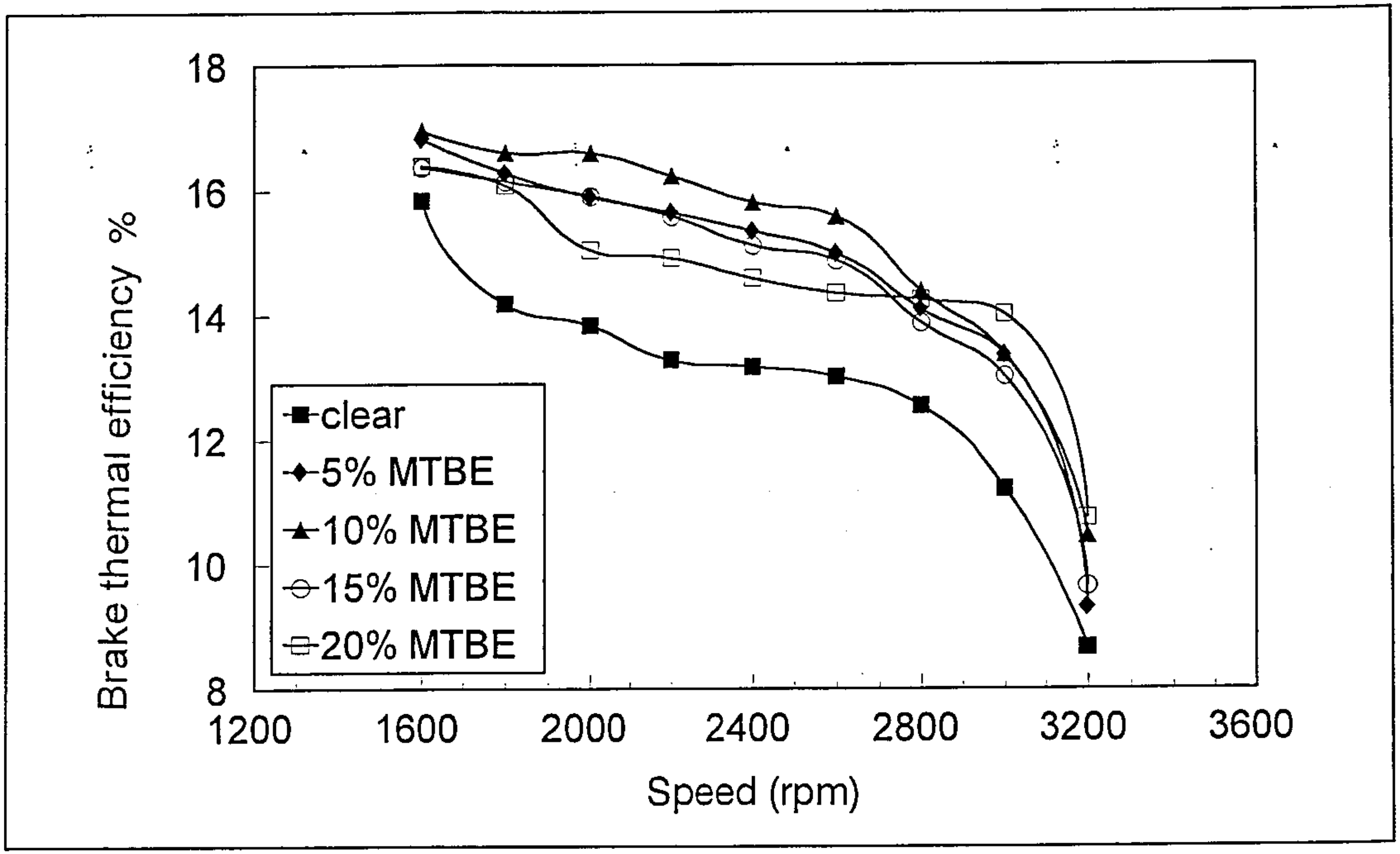
Figure(6.38): Brake power versus MTBE percent at constant speeds for group B.



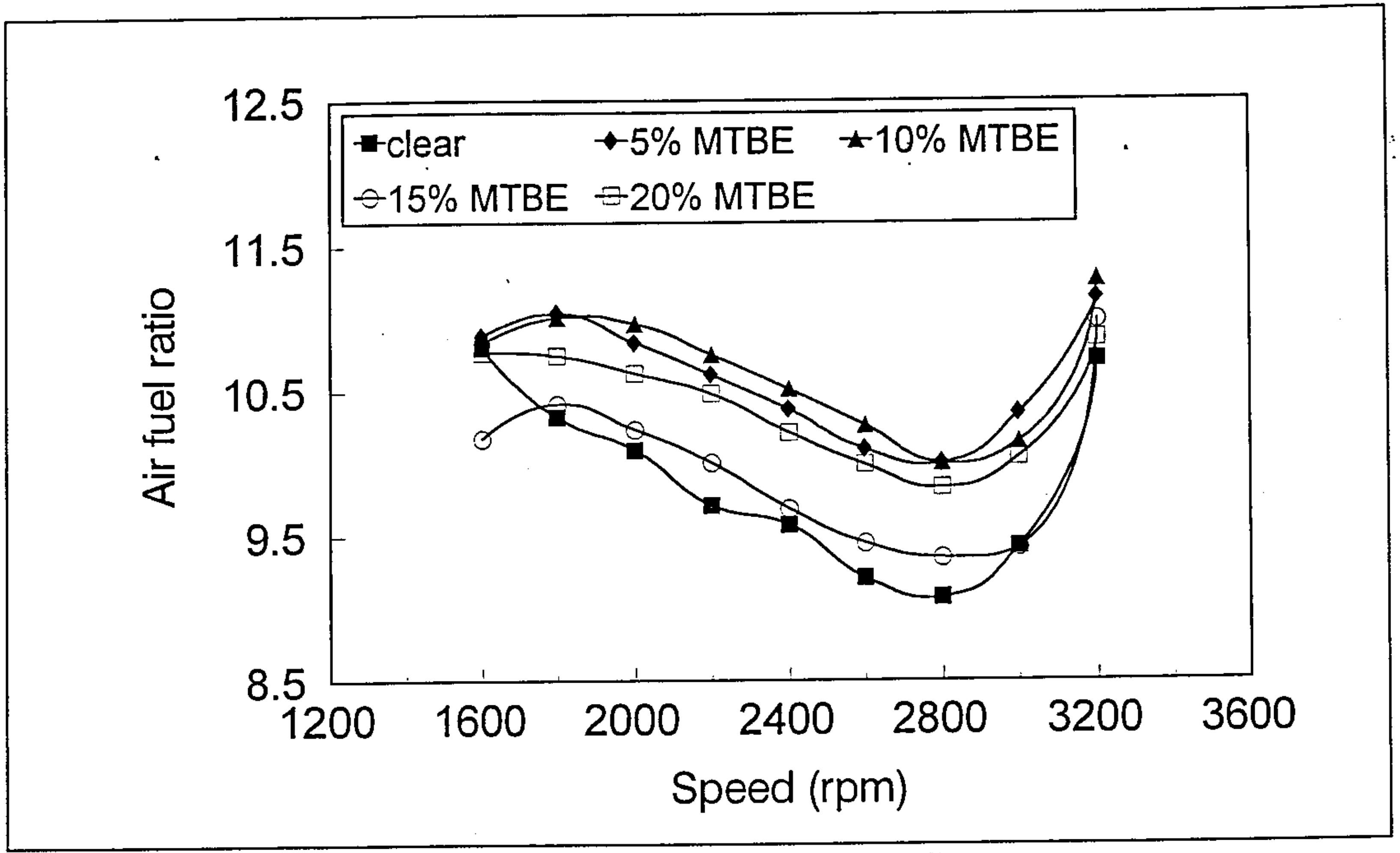
Figure(6.39): Specific fuel consumption (S.F.C) versus speed forgroup B.



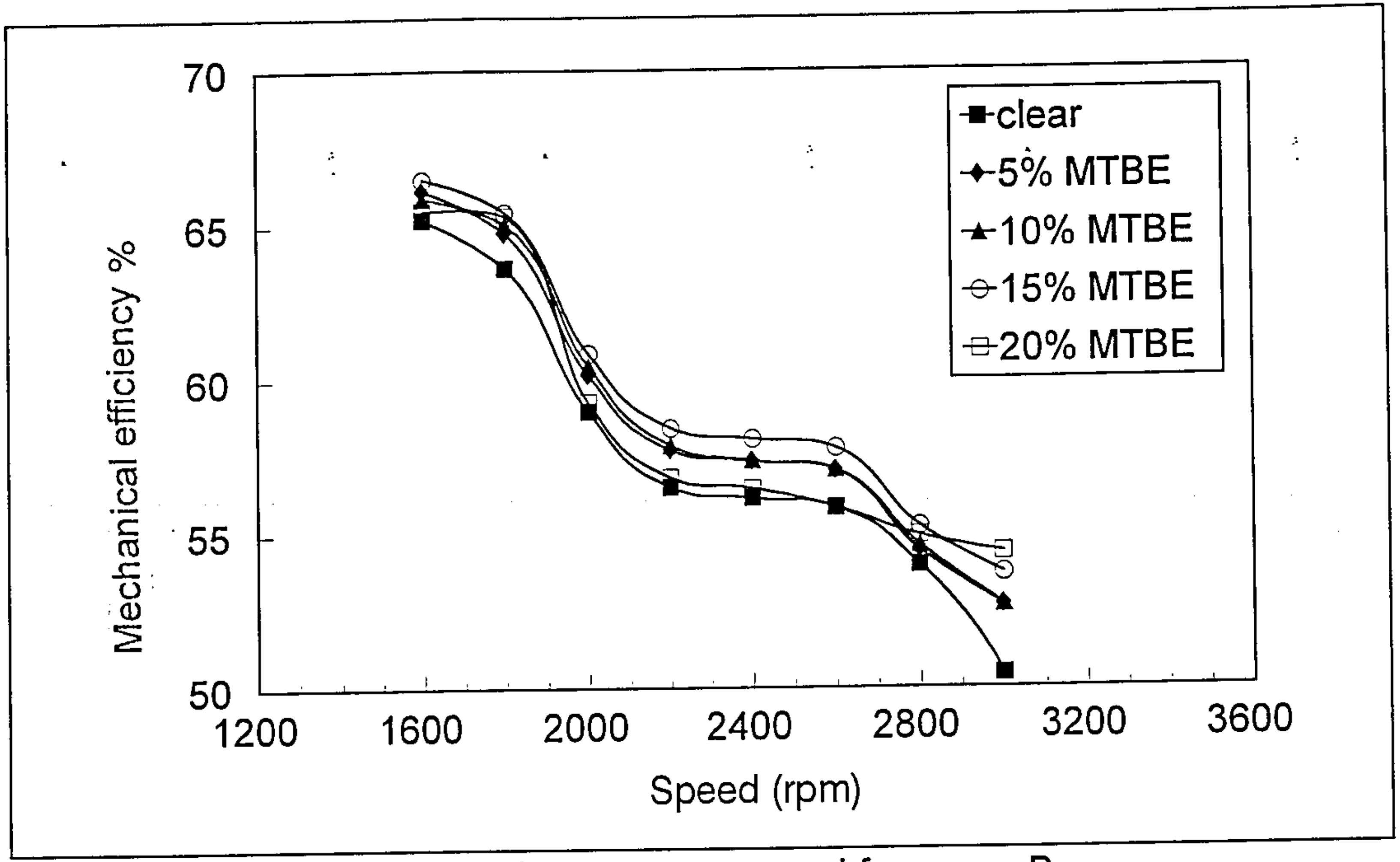
Figure(6.40): Thermal efficiency versus speed for group B.



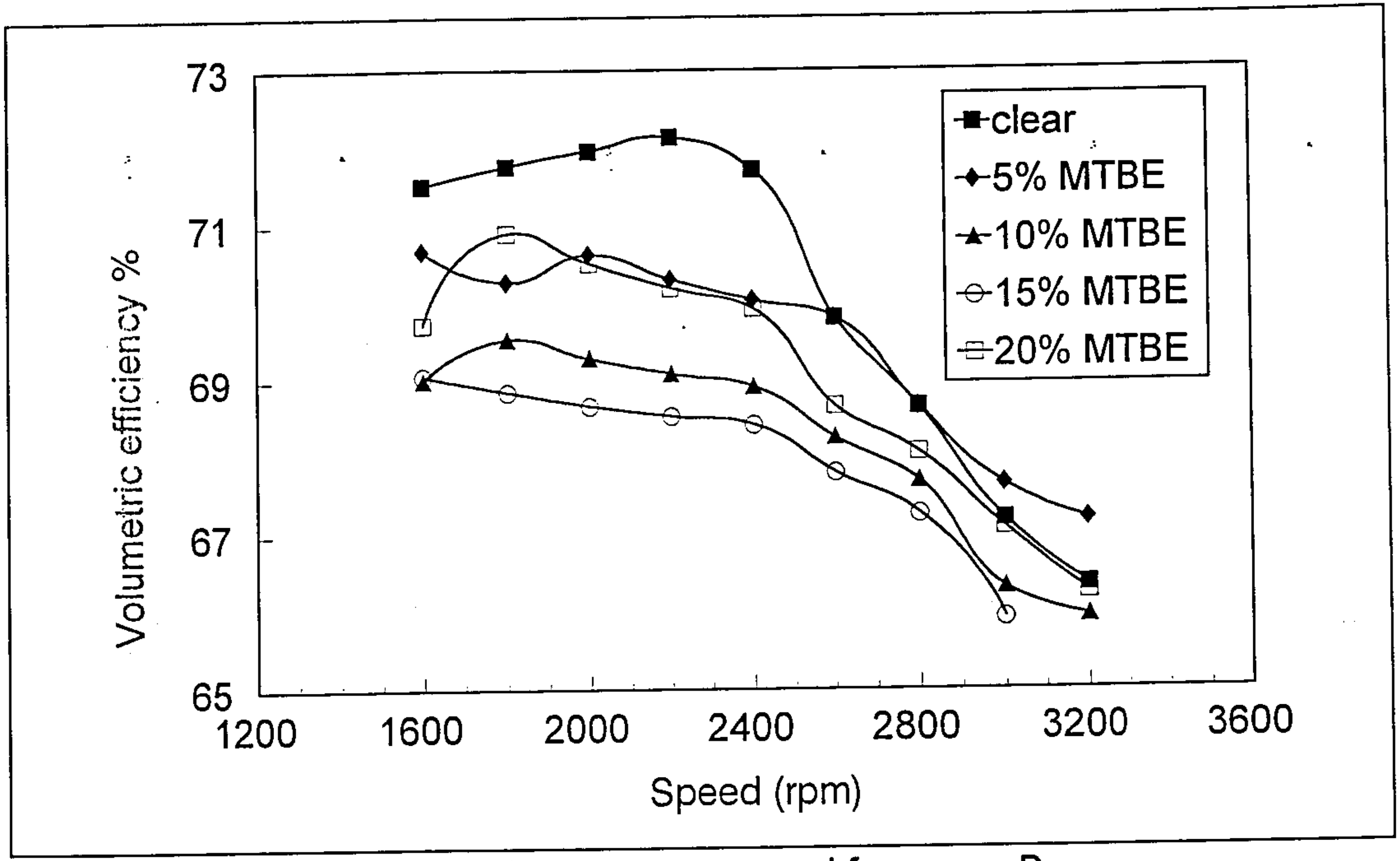
Figure(6.41): Brake thermal efficiency versus speed for group B.



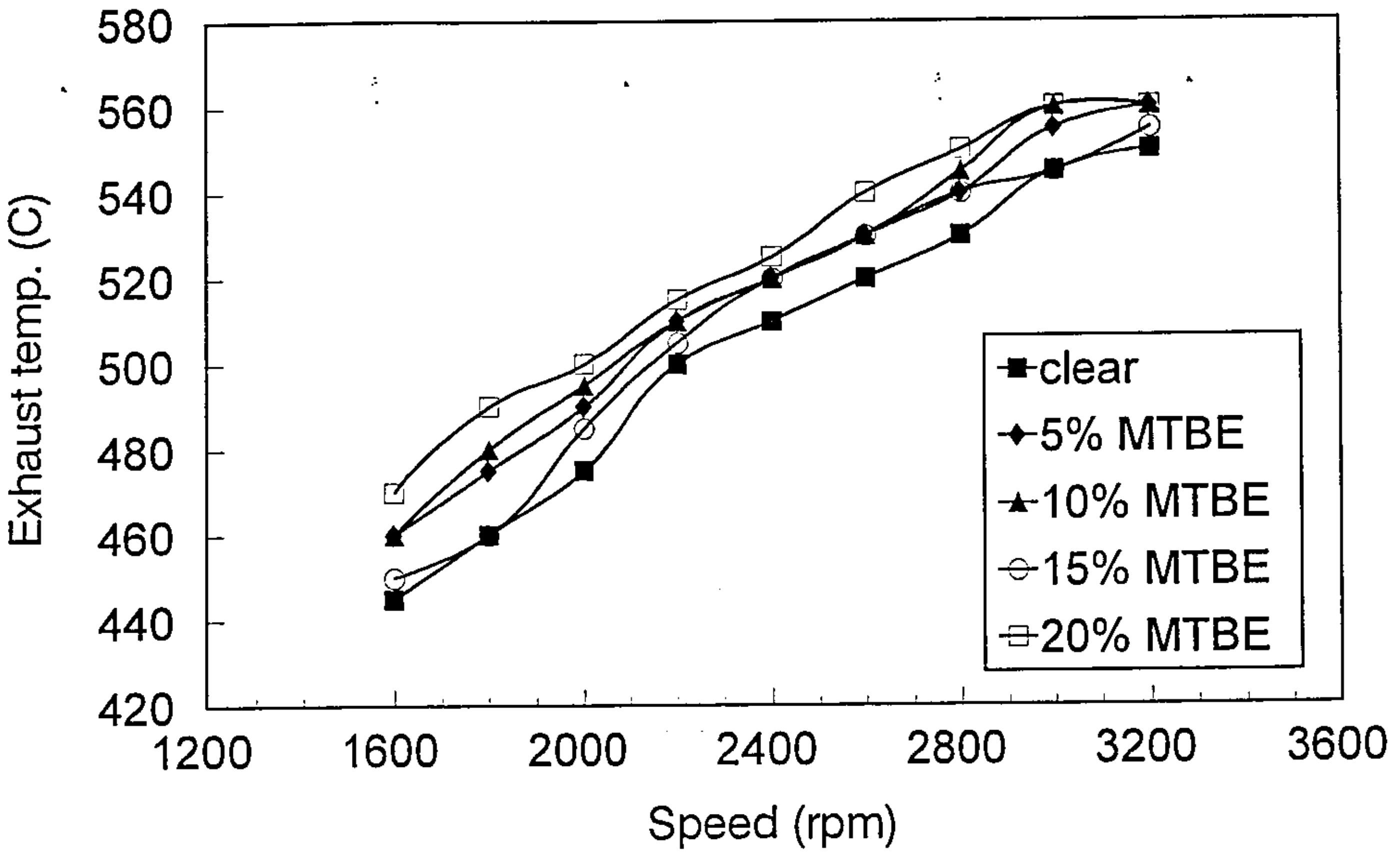
Figure(6.42): Air fuel ratio versus speed for group B.



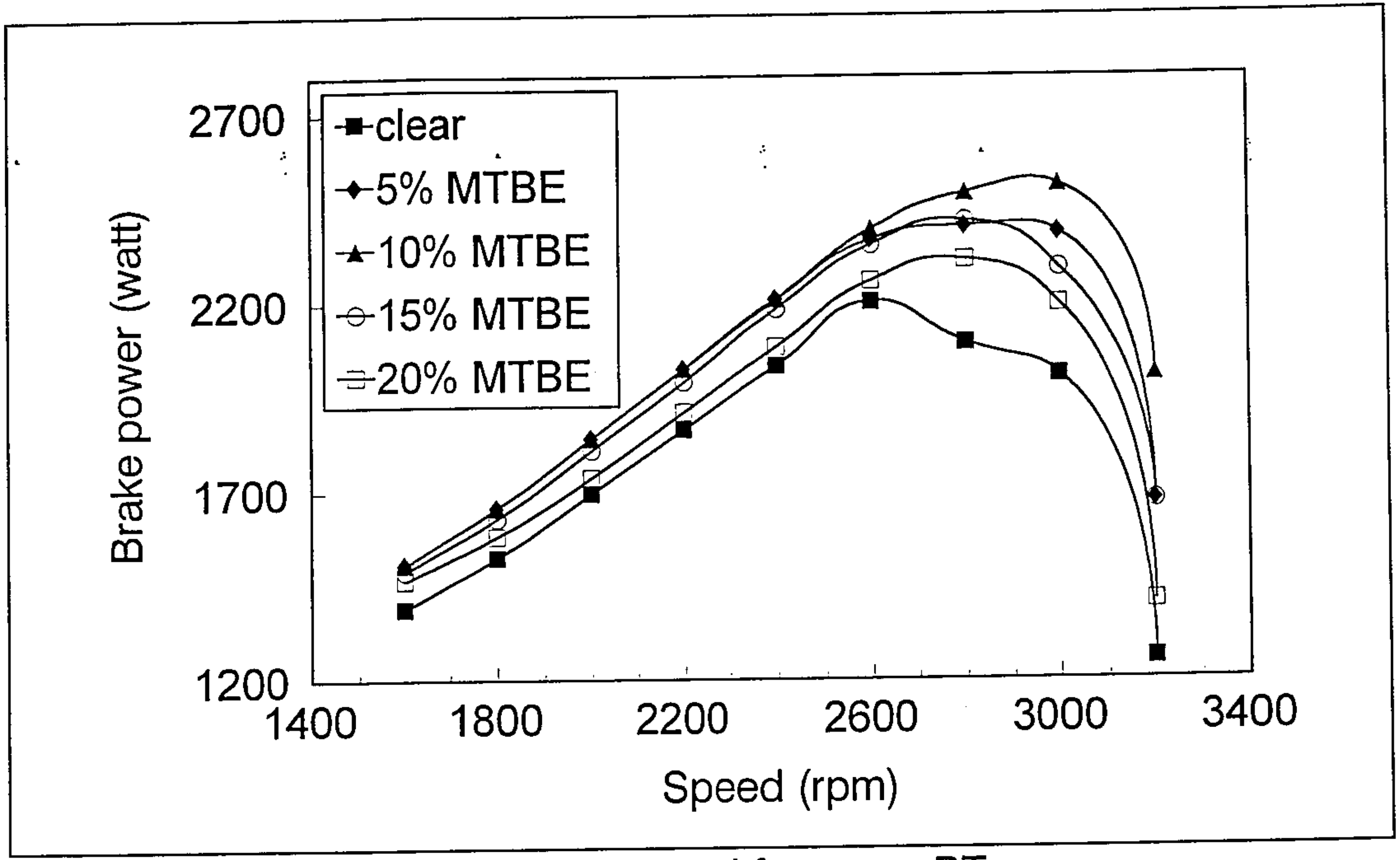
Figure(6.43): Mechanical efficiency versus speed for group B.



