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An Investigation on Gas Turbine with Mathematical Equations

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ABSTRACT:-

This paper was displayed the Mathematical investigation of thermodynamic execution on gas turbine power plant. The variety of working conditions (pressure proportion, turbine gulf and fumes temperature, air to fuel proportion, isentropic compressor and turbine effectiveness, and encompassing temperature) on the execution of gas turbine (warm effectiveness, compressor work, power, particular fuel utilization, heat rate) were examined. The expository recipe for the particular work and productivity were determined what's more, broke down. The programming of execution model for gas turbine was created using the MATLAB programming and mathematical equations. The outcomes demonstrate that the pressure proportion, encompassing temperature, air to fuel proportion and also the isentropic efficiencies are emphatically impact on the warm effectiveness. Moreover, the warm productivity and force yield diminishes straightly with expansion of the encompassing temperature and air to fuel proportion. In any case, the particular fuel utilization and warmth rate increments straightly with expansion of both surrounding temperature and air to fuel proportion. Along these lines the thermodynamic parameters on cycle execution are financially achievable and valuable for the gas turbine operations.

Key words: Gas turbine; compression ratio; air to fuel ratio; thermal efficiency; power; turbine inlet temperature.

INTRODUCTION

The gas turbine (GT) performance is affected by component efficiencies and turbine working temperature. The effect of temperature is very predominant for every 56°C increase in temperature; the work output increases approximately 10% and gives about 1.5% increase in efficiency (Johnke and Mast, 2002). Overall efficiency of the gas turbine cycle depends primarily upon the pressure ratio of the compressor. It is important to realize that in the gas turbine the processes of compression, combustion and expansion do not occur in a single component as they occurred in a reciprocating engine. It is well known that the performance can be qualified with respect to its efficiency, power output, specific fuel consumption as well as work ratio. There are several parameters that affect its performance including the com-pressor compression ratio, combustion inlet temperature and turbine inlet temperature (TIT) (Mahmood and Mahdi, 2009, Rahman et al., 2010). Taniquchi and Miyamae (2000) were carried out the study on the effects of ambient temperature, ambient pressure as well as the temperature of exhaust gases on performance of gas turbine as shown in Figure 1. There is an obvious drop in the power output as the ambient air temperature increases, if an increase of intake air ambient temperature from ISO condition 15 to 30°C which is 10% decrease in the net power output. This is particularly relevant in tropical climates where the temperature varies 25 to 35°C throughout the year (Boonnasa et al., 2006).The for the most part elegant approach to enhance the limit of the consolidated cycle power plant is to bring down the admission air temperature to around 15°C (ISO) and relative moistness (RH) of 100% preceding entering the air compressor of the gas turbine (Mohanty and Paloso, 1995; Ibrahim et al., 2010). As a rule, the operation conditions for the gas turbine module are measured to compute the yield power and the proficiency (Horlock et al., 2003). However much of the time, the assessed parameters are not generally ideal inside the gas turbine. It is required to control the info parameters with the point of upgrading the execution of gas turbine. Clearly, these parameters have been really enhanced by different gas turbine produces as said above. In the interim, the working parameters including the pressure proportion, encompassing temperature, air to fuel proportion, turbine gulf temperature, and both compressor and turbine efficiencies on the execution of gas turbine power plant were done. Thus, a parametric study on the impact of operation conditions requires dealing with the operation states of the framework. In this manner, the point of the present work is to add to a procedure to decide the execution of gas turbine .

THERMODYNAMIC DEMONSTARING OF GAS TURBINE

The primary handy achievement was acquired by the Society Anonym des Turbomoteurs French Organization, which manufactured a gas turbine in 1905. This motor, the main consistent weight gas turbine to keep running under its own energy, had a proficiency of 3% which is utilized into the motor with multistage radiating compressor (20 stages or all the more) having a weight proportion of 4 and compressor productivity not more than 60% and also the most extreme gas temperature was around 393ºC. However there was a slip by of numerous years, until in 1939, a Chestnut Boveri (BBC) unit for crisis electrical-power supply was put into operation in Neuchatel, Switzerland (Figure 2). The force yield was 4000 kW and productivity of 18%. The turbine with delta temperature 550°C was given 15,400 kW at 3000 rpm (Zurcher et al., 1988). Essentially, the gas turbine power plants comprise of four segments including the compressor, burning chamber (CC), turbine and generator. A schematic graph for a straightforward gas turbine is appeared in Figure 3. The new environmental air is drawn into the circuit consistently and vitality is included by the ignition of the fuel in the working liquid itself. The results of burning are extended through the turbine which creates the work lastly releases to the environment. It is expected that the compressor productivity and the turbine proficiency are spoken to η_C and η_T individually. The perfect and genuine procedures on the temperature-entropy outline are spoken to in full and dashed line separately as appeared in (Figure 1).

The compressor pressure proportion (rp) can be characterized as

$$R_p = p_1 / p_2 \qquad (1)$$

where p_1 and p_2 are compressor inlet and outlet air pressure,

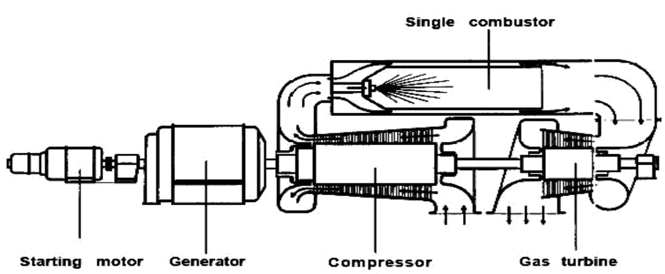

Figure 1. World's first industrial gas turbine set with single combustor (Zurcher et al., 1988).

The isentropic efficiency for compressor and turbine in the range of 85 to 90% is expressed as (Rahman et al., 2011):

$$\eta_C = \frac{T_{2s} - T_1}{T_2 - T_1} \qquad (2)$$

where T_1 and T_2 are compressor inlet and outlet air temperature respectively, and T_{2s} compressor isentropic out let temperature.

