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تأثير الوسط الملوث على أداء التوربينات الغازية

"ON THE EFFECT OF POLLUTED ENVIRONMENT ON THE GAS TURBINE PERFORMANCE"

By

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الخلاصة :ـ
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توصف هذه الدراسة تأثير الوسط الهوائى الملوث المحيط (مثل : درجة الحرارة ـ الرطوبة النسبية ـ النسبة الحجمية لثانى أكسيد الكربون به ـ النسبة الحجمية لأول أكسيد الكربون وكذلك جزيئات الرمل أو التراب) علي أداء توربين غازى . وقد أخذ فى الاعتبار أن خواص الهواء الملوث المحيط تتغير تبعا لما يأتى :ـ

١ ـ درجة الحرارة تتغير من ٢٧٠ الى ٣٣٠ درجة مطلقة .
٢ ـ الرطوبة النسبية تتغير من صفر الى ١٠٠ ٪ .
٣ ـ وهناك انخفاض من ضغط الدخول للضاغط عن الضغط الجوى نتيجة استعمال مرشح الهواء عند مدخل الضاغط فى حدود من ٦٠ الى ١٠٠ ٪ .

وباستخدام الحاسب الآلى لغة الأساس المتقدمة ، كتب البرنامج لحساب كل من الشغل المستفاد من الوحدة لوحدة الكتل من الهواء عند الدخول للضاغط والكفاءة الحرارية تحت الاعتبارات السابق ذكرها ـ كذلك تم حساب الأداء لوحدة التوربين الغازى باستعمال قيم متغيرة لدرجة الحرارة العضوى لغازات الاحتراق عند مدخل التوربين من ١٢٠٠ الى ١٦٠٠ درجة حرارة مطلقة كما تم حسابها أيضا عند نسب ضغوط مختلفة تتغير من ١٠ الى ١٦ .

الحرارة النوعية أخذت فى الاعتبار متغيرة بتغير درجة الحرارة ونسبة الوقود للهواء كما تم أيضا حساب تأثير نسبتى أول وثانى أكسيد الكربون الموجودين فى الوسط الهواء المحيط على أداء التوربينات الغازية .

ABSTRACT

This work describes the effect of environmental polluted air properties (such as; temperature, relative humidity, volume fraction ratios of carbondioxide and carbon-monoxide ratio, and dust/sand particles) on the gas turbine performance. The polluted air properties are considered variable as under:

i) Air temperature varying from 270 to 330°K,
ii) Air relative humidity changing from 0 to 100%, and
iii) Reduction ratio in atmospheric pressure, due to the use of air filter at compressor intake, varying from 60 to 100%.

The advanced BASIC Computer Programmes have been written for calculating the specific work and thermal efficiency of a gas turbine unit which works under the above conditions. The gas turbine performance values have been estimated by using various values of the maximum gas turbine inlet temperature (TIT) and pressure ratios (PR) (from 1200 to 1600° K, and from 10 to 16 respectively).

Specific heats of the mixture have also been considered as a function of temperatures and fuel air ratios.

The effect of environmental polluted air containing various ratios of CO, and CO_2, on the gas turbine performance has also been investigated.

NOMENCLATURE:

CP	Constant-Pressure specific heat of working substances (KJ/Kg°K)
CV	Constant-Volume specific heat of working substances (KJ/Kg°K)
F	Theoretical fuel/air ratio (Kg_F/Kg_a)
F	Actual fuel/air ratio (Kg_P/Kg_a)
h	Enthalpy (KJ/Kg)
K	Ratio of specific heats CP/CV –
LHV	Lower Heating Value (enthalpy of reaction) (KJ/Kg)
M	Molecular Weight (Kg.moL)
MD	Dry air molecular weight (Kg.moL)
MF	Fuel molecular weight (Kg.moL)
MM	Mixture molecular weight (Kg.mol)
MP	Products molecular weight (Kg.mol)
MS	Steam molecular weight (MS=18.01 Kg.mol)
m	Mass fraction
R	Gas constant (KJ/Kg.°K)
R	Universal gas constant (R = 8.314 KJ/Kg.mol.°K)
RD	Dry air gas constant (KJ/Kg°K)
RM	Mixture gas constant (KJ/Kg°K)
RP	Products gas constant (KJ/Kg°K)
RS	Steam gas constant (KJ/Kg°K)
r	Pressure reduction ratio
P	Pressure (N/m^2)
P_o	Atmospheric pressure (N/m^2)
Ps	Partial steam pressure (Saturated steam pressure corresponding to the dew-point temperature)(N/m^2)
Pss	Partial steam pressure (Saturated steam pressure corresponding to the dry-bulb temperatures(N/m^2)
PR	Pressure ratio (compression or expansion)
T	Temperature (°K)
TIT	Maximum turbine inlet gas temperature (°K)
V	Volume fraction, specific volume (m^3/Kg)
W	Specific net work (Net work per unit mass of air, KJ/Kg_a)
η	Overall thermal efficiency (%)
ρ	Density (Kg/m^3)
Φ	Relative humidity (%)
μJT	Joule-Thomson function

Subscripts:

a	environmental polluted air
c	compression process
d	dry air
e	expansion process
f	fuel
g	gas
m	mixture
o	atmospheric environmental condition
p	products
s	water vapor
ss	saturated water vapor
t	throttling process

0, 1, 2, 3, and 4 cycles state points as in Fig.1 (b)

Superscripts

-Bar over symbol denotes property on a molal basis

INTRODUCTION:

The widest applications of the industrial gas turbine have been in pumping sets for gas and oil transmission pipelines, both peak load and base load electricity generation, over-highway trucks, military vehicles, rail cars, and naval propulsion. Another possible future application of the gas turbine lies in its use as an energy storage device. The overall efficiency of a country's electricity system can be improved if sufficient energy storage capacity is provided to enable the most efficient base-load stations to run night and day under conditions yielding peak efficiency.

There are many man-made dust clouds in the Middle-East, caused by the vast construction projects. Drilling the desert rock to prepare foundations and movement of construction vehicles creates a severe problem. In recent years, many investigators have measured the quantity and character of dust clouds in both actual and potential gas turbine environments. The greatest amount of data have been developed in the measurement of military environments, and most measurements were made by helicopter operations.

Moud & Guhne (1970), presented gas turbines-dust-air cleaners experience and trends. Their experience covers three types of gas turbine air cleaners in both the laboratory and the field, on wheeled and tracked vehicles and on helicopters and air cushion vehicles.

Unfortunately, the environment in which gas turbines must work includes rain drops, sea spray, road splash and exhaust soot as well as dust.

Hobday & Havill (1988), described a new approach using available ship and meterological data and proved analytical techniques to generate a multivariable mathematical model of marine aerosol embracing a wide envelope of operating conditions.

When air pollution or dust problem are considered, the temperature inversion phenomenon is one of the most important weather conditions which must receive special attention.

El-Hadik (1990), studied the impact of atmospheric conditions, such as ambient temperature, pressure and relative humidity on the gas turbine performance.