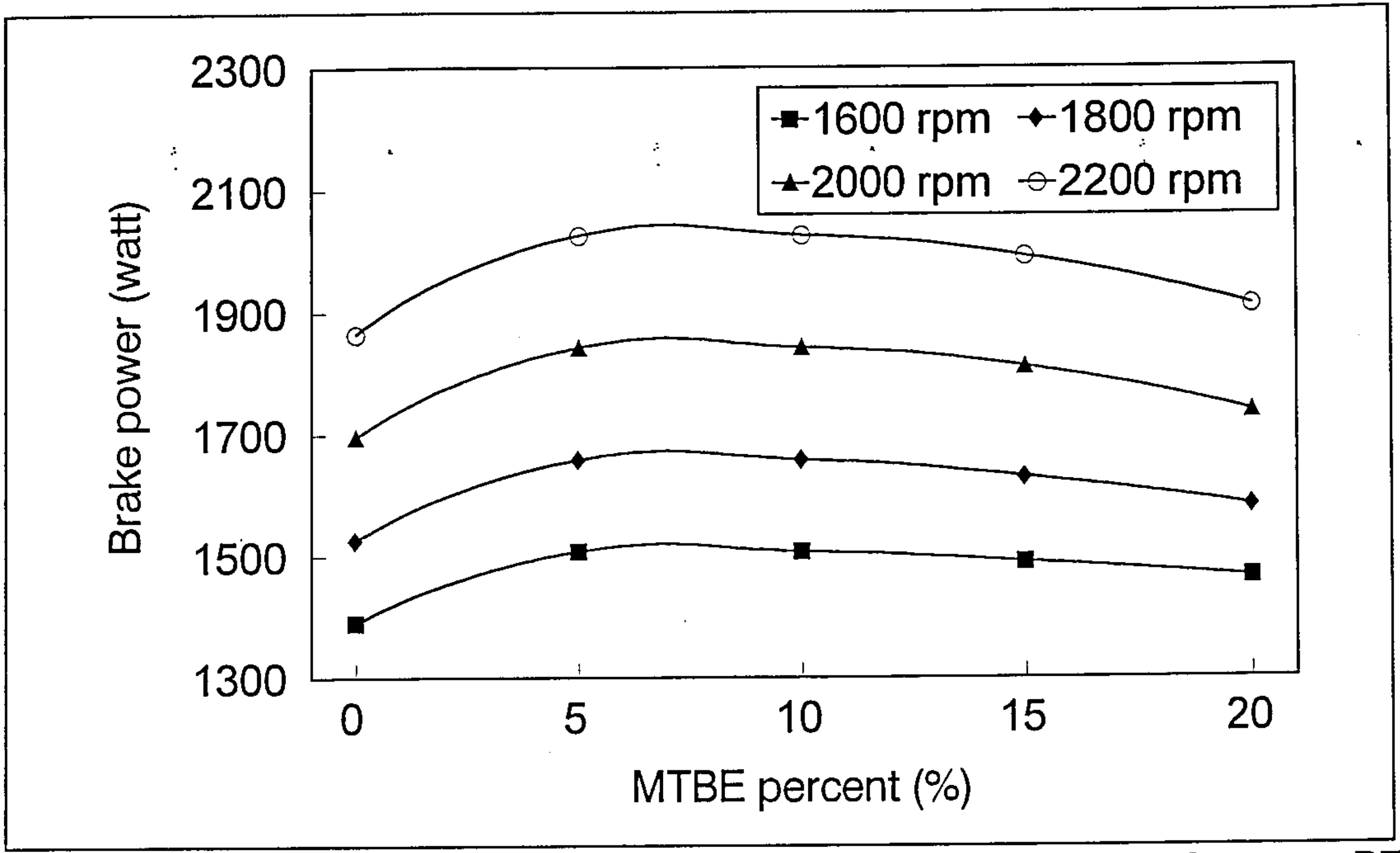
Figure(6.44): Volumetric efficiency versus speed for group B.



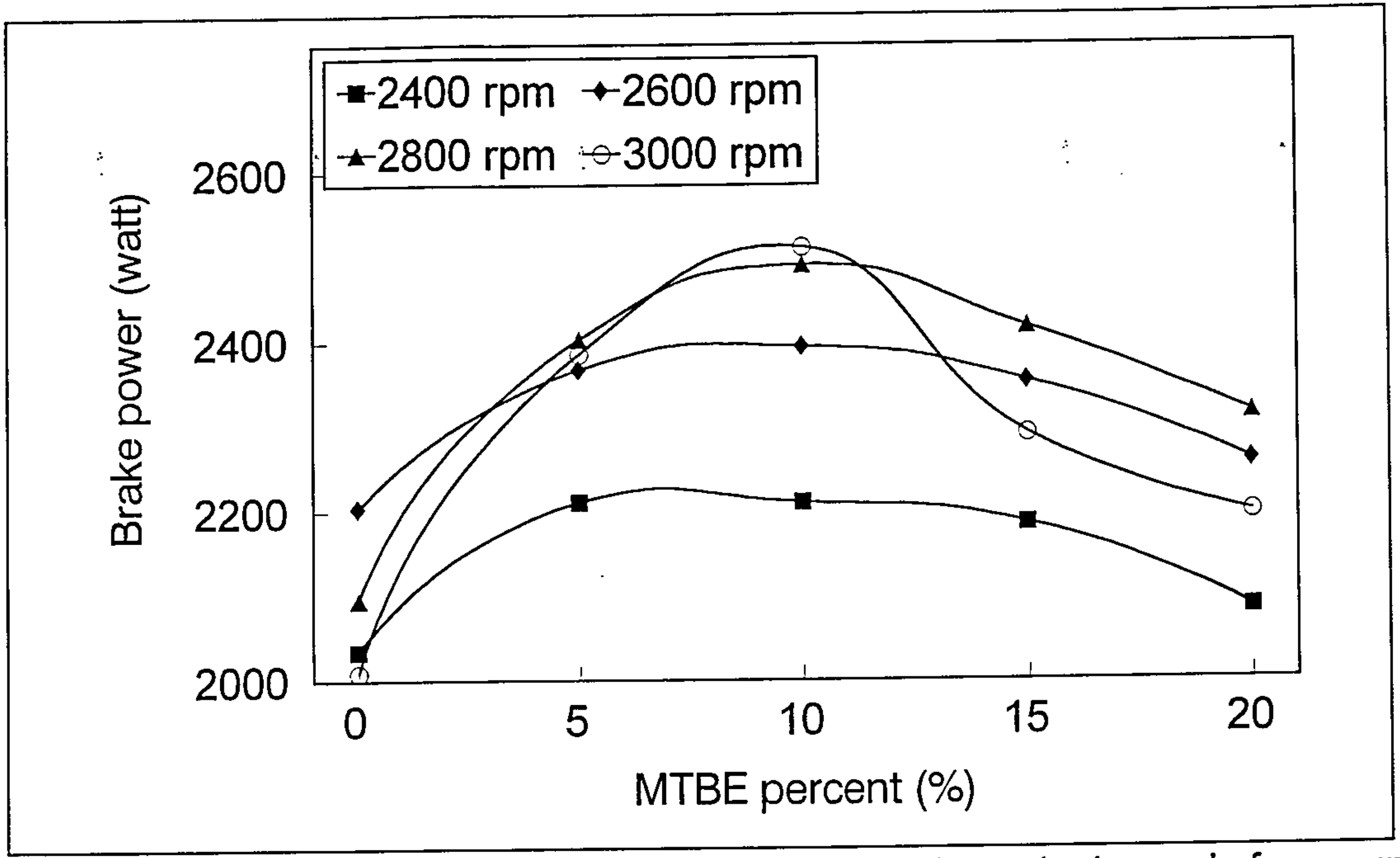
Figure(6.45): Exhaust temperature versus speed for group B.



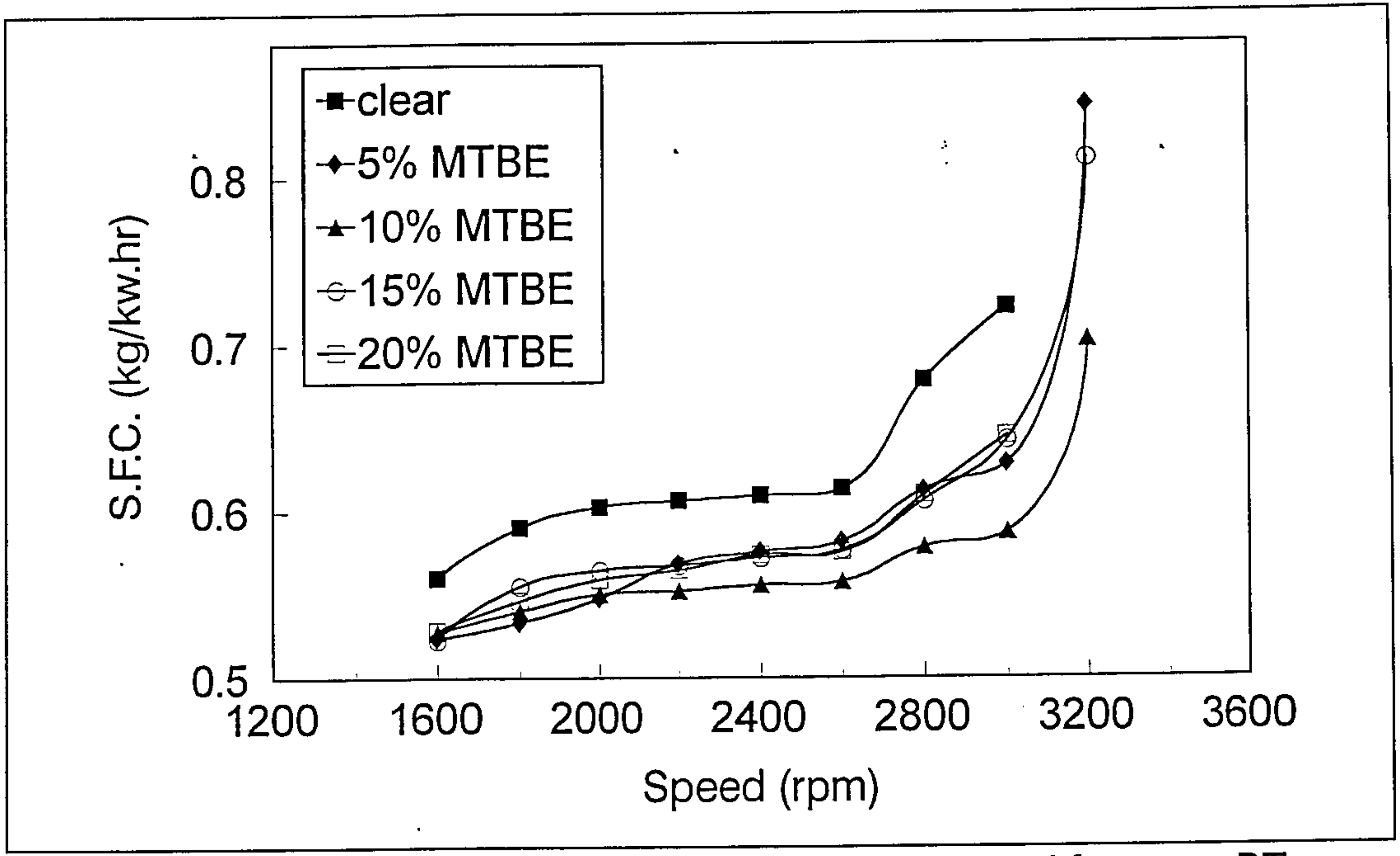
Figure(6.46): Brake power versus speed for group BT.



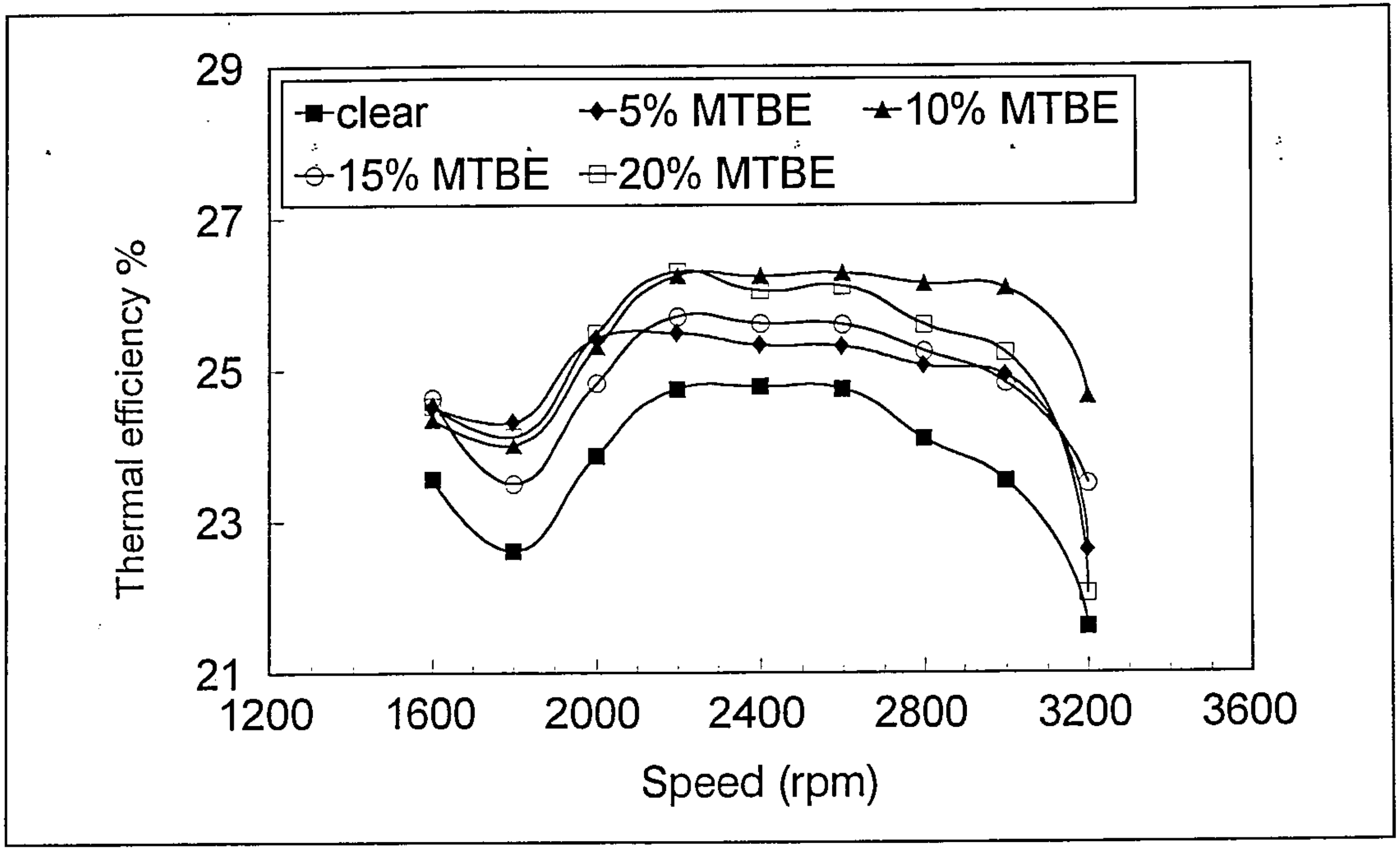
Figure(6.47): Brake power versus MTBE percent at constant speeds for group BT.



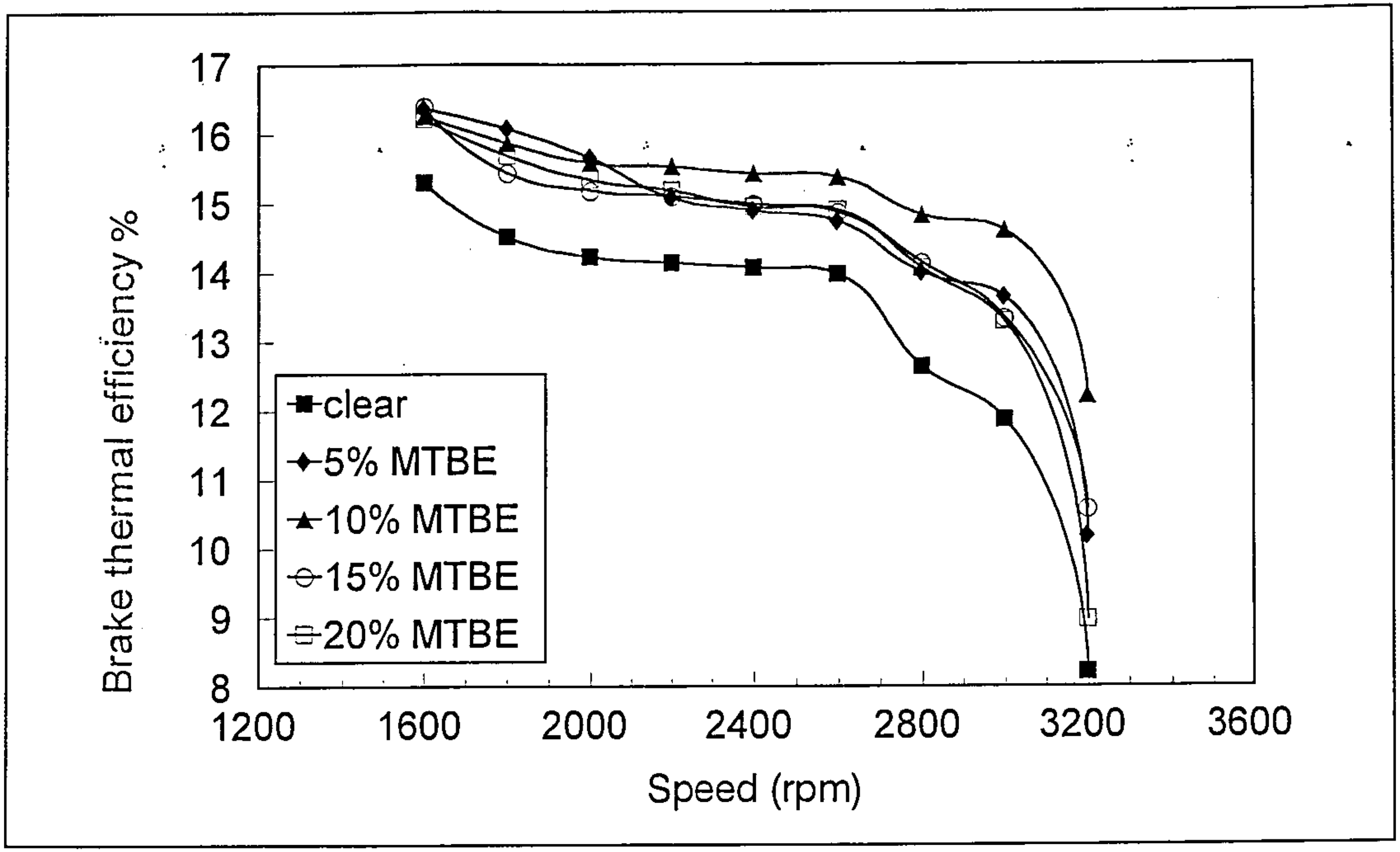
Figure(6.48): Brake power versus MTBE percentage at constant speeds for group BT.



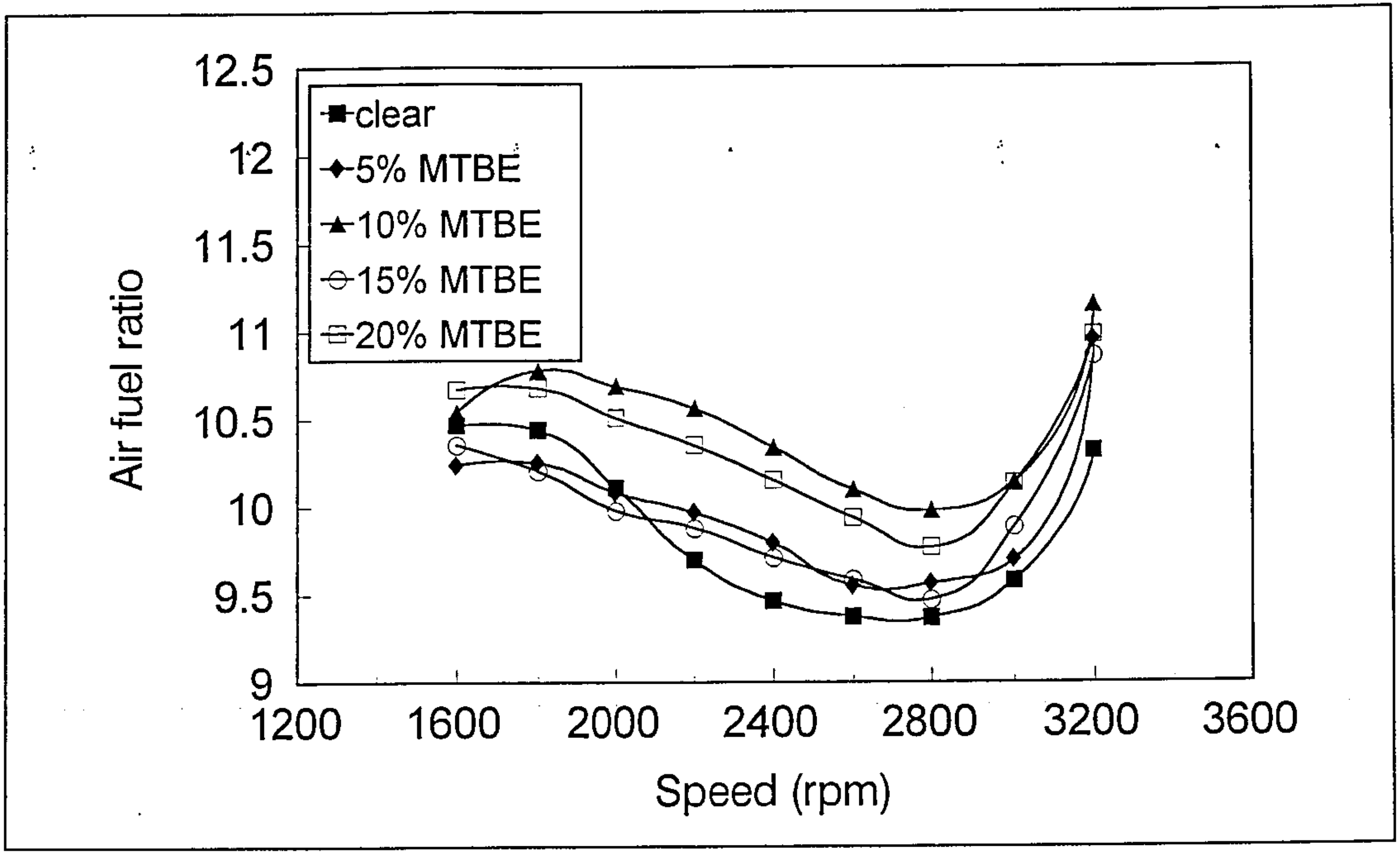
Figure(6.49): Specific fuel consumption (S.F.C) versus speed for group BT.



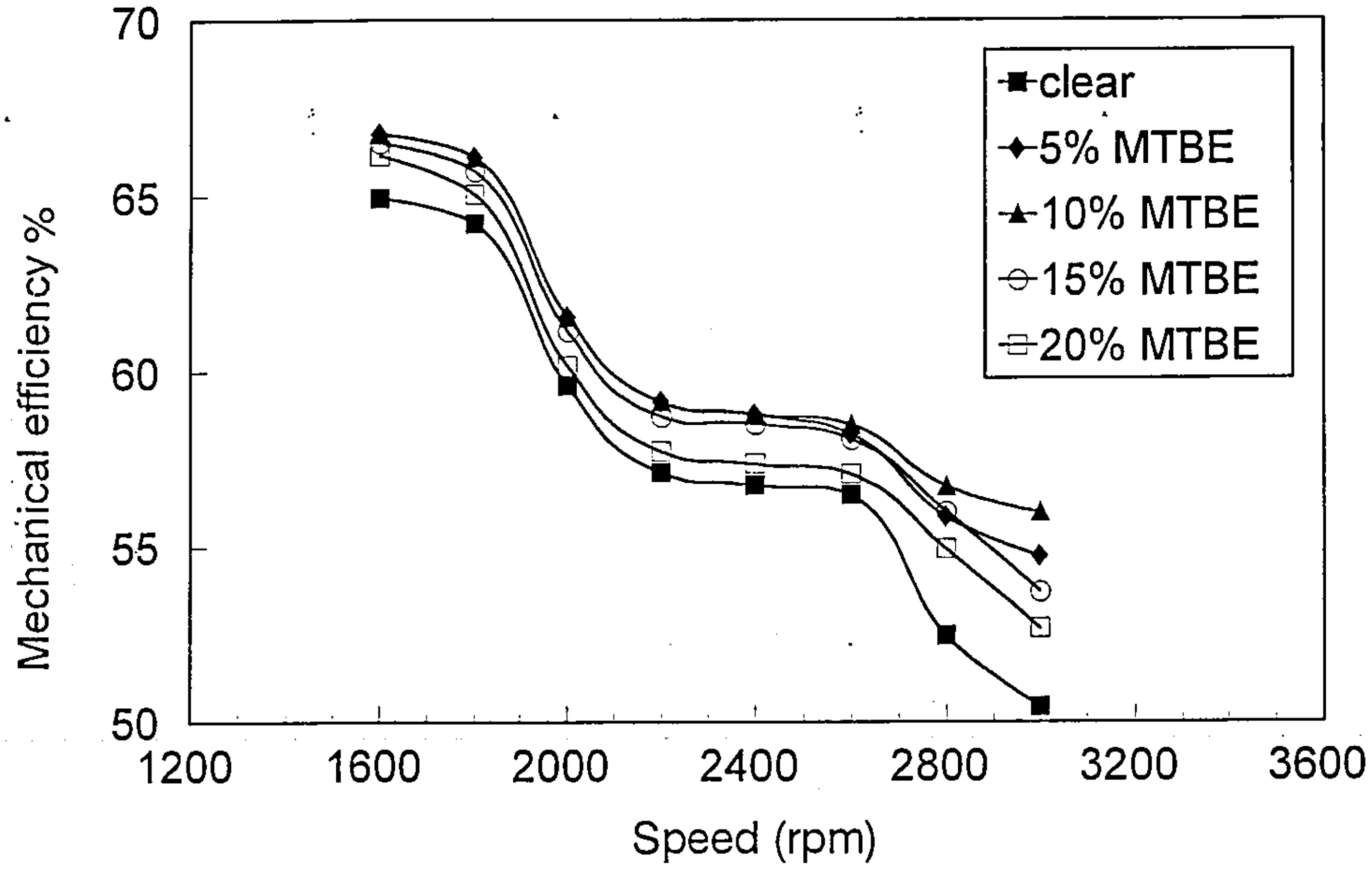
Figure(6.50): Thermal efficiency versus speed group BT.



