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EXERGY ANALYSIS IN BOILER OF AN EXPRIMENTAL POWER PLANT

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Abstract. As we know boiler has the maximum part of irreversibility in steam power plant .In this research we have focused on exergy analysis of boiler of an experimental steam power plant. In this experiments we have divided the boiler into three regions, (1: combustion, 2: heat transfer to water or steam and 3: exhaust) and calculated the irreversibility in each region .The experimental results show that the maximum part of irreversibility belongs to second region which is about 54.8% and for first region 39% and for third region 6% that occurs at maximum boiler pressure of 8 bar.

KeyWord**:irreversibility,exergy,steam powerplant,entropy**

1. Introduction

The increased awareness that the word energy resources are limited has caused some governments to reexamine their energy policies and take drastic measures in eliminating waste. It has also sparked interest in the scientific community to take a closer look at the energy conversion devices and to develop new techniques to better utilize the existing limited resources. The first law of thermodynamics deals with the quantity of energy and asserts that energy cannot be created or destroyed .This law merely serves as a necessary tool for bookkeeping of energy during a process and offers no challenges to the engineer. The second law, however, deals with the quality of energy. More specifically, it is concerned with the degradation of energy during a process, the entropy generation, the lost opportunities to do work; and it offers plenty of space for improvement.

The second law of thermodynamics has proved to be a very powerful tool in the optimization of complex thermodynamic systems. In this research, we examine the performance of an engineering device in light of the second law of thermodynamics. We start our discussion with the introduction of entropy generation and then we have discussed about reversible work and exergy, availability, irreversibility and stream exergy.

The purpose of this research is the analyzing the irreversibility of boiler of an experimental power plant that consist of turbine, boiler, and condenser and feed water tank. In this work we have have compared the irreversibility of boiler regions by doing some experiments.

2. Entropy Generation

According to equation $dS \geq \frac{\delta Q}{T}$, the $\frac{\delta Q}{T}$ is not the only reason or factor for entropy changes of an irreversible process .In fact this term is a factor in entropy changes .But the only difference between the internal reversible process and irreversible one is the irreversibility in systems. This means that the internal irreversibilities it self cause changes in entropy and its part show by symbol σ, and is called entropy generation. Entropy Generation is always positive, so it can be written in this from:

$$\sigma \equiv S_2 - S_1 - \int \frac{\delta Q}{T} \geq 0 \tag{1}$$

The above equation can be written for a closed system or control mass in this from:

$$dS_{CM} = \frac{\delta Q_{act}}{T} + \delta\sigma \tag{2}$$

So that equation $\Delta S \geq \int_1^2 \frac{\delta Q}{T}$ changes to an equal relation ship by adding a term shows the internal irreversibility.

Equation (2) Shows this concept that heat transfer always causes entropy changes in a closed system and it part can be positive, negative or zero.
In some cases, heat transfers can accurse in different temperatures in different regions in a surface, so the general from of (2) can he written like this:

$$dS_{CM} = \sum_{i=1} \frac{\delta Q_i}{T_i} + \delta\sigma_{CM} \tag{3}$$

Which Ti is the temperature of surface in which δQ transfers on that.
And equation (3) as per mass can be written like this:

$$ds_{CM} = \sum_{i=}^{n} \frac{q_i}{T_i} + \delta\sigma_{CM} \tag{4}$$

3. Reversible work and exergy

In this section we will work on deriving the general equation for work in a control volume by existing irreversibilities in it.
This work will enable us to the concept of potential work for closed and open systems. The first law of thermodynamic includes a term called work but there is no term for irreversibility factor in it.
But there is an especial term called entropy generation for irreversibility in second law of thermodynamic, but there is no any especial term for work in it.
We should make a relation ship between the first and second law of thermodynamic for obtaining direct relationship between work and entropy generation or irreversibilities.
Figure (1) shows a control volume that includes several iterance and exit points on it.
In this figure Q_0° is the heat transfer between control volume and surrounding atmosphere T_0 and Q_j° is the heat transfer with other thermal resources $T_j, ..., T_i$.
So the total heat transfer Q° will be:

$$Q^\circ = Q_0^\circ + \sum Q_j^\circ \tag{5}$$

In this control volume $W_{net,u}$ is the total possible works such as: volume changes, stresses, electrical and etc.
As can be seen in figure, volume changes can be against atmosphere p_0.
The conservation of mass for control volume is:

$$Q_0^\circ + W_{net}^\circ + \sum_{in}\left(h + \frac{v^2}{2} + gz\right)m^\circ - \sum_{out}\left(h + \frac{v^2}{2} + gz\right)m^\circ = \frac{dE_{cv}}{dt} \tag{6}$$