The present work is extended to cover the atmospheric pollution resulting from combustion equipment and uncleaned waste gases from commercial and industrial establishments.

Gamble et al (1987), have examined the chronic effects of diesel exhaust on the respiratory system in the diesel bus garage.

THEORETICAL ANALYSIS:

In theoretical analysis, the first major step was to carry out thermodynamic design studies which involved detailed calculations taking into account all important factors such as expected component efficiencies, variable fluid properties, and pressure losses. Such studies would be carried out over a reasonably restricted range of pressure ratio and turbine inlet temperature. Most of the atmospheric air is now polluted by artificial processes, automotive engines, and power plants. The use of such polluted air in gas turbine units will affect its thermal capability.

The main trace pollutants as from any air-breathing burning fossil fuel are (a) unburnt hydrocarbons, and carbon monoxide, (b) oxides of nitrogen and (c) oxides of sulphur.

Atmospheric air is a mixture of many gases plus water vapor and countless pollutants. Acid from pollutants may vary considerably from place to place. The composition of the dry air alone is relatively constant, varying slightly with time, location and altitude. The ASHRAE Handbook of Fundamentals (1985) gives the following approximate composition of environmental polluted dry air by volume fraction:

Table (1) Composition of environmental polluted dry air

Constituent	Molecular mass Kg/K.mol	Volume fraction	Mass in one Kg.mole	Mass fraction
Nitrogen	28.013	0.78084	21.876013	0.7551832
Oxygen	31.999	0.20848	6.67136	0.2303024
Argon	39.984	0.0094	0.375474	0.0129617
Carbon dioxide	44.01	0.00064	0.028166	0.0009724
Carbon monoxide	28.01	0.0006	0.016806	0.0005803
Neon, Helium, Methane, Sulphur dioxide, Hydrogen, and other minor gases	might be neglected because of very little fraction			
Sum		1.0000	28.967819	1.0000

The operating principle of gas turbine is simplified as follows. Basically the environmental air is drawn into an air cleaner filter by multistage compressor, which is driven by a gas turbine. By passing the ambient air through the filter, the air is throttled and its pressure is reduced. Then the air is compressed to about 14 times of reduced pressure by a multistage compressor. The compressed air then passes through the combustion chamber where fuel is injected and burned. The products of combustion enter the turbine and expand to approximately atmospheric pressure.

Therefore, the gas turbine performance is dependent on the compressor inlet air conditions, mainly the atmospheric temperature, pressure, relative humidity, and air pollutants.

In the present study the effect of polluted environment on the gas turbine performance was taken into consideration. The computer programmes were designed especially for calculating the overall thermal-efficiency and specific work. The governing equations are given as under.

a) <u>Throttling Process:</u>

By given polytropic efficiency, pressure reduction ratio, temperature and thus other state variables for each stream can be calculated. The specific enthalpy can be calculated from the specific heat polynomials.

$$h = {}_1\int^2 CP_m\ (T)dt \tag{1}$$

where

$$CP_m = [CP_d + H^*\ CP_s]/(1+H) \tag{2}$$

$$H = 0.622\ \frac{Ps}{Pa} = 0.622\ \frac{\phi\ Pss}{P - \phi\ Pss} \tag{3}$$

Kyle (1984), gave polynominal equations for calculating specific heats of various gases.

$$\overline{CP}_g = a+bT + CT^2 + d\ T^3 \ \text{(Temperature range 273-1800 °K)} \tag{4}$$

where a, b, c and d are constants which are given in the following table.

Table(2): The a,b,c and d constants in Equation (4)

Constituent	a	$b\times10^2$	$c\times10^5$	$d\times10^9$
Nitrogen (N_2)	28.9	-0.1571	0.8081	-2.873
Oxygen (O_2)	25.48	1.52	-0.7155	1.312
Air (0.79N2+0.21O2)	28.11	0.1967	0.4802	-1.966
Hydrogen (H_2)	29.11	-0.19116	0.4003	-0.8704
Carbon monoxide (CO)	28.16	0.1675	0.5372	-2.222
Carbon dioxide (CO_2)	22.26	5.981	-3.501	7.469
Water Vapor (H_2O)	32.24	0.1923	1.055	-3.595
Sulphur dioxide (SO_2)	25.78	5.795	-3.812	8.612
Methane (CH_4)	19.89	5.024	1.269	-11.01
Ethane (C_2H_6)	6.9	17.27	-6.4	7.285
Propane (C_3H_8)	-4.04	30.48	15.72	31.74

The environmental air is throttled during its passage through the air cleaner filter, and this causes a reduction in its pressure. These reduction values depend on the amount of the dust/sand suspended in air. The pressure reduction ratios are considered variable and may be taken as: 1.0, 0.8, 0.6, 0.4 and 0.2. By the nature of the throttling process, no shaft work is involved. In addition, the following assumptions are usually made in the study of this process:

1. Neglect heat transfer
2. Neglect change in potential energy.
3. Neglect change in kinetic energy

With these assumptions, the energy equation for the throttling process becomes:

$$h_o = h_1 \tag{5}$$

If entropy is expressed as a function of T and P, changes in entropy may be given as;

$$ds = \left(\frac{CP}{T}\right)_T dT - \left(\frac{\partial v}{\partial T}\right)_P dP \tag{6}$$

To obtain an expression for enthalpy changes, the following form may be given for a simple compressible substance

$$dh = Tds + vdp \tag{7}$$

Combining Eq. (6) with Eg.(7), the change of enthalpy becomes

$$dh = CpdT + \left[v - T\left(\frac{\partial v}{\partial T}\right)_p\right] dp \tag{8}$$

then

$$\left(\frac{\partial h}{\partial p}\right)_T = U - T\left(\frac{\partial u}{\partial T}\right)_p \tag{9}$$

or

$$\left(\frac{\partial T}{\partial p}\right)_h = \frac{U - T\left(\frac{\partial v}{\partial T}\right)_p}{Cp} \tag{10}$$

From Eq. (10), the partial derivative $(\partial T/\partial P)_h$, known as the Joule-Thomson coefficient μJT, is readily observed. It may be shown that μJT is always zero for ideal gas. However for a simple compressible substance is general, μJT will be greater or less than zero. A positive Joul-Thomson coefficient implies that there will be a temperature drop due to pressure drop in an adiabatic-throttling process, and that value is recommended by Huang (1988), equal to approximately 0.005°C/atm for air.