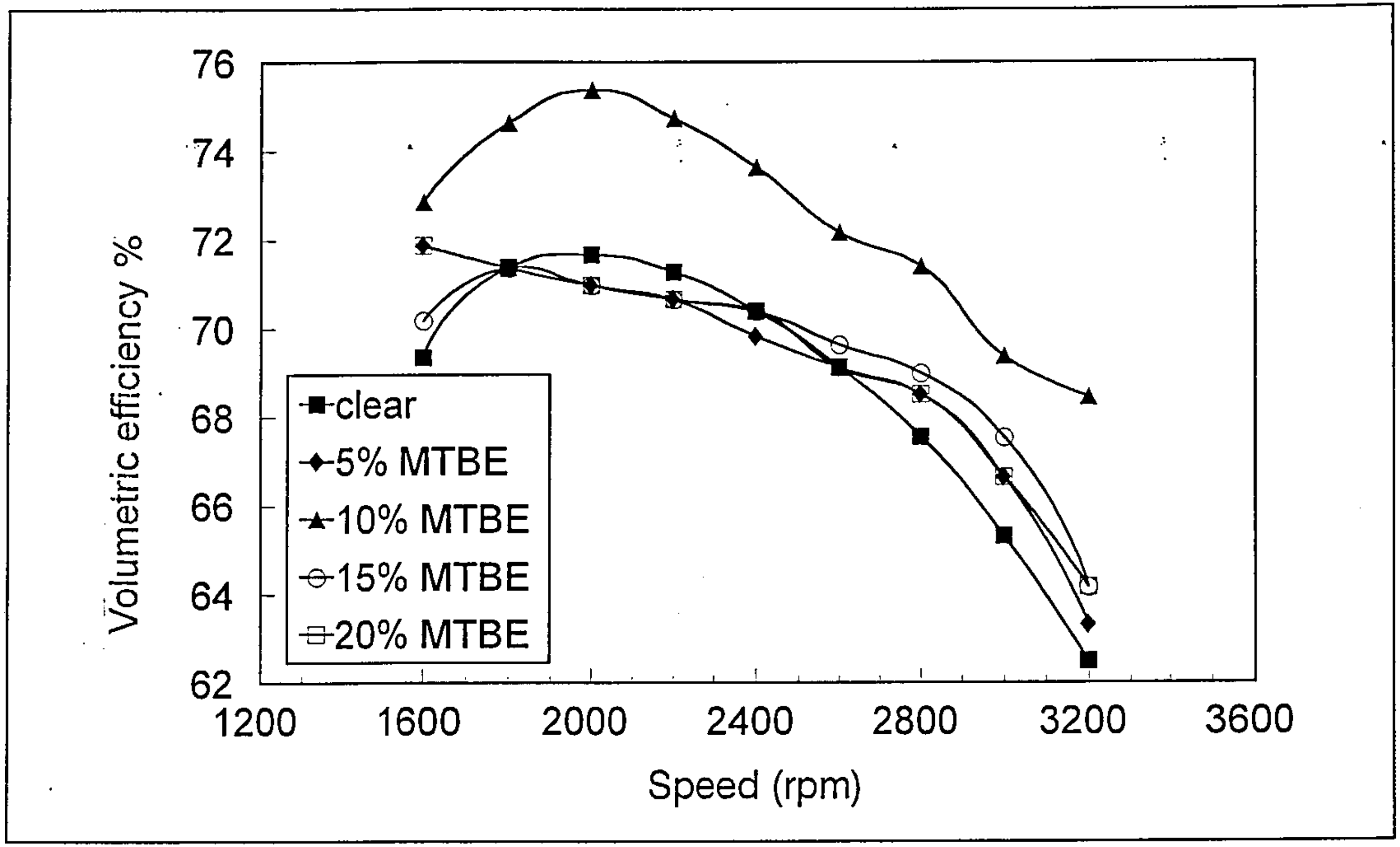
Figure(6.51): Brake thermal efficiency versus speed for group BT.



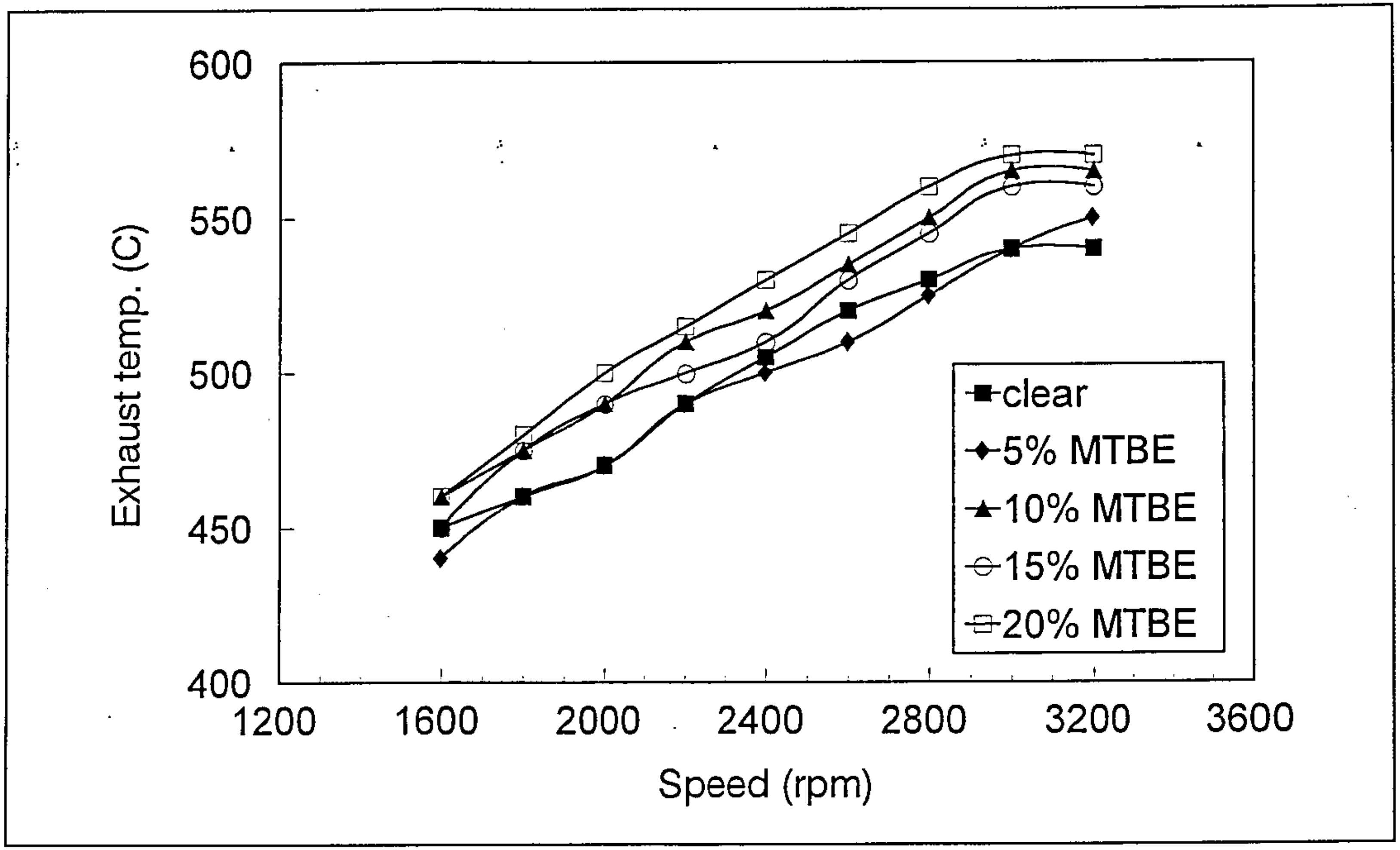
Figure(6.52): Air fuel ratio versus speed for group BT.



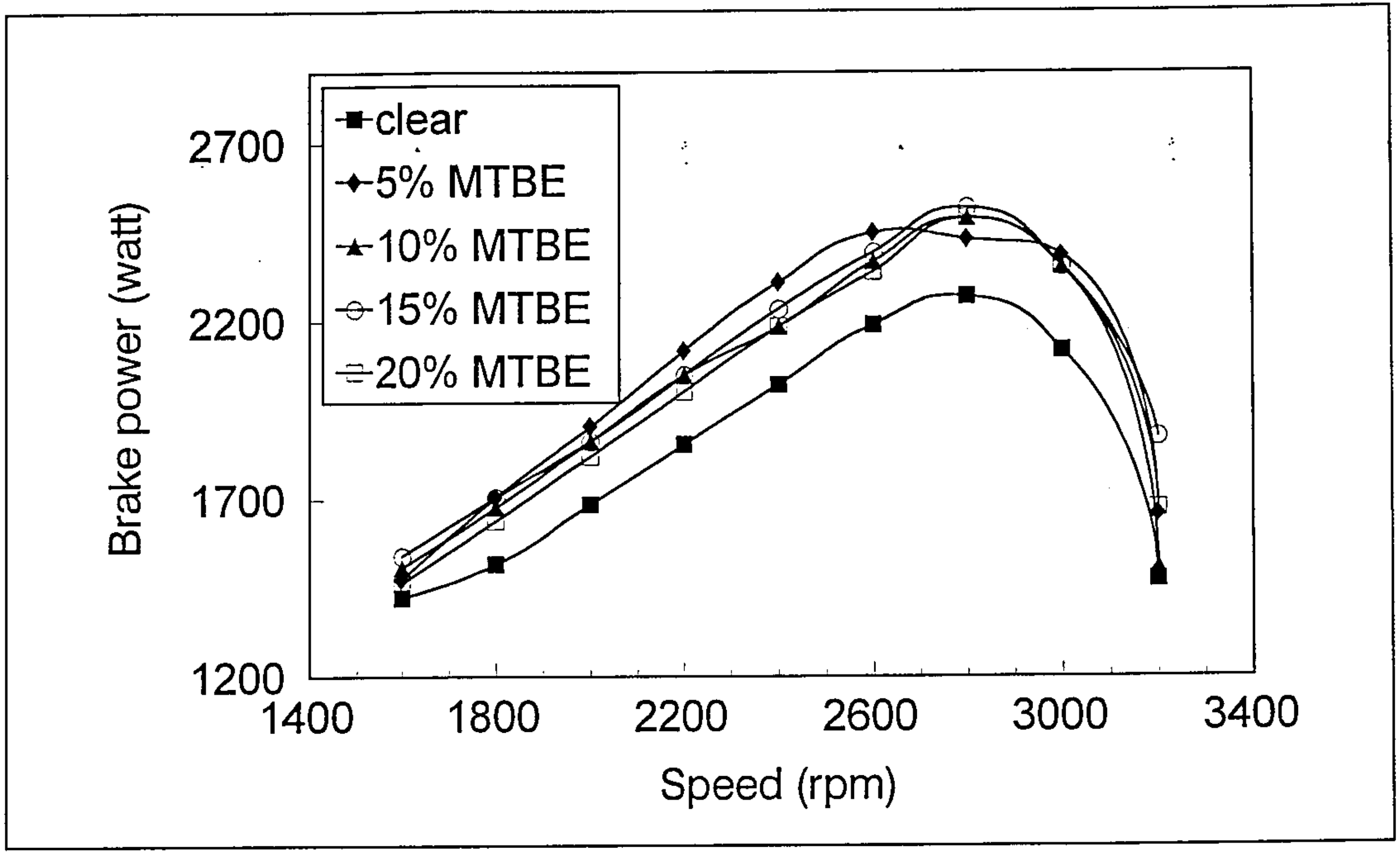
Figure(6.53): Mechanical efficiency versus speed for group BT.



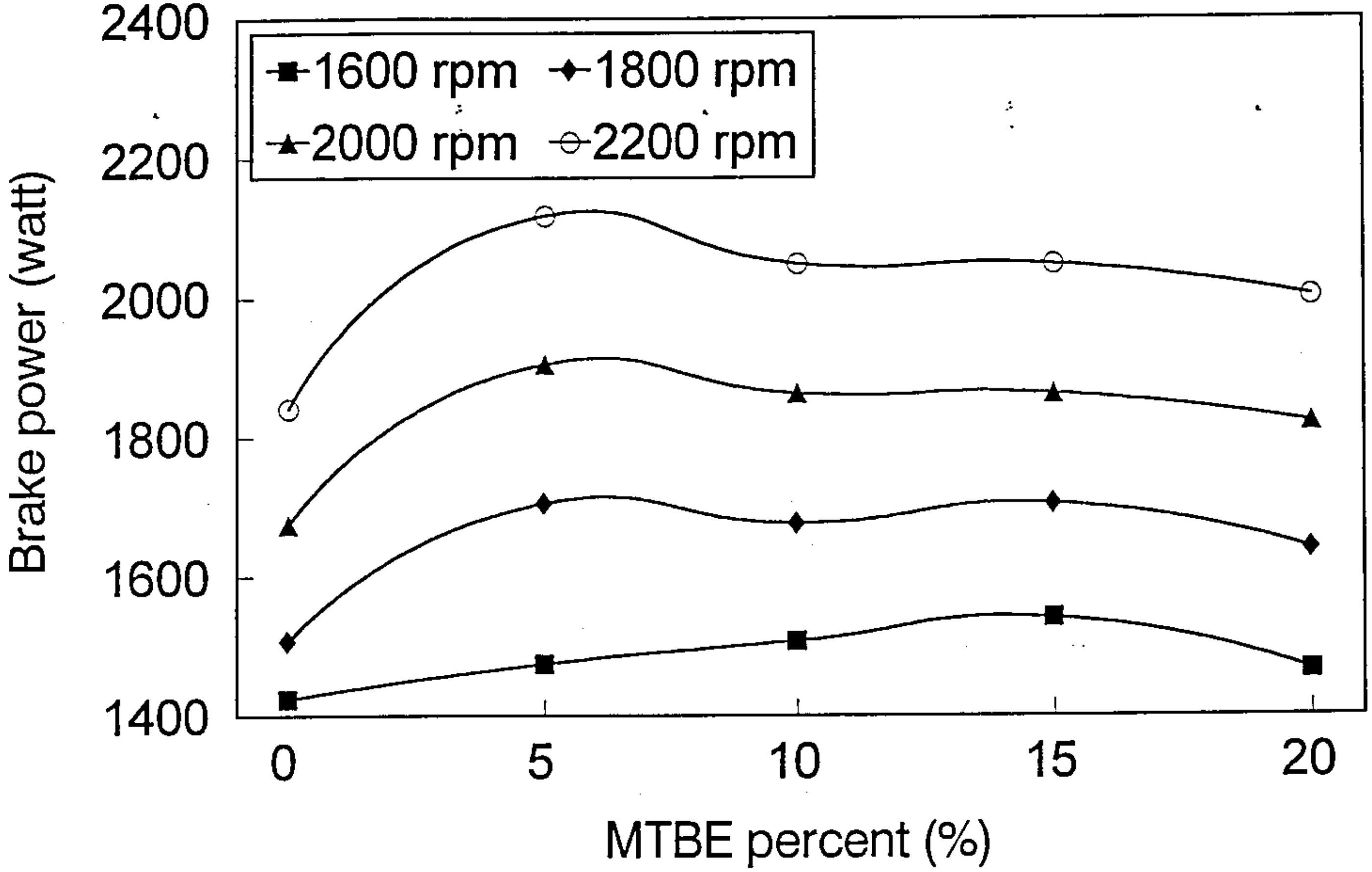
Figure(6.54): Volumetric efficiency versus speed for group BT.



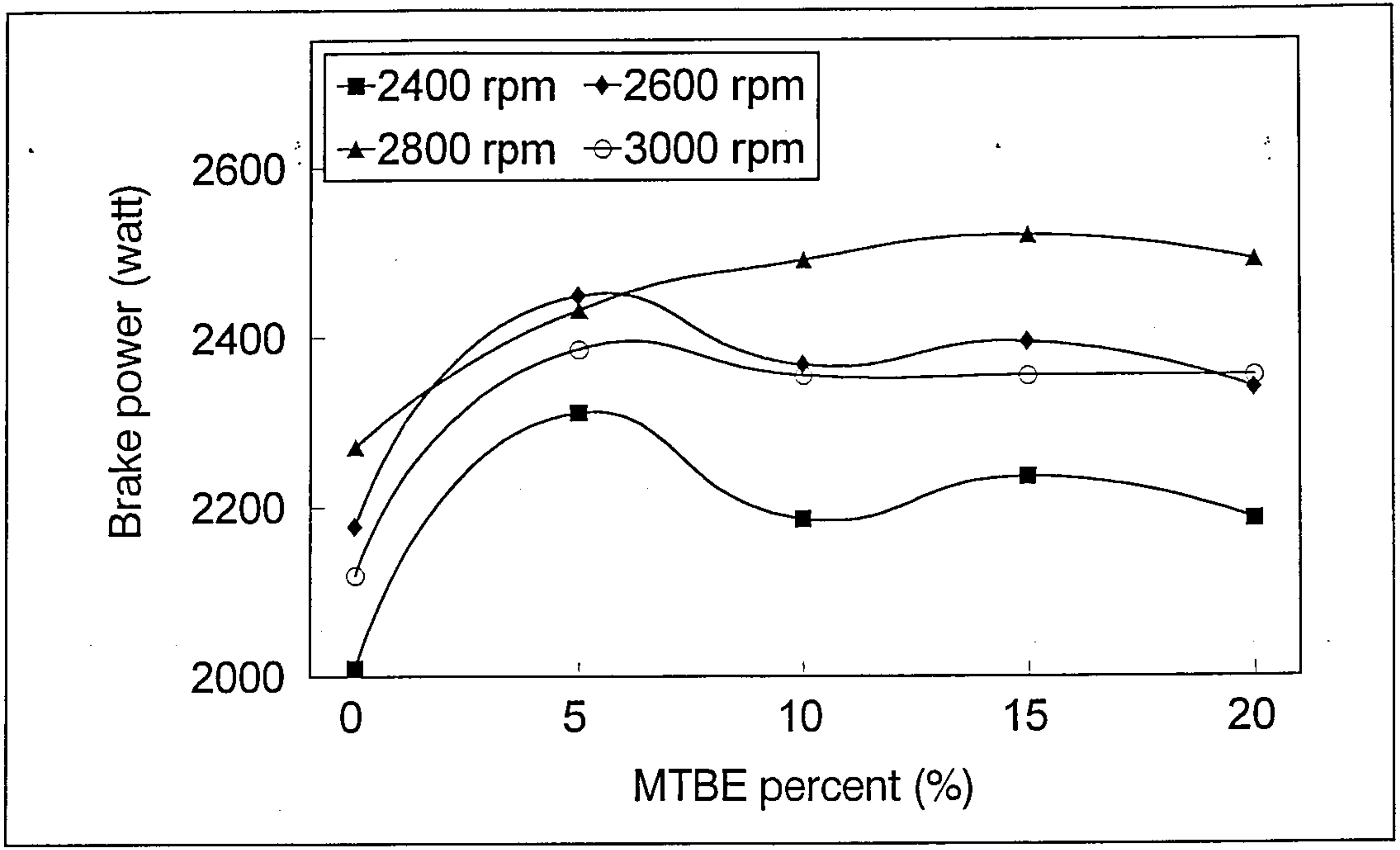
Figure(6.55): Exhaust temperature versus speed for group BT.



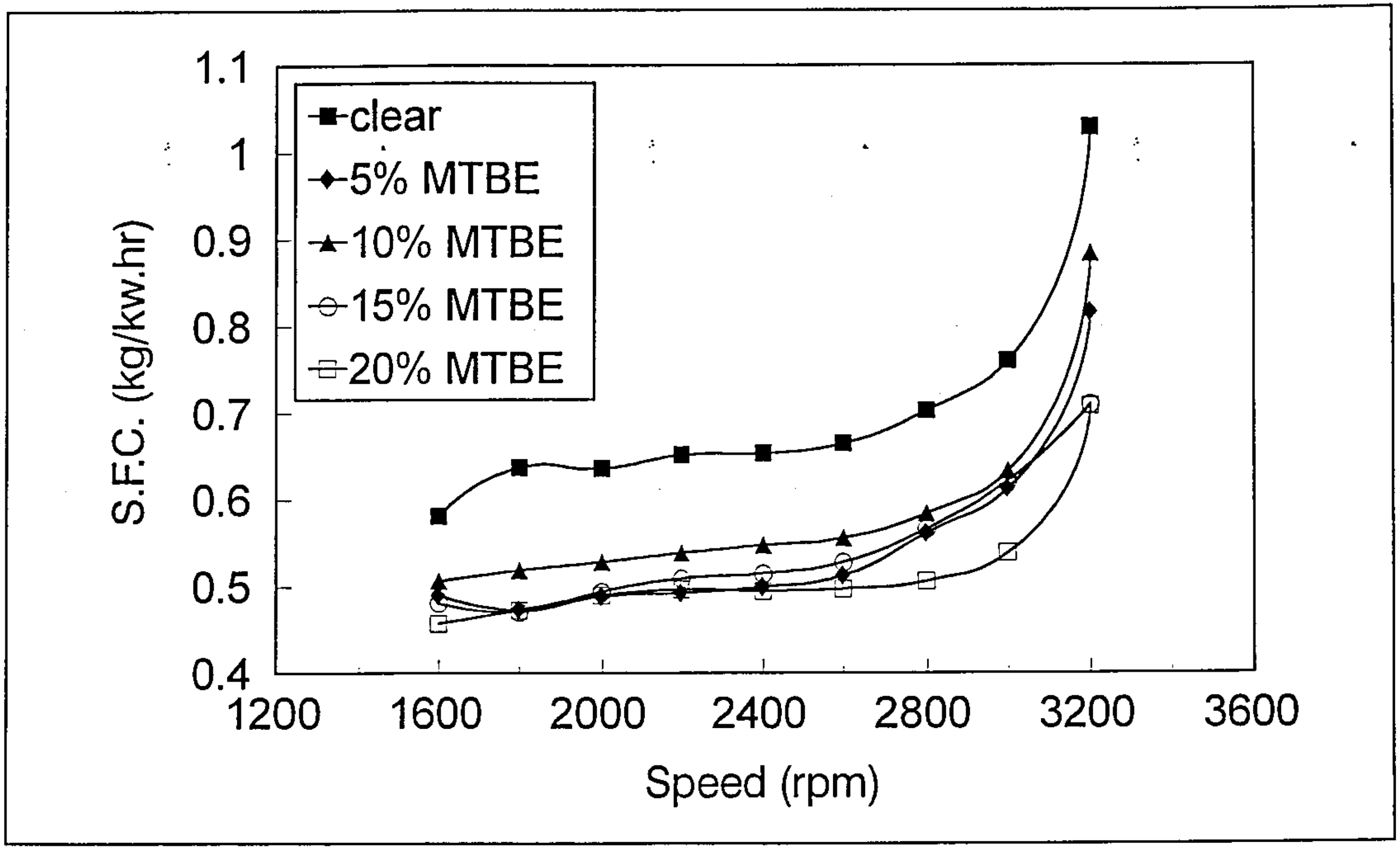
Figure(6.56): Brake power versus speed for group BS.



