MAE 570 – Intermediate Thermodynamics

Project Report

Topic: Thermodynamics Project-3

(Exergy Analysis of a Thermal Power Plant)

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Content

- **ABSTRACT**
- **INTRODUCTION**
- **METHODOLOGY**
- **RESULTS**
- **GRAPHS**
- **CONCLUSION**
- **APPENDIX - A**

ABSTRACT

Research on the exergy analysis of a thermal power plant is presented in this article. The heat balance diagrams for the power plant were used to know the model, which was taken from an online resource. In order to simulate the power plant, user-defined environmental factors and fuel are used (processed natural gas). The results show that both thermal and exergy efficiency fall between 36% and 35%, respectively. The primary focus of the investigation into energy losses at all components was combustion processes. The deaerator showed the lowest exergy loss (0.1%), while the combustor had the highest exergy loss (29.22%). It has been found that a variety of factors influence energy efficiency. MATLAB is used for calculation.

INTRODUCTION

The thermal power industry provides a significant of the world's energy requirements. In power plants that can produce up to 2000 MW of power, steam is a working fluid. Most power has a maximum efficiency of about 35% due to thermodynamics constraints. However, steam turbine power plants have a maximum efficiency of about 50%. A steam turbine power plant typically consists of a combustor, a steam generator, turbines, condensers, pumps, reheaters, and a deaerator They use coal and natural gas as fuel. Due to coal's high carbon and ash content, a switch has been made to other fuels that are far less damaging. The v alue of readily available energy is determined by the exergy analysis. It is to point to the location where useful energy is destroyed.

The generator is where the most energy is destroyed, according to the observation. It was discovered that efficiency increased as steam temperature and pressure increased. On the other side, it was found that efficiency decreased with increasing condenser pressure. Proper maintenance, such as regular cleaning of the condenser pipes, can lead to increased efficiency. Analyzing the gases emitted into the atmosphere can give us an idea of how harmful such power plants can be to the environment.

METHODOLOGY

- All calculations related to exergy are based on the standard concepts of exergy balance and some are based on energy conservation.
- Some of the notations and equations have been referred from Boles.

Energy balance equation
Assumption steady flow system

$$\sum_{in} \dot{E} = \sum_{out} \dot{E} \qquad (1)$$

The equation for a stream,

$$\dot{Q} - \dot{W} = \dot{m}\left[h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right] \qquad (2)$$

Now the Exergy balance in a steady flow system

$$\dot{X}_{in} - \dot{X}_{out} - \dot{X}_{destroyed} = 0 \qquad (3)$$

$$\dot{X}_{heat} = \left(1 - \frac{T_0}{T}\right)\dot{Q} \quad (4)$$

$$\dot{X}_{work} = \dot{W}_{useful} \quad (5)$$

$$\dot{X}_{mass} = \dot{m}\psi \quad (6) \quad \text{Where, } \psi = (h - h_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$$

$$\dot{X}_{destroyed} = T_0\dot{S}_{gen} \quad (7)$$

The maximum possible work, in a combustion process that does not involve any work, is equal to the exergy destroyed, and can be calculated as follows:

$$\dot{W}_{rev} = \dot{X}_{destroyed} = \sum N_r\left(\bar{h}_f^0 + \bar{h} - \bar{h}^0 + T_0\bar{s}\right)_r - \sum N_p\left(\bar{h}_f^0 + \bar{h} - \bar{h}^0 + T_0\bar{s}\right)_p \quad (8)$$

$$\eta_I = \frac{W_{useful}}{Q_{input}} \quad (9)$$

$$\eta_{II} = \frac{W_{useful}}{W_{reversible}} = \frac{\eta_I}{\eta_{I reversible}} = \frac{X_{recovered}}{X_{supplied}} \quad (10)$$

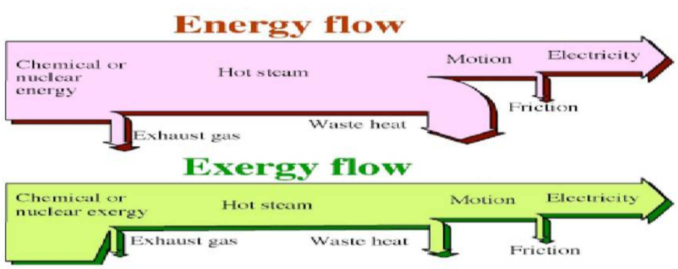

Fig-refered-Energy-and-exergy-flow-diagrams-of-a-thermal-power-slation_

The turbines, feed water heaters, condenser, deaerator, combustion chamber, and turbines make up the power plant under inquiry. Exergy analysis was carried out to determine the amount of exergy lost at various state points. The impact of many factors on energy efficiency, including condenser pressure, steam temperature, ambient temperature, etc., was examined. Environmental analysis was also conducted to some extent in order to determine the types of gases discharged into the environment and the potential harm that a power plant of this type could cause. Below is a sample of a model.