Therefore, with steady-state steady-flow conditions, the first Law equation becomes simply

$$T_1 = T_o \tag{11}$$

b) <u>Compression Process:</u>

For a given polytropic efficiency, the pressure ratio, temperature, and thus other state variables for each stream can be calculated. The compressor outlet temperature, T_2, can be calculated from specific heats polynomials as follows:

$$\begin{aligned}\overline{CP}_g = a_g + \frac{bg}{2} T_1\left[\left(\frac{PR}{r}\right)^{\frac{K_c-1}{K_c}} + 1\right] + \frac{Cg}{3} T_1^2\left[\left(\frac{PR}{r}\right)^{2\left(\frac{K_c-1}{K_c}\right)} + \left(\frac{PR}{r}\right)^{\frac{K_c-1}{K_c}} + 1\right] \\ + \frac{dg}{4} T_1^3\left[\left(\frac{PR}{r}\right)^{3\left(\frac{K_c-1}{K_c}\right)} + \left(\frac{PR}{r}\right)^{2\left(\frac{K_c-1}{K_c}\right)} + \left(\frac{PR}{r}\right)^{\frac{K_c-1}{K_c}} + 1\right]\end{aligned} \tag{12}$$

$$\overline{CP}_s = a_s + \frac{bs}{2} T_1\left[\left(\frac{PR}{r}\right)^{\frac{K_c-1}{K_c}} + 1\right] + \frac{Cs}{3} T_1^2\left[\left(\frac{PR}{r}\right)^{2\left(\frac{K_c-1}{K_c}\right)} + \left(\frac{PR}{r}\right)^{\frac{K_c-1}{K_c}} + 1\right]$$

$$+ \frac{ds}{4} T_1^3 \left[\left(\frac{PR}{r} \right)^{3\left[\frac{K_c-1}{K_c}\right]} + \left(\frac{PR}{r} \right)^{2\left[\frac{K_c-1}{K_c}\right]} + \left(\frac{PR}{r} \right)^{\frac{K_c-1}{K_c}} + 1 \right] \qquad (13$$

$$\overline{CP}_d = \sum_{n=1}^{n=n} v * \overline{CP}_g \qquad (14$$

$$MD = \sum_{n=1}^{n=n} v * Mg \qquad (15$$

$$RD = \overline{R}/MD \qquad (16$$

$$RS = \overline{R}/MS \qquad (17$$

$$RM = (RD+H*RS)/(1+H) \qquad (18$$

$$CP_m = \left[\frac{\overline{CP}_d}{MD} + H* \frac{\overline{CP}_s}{MS} \right] / (1+H) \qquad (19$$

$$K_c = CP_m / (CP_m - RM) \qquad (20$$

$$T_2 = T_1 \left[\left(\frac{PR}{r} \right)^{\frac{K_c-1}{K_c}} - 1 + \eta_{ic} \right] / \eta_{ic} \qquad (21$$

Where η_{ic}, can be considered equal to 0.87 (see El-Hadik (1990)), and the moisture content, H, can also be calculated at the mean temperature $(T_1 + T_2)/2$.

By solving equations from (12) to (21) with equation(3) simultaneously and iteratively the exit temperature T_2 may be calculated. By using the variable values of environmental polluted air temperature, T_o, relative humidity, Φ, reduction pressure ratio, r, pressure ratio, PR, and volume fraction of CO, and CO_2 in the previous Eqs. the effect of these variables on the exit temperature, T_2, may be found. Then the required work per unit mass for driving the compressor can be calculated as follows:

$$Wc = CP_m (T_2 - T_1) \qquad (22)$$

c) Combustion Process:

i) Before Combustion:

The specific heats of the mixture at entrance of the combustion chamber may be defined as follows. It is also assumed methane to be the used fuel (CH_4), thus:

$$CP_{m2} = CP_2 + f * CP_f \qquad (23)$$

where; CP_{m2} is the specific heat of mixture working substances at the entrance of combustion chamber, and CP_2 is the specific heat of mixture working substances at the exit condition(2) of compressor.

$$\overline{CP}_{g2} = a_g + bg\ T_2 + Cg\ T_2^2 + dgT_2^3 \qquad (24)$$

$$\overline{CP}_{d2} = \sum_{n=1}^{n=n} v_g * \overline{CP}_g \qquad (25)$$

$$\overline{CP}_{s2} = a_s + bs\ T_2 + Cs\ T_2^2 + ds\ T_2^3 \qquad (26)$$

$$H_2 = 0.622 \; [\, \Phi \, P_{ss2} \, / \, (P_2 - P_{ss2})] \qquad (27)$$

$$P_2 = PR \, * \, P_o \qquad (28)$$

$$CP_2 = [\, \frac{\overline{CP_{d2}}}{MD} + \frac{\overline{CP_{s2}}}{MS} \, * \, H_2 \,] \, / \, (1+H) \qquad (29)$$

$$CP_f = [a_f + b_f \, T_2 + C_f \, T_2^{\,2} + d_f \, T_2^{\,3} \,] \, / \, MF \qquad (30)$$

ii) After Combustion:

The specific heat of gaseous products after combustion may be determined by using a mathematical model formulated using regression analysis to relate combustion temperature and fuel air ratio to specific heat of gaseous products. The values of CP, for different fuel ratios (El-Hadik - 1990) were calculated in the form of the following equations:

$$CP_{p3} = 1.01 + 0.32 \, (\frac{T3-400}{1400}) - 0.04 \, (\frac{T3-400}{1400})^2 \text{(for; f=0)} \qquad (31)$$

$$CP_{p3} = 1.03 + 0.32 \, (\frac{T3-400}{1400}) - 0.02 \, (\frac{T3-400}{1400})^2 \text{(for;f=0.0135)} \qquad (32)$$

$$CP_{p3} = 1.05 + 0.34 \, (\frac{T3-400}{1400}) - 0.02 \, (\frac{T3-400}{1400})^2 \text{(for;f=0.027)} \qquad (33)$$

Any value in between these range limits can be interpolated to get the exact value of CP_p

Hence, the value of CP_{m3}, after combustion can be determined by using the following form:

$CP_{s3} = [a_s + b_s \, T_3 + C_s \, T_3^{\,2} + d_s \, T_3^{\,4}]/MS$ (34)

$H_3 = 0.622 \, [\, \Phi \, P_{ss3} \, / \, (P_3 - P_{ss3} \,)]$ (35)

$P_3 = P_2 \, * \, 0.97$ (36)

where 0.97 is considered to account for the duct pressure loss and

$CP_{m3} = (CP_{p3} + H_3 * CP_{s3}) \, / \, (1+H_3)$ (37)

and CP_{s3} is the specific heat of water vapor, which is calculated at the TIT (T_3),

H_3 is the humidity ratio calculated at the maximum turbine inlet temperature (TIT), and

CP_{m3} is the specific heat of mixture at (TIT).

The maximum turbine inlet temperature will be taken variable as 1200, 1400, and 1600 °K. Therefore the equations from 23 to 37 should be repeated to re-calculate them for each value of TIT.