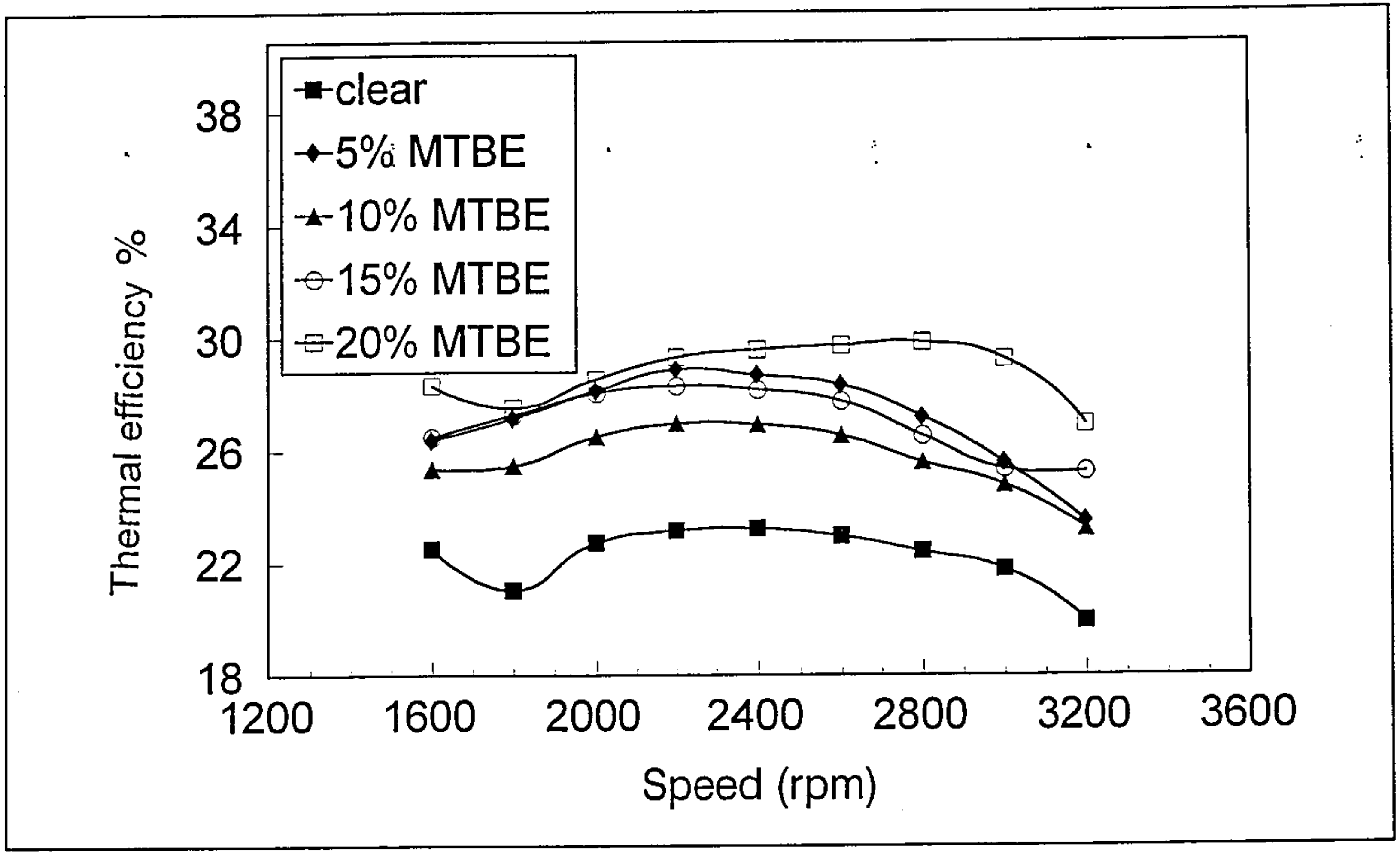
Figure(6.57): Brake power versus MTBE percentage at constant speeds for group BS.



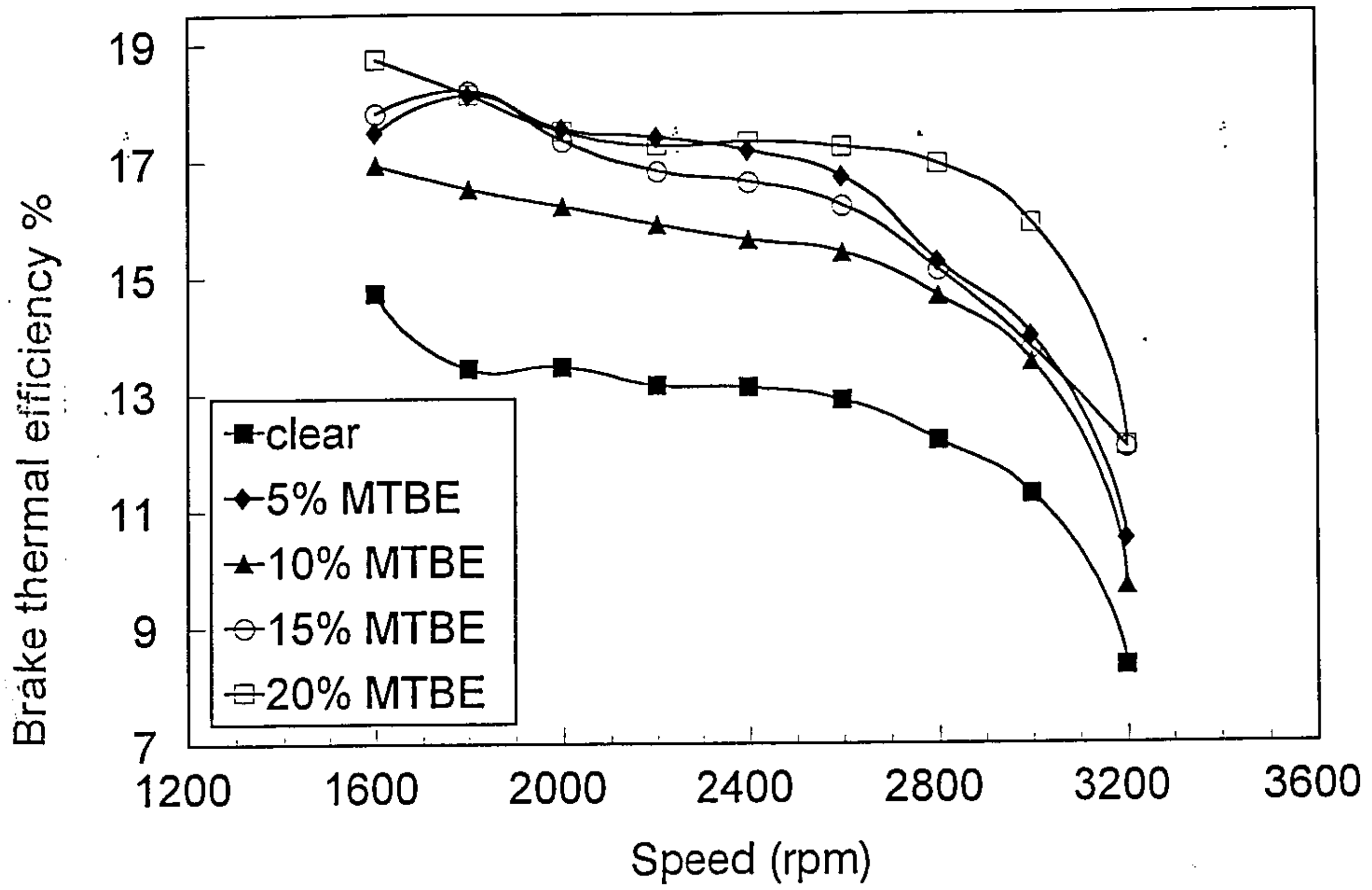
Figure(6.58): Brake power versus MTBE percentage at constant speeds for group BS.



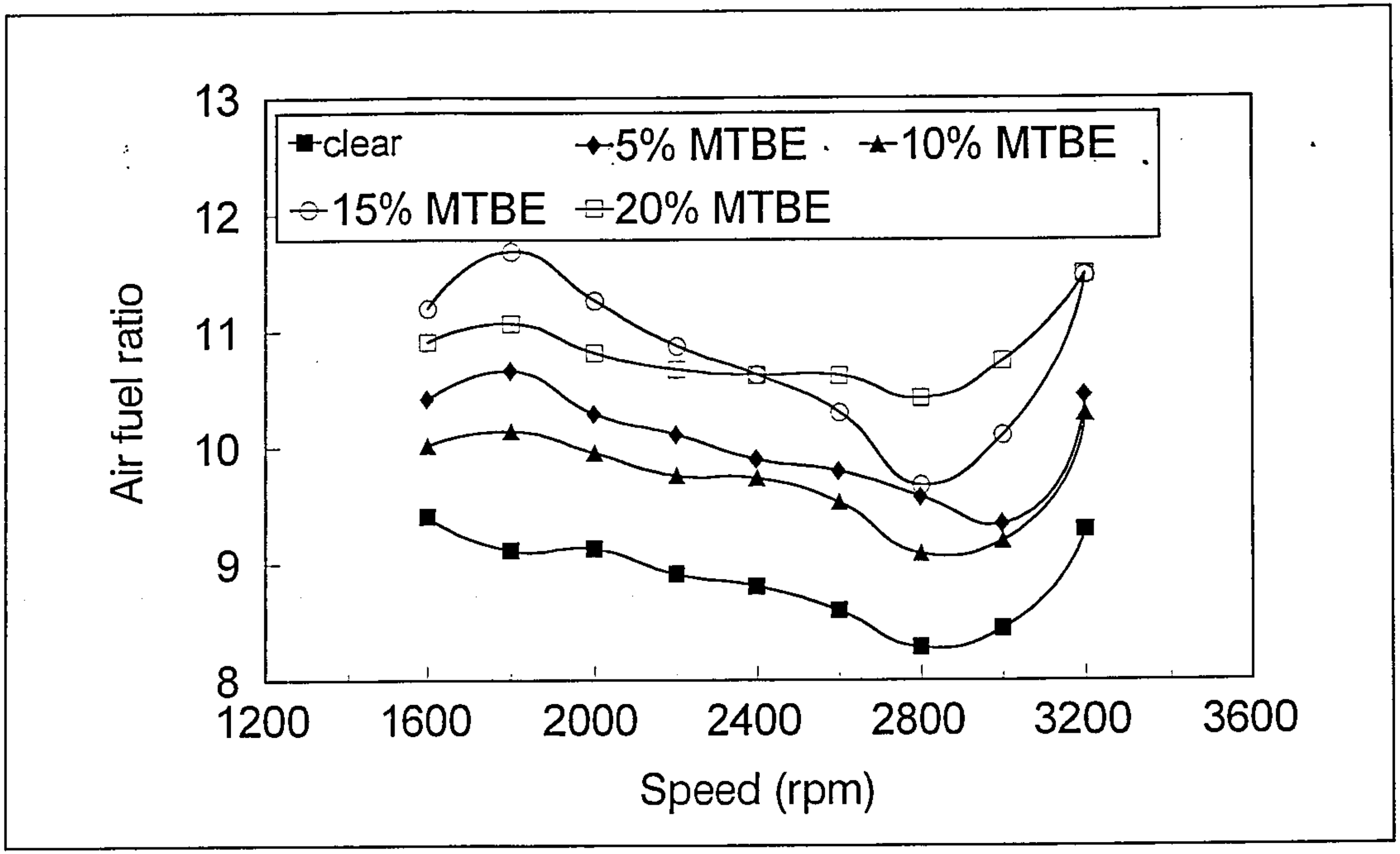
Figure(6.59): Specific fuel consumption (S.F.C) versus speed for group BS.



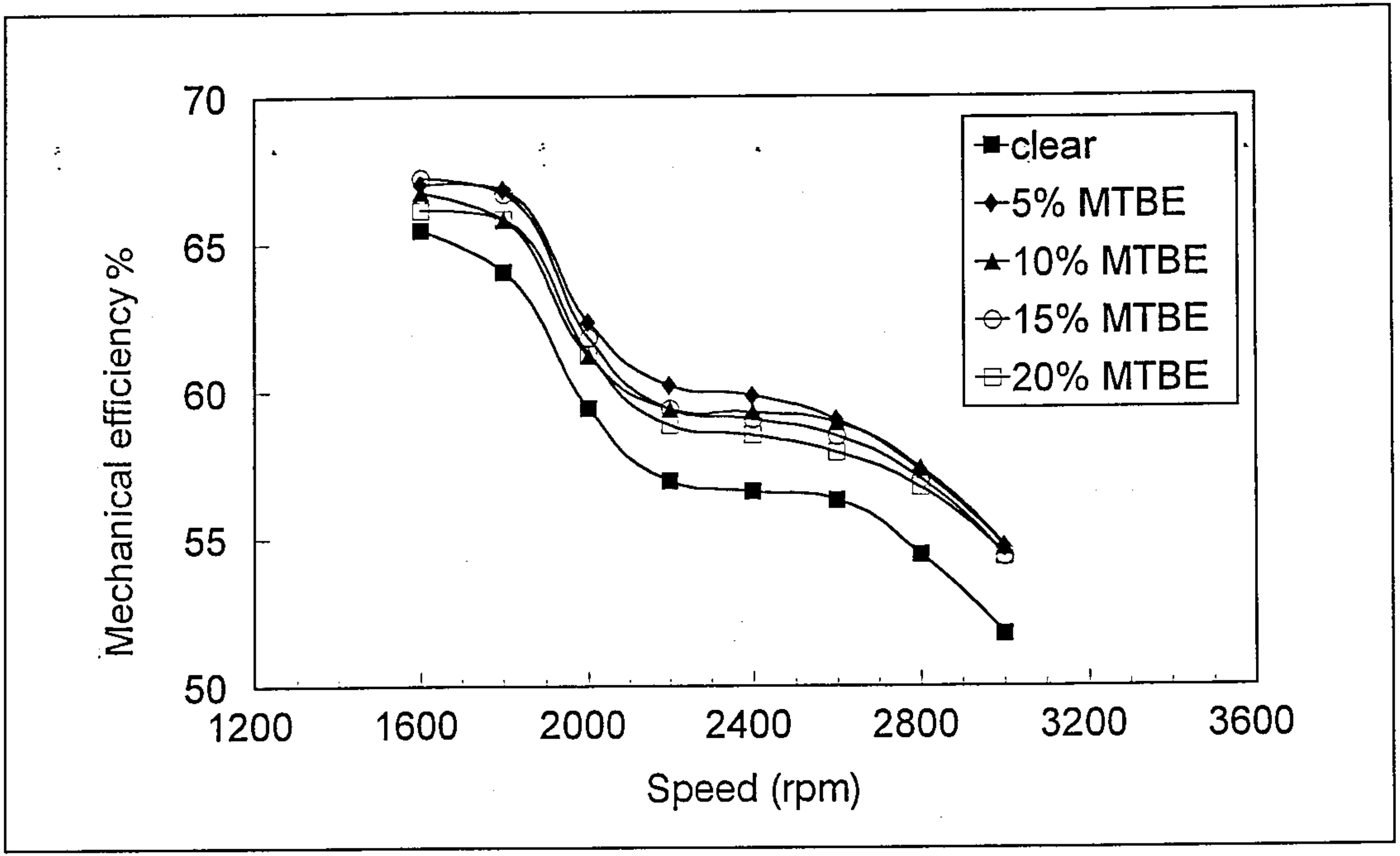
Figure(6.60): Thermal efficiency versus speed for group BS.



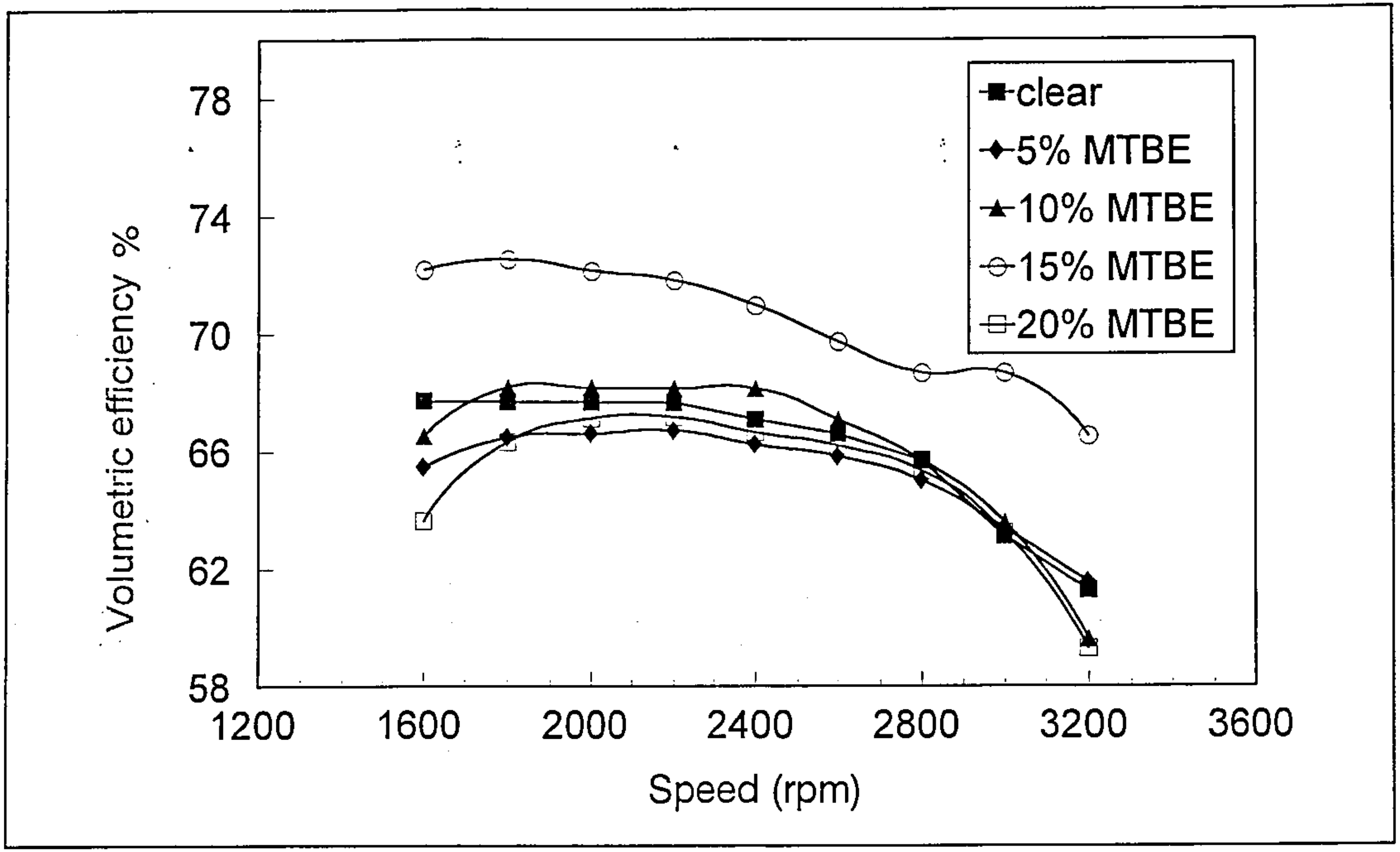
Figure(6.61): Brake thermal efficiency versus speed for group BS.



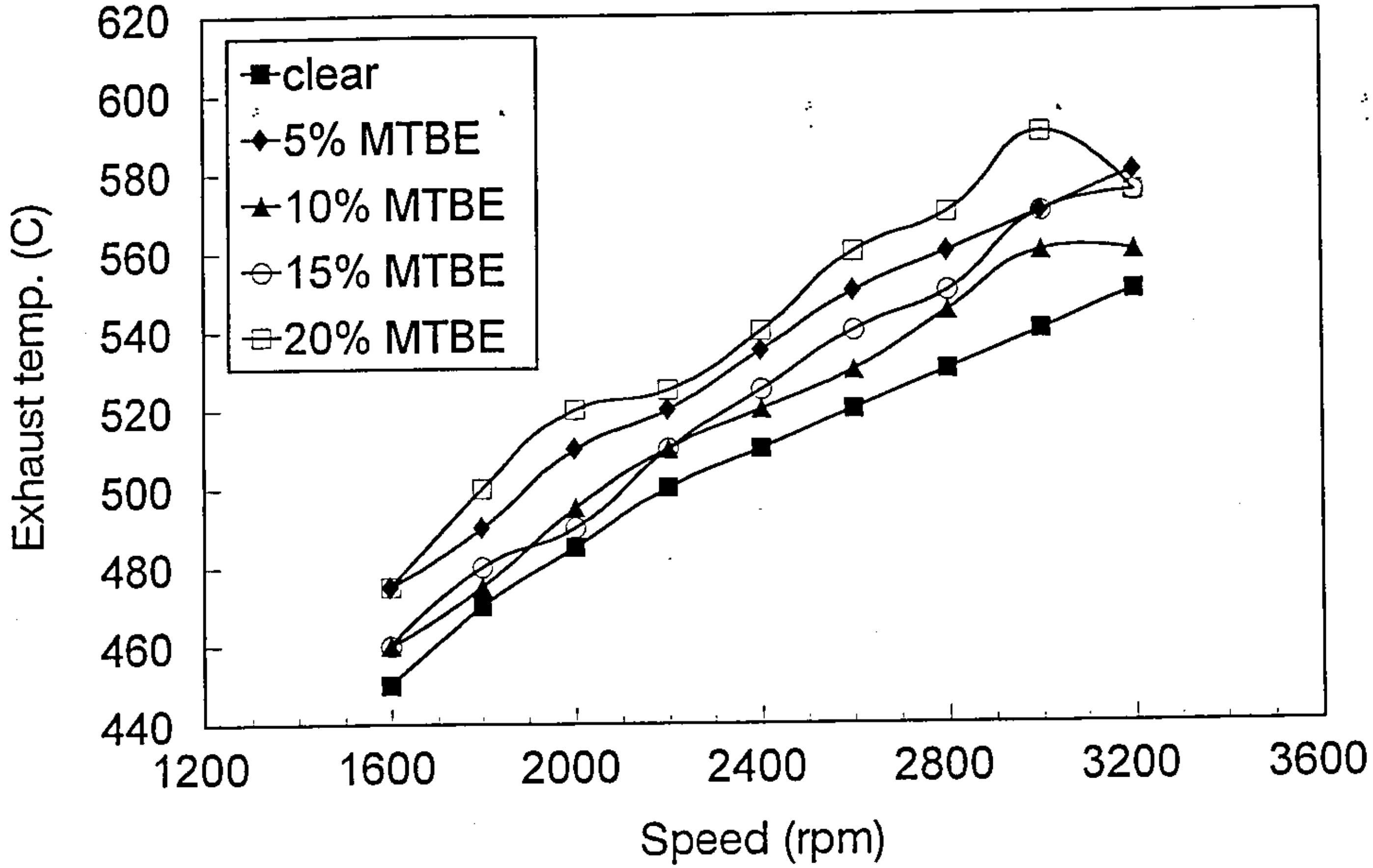
Figure(6.62): Air fuel ratio versus speed for group BS.



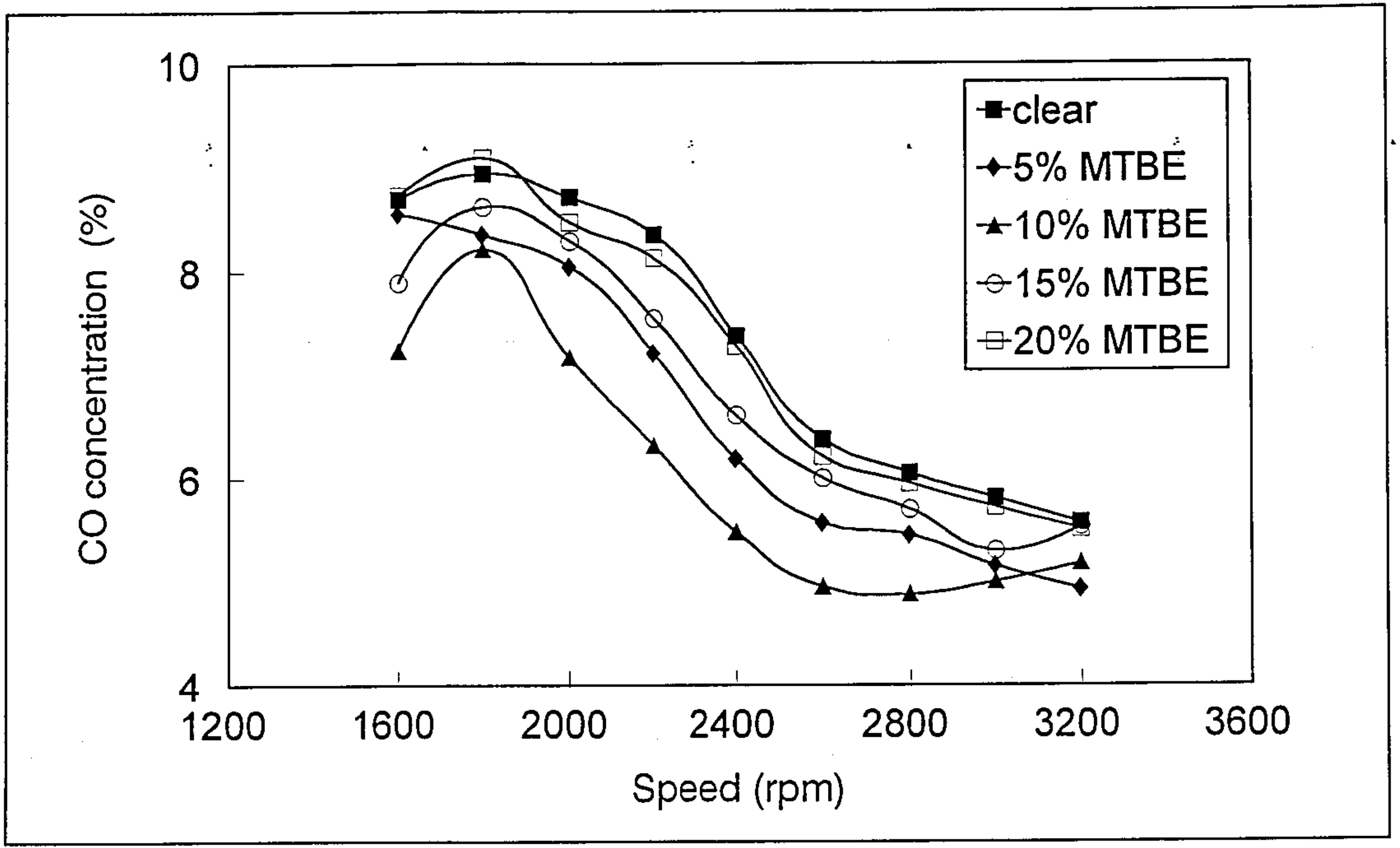
Figure(6.63): Mechanical efficiency versus speed for group BS.