By inserting equation (5) into (6), equation (6) will be:

$$Q_0^\circ + \sum_j Q_j^\circ + W_{net}^\circ + \sum_{iu}\left(h + \frac{v^2}{2} + gz\right)m^\circ - \sum_{out}\left(h + \frac{v^2}{2} + gz\right)m^\circ = \frac{dE_{cv}}{dt} \tag{7}$$

It is important to note that the reference points for velocity and enthalpy or internal energy references is the same for interance and exit points.
Therefore, actual useful work shown by $W_{act,u}^\circ$ can be written in this form:

$$W_{act,u}^\circ = W_{net}^\circ + p_0\left[\frac{d(vol)}{dt}\right]_{c.v} \tag{8}$$

And by according equation (9):

$$\sigma_{tot}^\circ = \sigma_{c.v}^\circ + \sigma_Q^\circ = \frac{dS_{c.v}}{dt} + \sum_{out} m^\circ s - \sum_{in} m^\circ s - \frac{Q_0^\circ}{T_0} - \sum_j \frac{Q_j^\circ}{T_j} \tag{9}$$

By using (7, 8 and 9) and omitting Q_0° we will have:

$$W_{act}^\circ = \frac{d(E + p_0 v - T_0 s)_{c.v}}{dt} + \sum_{out} m^\circ\left(h + \frac{v^2}{2} + gz - T_0 s\right) - \sum_{in} m^\circ\left(h + \frac{v^2}{2} + gz - T_0 s\right) - \sum_j Q_j^\circ\left(1 - \frac{T_0}{T_j}\right) + T_0\sigma_{tot}^\circ \tag{10}$$

Equation (10) shows the general equation for actual useful work in a control volume with thermal resources that their is a heat transfer between them.
Although Q_0° cannot be seen in this equation but heat transfer to or from surrounding atmosphere can be seen in this equation.
σ_{tot}° Include entropy generation in control volume and entropy generation because of irreversible heat transfer and is the total entropy generation. We can rewrite equation (10) to deals only with control volume surface. For this purpose by having conservation of mass or:

$$\sum_{i=1}^{n} Q_i^\circ + W_{net}^\circ + \sum_{in}\left(h + \frac{v^2}{2} + gz\right)m^\circ - \sum_{out}\left(h + \frac{v^2}{2} + gz\right)m^\circ = \frac{dE_{c.v}}{dt} \tag{11}$$

As we see in this equation $\sum Q_i^\circ$ is the heat transfer on surface of a control volume.
By using equation (12):

$$\sigma_{c.v}^\circ = \frac{ds_{c.v}}{dt} + \sum_{out} m^\circ s - \sum_{in} m^\circ s - \sum_{i=1}^{n} \frac{Q_i^\circ}{T_i} \tag{12}$$

And inserting it into (11) we will have:

$$W^{\circ}_{act,u}=\frac{d(E+p_0v-T_0s)_{c.v}}{dt}+\sum_{out}m^{\circ}\left(h+\frac{v^2}{2}+gz-T_0s\right)-\sum_{in}m^{\circ}\left(h+\frac{v^2}{2}+gz-T_0s\right)-\sum_{i=1}^{n}Q^{\circ}_i\left(1-\frac{T_0}{T_i}\right)+T_0\sigma^{\circ}_{c.v} \quad (13)$$

When $\sigma^{\circ}_{C.V}$ is zero, the process is internally reversible, so amount of useful reversible work will be:

$$W^{\circ}_{rev,u}=\frac{d(E+p_0v-T_0s)}{dt}+\sum_{out}m^{\circ}\left(h+\frac{v^2}{2}+gz-T_0s\right)-\sum_{in}m^{\circ}\left(h+\frac{v^2}{2}+gz-T_0s\right)-\sum_{j}Q^{\circ}_j\left(1-\frac{T_0}{T_j}\right) \quad (14)$$

And:

$$W^{\circ}_{rev,u}=\frac{d(E+p_0v-T_0s)}{dt}+\sum_{out}m^{\circ}\left(h+\frac{v^2}{2}+gz-T_0s\right)-\sum_{in}m^{\circ}\left(h+\frac{v^2}{2}+gz-T_0s\right)-\sum_{i}Q^{\circ}_i\left(1-\frac{T_0}{T_i}\right) \quad (15)$$

Equation (14) deals with control volume and thermal resources, but equation (15) deals only with control volume.