Then, the heat transfer per unit mass into the combustion chamber can be calculated by this way:

$Q_{in} = (CP_{m3} * T_3 - CP_{m2} \, T_2)$ (38)

c) Gas Turbine:

Equation of reaction is;

Air + Fuel → Products (39)

[0.78084N2 + 0.20848O2 + 0.0094 Ar + 0.00064 CO2 + 0.0006CO

$$+ \frac{F*MD}{MF} CH_4 \rightarrow (0.00124 + \frac{F*MD}{MF}) CO_2 + \frac{F*MD}{MF} H_2O + 0.0094\ Ar$$

$$+ 0.78084 N_2 + (0.20818 - \frac{2F*MD}{MF}) O_2 \qquad (40)$$

Specific heat can be calculated as follows:

$$\overline{CP}_g = ag + \frac{bg}{2} T_3 [1 + (\frac{1}{0.99PR})^{(\frac{K_t-1}{K_t})}] + \frac{cg}{3} T_3^2 [1 + (\frac{1}{0.99PR})^{\frac{K_t-1}{K_t}} + (\frac{1}{0.99PR})^{2(\frac{K_t-1}{K_t})}] + \frac{dg}{4} T_3^3 [1 + (\frac{1}{0.99PR})^{(\frac{K_t-1}{K_t})} + (\frac{1}{0.99PR})^{2(\frac{K_t-1}{K_t})} + (\frac{1}{0.99PR})^{3(\frac{K_t-1}{K_t})}] \qquad (41)$$

$$\overline{CP}_p = \sum_{n=1}^{n=n} v_p * \overline{CP}_g \qquad (42)$$

$$\overline{CP}_s = a_s + \frac{bs}{2} T_3 [1 + (\frac{1}{0.99PR})^{(\frac{K_t-1}{K_t})}] + \frac{c_s}{3} T_3^2 [1 + (\frac{1}{0.99PR})^{\frac{K_t-1}{K_t}} + (\frac{1}{0.99PR})^{2[\frac{K_t-1}{K_t}]}] + \frac{d_s}{4} T_3^3 [1 + (\frac{1}{0.99PR})^{(\frac{K_t-1}{K_t})} + (\frac{1}{0.99PR})^{2(\frac{K_t-1}{K_t})} + (\frac{1}{0.99PR})^{3(\frac{K_t-1}{K_t})}] \qquad (43)$$

(where 0.99 is considered to account for the exit pressure loss i.e. $P_4 = P_o / 0.99$)

$$H = 0.622 \frac{\Phi\ P_{ss}}{P - P_{ss}} \qquad (44)$$

the moisture conent, H should be calculated at mean condition between (3) & (4) i.e.

$$T_m = \frac{T_3 + T_4}{2} \quad \& \quad P = \frac{P_3 + P_4}{2} \quad \text{also}$$

$$MP = \sum_{n=1}^{n=n} v_p * MP \qquad (45)$$

$$RP = R/MP \qquad (46)$$

$$RM_p = (RP + H * RS) / (1+H) \qquad (47)$$

$$Cp_{mp} = (\frac{\overline{Cp}_p}{MP} + H * \frac{\overline{Cp}_s}{MS}) / (1+H) \qquad (48)$$

$$K_t = CP_{mp} / (CP_{mp} - R_{mp}) \qquad (49)$$

$$T_4 = T_3 \{ 1 - \eta_{it}[(\frac{1}{0.99PR})^{(\frac{K_t-1}{K_t})} - 1] \} \qquad (50)$$

Where η_{ist} is the isotropic turbine efficiency which may be recommended 0.85.

Then, T_4 can be calculated by solving equations from 40 to 50 simultaneously and iteratively. To investigate the effect of polluted environmental condition, maximum turbine inlet temperature, pressure ratio, and cleaner filter, the above procedure should be repeated. Thus the useful work by the turbine may be calculated by using the following formula:

$$W_T = CP_{mp} (T_3-T_4) / (0.95 + F) \qquad (51)$$

where, 0.95 is the ratio of the air after combustion assuming 5% air loss compressor, and f is the fuel air ratio, then:

$$W_n = W_T - W_c \qquad (52)$$

and

$$\eta_{the} = \frac{W_n}{Q_{in}} \qquad (53)$$

where, W_n is the net work per unit mass, and η_{the} is the thermal efficiency for the gas turbine unit.

Finally the computer programmes were written in advanced BASIC language and run on a PC unit.

The results obtained are given in Figs. [2 to 12] and discussed to interpret the meaning.

RESULTS AND DISCUSSIONS:

Effect of polluted environmental air on the gas turbine performance (temperature, pressure, relative humidity, dust/sand, and volume fraction ratios of CO_2 and CO) is studied. The simple gas turbine schematic diagram is shown in Fig.[1]. The polluted air is withdrawn by the multi-stage compressor through the air cleaner filter which is located at the compressor inlet. Air is then compressed to the combustion chamber, while the propane fuel is injected into air in the combustion chamber, which combines with oxygen of air and burnt. Then the combustion products are expanded in the gas turbine to get work. The net work is the difference of gas turbine work and the compressor work. Fig.[1-b] shows the absolute temperature-entropy diagram. In that Figure point (o) represents the polluted air condition, point (1) illustrates the condition of air after passing through the air cleaner filter. Point (2) also indicates the state of compressed air at compressor exit, Point (3) represents the combustion products at turbine inlet, and the point (4) indicates the exhaust gas condition at the turbine exit.

Equation (1) to (53) are fed into the BASIC Computer Program and computed simultaneously and iteratively to get convergent values and the results are plotted in Figs. [2] to [12].

The variation of specific net work with polluted air temperature is shown in Figs.[3,4, and 5] for various compression pressure ratios (PR = 10, 12, 14, and 16), and constant pressure reduction ratio (r = 1). In these Figures the present results are compared with El-Hadik (1990) results at same values of the maximum gas inlet temperatures, which are equal to 1200, 1400, and 1600°K, respectively. Although both results are found in a good agreement, the present results have a lower values than the others. This is so because the percentage ratios of CO, and CO_2 in polluted environmental air have been considered when solving the equations. Also the variation of overall thermal efficiency with the polluted environment temperature for various compression ratios, are indicated in Figs. [6, 7, and 8]. The present results are plotted alongwith El-Hadik (1990) results when the maximum inlet gas turbine temperature values are, 1200, 1400, and 1600°K, respectively. As is seen the present results have lower values than those obtained by El-Hadik (1990), because the pollution has been taken into consideration.

It is also observed in Figs. 3, 4, 5, 6 and 7 that at low compression value gives low specific net work, and overall thermal efficiency. This is physically expected due to the divergency of constant pressure lines at high temperatures on the temperature-entropy chart.

The effect of polluted environment temperature on the specific net work, and overall thermal efficiency of gas turbine units are shown also in these Figures. The increase of the polluted environment temperature decreases both the specific net work and the overall thermal efficiency.

Figures 9, and 10 show the variations of specific net work and overall thermal efficiency with the pressure reduction ratios in air cleaner filter for maximum turbine inlet temperature of 1200°K and 1600°K. The decrease of the pressure reduction ratios decreases both the specific net work and overall thermal efficiency. The decrease of pressure reduction ratios increases the compression ratio at compressor side, and consequently more power is consumed in the compressor to operation. The figures also show that the increase of maximum turbine inlet temperature increases the specific net work and overall thermal efficiency.

The effect of carbon-monoxide and carbon-dioxide volume fraction ratio in polluted environment on specific net work and overall thermal efficiency are shown in Figs. 11, and 12 respectively. The increase of carbon-monoxide, and carbon-dioxide volume fraction ratios decreases both the specific net work and overall thermal efficiency.