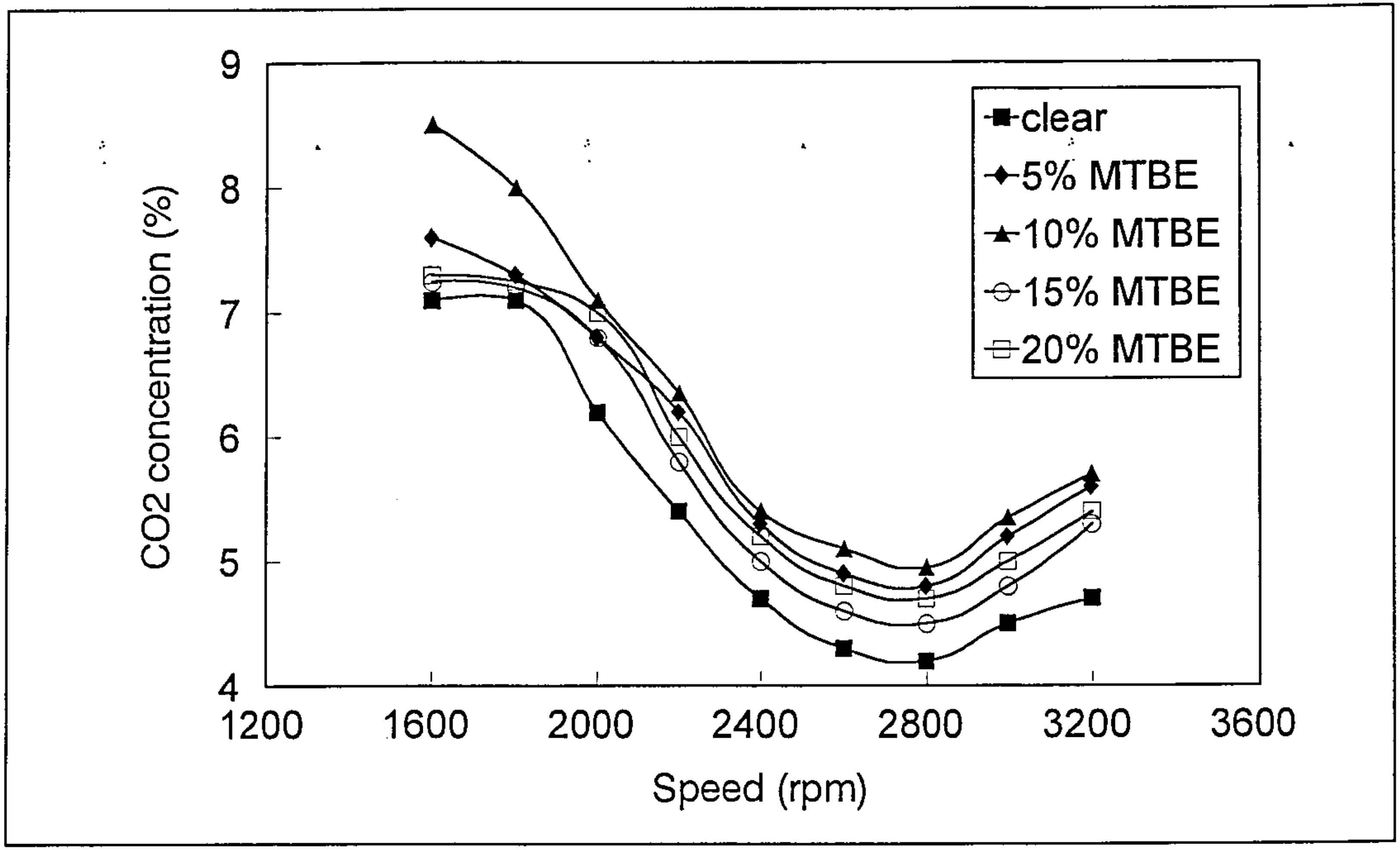
Figure(6.64): Volumetric efficiency versus speed for group BS.



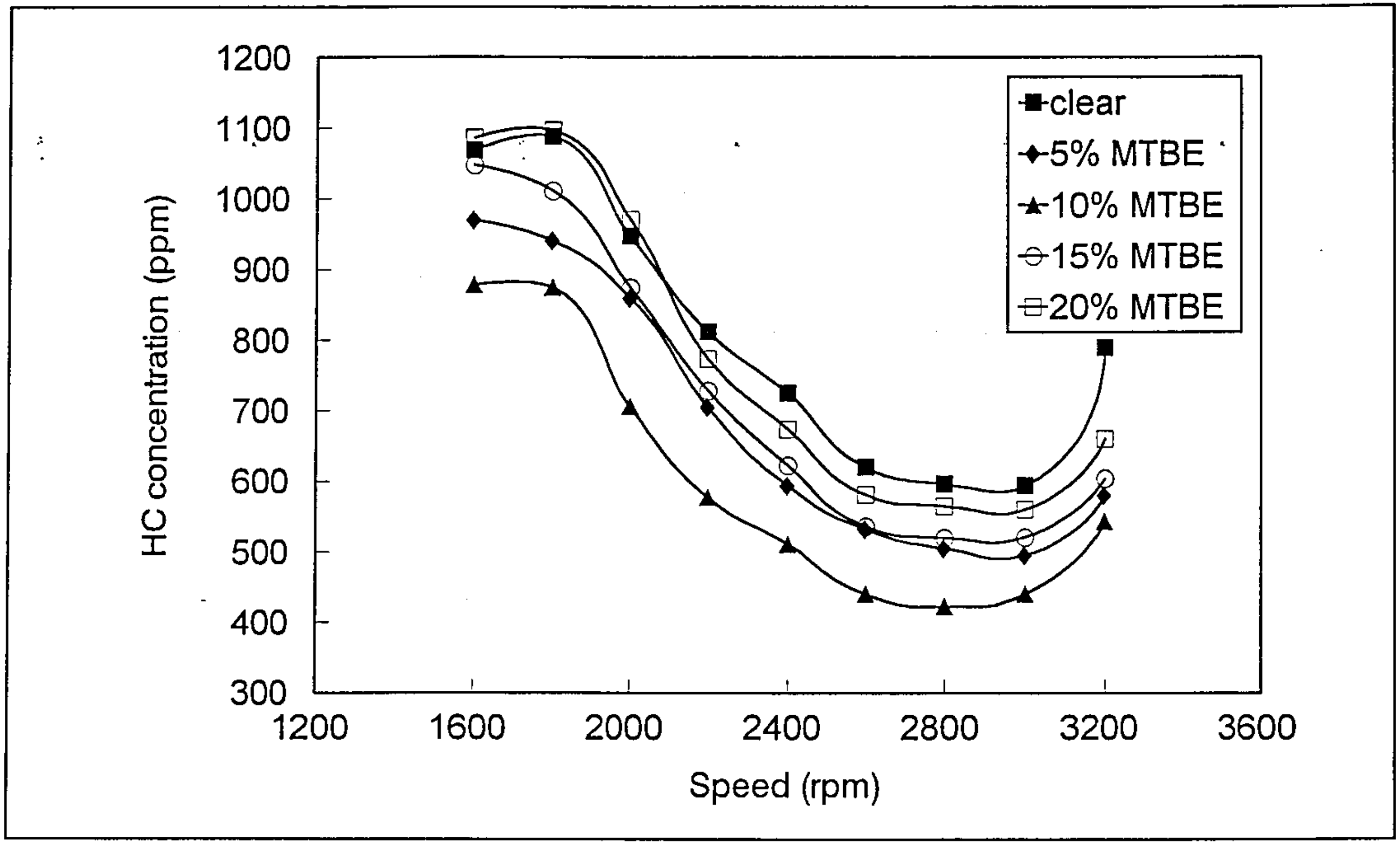
Figure(6.65): Exhaust temperature versus speed for group BS.



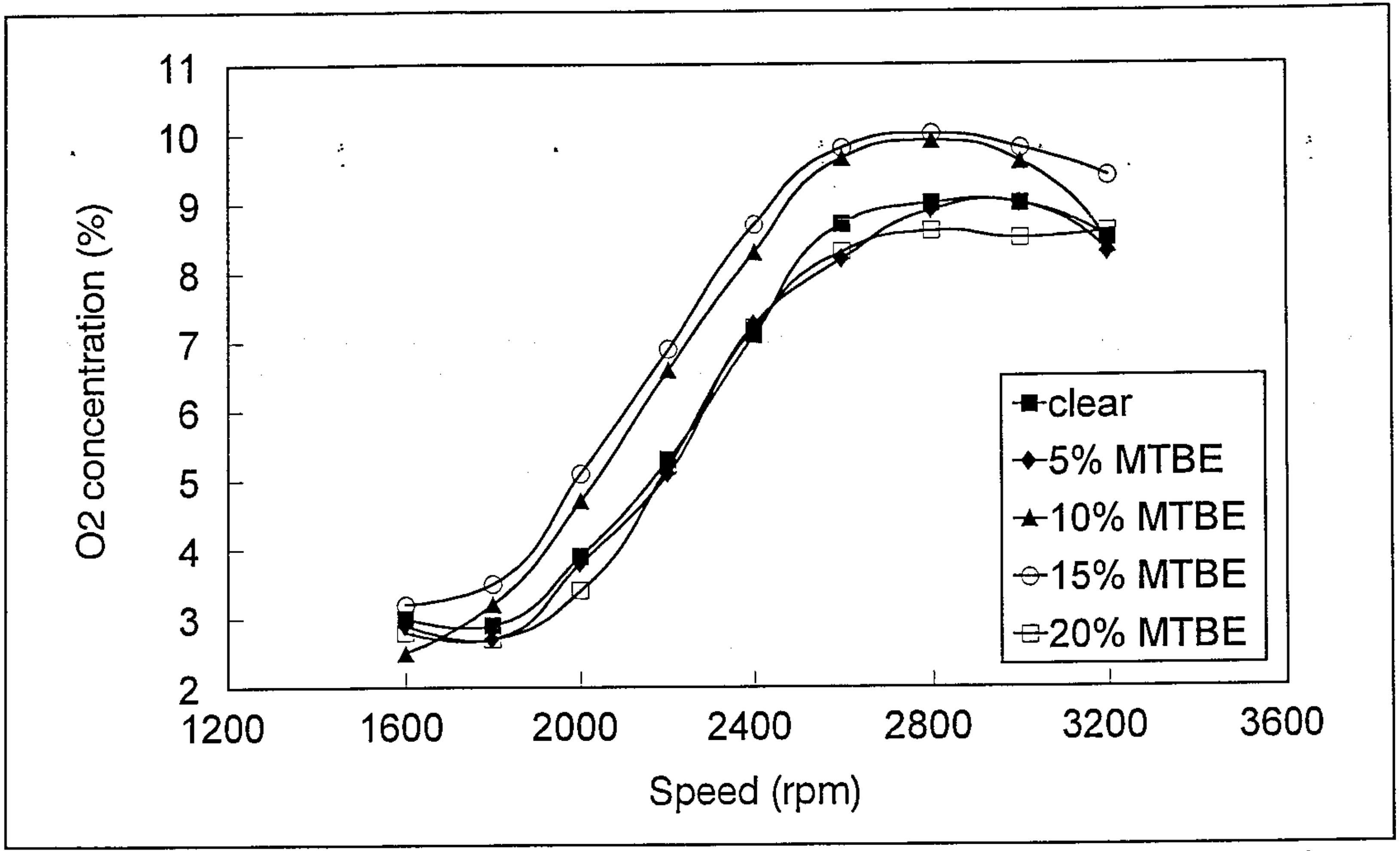
Figure(6.66): Concentration of Carbon monoxide in the exhaust gases for group A



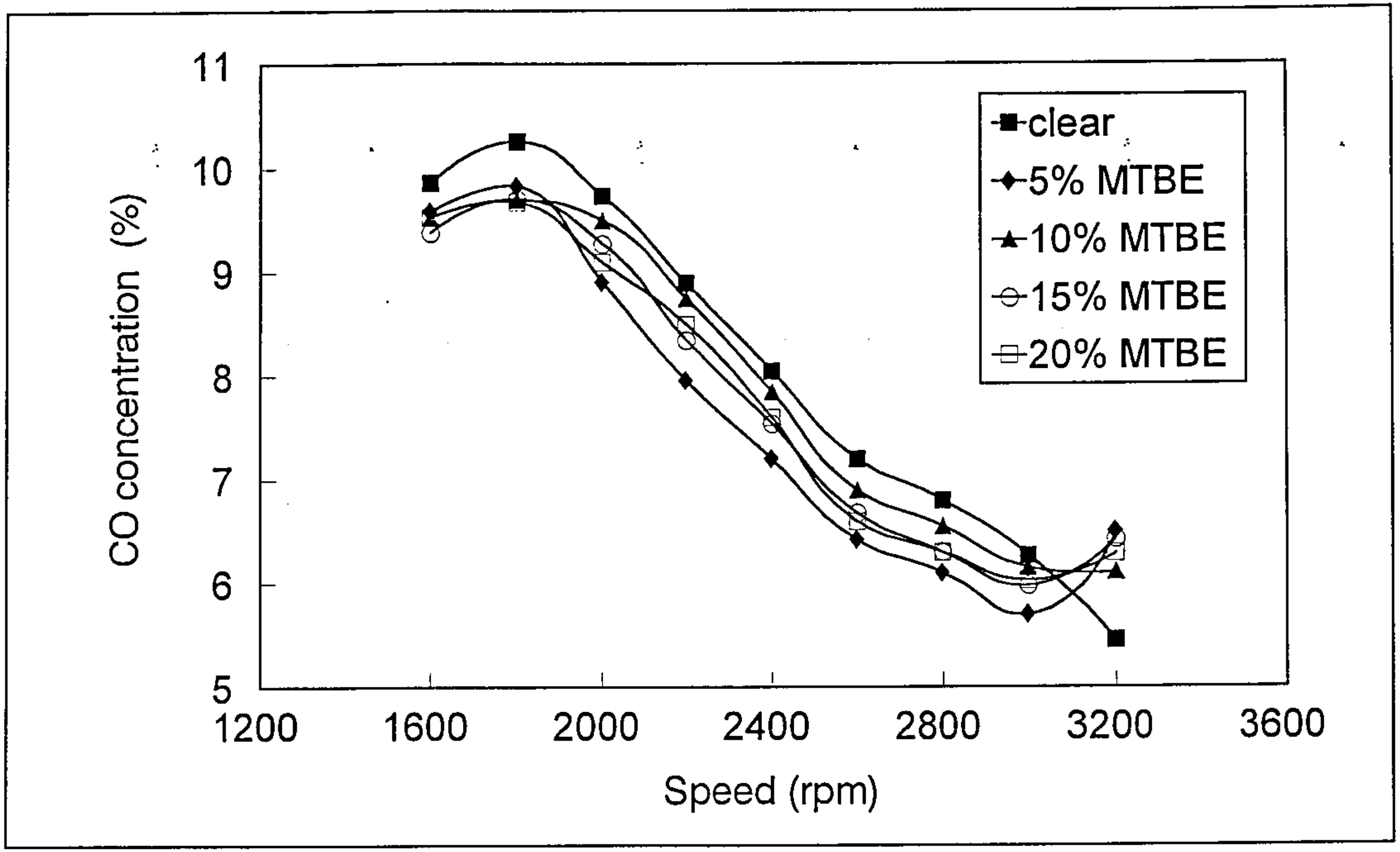
Figure(6.67): Concentration of Carbon dioxide in the exhaust gases for group A



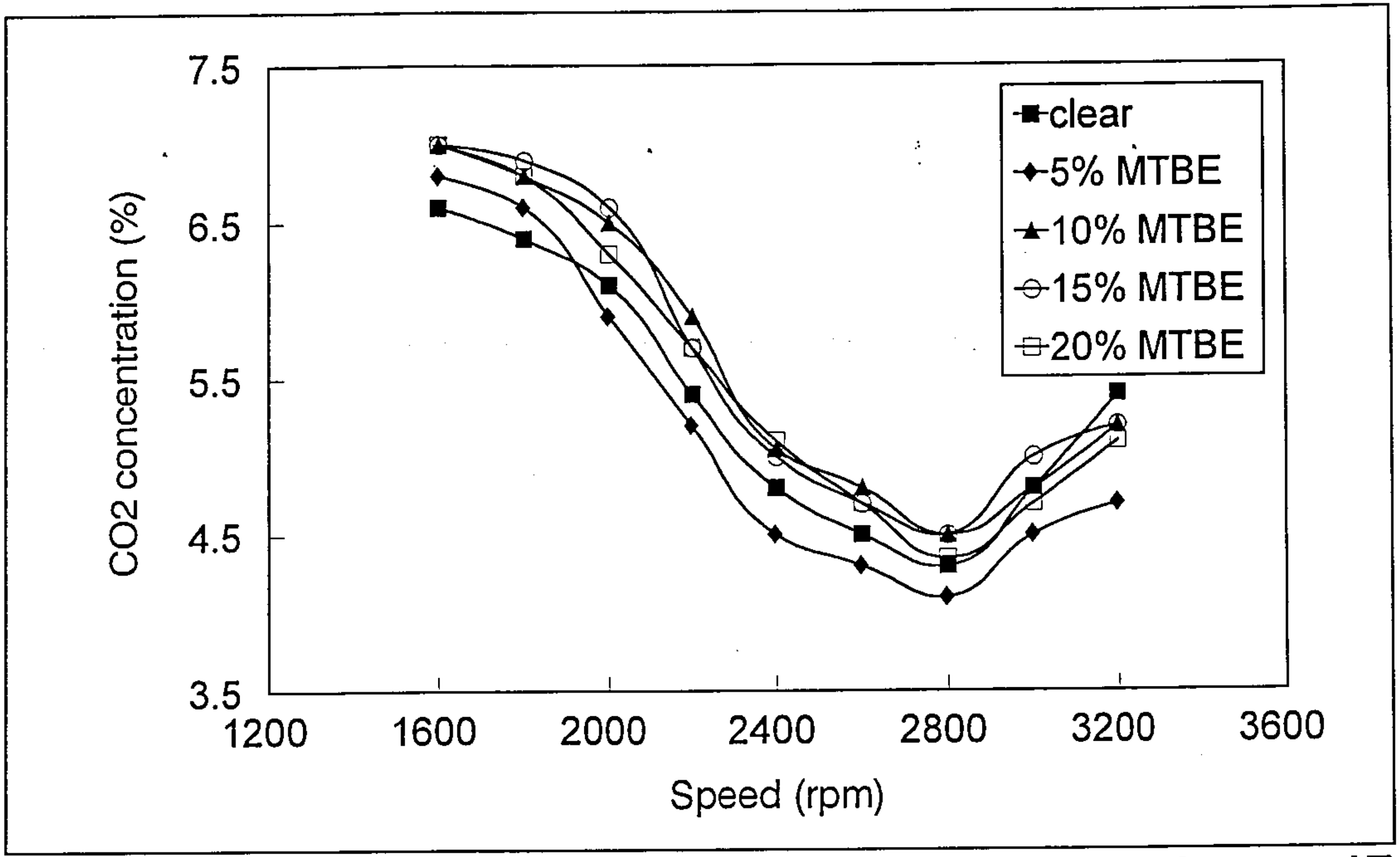
Figure(6.68): Concentration of Hydro-Carbons in the exhaust gases for group A



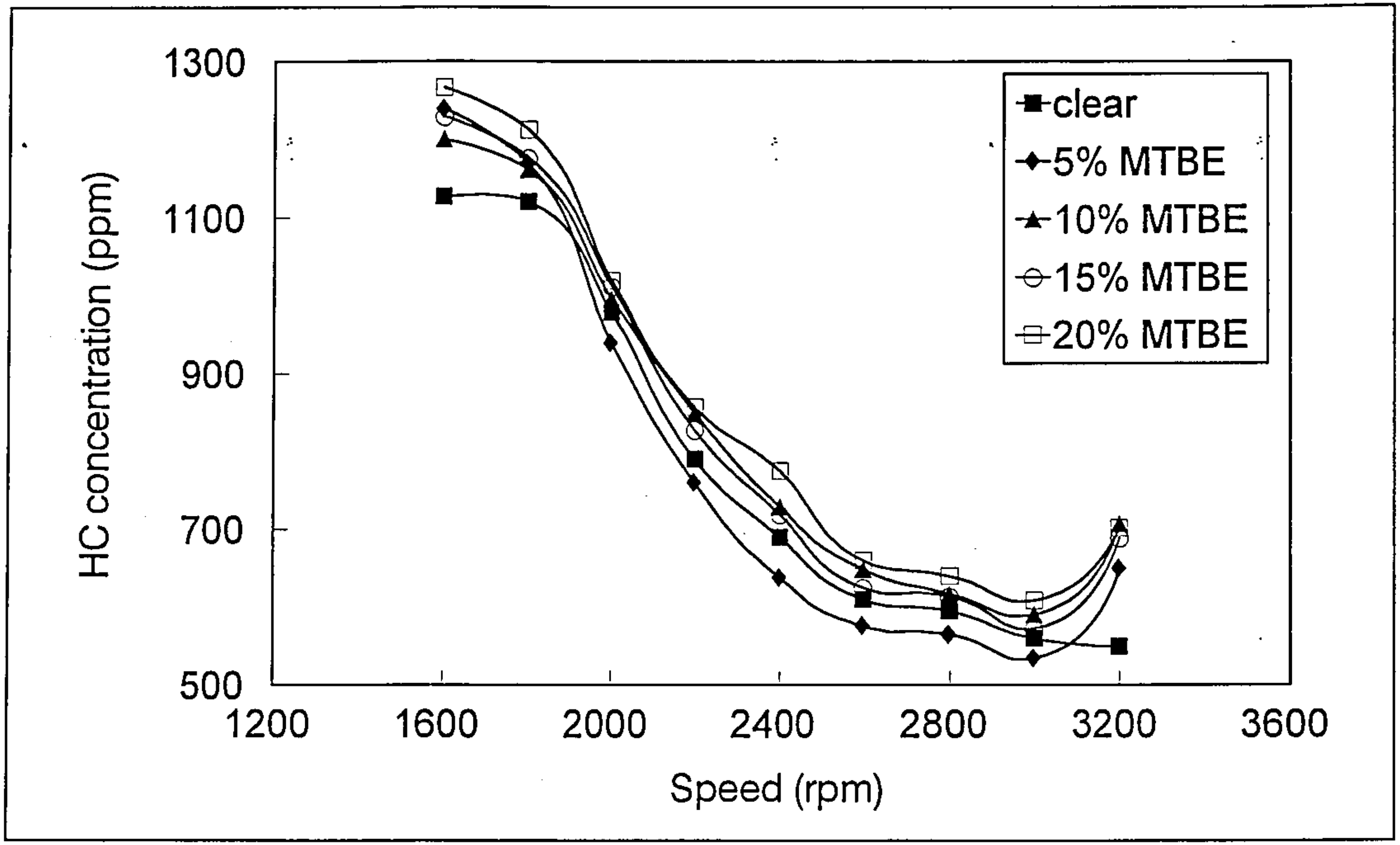
Figure(6.69): Concentration of Oxygen in the exhaust gases for group A