The final temperature of the compressor is calculated from Equation (3) (Rahman et al., 2010):

$$T_2 = T_1 \left[1 + \frac{r_p^{\frac{\gamma_a - 1}{\gamma_a}} - 1}{\eta_c} \right] \qquad (3)$$

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Therefore it can be simplified these relations by Equation (4):

$$Rpa = \frac{r_p^{\frac{\gamma_a - 1}{\gamma_a}} - 1}{\eta_c} \quad \text{and} \quad Rpg = 1 - \frac{1}{(r_p)^{\frac{\gamma_g - 1}{\gamma_g}}} \qquad (4)$$

where $\gamma_a = 1.4$ and $\gamma_g = 1.33$.

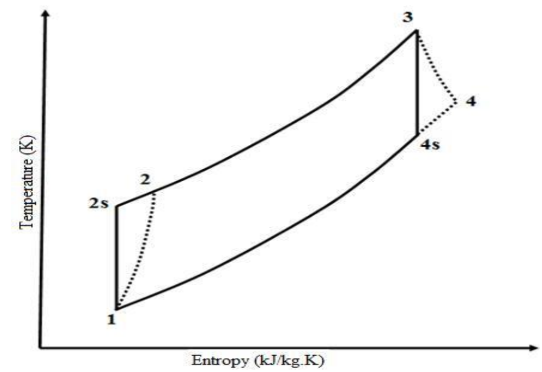

Figure 2. Temperature-Entropy diagram for gas turbine.

The work of the compressor (W_c) when blade cooling is not taken into account can be calculated as:

$$W_c = \frac{c_{pa} \cdot T_1 \left(r_p^{\frac{\gamma_a - 1}{\gamma_a}} - 1 \right)}{\eta_m \cdot \eta_c} = \frac{C_{pa} \cdot T_1 \cdot Rpa}{\eta_m} \qquad (5)$$

Where C_{pa} is specific heat of air which can be fitted by equation (6) for the range 200k<t<800k and mechanical efficiency of turbine

$$C_{pa} = 1.0189 \cdot 10^3 - 0.13784 T_a + 1.9843 \cdot 10^{-4} T_a^2 + 4.2399 \cdot 10^{-7} T_a^3 - 3.7632 \cdot 10^{-10} T_a^4 \qquad (6)$$

where $T_a = \frac{T_2 - T_1}{2}$ in Kelvin.

The specific heat of flue gas (C_{pg}) is given by Naradasu et al. (2007):

$$C_{pg} = 1.8083 - 2.3127 \cdot 10^{-3} T + 4.045 \cdot 10^{-6} T^2 - 1.7363 \cdot 10^{-9} T^3 \qquad (7)$$

From the energy balance in the combustion chamber is expressed as:

$$m_a C_{pa} T_2 + m_f \cdot LHV + m_f C_{pf} T_f = (m_a + m_f) C_{pg} \cdot TIT \quad (8)$$

where, m_f is fuel mass flow rate (kg/s), $\dot{m}_a$ is air mass flow rate (kg/s), LHV is low heating value, T_3 = TIT = turbine inlet temperature C_{pf} is specific heat of fuel anf T_f is temperature of fuel.

After manipulating Equation (8), the fuel air ratio (f) is expressed as:

$$f = \frac{\dot{m}_f}{\dot{m}_a} = \frac{C_{pg} \cdot TIT - C_{pa} T_2}{LHV - C_{pg} \cdot TIT} \quad (9)$$

The exhaust gases temperature from gas turbine is given by Eq. (10):

$$T_4 = T_3 \left(1 - \eta_t \cdot \left(1 - \frac{1}{r_p^{\frac{\gamma_g - 1}{\gamma_g}}}\right)\right) = T_3 \left(1 - \eta_t \cdot Rpg\right) \quad (10)$$

The shaft work (W_t) of the turbine is given by Equation (11):

$$W_t = C_{pg} \cdot TIT \cdot \eta_t \cdot Rpg / \eta_m \quad (11)$$

The network of the gas turbine (W $_{net}$) is calculated from the equation:

$$W_{net} = W_t - W_C \quad (12)$$

The output power from the turbine (*P*) is expressed as:

$$P = \dot{m}_a \cdot W_{net} \quad (13)$$

The specific fuel consumption (*SFC*) is determined by Equation (13):

$$SFC = \frac{3600\, f}{W_{net}} \quad (14)$$

The heat supplied is also expressed as:

$$Q_{add} = C_{pg\,m} (TIT - T_1 (1 + Rpa)) \quad (15)$$

The gas turbine efficiency (η_{th}) can be determined by Equation (15) (Ibrahim et al., 2010):

$$\eta_{th} = \frac{W_{net}}{Q_{add}} \quad (16)$$

$$HR = \frac{3600}{\eta_{th}} \quad (17)$$

RESULTS AND DISCUSSION

The parameter influence in terms of compression ratio, turbine inlet temperature, air to fuel ratio, and ambient temperature on the performance of gas turbine cycle power plant are presented in this section. The effects of operation conditions on the power output and efficiency are obtained by the energy-balance utilizing MATLAB10 software. The flowchart of simulation of performance process for simple gas turbine power plant is shown in Figure 5.

Effect of compression ratio

Figure 6a presents a relation between the gas turbine cycle thermal efficiency versus compression ratios for different turbine inlet temperature. It can be seen that the thermal efficiency increases with compression ratio at higher turbine inlet temperature. The deviation of thermal efficiency at lower compression ratio is not significant while the variation at higher compression ratio is vital for thermal efficiency. The certain limit depends on the turbine inlet temperature which reveals an ejective relationship as the efficiency increases as turbine inlet temperature increases. Also the thermal efficiency in-crease with increase the compression ratio and decrease the ambient temperature as shown in Figure 6b, but the increase in the air to fuel ratio cause low decrease in the thermal efficiency comparing with effect the compression ratio that caused high increased in the thermal efficiency as shown in Figure 7. Figure 8 present the effect of compression ratio on compressor work, this work increase with increase the compression ratio and the ambient temperature.