4. Exergy

When a new energy source, such as a geothermal well, is discovered, the first thing the explorers do is estimate the amount of energy contained in the source. This information alone, however, is of little value in deciding whether to build a power plant on that site. What we really need to know is the work potential of the source – that is, the amount of energy that we can extract as useful work and, say, run a generator. The rest of the energy, i.e., the portion that is not available for converting to work , will eventually be discarded as waste energy and is not worthy of our consideration. Thus is would be very desirable to have a property to enable us to determine the useful work potential of a given amount of energy at some specified state. This property is availability.

The work potential of the energy contained in a system at a specified state is simply the maximum useful work that can be obtained from the system. You will recall that the work done during a process depended on the initial state, the final state, and the process path. That is,

Work= f (initial state, process path, final state)

In an availability analysis, the initial state is specified, and thus it is not a variable. As will be shown, the work output is maximized when the process between two specified states is executed in a reversible manner. Therefore, all the irreversibilities are disregarded in determining the work potential. Finally, the system must be in the dead state at the end of the process to maximize the work output.

5. Reversible work and reversibility

Reversible work W_{rev} is defined as the maximum amount of useful work that can be obtained as a system undergoes a process between the specified initial and final state .This is the useful work output (or input) obtained when the process between the initial and final states is executed in a totally reversible manner .That is, any heat transfer between the system and the surroundings must take place reversibly, and no irreversibilities should be present within the system during the process .When the final state is the dead state , the reversible work equals availability .For processes that require work, reversible work represents the minimum amount of work necessary to carry out that process.

Any difference between the reversible work W_{rev} and the useful work W_u is due to the irreversibilities present during the process, and this difference is called irreversibility I. [1]

$$I = W_{rev} - W_{act} \quad (16)$$

For a totally reversible process, the actual and reversible work terms are identical, and thus irreversibility is zero. This is expected since totally reversible processes generate no entropy, which is a measure of irreversibilities occurring during a process. For all actual (irreversible) processes, irreversibility is a positive quantity since the work term is positive and W rev > W u for work – producing devices, and the work term is negative and $|W_{rev}| < |W_u|$ for work – consuming devices.

Irreversibility can be viewed as the lost opportunity to do work. It represents the energy that could have been converted to work but was not. The smaller the irreversibility associated with a process, the greater the work that will be produced (or the smaller the work that will be consumed).To improve the performance of complex engineering systems, the primary sources of irreversibility associated with each component in the system should be located , and efforts should be made to minimize them.

6. Stream exergy

In a control volume, we call an exergy accompanied with a flow that inters a control volume, stream exergy.

So the stream exergy of a fluid is the maximum work that can be obtained from it when it undergoes a reversible and steady process from its initial state to the atmosphere state and during this process there is heat transfer only with surrounding atmosphere.

By assuming $q_R = 0$ and under steady flow condition equation (4) changes to this form:

$$w_{rev,u} = (h + ke + pe + T_0 s)_2 - (h + ke + pe + T_0 s)_1 \quad (17)$$

By assuming the second state as a dead state we will have:

$$w_{rev,u} = (h_0 - T_0 s_0) - (h + \frac{v^2}{2} + gz - T_0 s) \quad (18)$$

According to this fact that the work taken from equation (18) is negative and exergy is positive one, so stream exergy in per mass will be in this form [5]:

$$\psi = \left(h + \frac{v^2}{2} + gz - T_0 s\right) - (h_0 - T_0 s_0) \quad (19)$$

And it can be writhen in this form:

$$\Psi = (h - h_0) - T_0(s - s_0) + \frac{v^2}{2} + gz \quad (20)$$

So the difference between the stream exergy between iterance (index1) and exit (index2) flow by using equation (20) will be:

$$\psi_2 - \psi_1 = (h_2 - h_1) - T_0(s_2 - s_1) + (ke_2 - ke_1) + (pe_2 - pe_1) \quad (21)$$