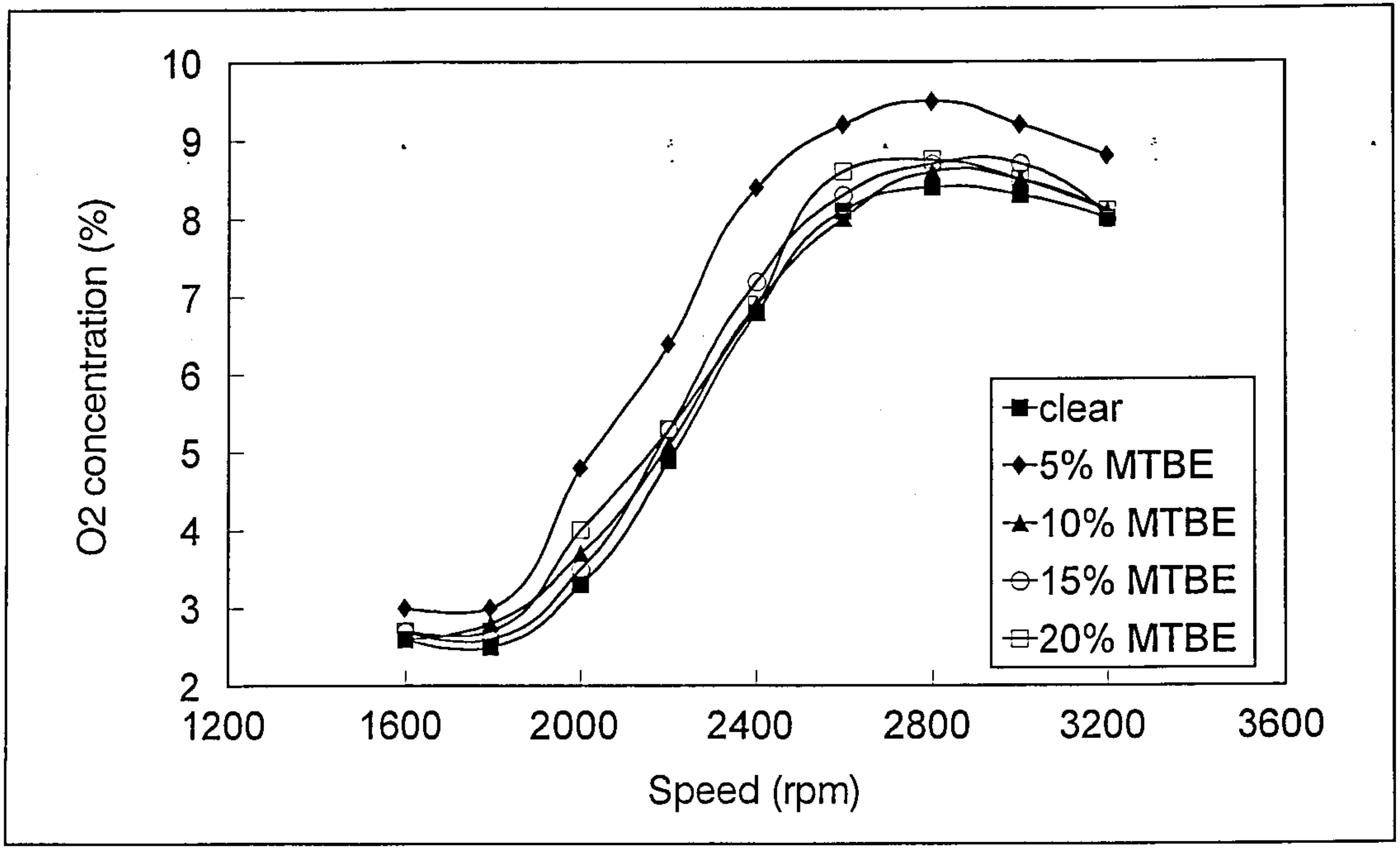
Figure(6.70): Concentration of Carbon monoxide in the exhaust gases for group AT



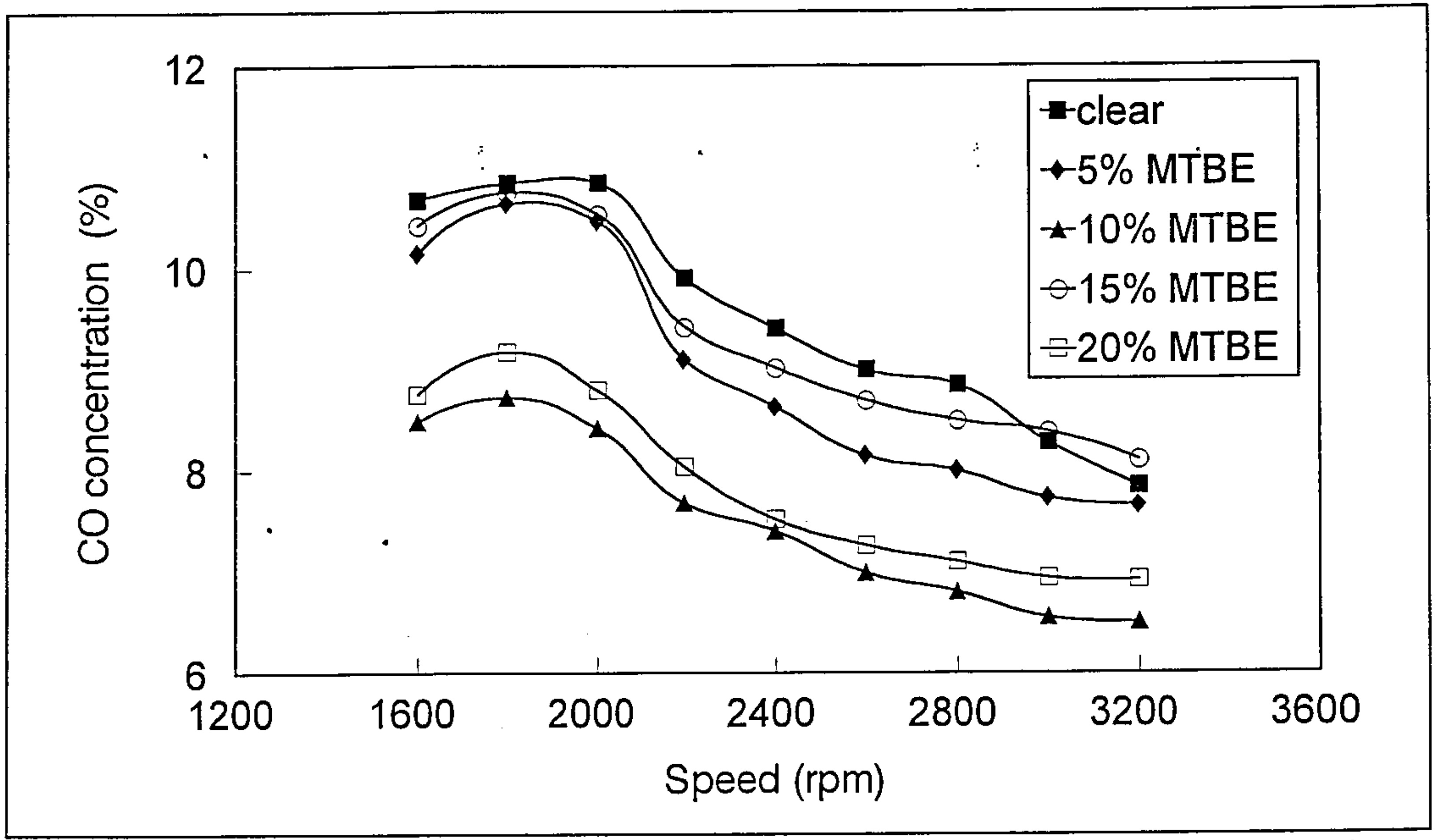
Figure(6.71): Concentration of Carbon dioxide in the exhaust gases for group AT



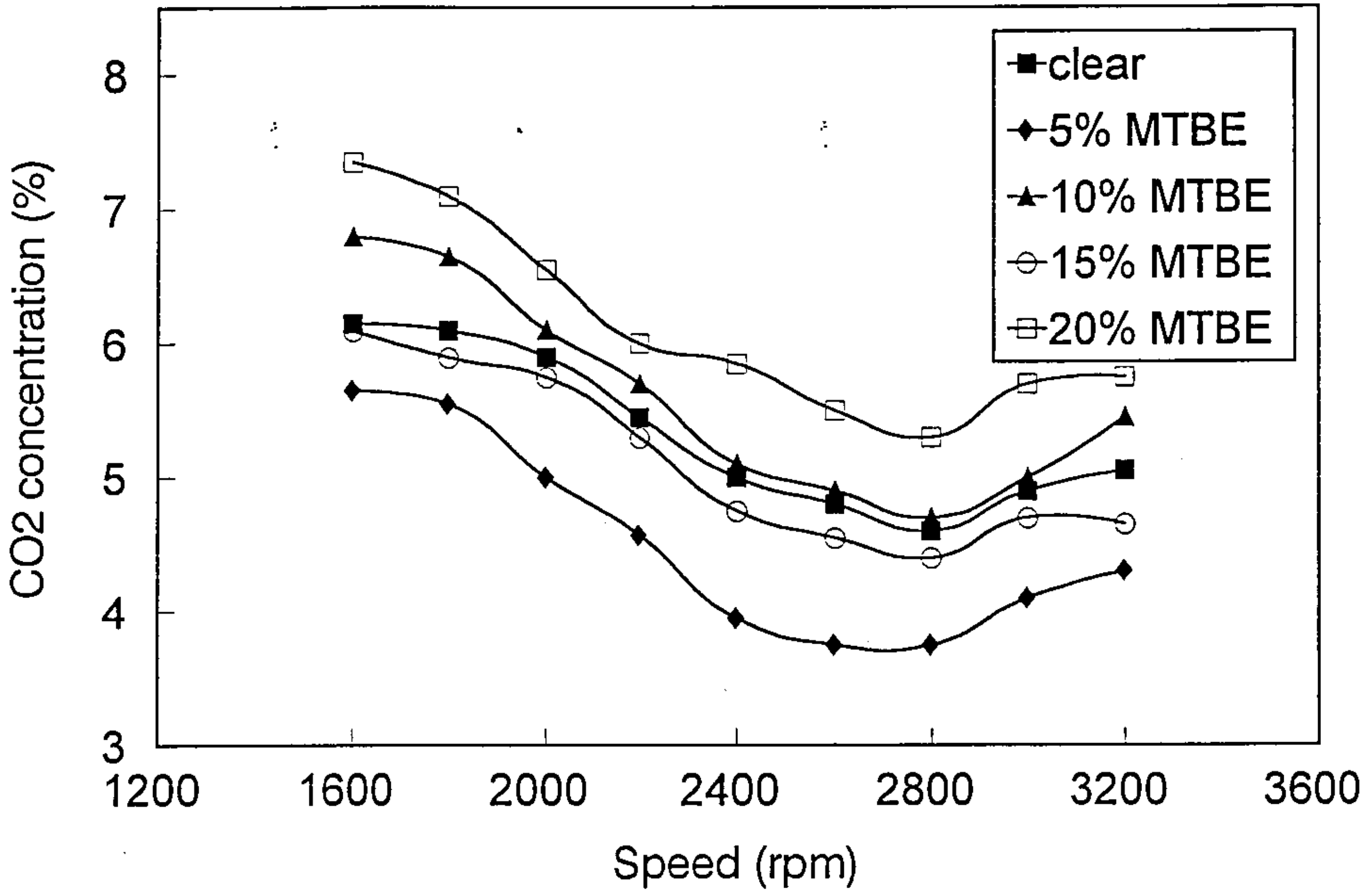
Figure(6.72): Concentration of Hydro-Carbons in the exhaust gases for group AT



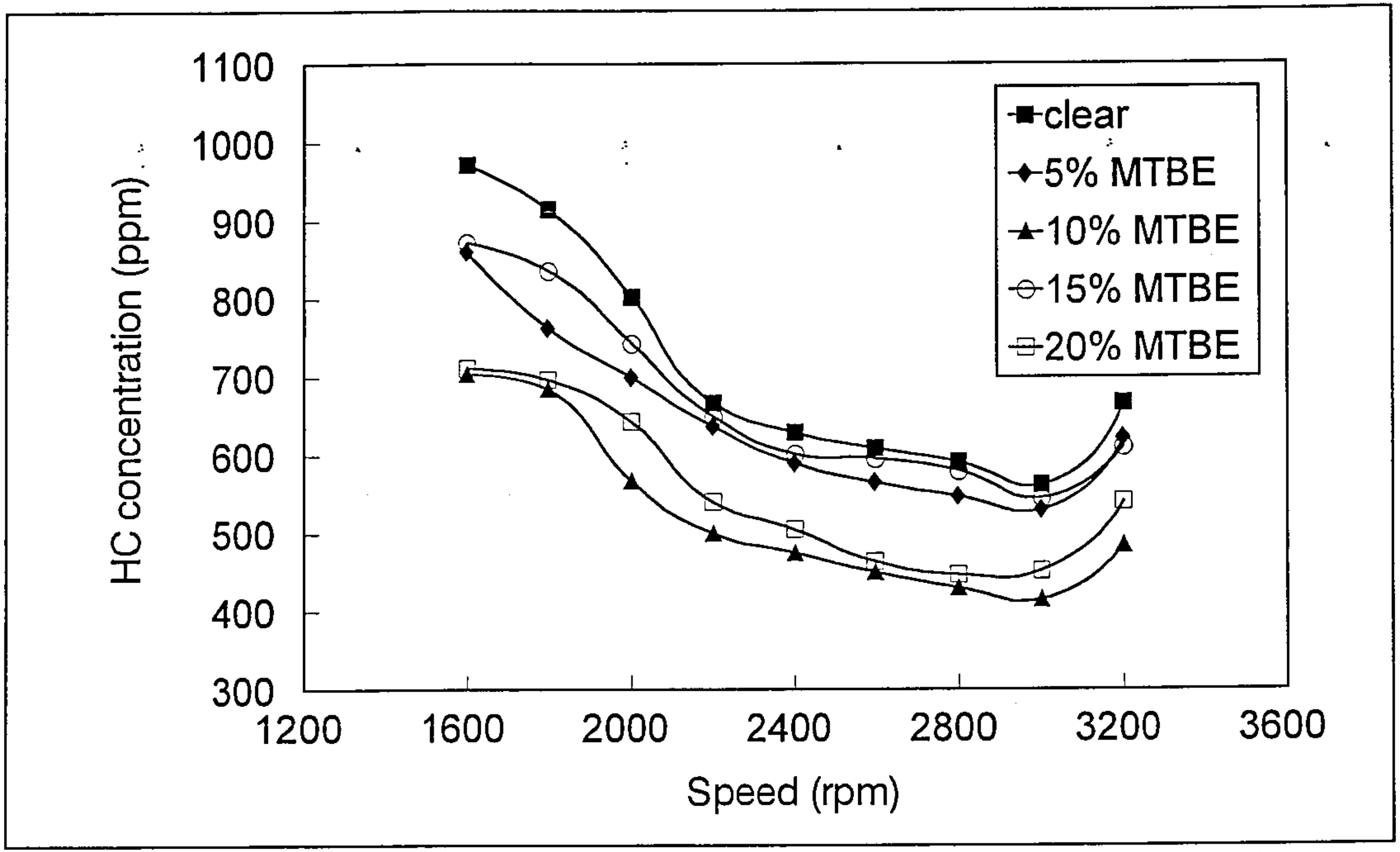
Figure(6.73): Concentration of Oxygen in the exhaust gases for group AT



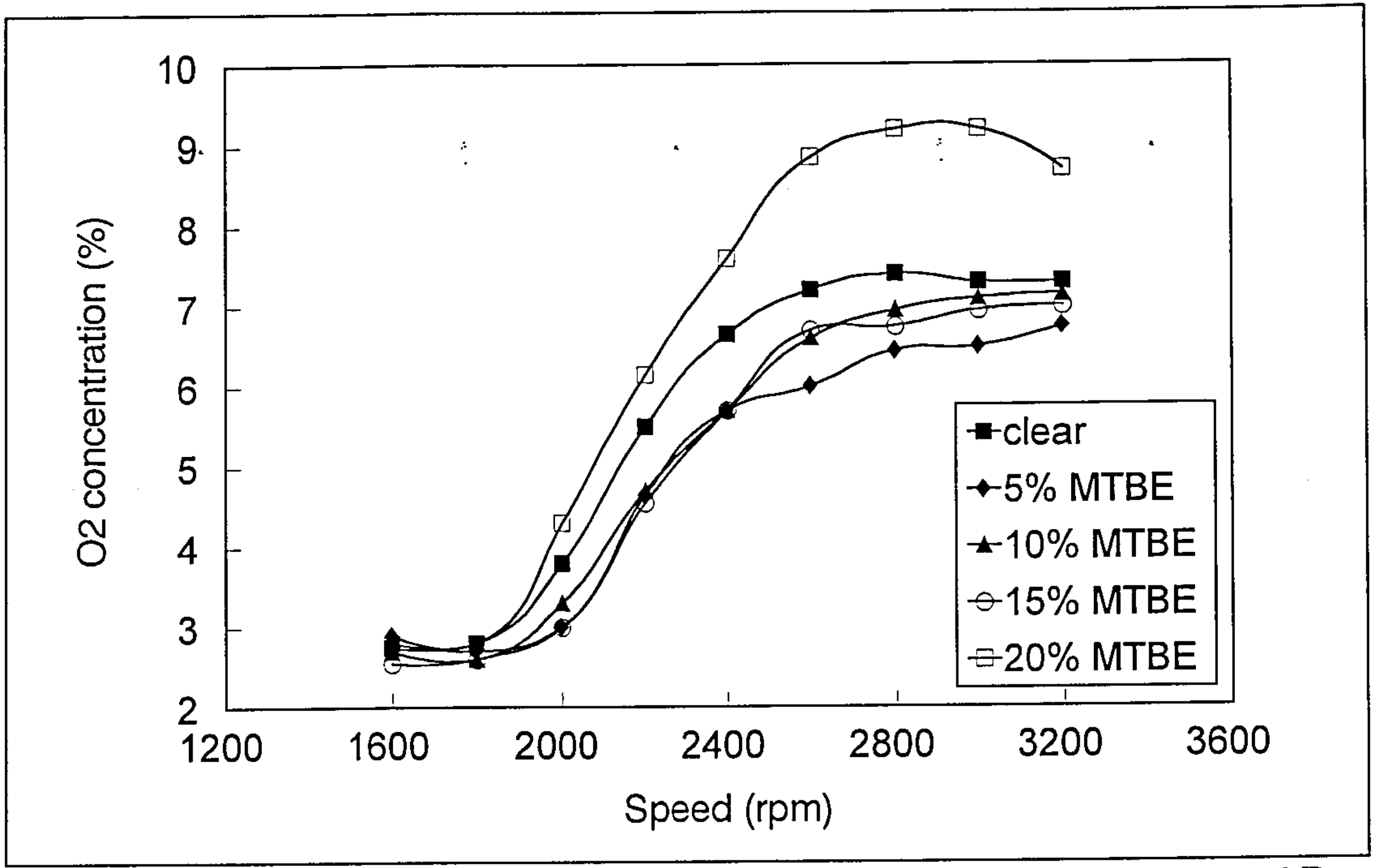
Figure(6.74): Concentration of Carbon monoxide in the exhaust gases for group AR



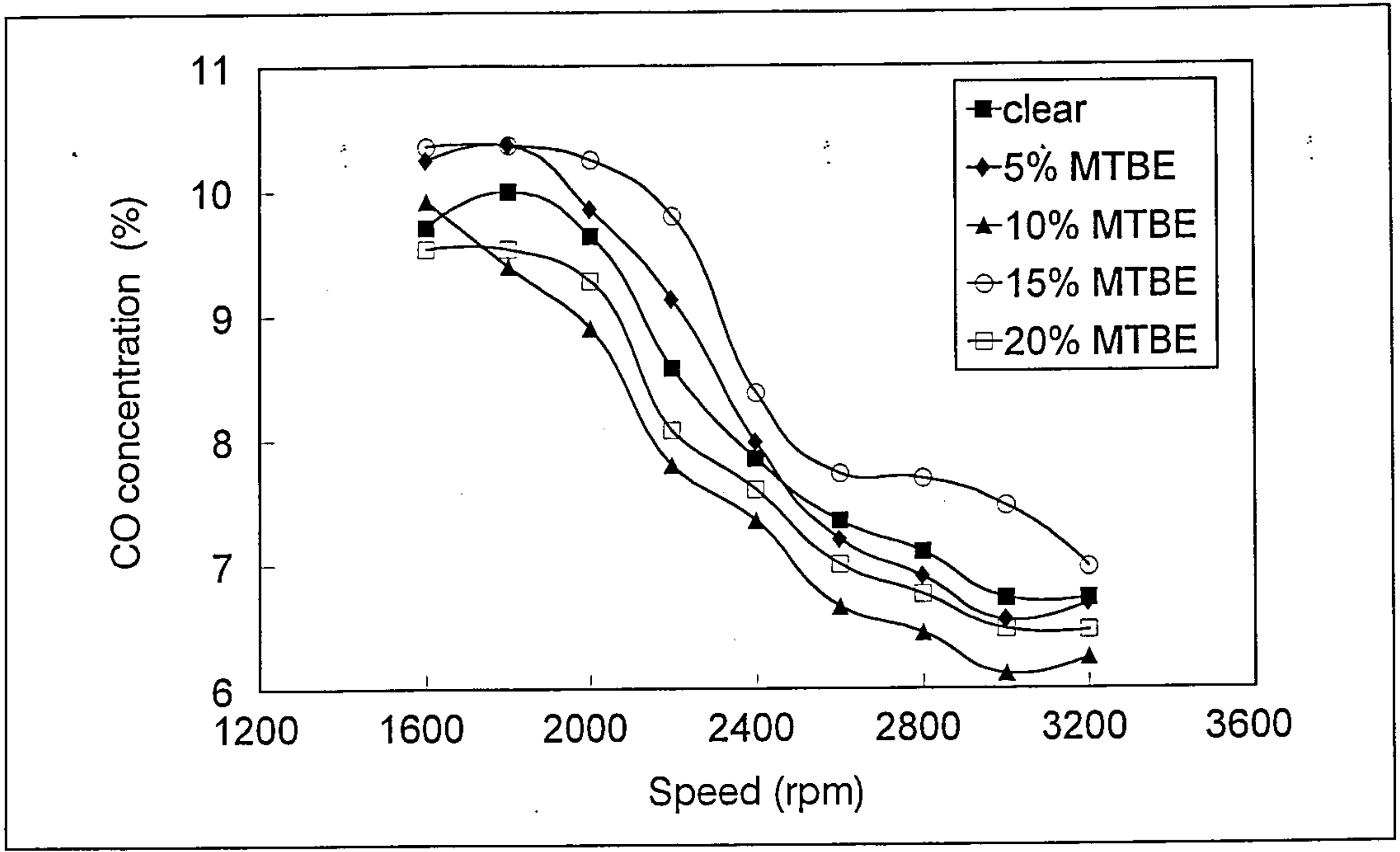
Figure(6.75): Concentration of Carbon dioxide in the exhaust gases for group AR



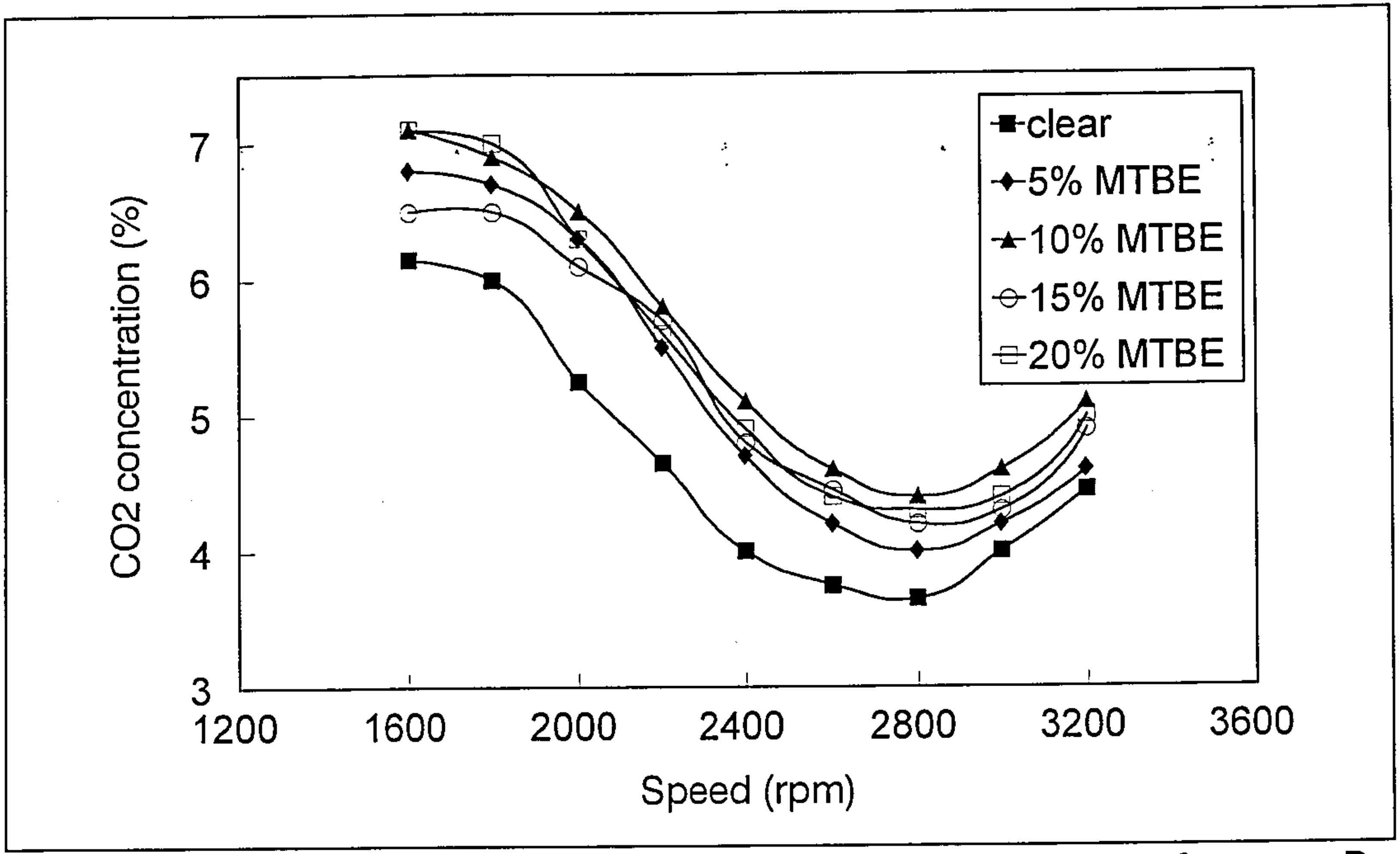
Figure(6.76):Concentration of Hydro-Carbons in the exhaust gases for group AR