CONCLUSION:

The effect of environmental polluted air condition (temperature, relative humidity, dust/sand, volume fraction ratios of carbon-dioxide, and carbon-monoxide) on the performance of simple gas turbine unit have been clearly shown. The increase of the air contaminates decreases both the specific net work and overall thermal efficiency.

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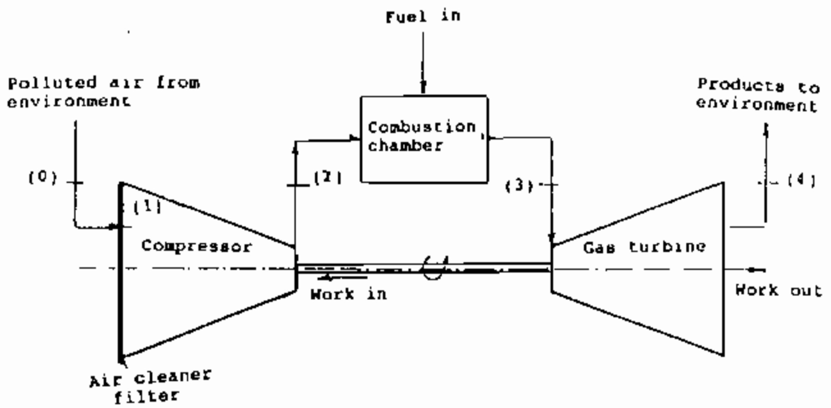
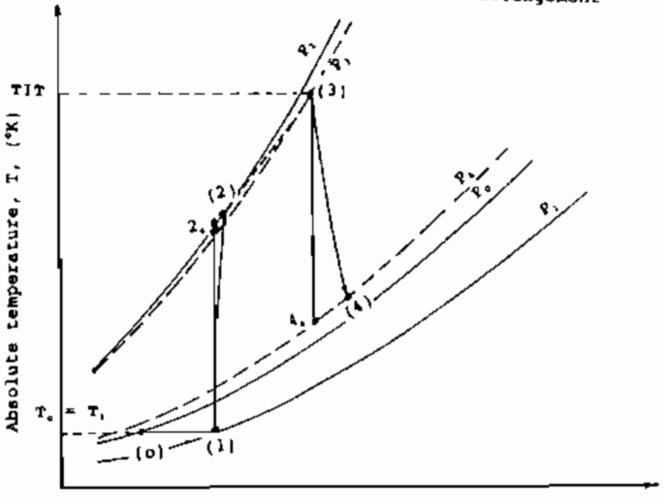


a) Simple gas turbine unit arrangement



b) Absolute temperature-entropy diagram

Fig.(1): Simple gas turbine unit schematic diagram

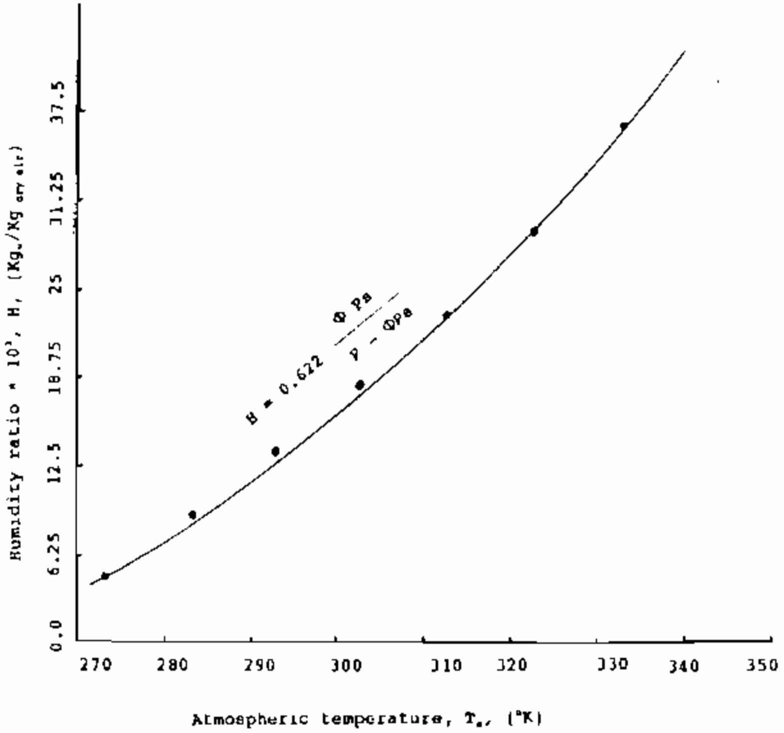


Fig.(2): Variation of humidity ratio with atmospheric temperature at constant atmospheric pressure

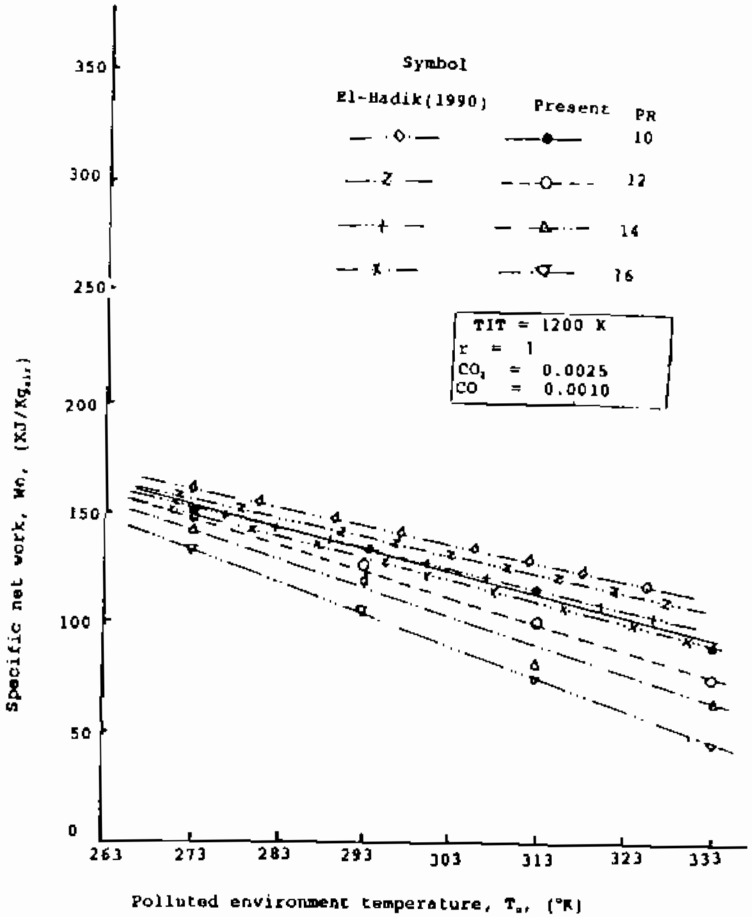


Fig.(3): Variation of specific net work with polluted environment temperature comparing with El-Hadik (1990) results, for various compression ratios.