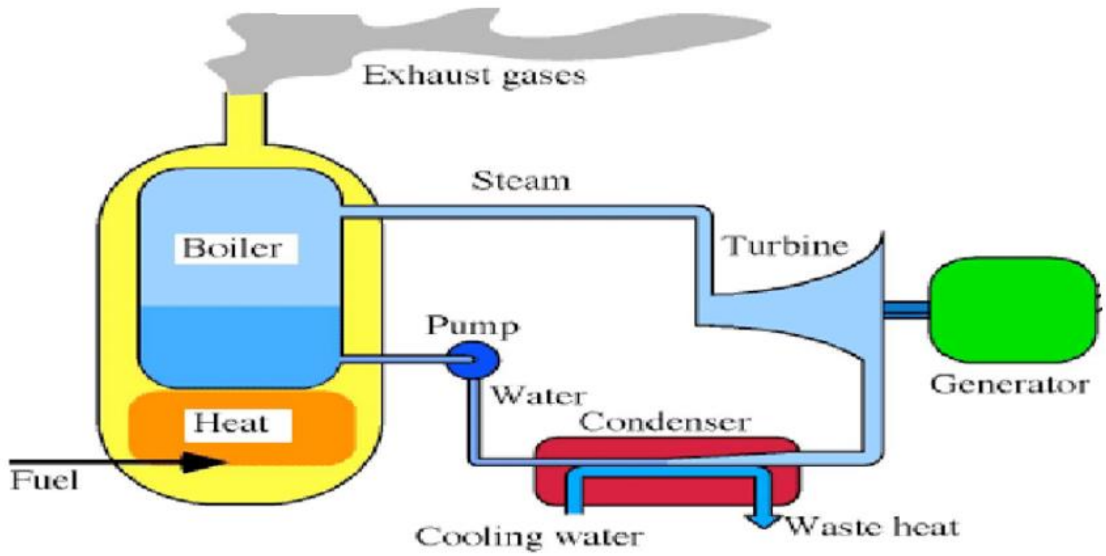

Figure 1: Process flow diagram
(Fig-refered-Energy-and-exergy-flow-diagrams-of-a-thermal-power-slation_fig2_49467074)

Pumps and turbine with isentropic efficiency the taken as 92% and 95%, respectively. The blue lines depict steam pipelines. Pipelines that carry steam in mixed state or water are depicted in blue.

The composition of processed gas (mixture of methane and ethylene) and atmospheric air is given below. The composition of gas was obtained from Natural Gas Specs Sheet, naesb.org.

Composition of processed Gas components CH4, C2H2, CO2, N2 with mass % of 88.56, 9.17, 9.17, 0.42, 0.65, 1.2 respectively. ie. Total= 100

Composition of atmospheric air components Ar, CO2, H2O, N2, O2 with Mole % of 0.9, 0.03, 3.12, 75.63, 20.3 respectively. Ie. Total =100.

RESULTS AND RELATED DISCUSSION

Exergy efficiency was found to be 33.358%. Exergy loss across various components of the power plant has been depicted in the table given below. The exergy loss was calculated by MATLAB and excel manipulation. It uses equations (3) – (8) to calculate the exergy losses at various state points.

Component	Exergy Loss (%)
Turbines	2.3
Condenser	4.31
Stack	5.7
Combustor	29.22
Steam Generator	16.88
Feedwater heaters	0.64
De-aerator	0.1
Pumps	8.01
Total available exergy	33

Table1: Exergy lost at various components of the plant

Therefore, total exergy loss will be around 66 % to sum up the total of 100 %. Additionally, the impact of different parameters on the power plant's efficiency was researched. The graphs below show how the findings came out. Each graph's X-axis parameter, such as the air preheater's inlet air temperature or the combustion chamber's outlet temperature, was changed while remaining constant. This was done in order to determine the impact of each parameter on efficiency on its own.