7. Exergy balance for a control volume

We can write the balance of an exergy for a control volume by knowing the concept of stream and non stream exergy [1]:
By using equations (13, 22, and 23):

$$W^{\circ}_{act,u} = \frac{d(E + p_0 v - T_0 s)_{c.v}}{dt} + \sum_{out} m^{\circ}\left(h + \frac{v^2}{2} + gz - T_0 s\right) - \sum_{in} m^{\circ}\left(h + \frac{v^2}{2} + gz - T_0 s\right) - \sum_{i=1}^{n} Q^{\circ}_i\left(1 - \frac{T_0}{T_i}\right) + T_0 \sigma^{\circ}_{c.v} \quad (13)$$

$$b = h^* - T_0 s = h + ke + pe - T_0 s \quad (22)$$

$$\sum Q^{\circ}\left(1 - \frac{T_0}{T_i}\right) = \phi^{\circ}_Q \quad (23)$$

We will have:

$$\frac{d\phi_{c.v}}{dt} = \sum Q^{\circ}_i\left(1 - \frac{T_0}{T_i}\right) + \sum_{in} m^{\circ} b - \sum_{out} m^{\circ} b + \left(W^{\circ}_{act} + p_0 \frac{dv_{c.v}}{dt}\right) - I^{\circ}_{c.v} \quad (24)$$

Or in other form:

$$\frac{d\phi_{c.v}}{dt} = \sum Q^{\circ}_i\left(1 - \frac{T_0}{T_i}\right) + \sum_{in} m^{\circ} b - \sum_{out} m^{\circ} b + \left(W^{\circ}_{act} + p_0 \frac{dv_{c.v}}{dt}\right) - i_{tot} \quad (25)$$

8. Boiler characteristics

Type: fire tube
Maximum boiler pressure: 12 bar
Operational pressure: 11 bar
Thermal surface: 8 m 2
Super heat surface: 0.6 m2
Number of tubes: 14
Weigh: 2500 kg
Fuel: liquid diesel fuel

9. Experiment procurer

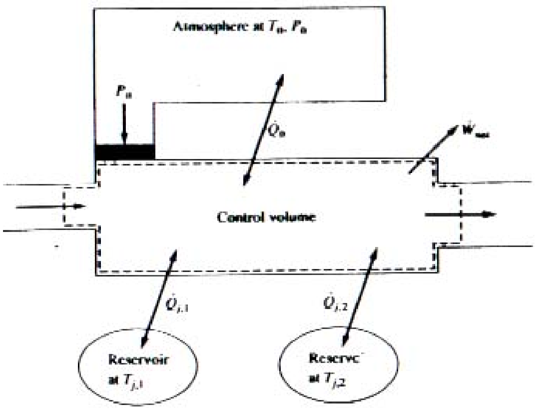
In this experiment we have obtained different output works: w1=1.2kw, w2=2.6kw w3=4.1kw in every fixed boiler pressure and then we have analyzed the exergy and irreversibility in each experiment.
In this research experiments have been done in four different boiler pressure from 5 bar to 8 bar (5,6,7,8),so it means that we have done 12 experiments on the boiler of this power plant.
b. =boiler , tur. =turbine
cond. =condenser, c, t=cooling tower
f.w. =feed water , p.b. =pressure of boiler
w=out put work
I.R.1=irreversibility of region 1(combustion).
I.R.2=irreversibility of region 2(heat transfer).
I.R.3=irreversibility of region 3(exhaust)

10. Analyzing the results

According to the results of 12 experiments that some of them have been shown on this paper, we found that the maximum portion of irreversibility belongs to region 2 or heat transfer to water, and this irreversibility is mainly because of heat transfer and temperature difference between two hot and cold resources. For example in figure (6) that has been drawn in boiler pressure of 6 bar and output work of w1=1.2kw,the portion of irreversibility of region 2 or heat transfer is about 53% and for region 2 is about 41% and for region 3 is 6%.
Also in figure (7) the portion of irreversibility of regions has been drawn in boiler pressure of 8 bar and output work of w1=1.2 kw.
The results shows that by increasing the out put work in a fixed boiler pressure ,the irreversibility of total boiler increases because of heat transfer and increasing of iterance exergy by fuel. Figure (9)
Although the portion of irreversibility in heat transfer region is maximum, but its portion or percentage

decreases in a non sensitive manner due to increasing of output work, and the percentage of irreversibility of combustion chamber or region 1 increases in non sensitive manner due to increasing of output work .The portion of irreversibility of exhaust or region 3 is minimum and its changes is little.figure (10)