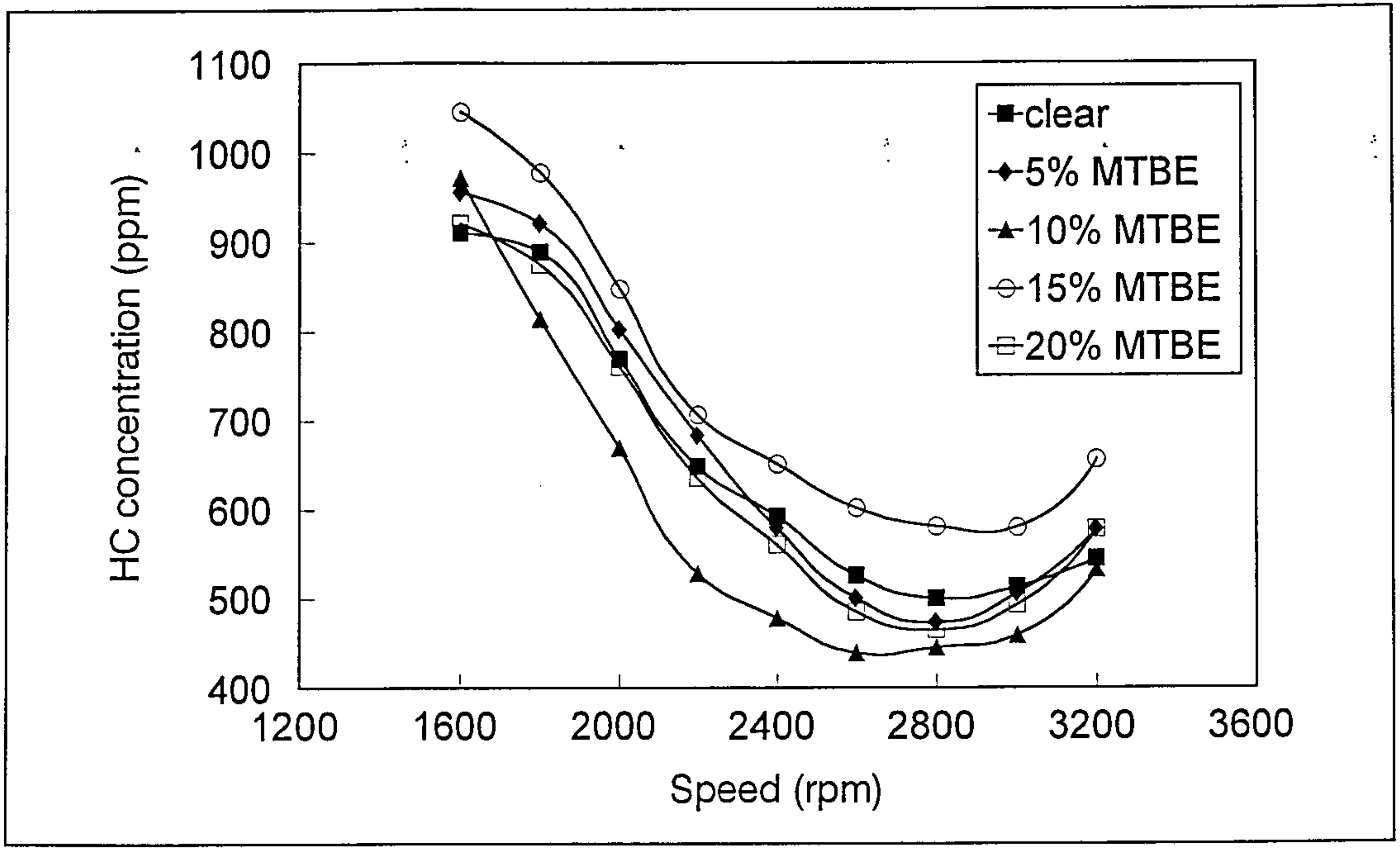
Figure(6.77): Concentration of Oxygen in the exhaust gases for group AR



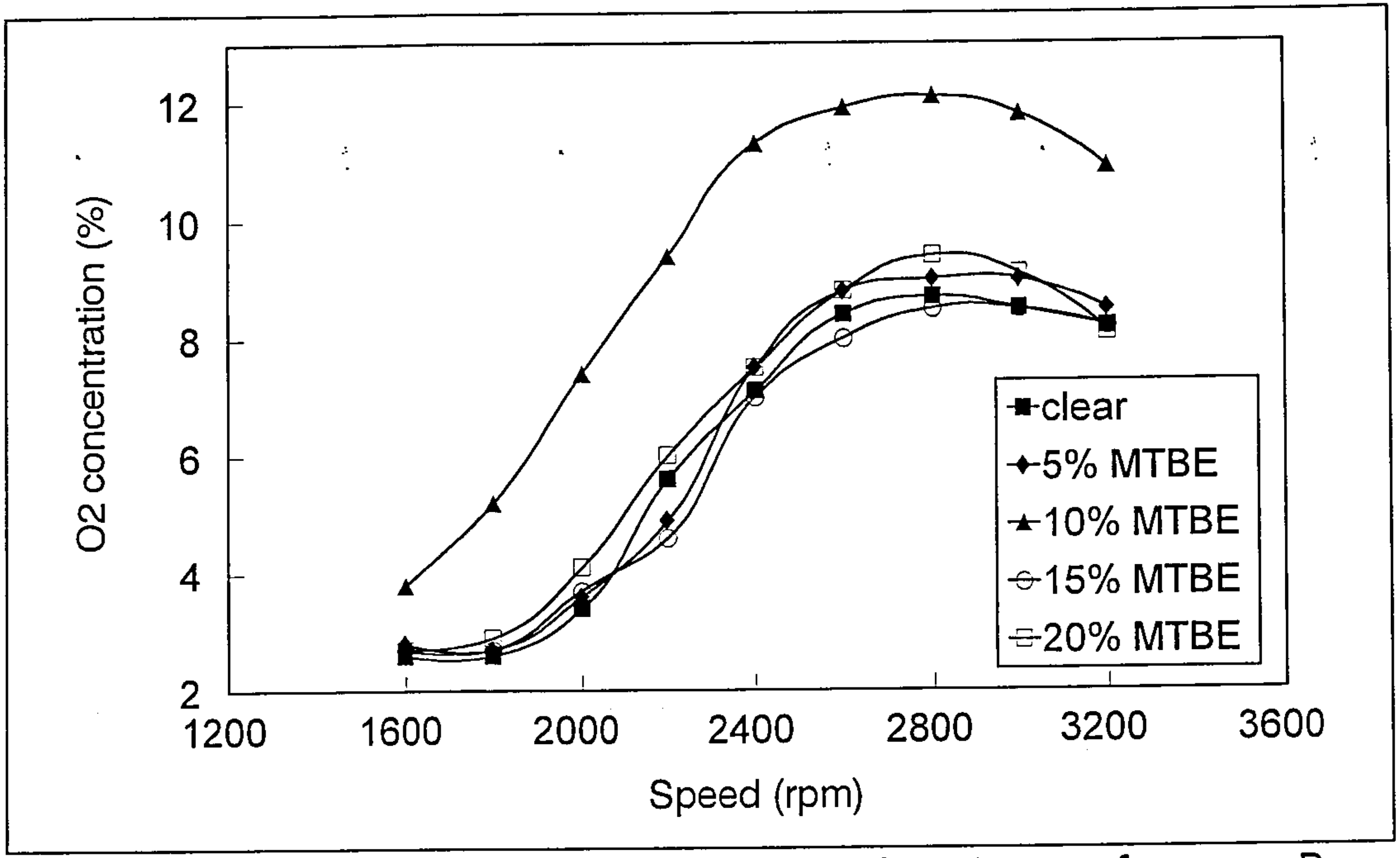
Figure(6.78): Concentration of Carbon monoxide in the exhaust gases for group B



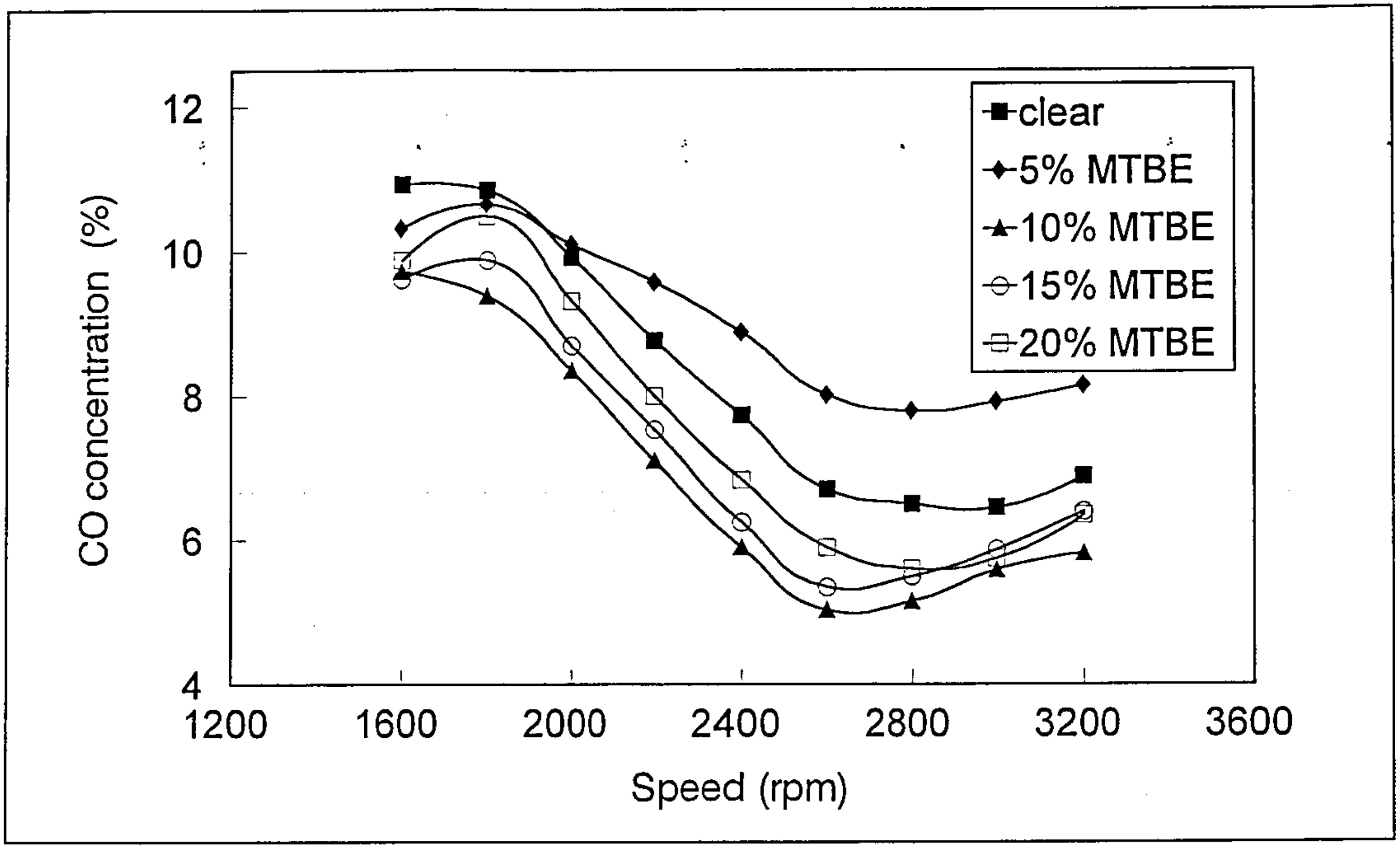
Figure(6.79): Concentration of Carbon dioxide in the exhaust gases for group B



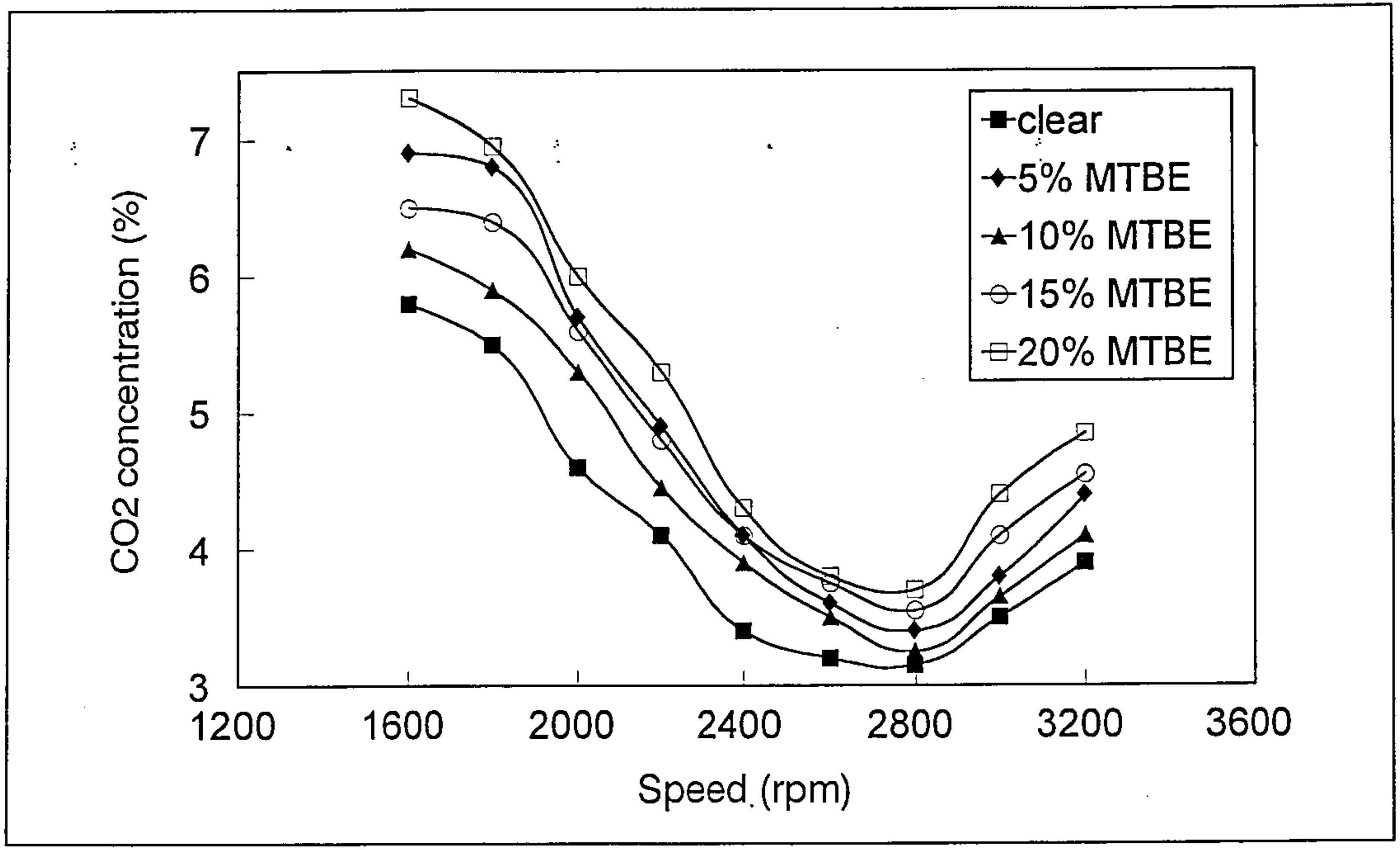
Figure(6.80):Concentration of Hydro-Carbons in the exhaust gases for group B



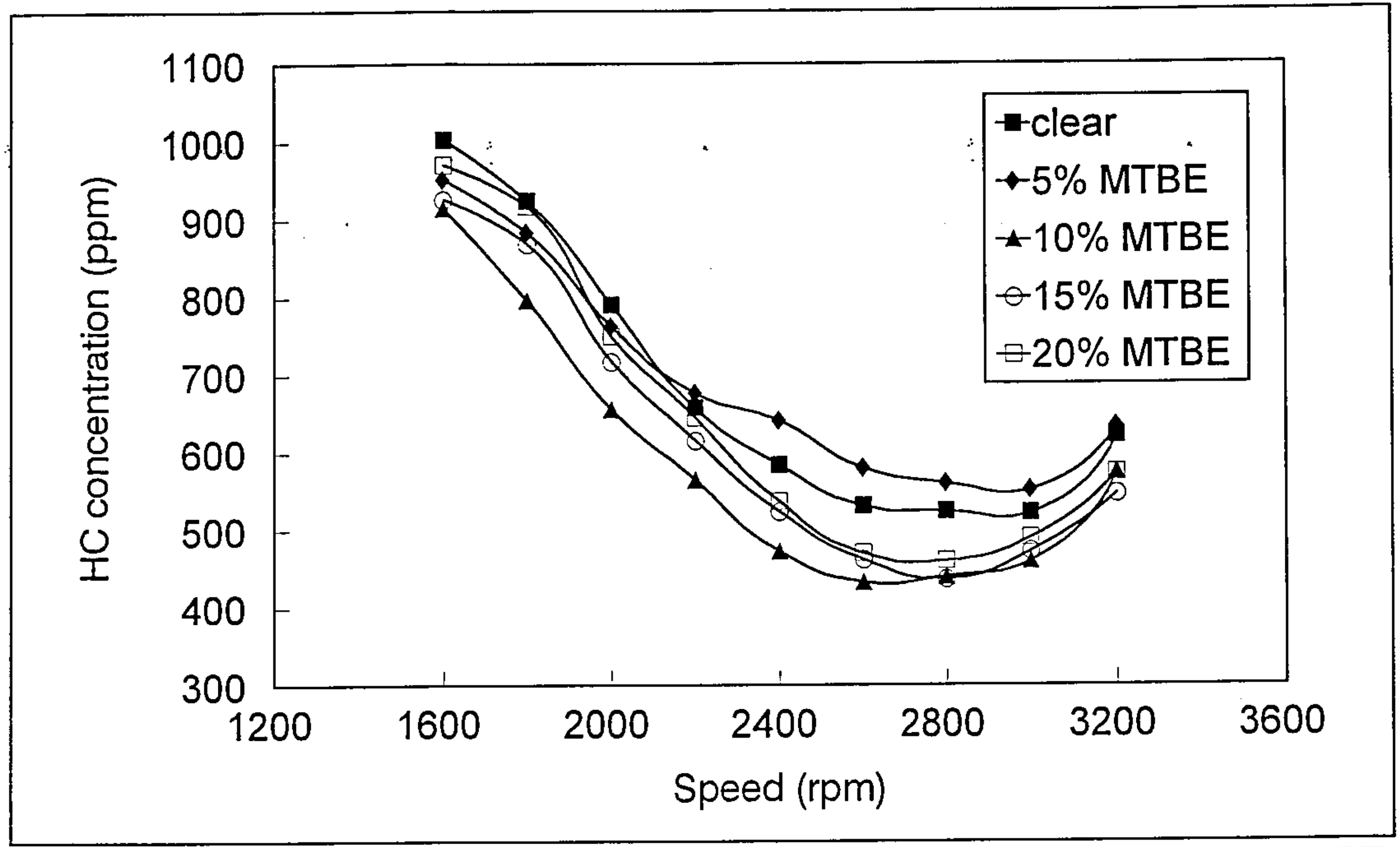
Figure(6.81): Concentration of Oxygen in the exhaust gases for group B



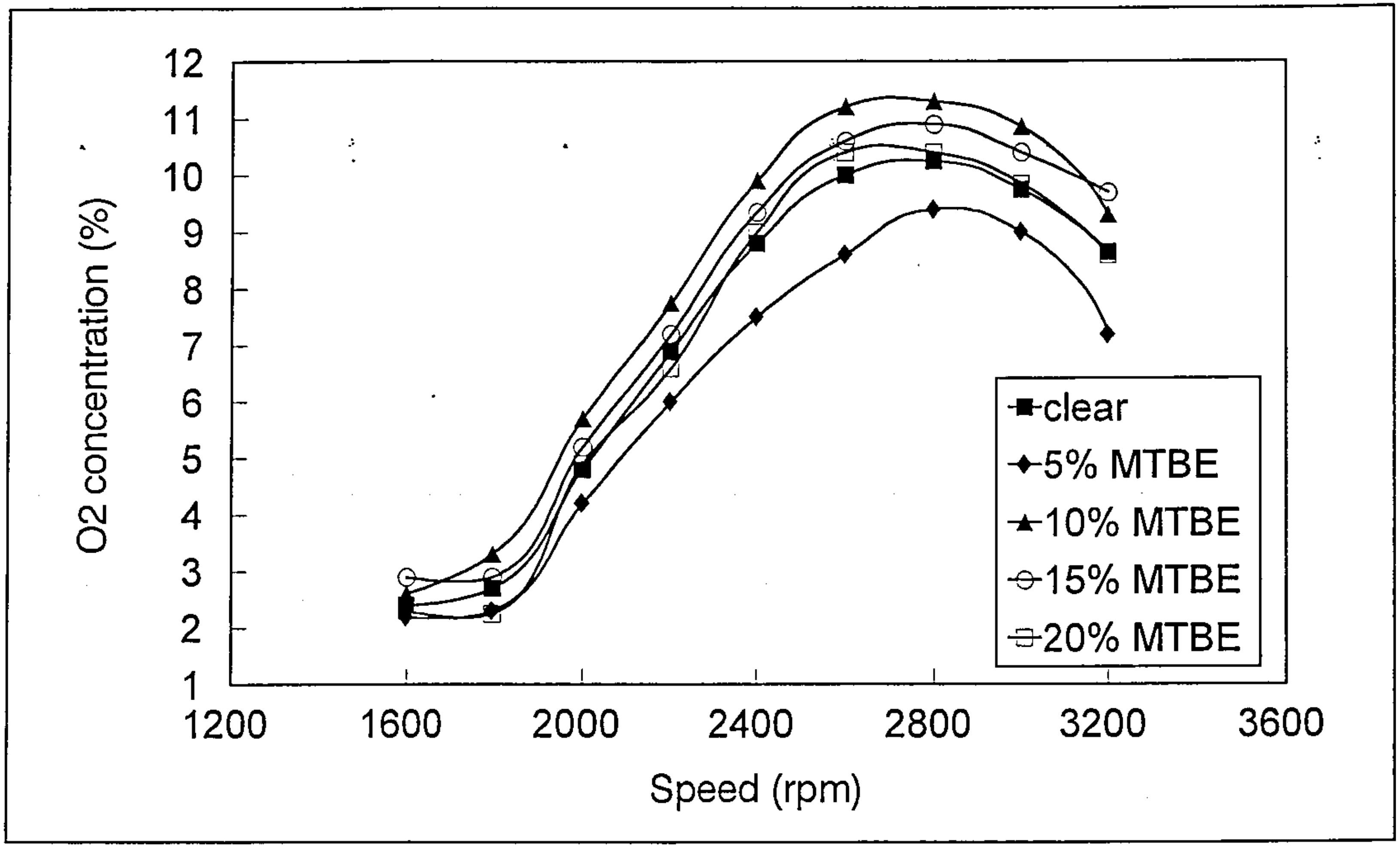
Figure(6.82): Concentration of Carbon monoxide in the exhaust gases for group BT