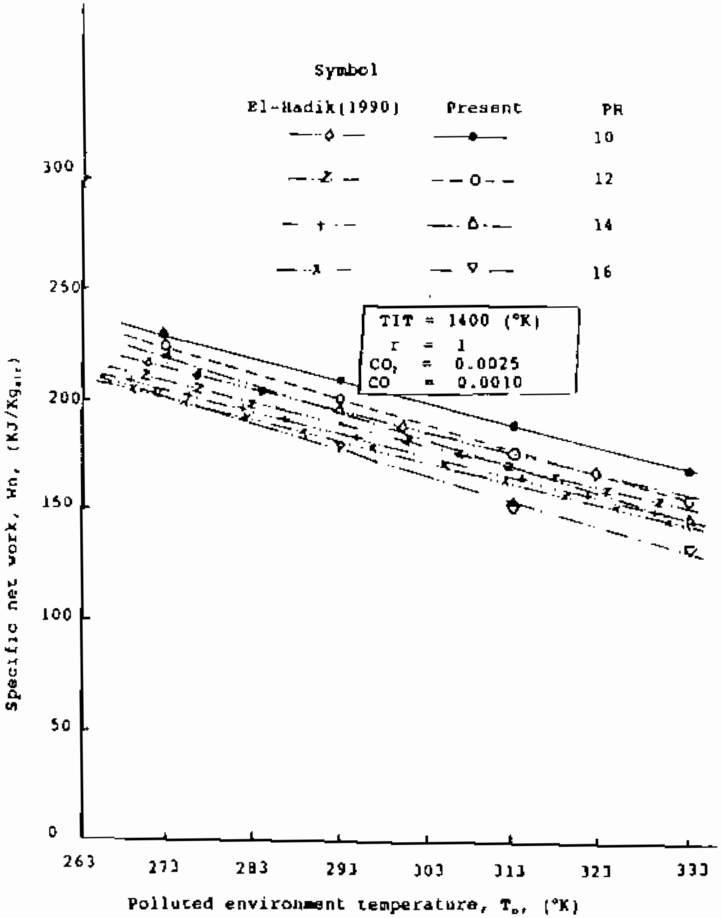


Fig.(4): Variation of specific net work with polluted environment temperature comparing with El-Hadik (1990) results, for various compression ratios.

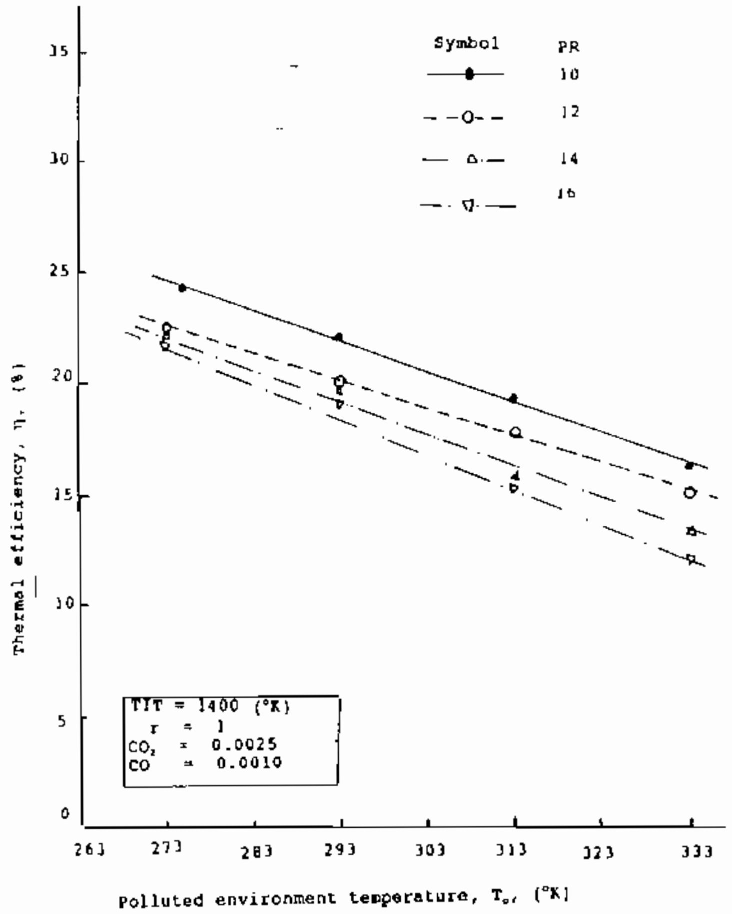


Fig.(6): Variation of overall thermal efficiency with polluted environment temperpature, forvarious compression ratios.

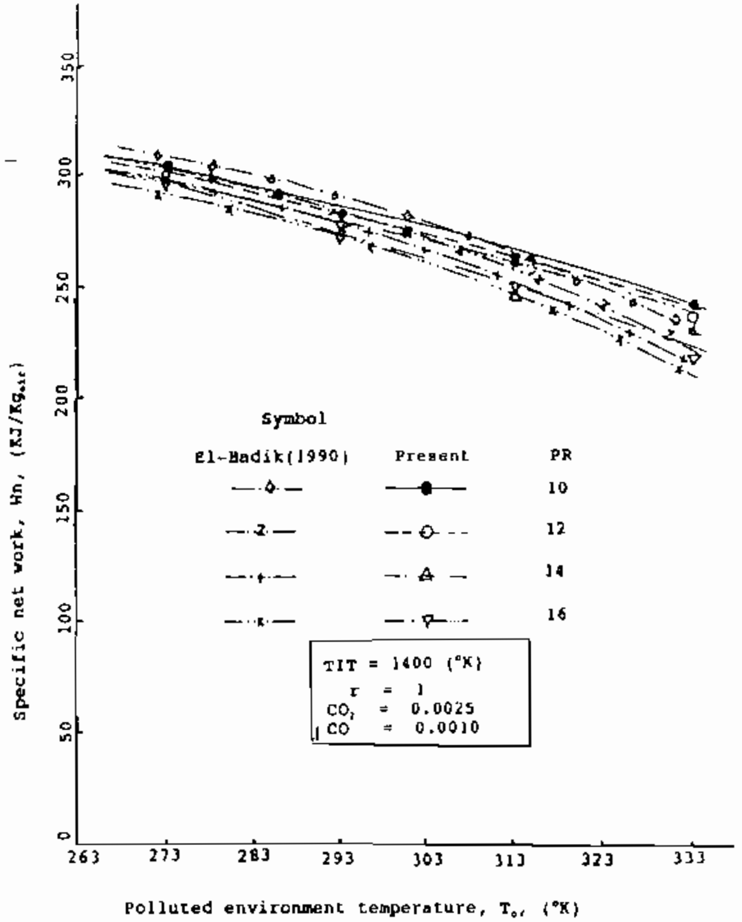


Fig.(5): Variation of specific net work with polluted environment temperature comparing with El-Badik (1990) results, for various compression ratios.