GRAPHS

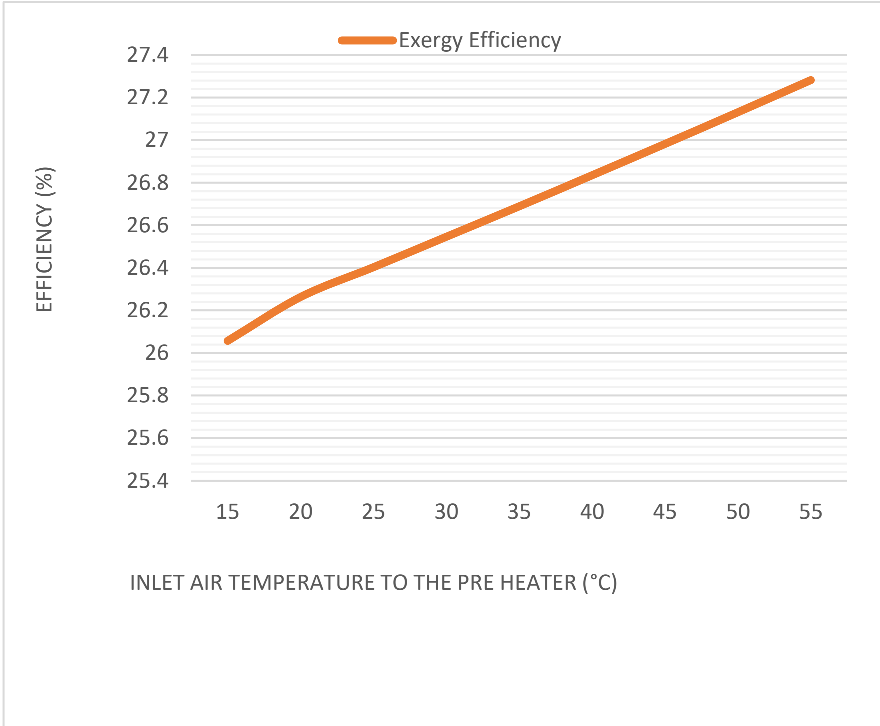

Figure 2. Effect of inlet air temperature to preheater

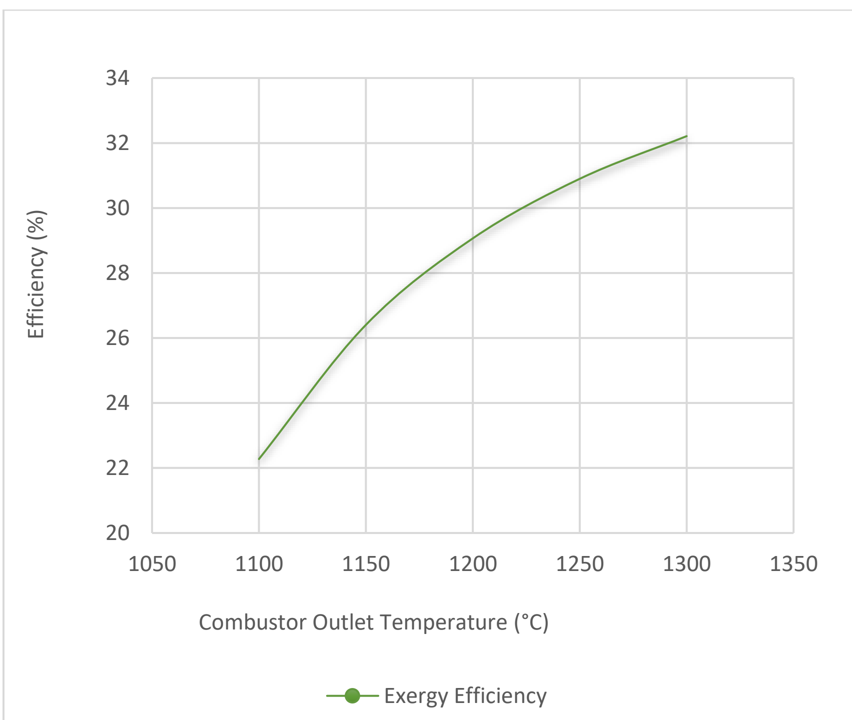

Figure 3. Effect of combustor outlet temperature

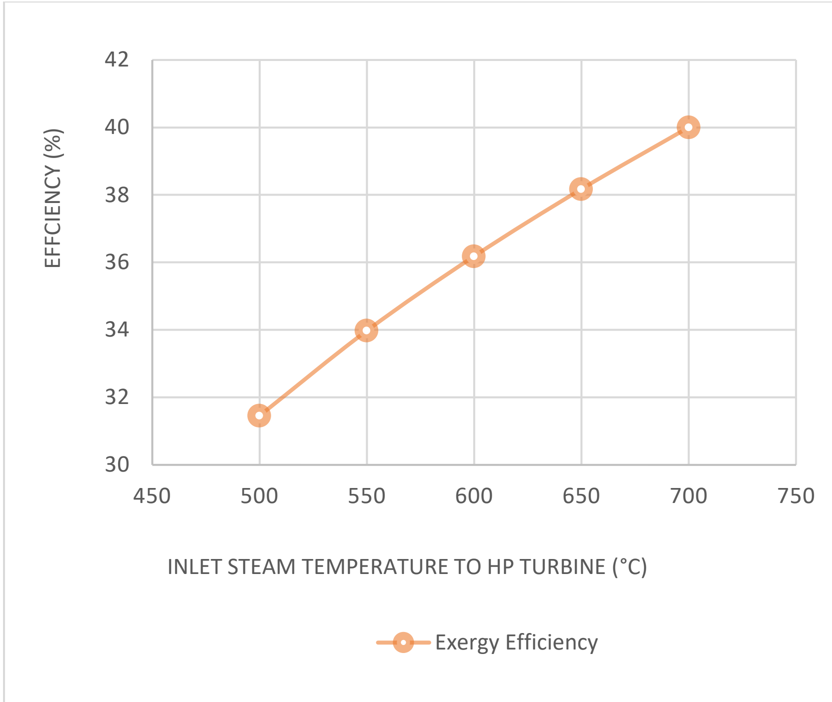

Figure 4. Effect of Inlet steam temperature to high pressure turbine

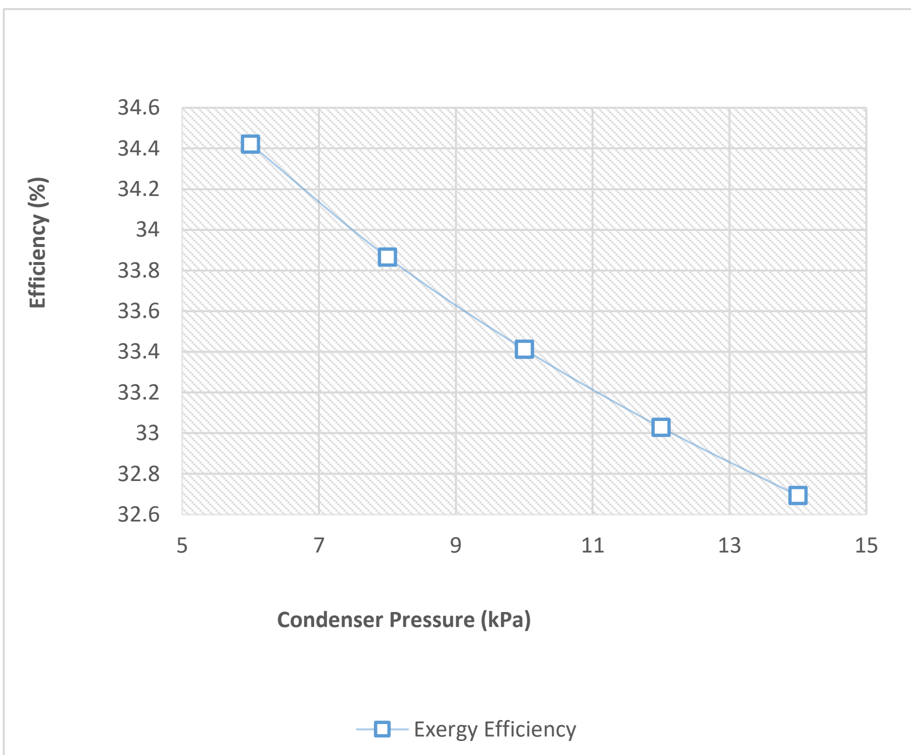

Figure 5. Effect of condenser pressure

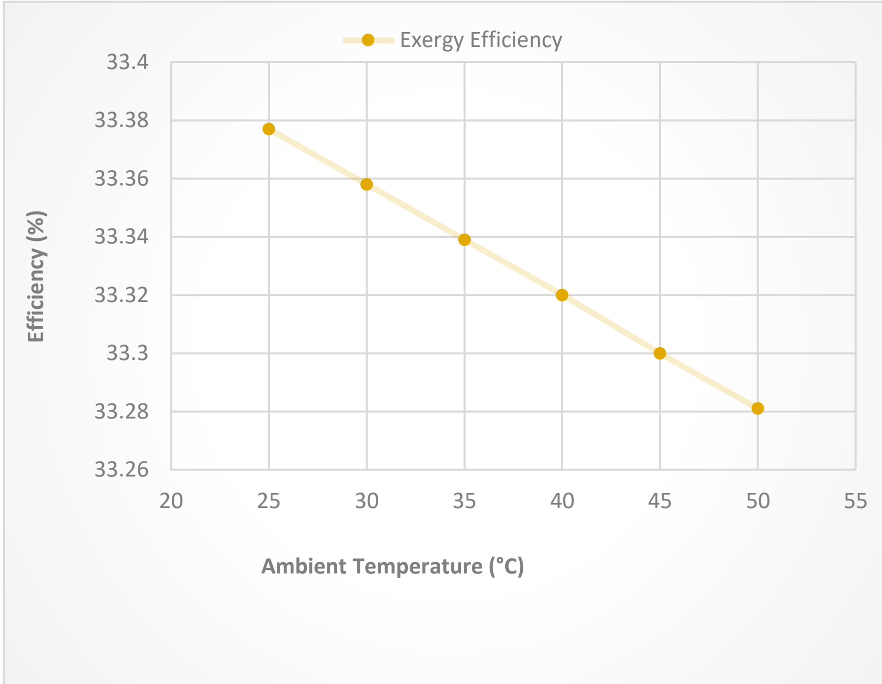

Figure 6. Effect of ambient temperature

It is discovered that efficiency rises as the air preheater's incoming air temperature rises (Figure 2). Less energy will be needed to preheat the air to the appropriate te mperature when the inlet air temperature rises. This boosts overall effectiveness. Efficiency has been observed to rise with an increase in combustor outlet temperat ure (Figure 3). This is due to the fact that increased combustion