Figure 9a shows the effect of compression ratio on the thermal efficiency with variation isentropic compressor efficiency. Note that the thermal efficiency is increased with compression ratio and isentropic compressor efficiency. Also the increased in compression ratio and isentropic turbine efficiency caused increased in the thermal efficiency as shown in Figure 9b. Figure 10 represented the relation between the thermal efficiency and turbine inlet temperatures for five values of air to fuel ratio (40 to 56 kg air/fuel) and six values compression ratios (3 to 23). Thermal efficiency has an ejective relationship with turbine inlet temperature, the efficiency

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increases when turbine inlet temperature increases.

The heat rate (HR)

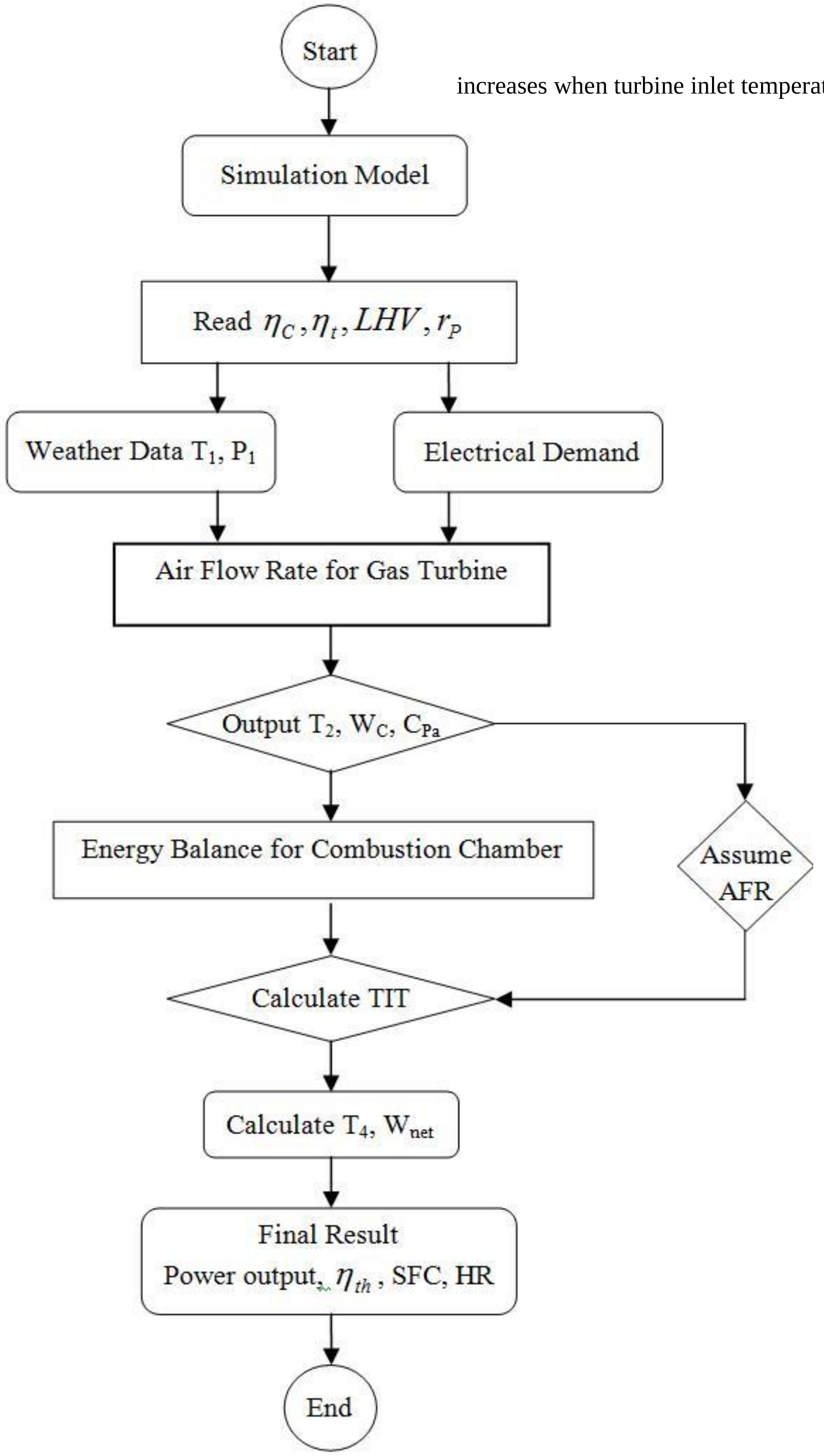

Figure 3. Flowchart of simulation of performance process for simple gas turbine power

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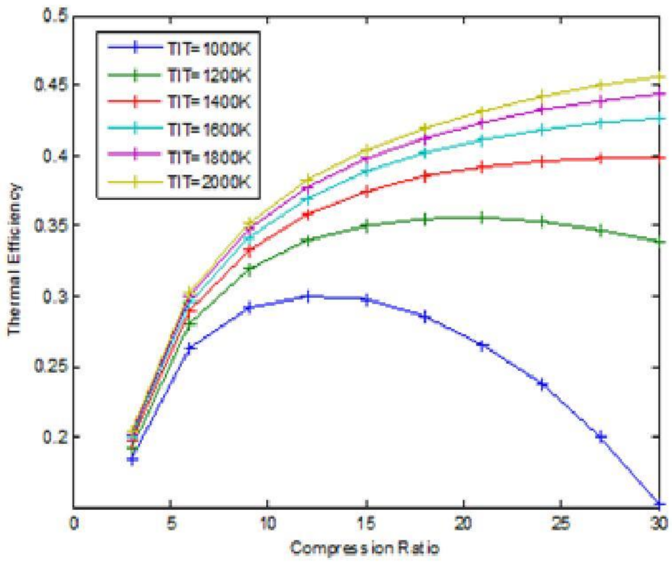
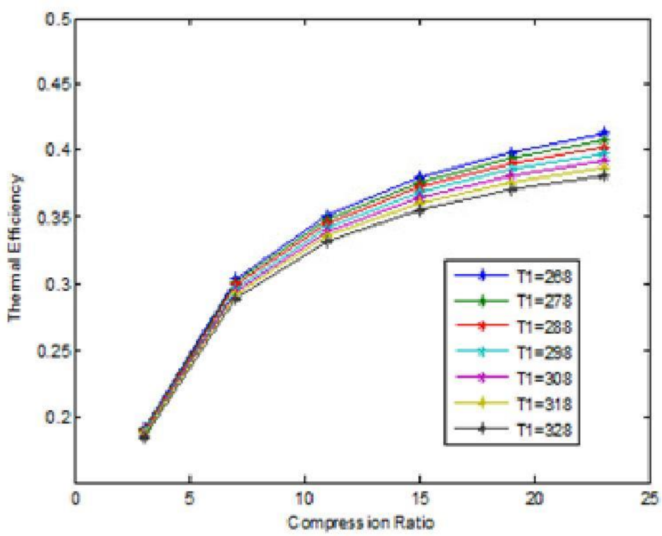


(a) Turbine inlet temperature



(b) Ambient temperature

Figure 5. Variation of compression ratio, turbine inlet temperature and ambient temperature on thermal efficiency.