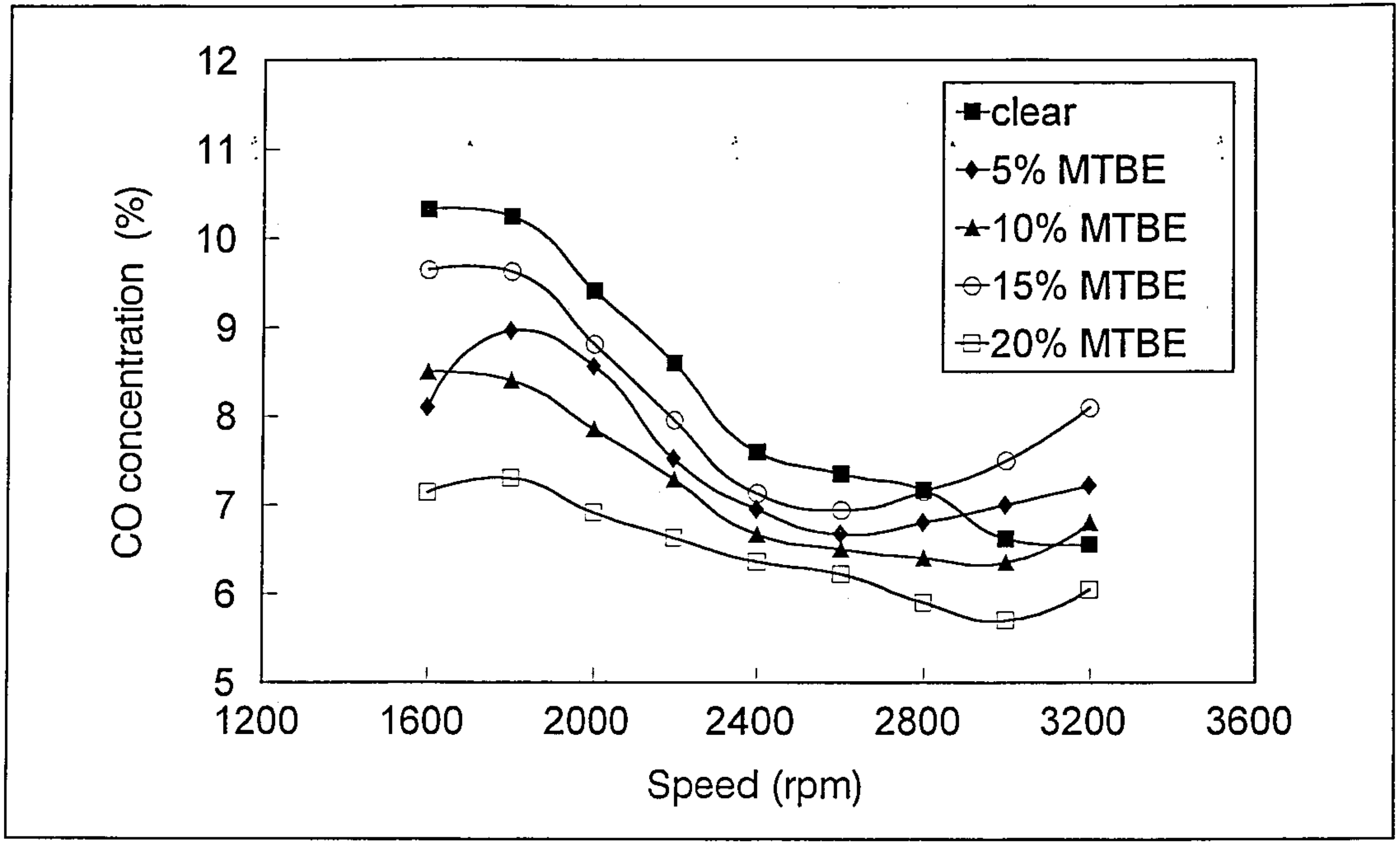
Figure(6.83): Concentration of Carbon dioxide in the exhaust gases for group BT



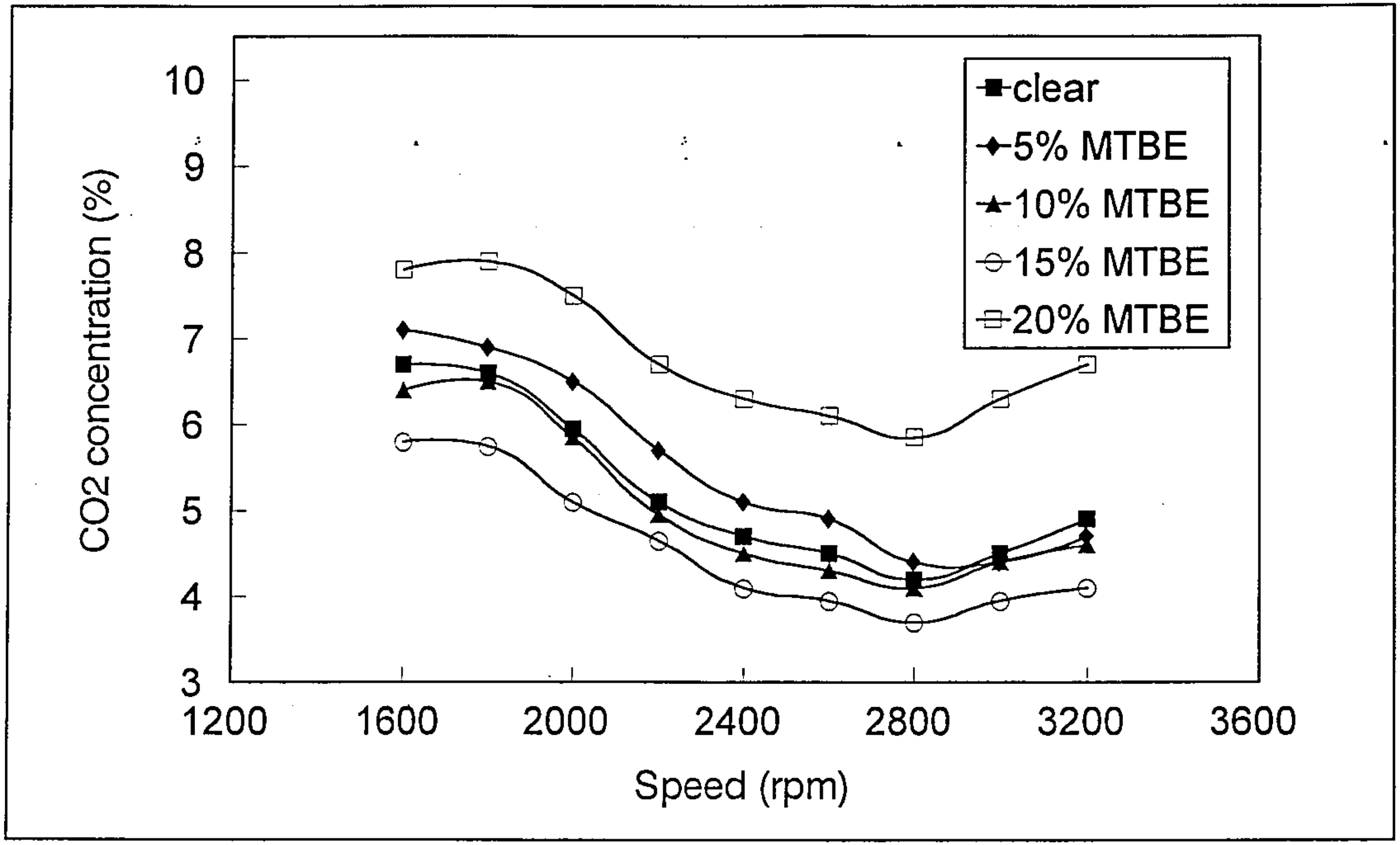
Figure(6.84):Concentration of Hydro-Carbons in the exhaust gases for group BT



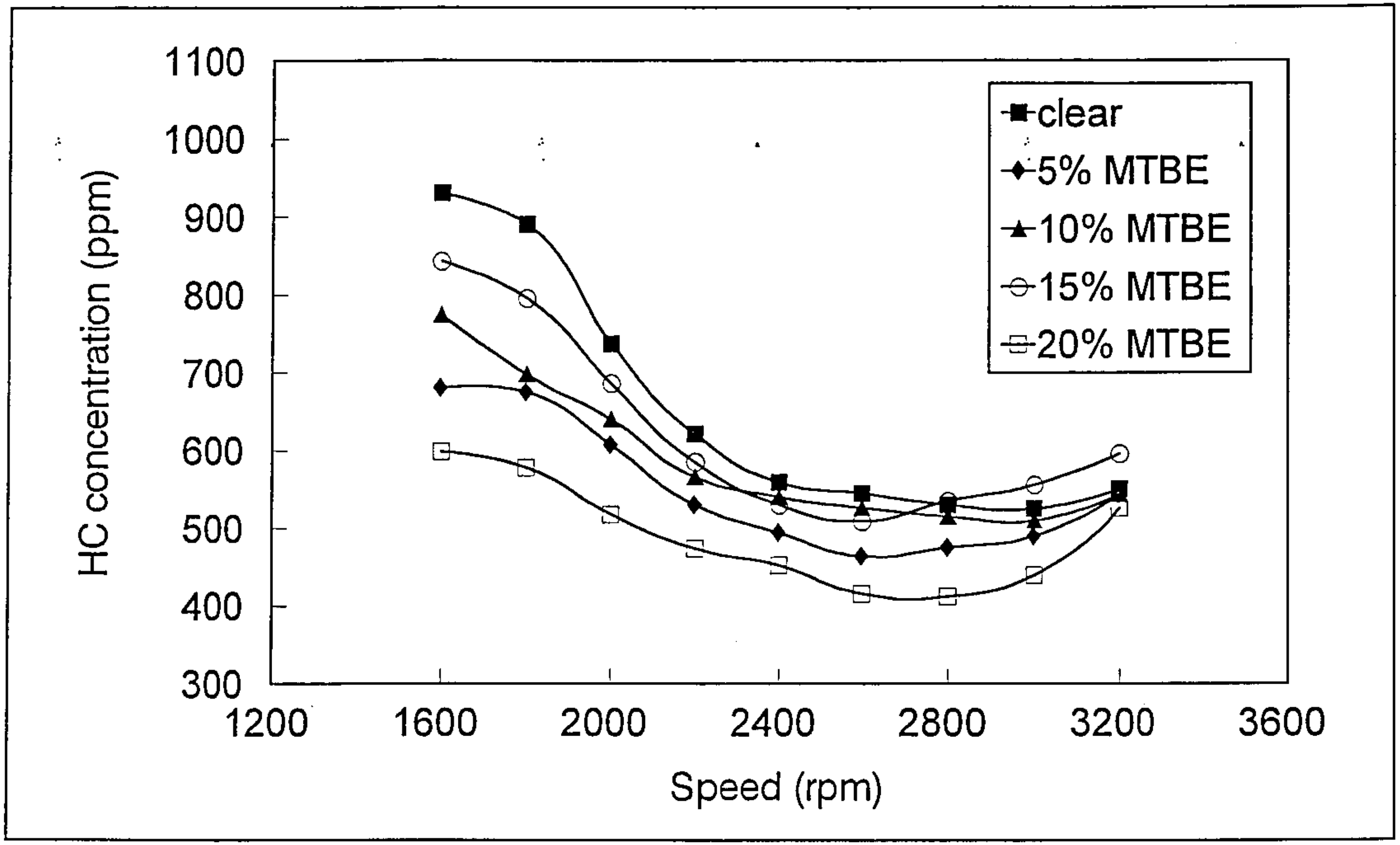
Figure(6.85): Concentration of Oxygen in the exhaust gases for group BT



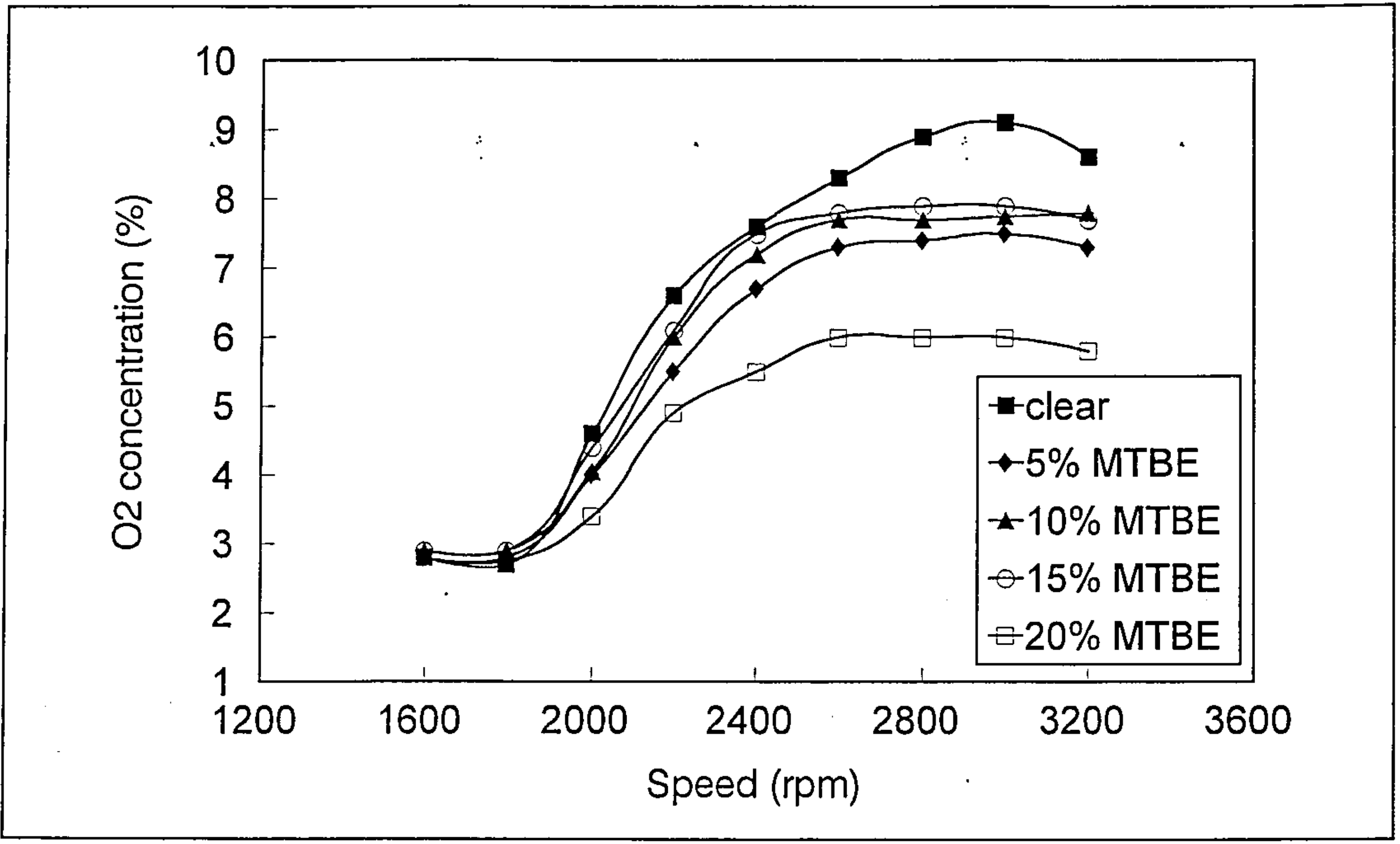
Figure(6.86): Concentration of Carbon monoxide in the exhaust gases for group BS



Figure(6.87): Concentration of Carbon dioxide in the exhaust gases for group BS



Figure(6.88):Concentration of Hydro-Carbons in the exhaust gases for group BS



Figure(6.89): Concentration of Oxygen in the exhaust gases for group BS

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions:

Several important points emerged from this experimental work, which can be summarized as follow :

1. It was found that MTBE is a good compound for mixing with gasoline to increase it's octane number, MTBE addition increases the octane number linearly and the rate of increase depends on the octane number of the gasoline used.
2. For blend A, the best performance of the engine occurs when 5% MTBE is added, while adding 10% MTBE gives the best reduction in the exhaust gases.
3. For blend AT, the best performance of the engine occurs when 15% MTBE is added, while the best reduction in the exhaust gases was at 5% of MTBE.
4. For blends AR, B and BT, the best performance was at 10% of MTBE addition and it was best reduction in the exhaust gases at the same percentage of MTBE.
5. For blend BS the best both performance of the engine and reduction of exhaust gases occur when 20% MTBE is added.

Finally and in general, the best performance of the engine occurs around 10% MTBE addition and it gives also the best reduction in exhaust gases.

7.2 Recommendations:

The present work suggests that the following point s need to be investigated:

1. The study may be concentrated over the range 5-15% MTBE addition and intervals are smaller than 5% should be used.
2. It is preferred that the gas analyzer covers more exhaust gases like aldehydes and nitrogen oxides.
3. Using engine with larger cylinder and digital instruments to over come any errors or interfaces in readings.
4. It is recommended to use other ethers such as ETBE and comparison with MTBE should be carried out.

REFERENCES

Arco Chemical Europe, Inc., 1988, *Oxygenated Fuels Technical Bulletin*, Oxygenated Fuels Department, United Kingdom.

Baur, C. Kim, B. Jenkins, P. E. and Cho, S. Y. 1990. Performance Analysis of SI Engine with ETBE as a Blending Component in Motor Gasoline and Comparison with Other Blending Components. *Proceedings of the Intersociety Energy Conversion Engineering Conference*, Piscataway, NJ, U.S.A, **4:** 337-342.

Brockwell, H. L. Sarathy, P. R. and Trotta, R. 1991. Synthesize Ethers. *Hydrocarbon Processing*, **:** 133-141.

Dorn, P. Mourao, A. M. and Herbstman, S. 1987. The Properties and Performance of Modern Automotive Fuels. *Society of Automotive Engineers (SAE),* **:** 323-339.

Douthit, W. H. Davis, B. C. Steinke, E. D. and Doherty, H. M. 1989. Performance Features of 15% MTBE/Gasoline Blends. *Society of Automotive Engineers (SAE)*, **:** 981-999.

Hamid, S. H. and Ali, M. A. 1995. Effect of MTBE Blending on the Properties of Gasoline. *Fuel Science & Technology International*, **13(5):** 509-544.

Master, K. R. and Prohska, E. A. 1988. Add of MTBE Unit Ahead of Alkylation. *Hydrocarbon Processing*, **:** 48-50.

Most, W. 1990. Coordinating Research Council Study of Winter Exhaust Emissions With Gasoline/Oxygenate Blends. *Society of Automotive Engineers (SAE)*, **:** 976-1001.

Obert, E. F. 1973. *Internal Combustion Engines and Air pollution. 3rd. edition*. Harper & Row,Publishers. United States of America.

Oda, K. Hosono, K. Isoda, T. Aihara, H. Kojima, K. and Shibata, G. 1993. Effect of Gasoline Composition on Engine Performance. *Society of the Automotive Engineers (SAE)*, **:** 77-82 .

Saudi Basic Industries Corporation (SABIC), 1996, *MTBE 'Clear air and a brighter future'*, SABIC Industrial Center for Research and Development, Kingdom of Saudi Arabia.

Stump, F. D. Knapp, K. T. and Ray, W. D. 1990. Seasonal Impact of Blending Oxygenated Organics with Gasoline on Motor Vehicle Tailpipe and Evaporative Emissions. *Journal of the Air and Waste Management Association*, **40(6):** 872-880.

Stump, F. D. Knapp, K. T. Ray, W. D. Burton C. and Snow R. 1990. The Seasonal Impact of Blending Oxygenated Organics with Gasoline on Motor Vehicle Tailpipe and Evaporative Emissions Part II. *SAE (Society of the Automotive Engineers) Transactions*, **99(4):** 776-809.

APPENDIX A

Table(A.1) Properties of MTBE :

Flash point	(°C)	-26
Ignition temperature	(°C)	430
Flammable limits	(Vol % in air)	1.6 - 8.4
Sp. Gravity	(at 20 °C)	0.74
IBP	(at 1.0 Atm, °C)	50.5 Min.
FBP	(at 1.0 Atm, °C)	74.5 Max.
Solubility in water	(Wt % at 20 °C)	4.3
Solubility of water in MTBE	(Wt % at 20 °C)	1.4
Vapor Density	(Air = 1.0)	3.1
Molecular Weight		88.1
Composition, Weight %		
Carbon		68.2
Hydrogen		13.6
Oxygen		18.2
Research Octane Number	(RON)	118
Motor Octane Number	(MON)	102
Average Octane Number	(RON+MON)/2	110

Source : (SABIC, 1996)

Note : RON - Fuel octane number measured when a vehicle's engine runs at low speed and in low severity conditions.

MON - Fuel octane number measured when the engine runs at high speed and in high severity conditions.

(RON + MON)/2 - As vehicles on the road operate mostly at speed and severity somewhere between these two levels.

Table(A.2): Properties of local regular gasoline

TESTS	Typical Lab Test	Specificaions
Distillation		
Fuel Recovered		
10% Vol. @ °C	46.5	60 Max
50% Vol. @ °C	71.5	120 Max
90% Vol. @ °C	142	180 Max
End Point °C	177	205 Max
Vapor Pressure @ 100 °F kg/cm^2	0.640	0.7 Max
Color	Pink	Standard Red
Total Sulfur %wt.	0.017	0.2 Max
Corrosion, Copper (3hr. at 50 °C) Classification	1a	NO.1 Strip
Oxidation Stability Minutes	≥360	360 Min
Existent Gum mg/100cc	1.3	4 Max
TEL Content CC/USG	0.24	3 Max
Octane No. R. M.	88	88
Lead gr /L	0.065	
Density @ 15 °C gm/ml	0.723	

Source: *(Jordan Petroleum Refinery Co. Ltd., 1996)*

Table(A.3): Properties of local super gasoline

TESTS	Typical Lab Test	Specifications
Distillation		
Fuel Recovered		
10% Vol. @ °C	58.5	70 Max
50% Vol. @ °C	93.5	120 Max
90% Vol. @ °C	146.5	180 Max
End Point °C	178	205 Max
Vapor Pressure @ 100 °F kg/cm²	0.430	0.7 Max
Color	Yellow	Yellow
Total Sulfur %wt.	0.013	0.2 Max
Corrosion, Copper (3hr. at 50 °C) Classification	1a	NO.1 Strip
Oxidation Stability Minutes	>480	360 Min
Existent Gum mg/100cc	0.6	4 Max
TEL Content CC/USG	0.59	3 Max
Octane No. R. M.	96	96
Lead gr/L	0.175	
Density @ 15 °C GM/ml.	0.760	

Source: (Jordan Petroleum Refinery Co. Ltd., 1996)

APPENDIX B

Air fuel ratio

The general chemical equation that represents burning of hydrocarbon is:

$$C_xH_y + wO_2 + zN_2 \longrightarrow$$

$$aCO_2 + bCO + YO_2 + XCH_4 + zN_2 + WH_2O\text{(condensed)}$$

where a,b,X and Y are known from gas analysis.

The gas analysis for blend BS with 15% MTBE at speed 1800 rpm is taken as an example to calculate air fuel ratio. Thus from gas analysis sample:

$a = 5.75$, $b = 9.63$, $Y = 2.9$ and $X = 0.0796$ then the equation becomes:

$$C_xH_y + wO_2 + zN_2 \longrightarrow$$

$$5.75CO_2 + 9.63CO + 2.9O_2 + 0.0796CH_4 + zN_2 + WH_2O\text{(cond.)}$$

Applying nitrogen balance gives:

$z = 100 - [\ 5.75 + 9.63 + 2.9 + 0.0796\ ] = 81.64$

$w = z / 3.764 = 81.64 / 3.764 = 21.69$

Carbon balance gives: $x = 5.75 + 9.63 + 0.0796 = 15.4596$

Oxygen balance gives: $W = 2(21.69) - [\,9.63 + 2(5.75) + 2(2.9)\,]$

$$W = 16.45$$

Hydrogen balance gives: $y = 4(0.0796) + 2(16.45) = 33.22$

$$C_{15.46}H_{33.22} + 21.69O_2 + 81.64N_2 \longrightarrow$$

$$5.75CO_2 + 9.63CO + 2.9O_2 + 0.0796CH_4 + 81.64N_2 + 16.45H_2O$$

Then from this equation the mass of air and fuel may be estimated as:

The mass of air = 29(21.69 + 81.64) = 2996.57

The mass of fuel = 12(15.46) + 1(33.22) = 218.74

Then the air fuel ratio A/F = (The mass of air) / (The mass of fuel)

$$A/F = [\,2996.57\,] / [\,218.74\,] = 13.7$$

While the experimental value for this sample is 11.69 . This large difference because the gas analyzer does not give all gases in the exhaust pipe and may be also there is water in the vapor form which was not condensed.

ملخص

تحسين الجازولين المنتج محليا ودراسة تأثيره على كفاءة المحرك والبيئة

إعداد

طارق عبد الرحمن علي الصبيح

المشرف

الأستاذ الدكتور محمد أحمد حمدان

يهدف هذا البحث إلي دراسة تأثير إضافة مركب بيوتال الإيثر الثلاثي المثيلي إلي الجازولين على كفاءة المحركات و على الغازات المنبعثة من العادم، أيضا تم دراسة تأثير إضافة هذا المركب إلي الجازولين على الرقم الأوكتاني للجازولين.

ستة أنواع رئيسية من الوقود استخدمت في محرك من نوع (TD١١٠) والذي قرن بجهاز تحليل للغازات المنبعثة من العادم. كل وقود من هذه الستة تم خلطه مع خمسة نسب مئوية من بيوتال الإيثر الثلاثي المثيلي وهي ٠، ٥، ١٠، ١٥، ٢٠٪.

وقد وجد أن الرقم الأوكتاني للجازولين يزداد بشكل متصل وبعلاقة خطية مع نسبة إضافة بيوتال الإيثر الثلاثي المثيلي، وأن معدل هذه الزيادة يعتمد على الرقم الأوكتاني للجازولين قبل الإضافة. وبشكل عام وجد أن أداء المحرك كان الأفضل عند إضافة ١٠٪ من بيوتال الإيثر الثلاثي المثيلي إلى الجازولين، كذلك فان هذه النسبة أدت إلى أفضل تقليل للغازات المنبعثة من العادم.