efficiency reduces energy loss in the combustor by increasing the combustor output temperature. The efficiency of the highpressure turbine rises as the steam temperature does (Fig ure 4). The saturation temperature of the system rises with rising incoming air; it w as discovered with an increase in condenser pressure (Figure 5).

The efficiency decreases when condenser pressure rises because it raises the condenser's mean temperature of heat rejection. For maximum efficiency, heat should be rejected at low temperatures and absorbed at high temperatures. Efficiency was discovered to rise when cooling water temperature gain in the condenser increased (Figure 5). The power plant's energy efficiency was shown to decline when the ambient temperature rose (Figure 6). This is because as ambient temperature rises, heat rejection occurs at a higher temperature. On the other hand, because it is unaffected by temperature or pressure, energy efficiency is unaffected by an increase in ambient temperature. Exergy is determined by the dead state; hence exergy efficiency varies with ambient temperature.

Below are some of the environmental analyses that were analyzed. These conclusions are drawn from an analysis of the gases flowing into the combustor by MATLAB. It has the ability to ascertain the mole fraction of the gases discharged into the atmosphere via the combustor. Calculating the mass fraction of each component involves multiplying the mole fraction by the ratio of the component's molecular mass to the mixture's molecular mass. The exhaust emissions are influenced by the fuel's composition. Both carbon and nitrogen monoxide are absent from the exhaust stream. Other gases may be present if the fuel is made of a different composition.