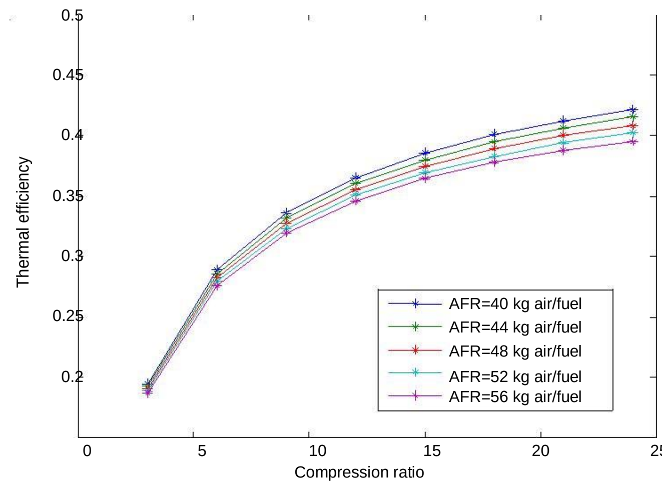


Figure 4. Variation of compression ratio and air to fuel ratio on thermal efficiency.

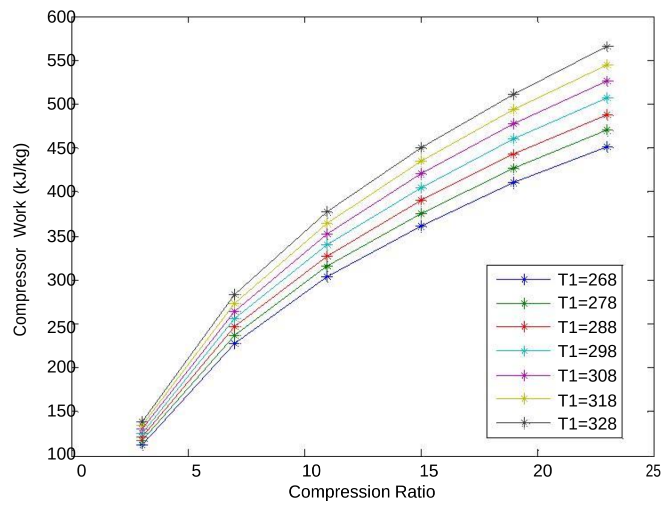


Figure 6. Effect of compression ratio and ambient temperature on compressor work.

effectiveness and turbine gulf temperature.

Impact of surrounding temperature

Figure 4 demonstrate that the gas turbine warm effectiveness is influenced by surrounding temperature because of the change of air thickness and compressor work subsequent to; a lower encompassing temperature prompts a higher air thickness and a lower compressor work that thusly gives a higher gas turbine output power as shown in Figure5 . Figure 4 shows that at

The point when the encompassing temperature expands the warm productivity diminishes. This is on account of, the air mass stream rate gulf to compressor increments with lessening of the surrounding temperature. In this way, the fuel mass stream rate will increment, since air to fuel proportion is kept steady. The force increment is not as much as that of the gulf compressor air mass stream rate; in this way, the particular fuel consumption increments with the expansion of encompassing temperature. This happens due to expanded misfortunes because of the expanded measure of pipe gasses. The yield power from

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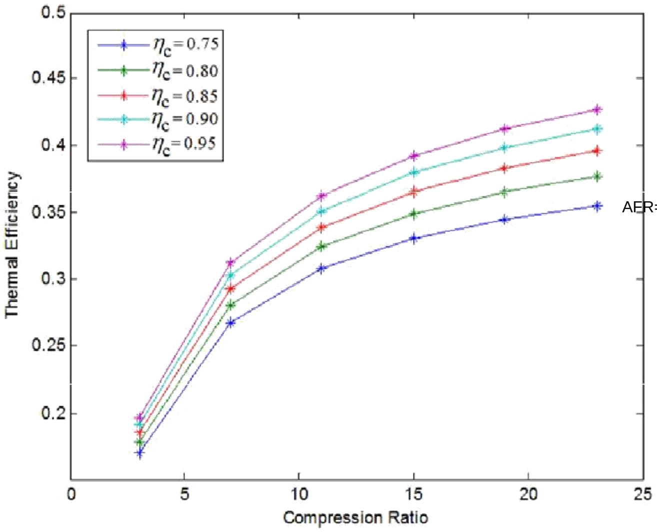


(a)