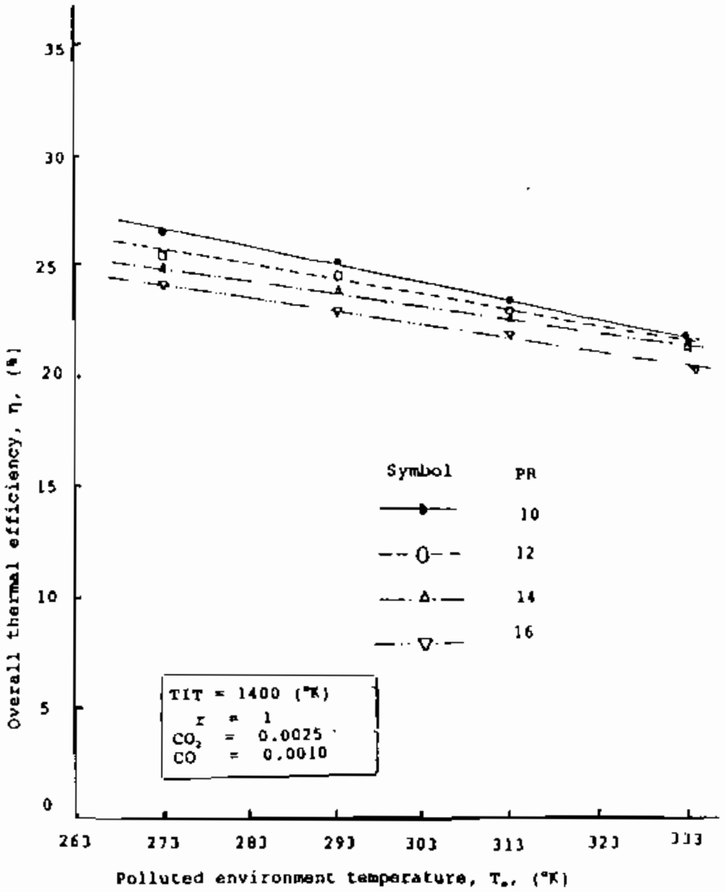


Fig.(7): Variation of overall thermal efficiency with polluted environment temperpature, for various compression ratios.

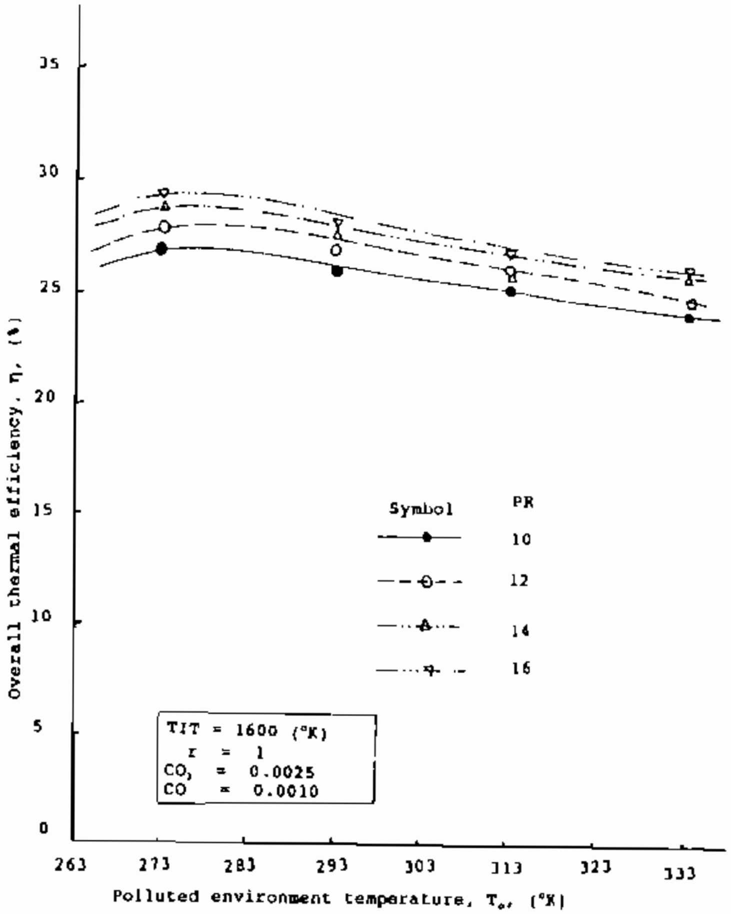


Fig.(8): Variation of overall thermal efficiency with polluted environment temperpature, for various compression ratios.

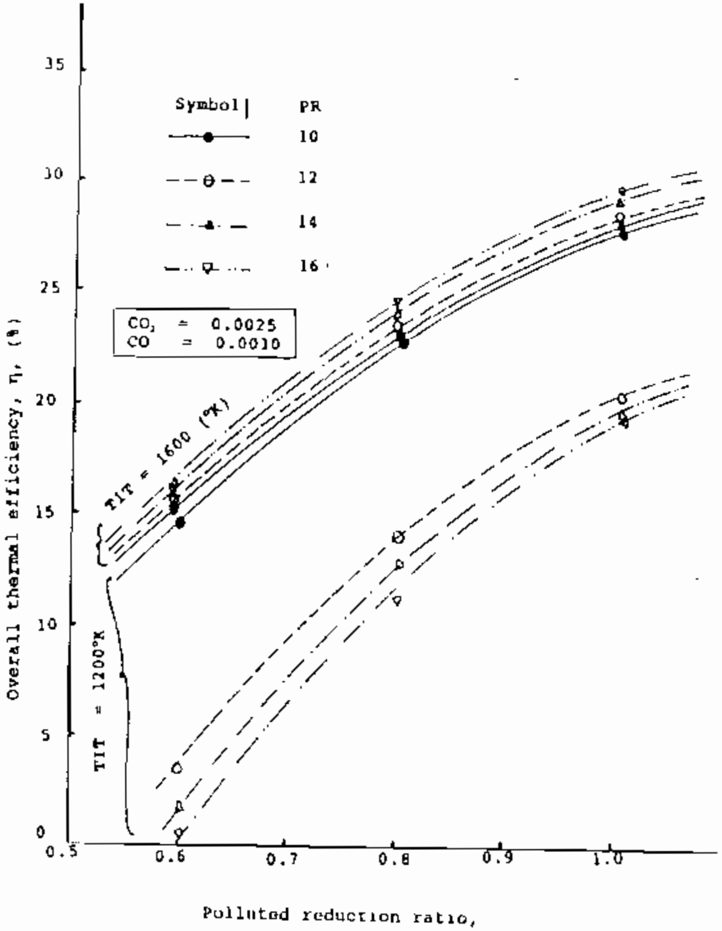


Fig.(10): Variation of overall thermal efficiency with the pressure reduction ratios due to air cleaner filter for maximum turbine inlet temperature of 1200 °K, and 1600°K