Component	**Mole fraction**	**Mass fraction**
CO_2	0.0503	0.1166
N_2	0.7353	0.7899
O_2	0.0989	0.2101
H_2O	0.1067	0.7669
Ar	0.0087	0.00123

Table 2: Mass fraction of the gases emitted

Conclusion

- The overall exergy efficiency of the given power plant was found to be 35.5%.
- Exergy analysis shows that maximum exergy loss took place at the combustor (29.22%), followed by the steam generator (16.88%). Exergy loss was minimum in the de-aerator (0.1%).
- Efficiency was found to increase with the increase in parameters like inlet air temperature to the combustor, combustor outlet temperature and steam inlet temperature at the high-pressure turbine.
- Energy efficiency is independent of the ambient temperature.
- Efficiency tends to decrease with an increase in condenser-pressure,

References

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- Yunus A Cengel and Michael A Boles, "Thermodynamics: An Engineering Approach", 6th Edition, Tata Mc Graw-Hill Companies. 2010.
- NAESB. Natural Gas Specs Sheet, 2004.
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Appendix- A

(MATLAB code for)

Exergy analysis of combustor (As **Primary component for loss in exergy**)

```
%%start of code%%

clc;
clear;
T_0 =  298;           %[K]
T_1 = 298;
X_0 = 0 ;
P_1 = 101.325;        %[KPa]
T_2 = 500;             %[K]
p_2= P_1;
p_3=500;           %[kPa]
T_3 = 350;         %[K]
T_4=283 ;          %[K]
P_4 = 200;         %[kPa]
P_5=200;           %[kPa]
m_1=1;             %[kg/s]
m_4=15;            %[kg/s]
m_5 = m_4 ;
m_3 = m_4;
"C2H2+3.5 O2+ 13.16 N2= 2CO2+ H2O+ O2+ 13.16 N2"; combustion process
n_C2H2=1 ;
n_O2= 3.5;
n_N2=13.16;
n_t=n_O2+n_N2;
y_O2=n_O2/n_t;
y_N2=n_N2/n_t;

%"Products"
n_p_CO2=2 ;
n_p_H2O=1;
n_p_O2=1;
n_p_N2=13.16;
n_p_t=n_p_CO2+n_p_H2O+n_p_O2+n_p_N2;
y_p_CO2=n_p_CO2/n_p_t;
y_p_H2O =n_p_H2O/n_p_t;
y_p_O2=n_p_O2/n_p_t ;
y_p_N2=n_p_N2/n_p_t;

% "Molar mass"
M_C2H2=2*12+2*1;
M_H2O=(2*1)+16;
M_p=y_p_CO2*(12+2*16)+y_p_H2O*(2+16)+y_p_O2*(32)+y_p_N2*(28);
M_air=y_O2*(32)+ y_N2*(28);

%"Enthalpy"
h_1=(n_C2H2*226730)/M_C2H2;    %t1 = 298
h_2=(n_O2*14770)+(n_N2*14581)/M_air; %t2 =500
h_3=(n_p_CO2*11351)+(n_p_H2O*11352)+(n_p_O2*10213)+(n_p_N2*10180)/M_p; %t3=350
```

```
h_4= 9297/M_H2O; %t4=280 for H2O

% "mass"
AF_r =(3.5*32+13.16*28)/(24+2);
m_2=m_1*AF_r;
% m_1+ m_2- m_3 == 0;

% "Thermal anaylsis"
% m_1*h_1+m_2*h_2+m_4*h_4-m_3*h_3-m_5*h_5 == 0;
h5=h_4*M_H2O;

% "Entropy"
s_1=200.85/M_C2H2;
s_2=n_O2*200.589+n_N2*206.8*M_air;

% "products"

 s_3=(n_p_CO2*219.83)+(n_p_H2O*194.125)+(n_p_O2*209.765)+(n_p_N2*196.173)/M_p;
s_4=186.61/M_H2O;
s_5=s_4;

% s(5)=entropy(water, P=P_5,h=h_5)/M_H2O;

%"gases"
Delta_psi_g=m_1*(h_1-T_0*s_1)+m_2*(h_2-T_0*s_2)-m_3*(h_3-T_0*s_3);
Delat_psi_s=m_4*(h_4-T_0*s_4)-m_5*(h5-T_0*s_4);
% Delta_psi_g+ Delat_psi_s-psi_d_t == 0;
eta_exe_t=abs(Delat_psi_s)/abs(Delta_psi_g)
```

%% Answer

```
eta_exe_t = 3.5417e-01 *100

eta_exe_t = 35.04



%% End of Code%%
```