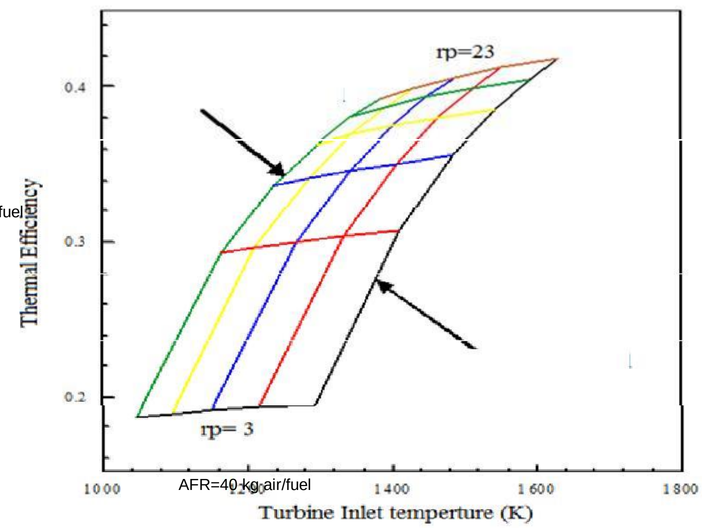
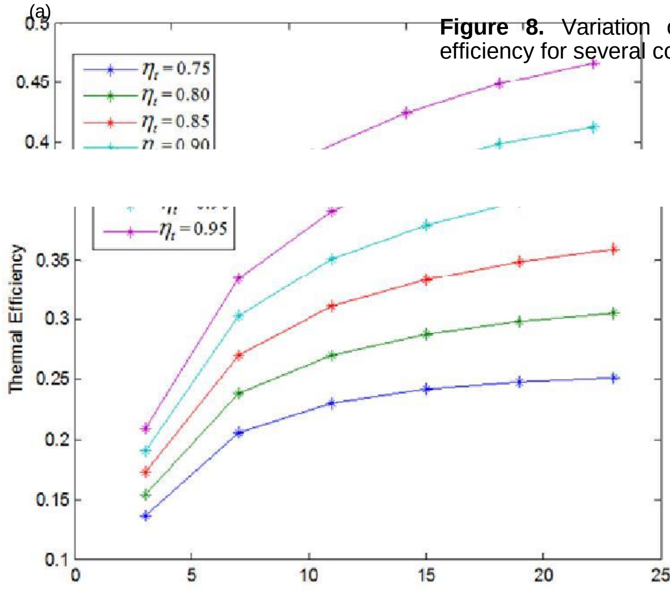


Figure 8. Variation of turbine inlet temperatures with thermal efficiency for several compression ratio and air to fuel ratio.



(b)

Figure 7. Variation of compression ratio, isentropic compressor efficiency and isentropic turbine efficiency on thermal efficiency. (a) Isentropic compressor efficiency (b) Isentropic turbine efficiency.

reenactment model is higher than the commonsense information from Baiji gas turbine power plant as appeared in Figure 7. In any case, expanded the encompassing temperature and expanded the air to fuel proportion brought about expanded of particular fuel utilization and warmth rate as appeared in Figures 8 and 9.

Figure 9 demonstrated impact of air to fuel proportion on warm productivity with variety encompassing temperatures. The warm productivity diminishes with expansion the air to fuel

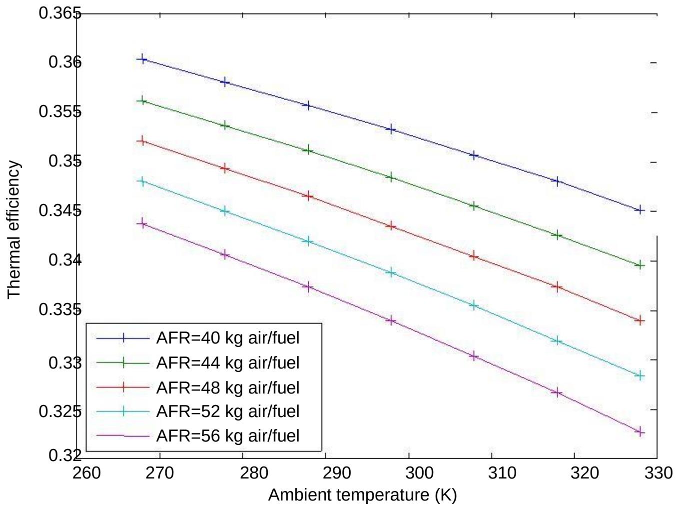


Figure 9. Effect of ambient temperature and air to fuel ratio on thermal efficiency.

fuel proportion since expansions the vent gasses misfortunes, however the particular fuel utilization expanded with expansion air to fuel proportion as appeared in Figure 10. Figure 11 speak to the variety of fumes temperatures with warm effectiveness for a few encompassing temperature and air to fuel proportion. Noticed the warm proficiency is expanded with reduction the encompassing temperature and air to fuel proportion, yet the warm effectiveness diminishes with expansion the fumes temperature.

The warm productivity diminishes with expansions the

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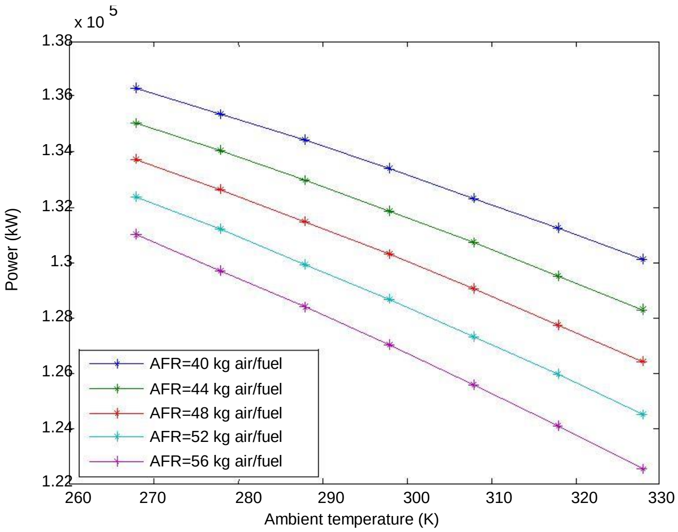

Figure 10. Effect of ambient temperature and air to fuel ratio on power.

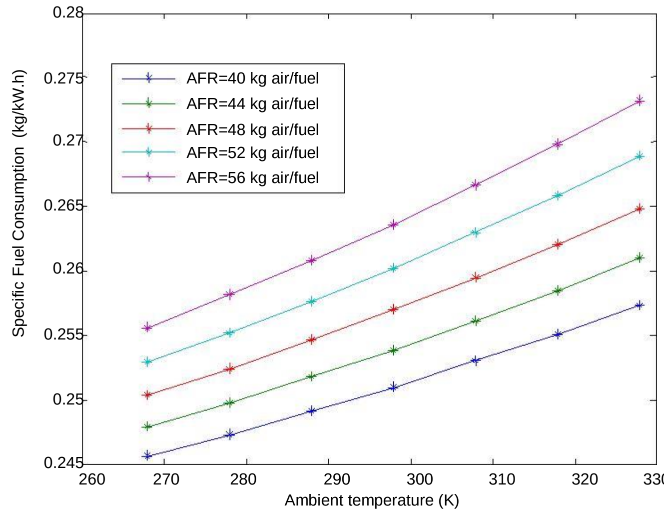

Figure 12. Effect of ambient temperature and air to fuel ratio on specific fuel consumption.