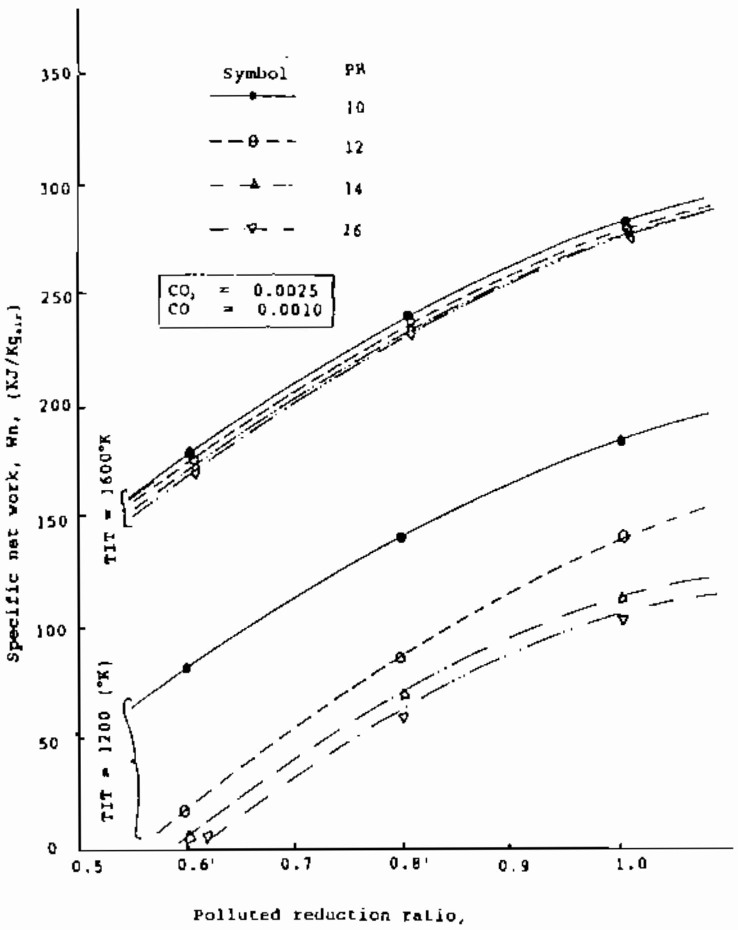


Fig.(9): Variation of specific net work with the pressure reduction ratios due to air cleaner filter for maximum turbine inlet temperature of 1200 °K, and 1600°K

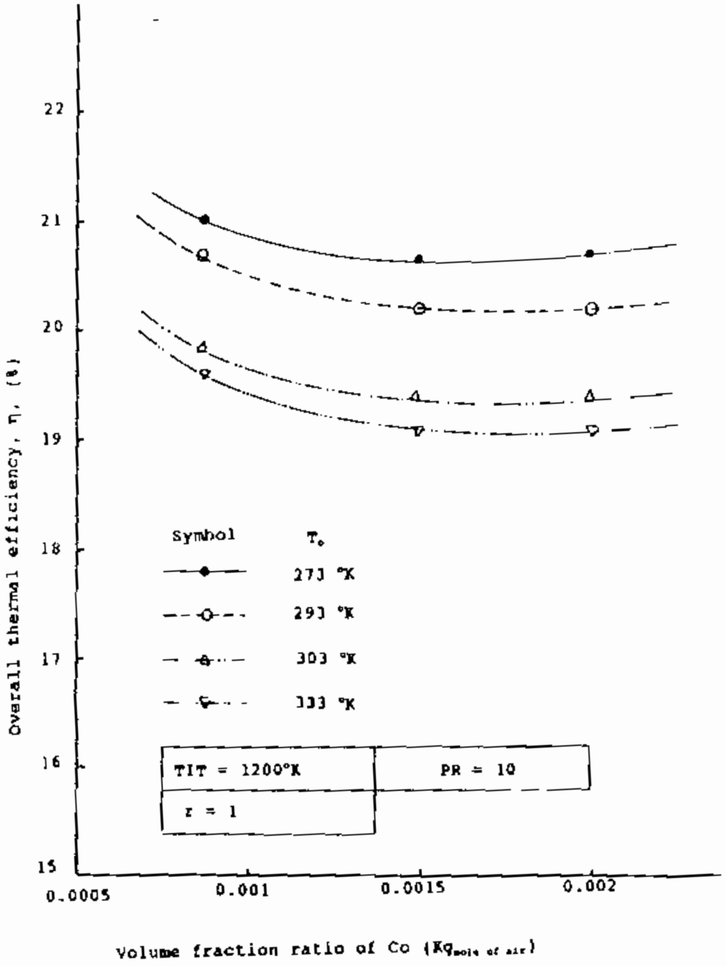


Fig.(11): Variation of overall thermal efficiency with the Co, volume ratios due to the polluted environment.

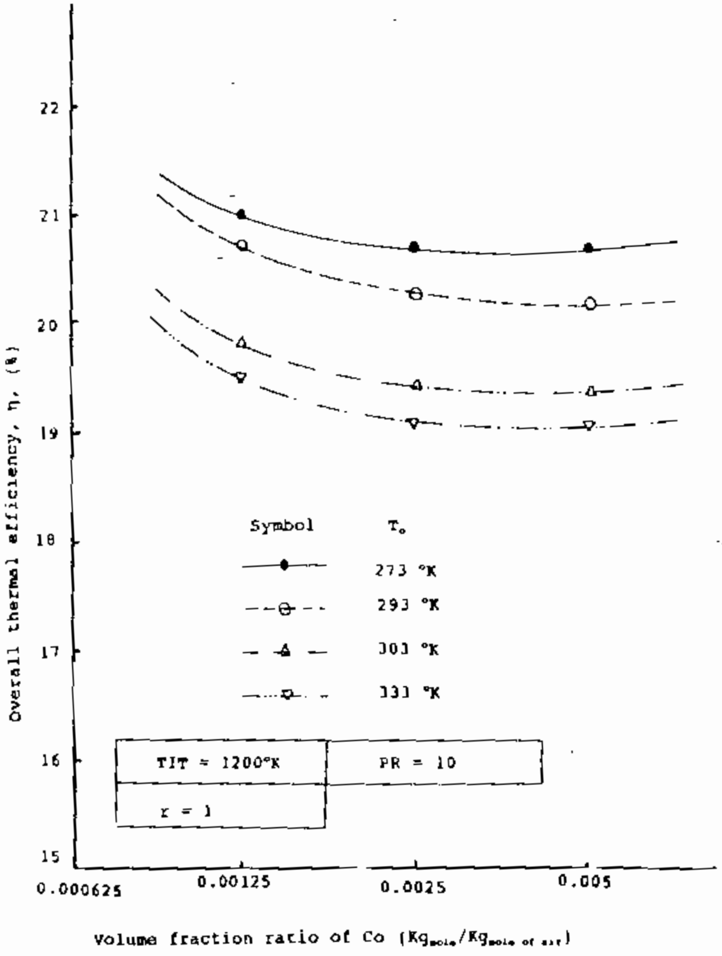


Fig.(12): Variation of overall thermal efficiency with the volume fraction ratios of CO_2, due to the polluted environment.