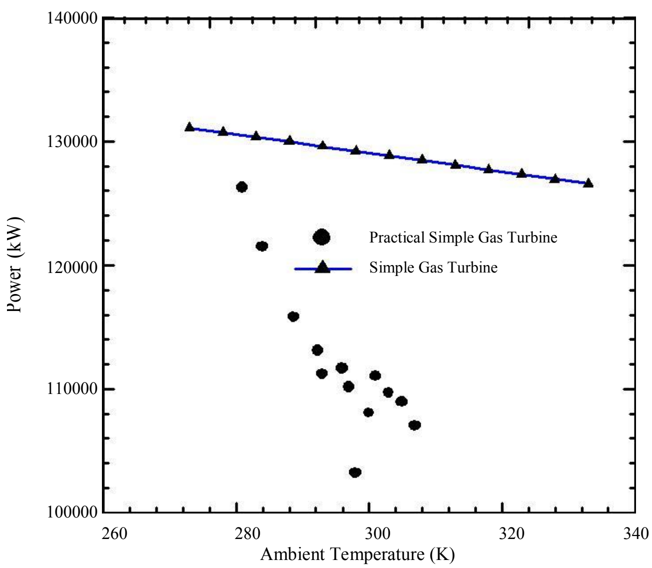

Figure 11. Effect of ambient temperature on power output.

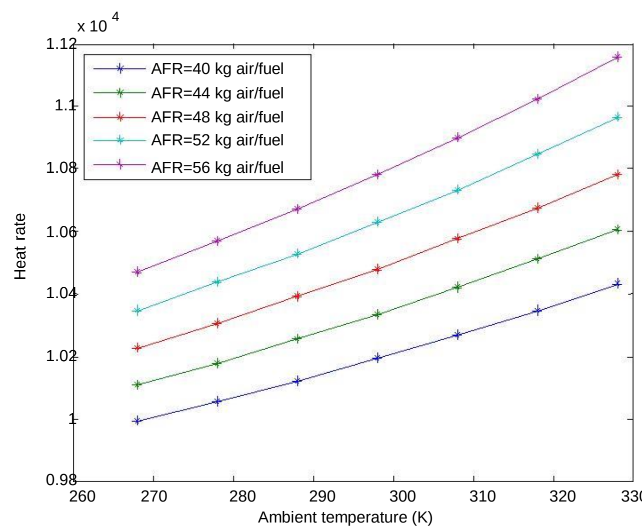

Figure 13. Effect of ambient temperature and air to fuel ratio on heat rate.

debilitate temperature. Impact of compressor and turbine efficiencies Figures 12 and 13 highlight the impact of the compressor and turbine isentropic efficiencies on the warm effectiveness for various air fuel proportion. The warm effectiveness increment with expansion the compressor and turbine isentropic efficiencies, this is mean the warm misfortunes have been diminished in both compressor and turbine individually, this lead to expanded force yield.

Dialog (discussion)

The productivity and force yield of gas turbine relies on upon the operation conditions were exhibited in before area. The variety of warm effectiveness at higher

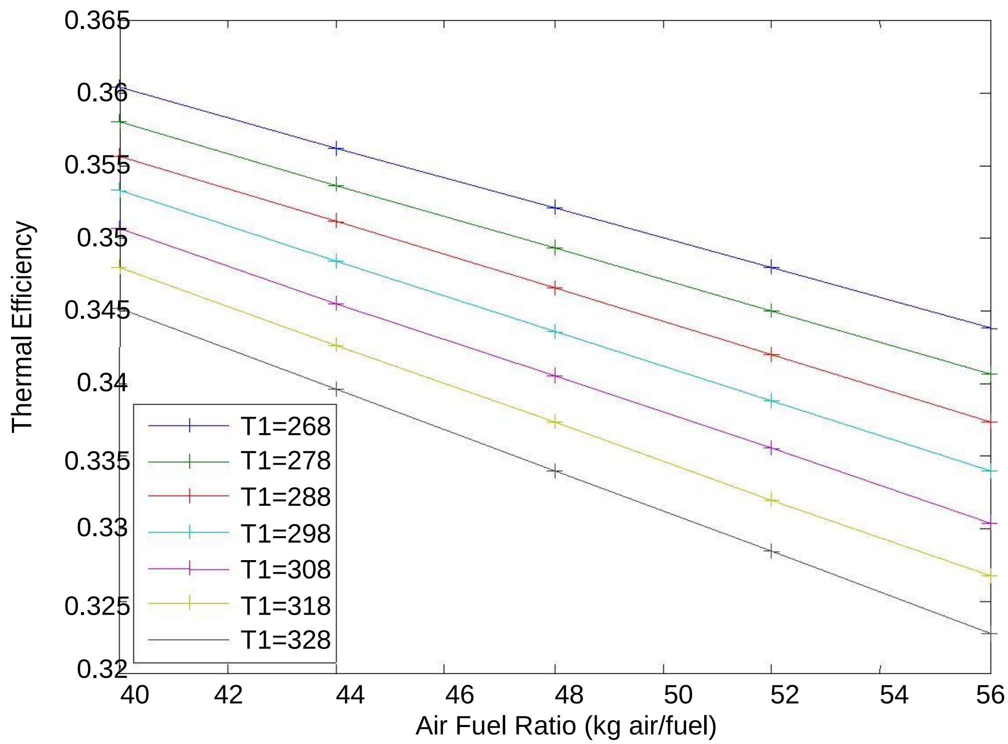

Figure 14. Effect of air to fuel ratio and ambient temperature on thermal efficiency.

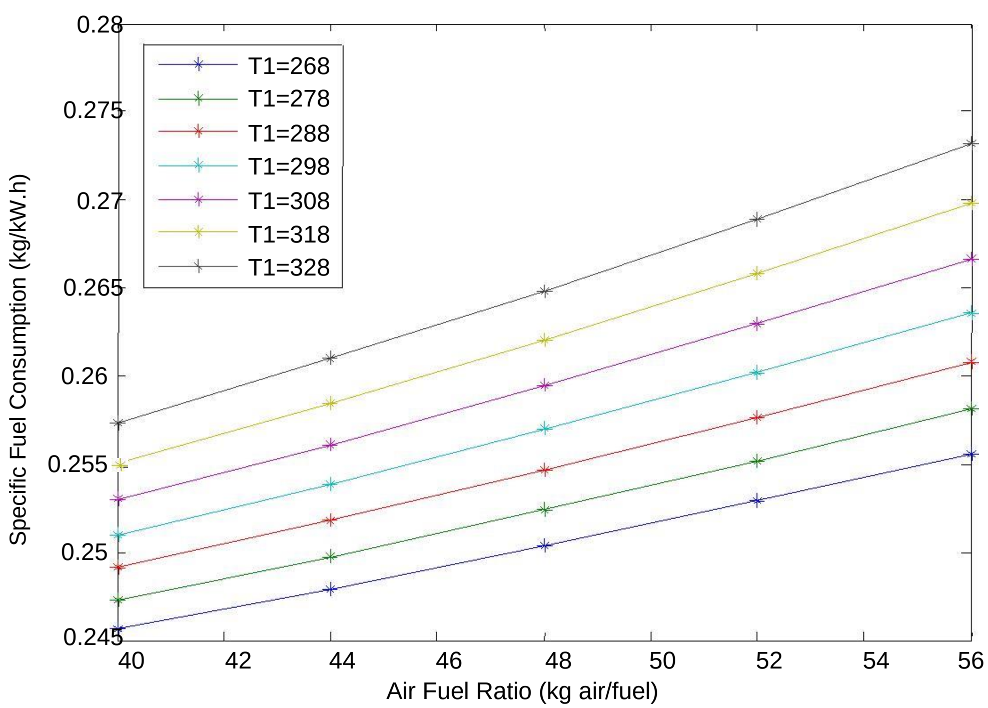

Figure 15. Effect of air to fuel ratio ambient temperature on specific fuel consumption.

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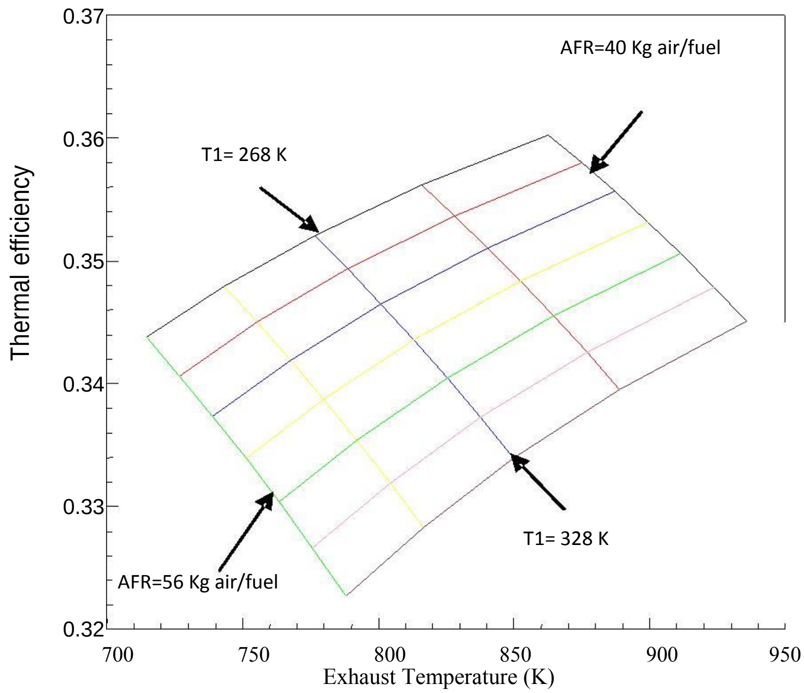

Figure 16. Variation of exhaust temperatures with thermal efficiency for several ambient temperature and air to fuel ratio.

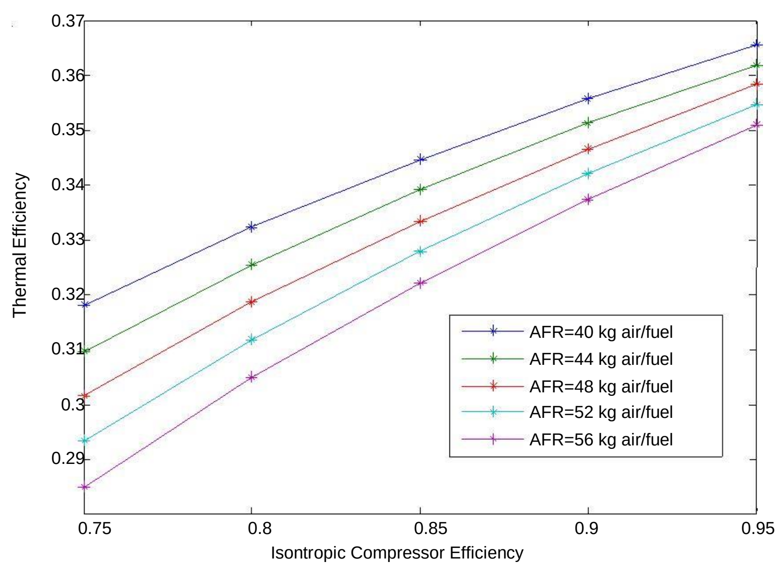

Figure 17. Effect of isentropic compressor efficiency air to fuel ratio on thermal efficiency.

pressure proportion and encompassing temperature are extremely vital. The warm effectiveness is influenced by encompassing temperature because of the change of air thickness and compressor work following a lower encompassing temperature prompts a higher air thickness and a lower compressor work that thusly gives a higher gas turbine yield power

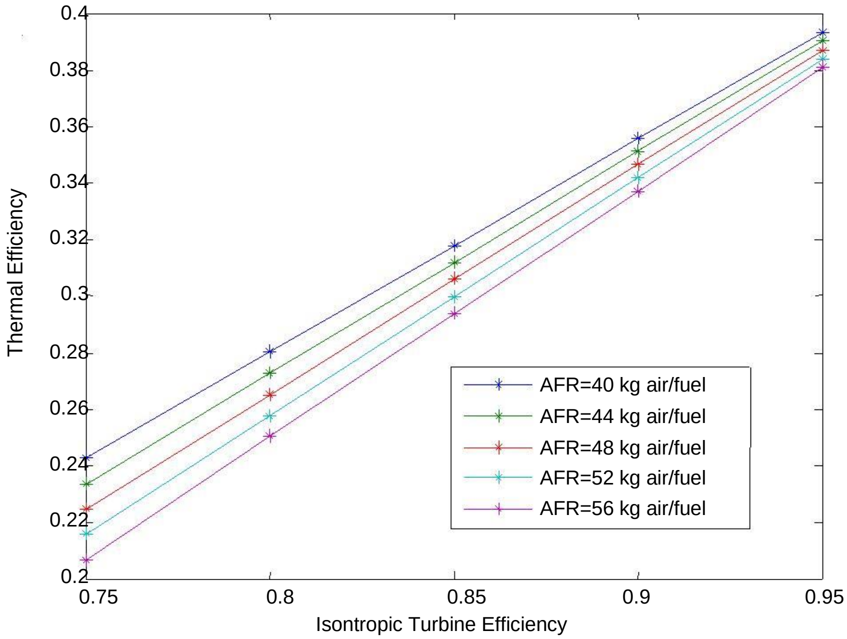

Figure 18. Effect of isentropic turbine efficiency air to fuel ratio on thermal efficiency.

as appeared in Figure 11. The expansions of encompassing temperature lead to diminish the warm proficiency. It can likewise be seen that the particular fuel utilization increments with expansion of air to fuel proportion and surrounding temperature in view of the air mass stream rate channel to compressor increments with reduction of the encompassing temperature. In this way, the fuel mass stream rate increments since the air to fuel proportion is kept consistent. The variety of force out is not as much as that of the bay compressor air mass stream rate. In this manner, the particular fuel utilization increments with the expansion of surrounding temperature because of the pipe gasses misfortunes. The expansion in pressure proportion for gas turbine power plant lead to a consistent increment of warm effectiveness and this outcome move the gas turbine power plant to achieves the most elevated productivity and after that starts to diminish. Accordingly, the general improvement of the impact of operation conditions on productivity of gas turbine can be exceptionally positive, particularly while thinking about how possible it is to take advantage from expansion turbine channel temperature and afterward build the yield power and the warm effectiveness.

CONCLUSION

The reenactment result from the displaying of the impact of parameter demonstrated that pressure proportion, surrounding temperature, air to fuel proportion and turbine channel temperature impact on execution of gas turbine power plant. The outcomes were compressed as takes after:

1. The pressure proportions, surrounding temperature, air to fuel proportion and in addition the isentropic efficiencies are unequivocally impact on the warm proficiency of the gas turbine power plant.

2. The variety of warm proficiency at higher pressure proportion, turbine bay temperature and encompassing temperature are essential.

3. The warm proficiency and force yield diminishes directly with expansion of surrounding temperature and in addition the air to fuel proportion.

4. The particular fuel utilization and warmth rate increment straightly with expansion of both surrounding temperature and air to fuel proportion.

5. The top proficiency, force and particular fuel utilization happen at higher pressure proportion with low surrounding temperature.

REFERENCES

[1] Al-Sayed AF (2008). Aircraft Propulsion and Gas Turbine Engines. Taylor and Francis, ISBN 978-0-8493-9196-5.

[2] Boonnasa S, Namprakai P, Muangnapoh T (2006). Performance

[3] improvement of the combined cycle power plant by intake air cooling

[4] using an absorption chiller. Energy, 31(12): 2036-2046.

[5] Horlock JH (2003). Advance Gas Turbine Cycles. Elsevier Sci. Ltd., UK. Ibrahim TK, Rahman MM, Alla AN (2010). Study on the effective parameter of gas turbine model with intercooled compression process.

[6] Sci. Res. Essays, 5(23): 3760-3770.

[7] Johnke T, Mast M (2002). Gas Turbine Power Boosters to enhance power output. Siemens Power for generation, Siemens Power J.

[8] Mahmood FG, Mahdi DD (2009). A new approach for enhancing performance of a gas turbine (Case study: Khangiran Refinery). Appl. Energy, 86: 2750–2759.

[9] Mohanty B, Paloso G (1995). Enhancing gas-turbine performance by intake air cooling using an absorption chiller. Heat Recovery Sys.

[10] CHP, 15(1): 41-50.

[11] Naradasu RK, Konijeti RK, Alluru VR (2007). Thermodynamic analysis of heat recovery steam generator in combined cycle power plant. Therm. Sci., 11(4): 143-156.

[12] Rahman MM, Ibrahim TK, Kadirgama K, Mamat R, Bakar RA (2011). Influence of operation conditions and ambient temperature on performance of gas turbine power plant. Adv. Mater. Res., 189-193: 3007-3013.

[13] Rahman MM, Ibrahim TK, Taib MY, Noor MM, Kadirgama K, Bakar RA (2010). Thermal analysis of open-cycle regenerator gas-turbine power-plant. WASET. 68: 94-99.

[14] Saravanamuttoo H, Rogers G, Cohen H, Straznicky P (2009). Gas Turbine Theory. Prentice Hall, ISBN 978-0-13-222437-6.

[15] Taniquchi H, Miyamae S (2000). Power generation analysis for high temperature gas turbine in thermodynamic process. J. Propul. Power. 16: 557-561.

[16] Zurcher U, Badoux JC, Mussard M (1988). The world's first industrial gas turbine set at Neuchatel. An International Historic Mechanical Engineering Significance of Landmark, September 2, Neuchatel Switzerland, ASME.