11. Curves and figures



FGURE 1. Control volume

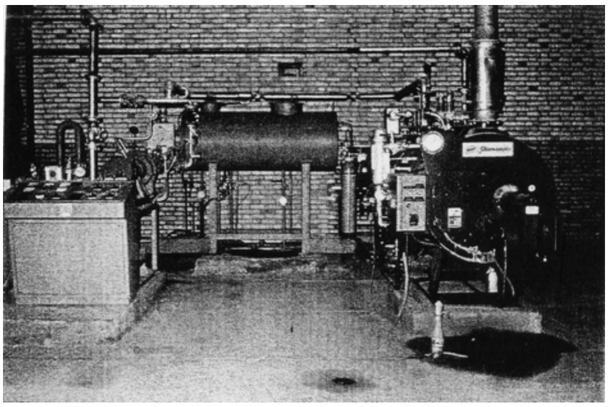


FIGURE 2. Experimental power plant

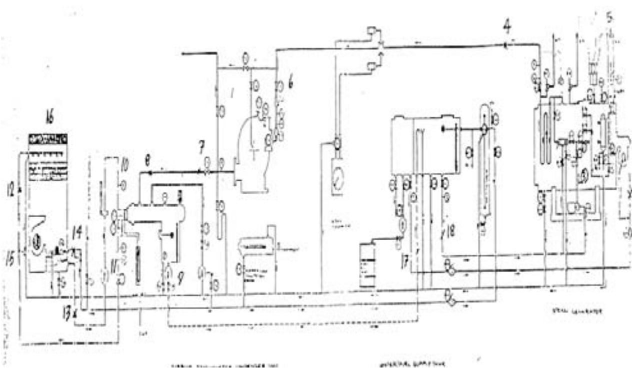


FIGURE 3. Experimental power plant plan

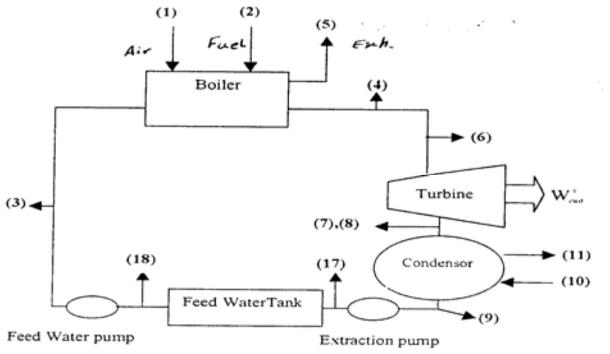


FIGURE 4. Diagram of cycle

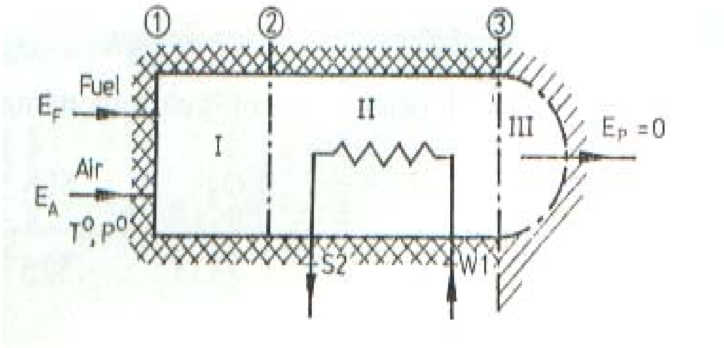


FIGURE 5. Dividing the boiler to 3 regions (combustion,heat transfer and exhaust)

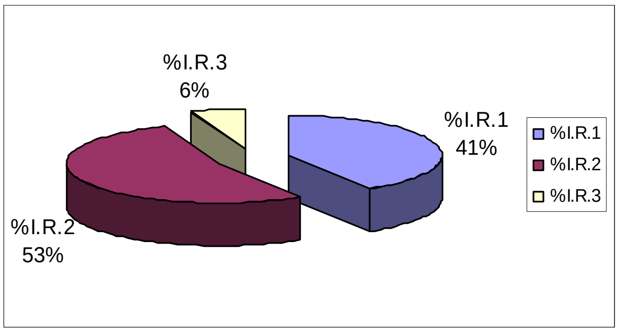


FIGURE 6. Percentage of irreversibilities in rigions of boiler in boiler pressure of 6 bar and out put work of 1.2 kw

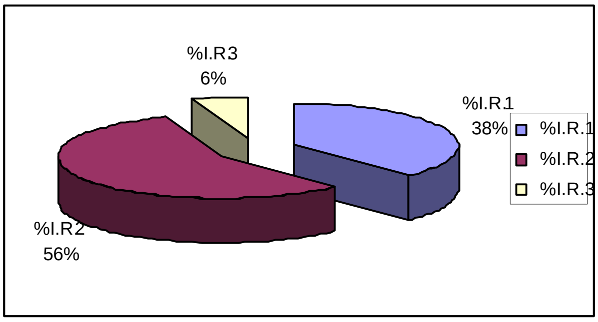


FIGURE 7. Percentage of irreversibilities in rigions of boiler in boiler pressure of 8 bar and out put work of 1.2 kw

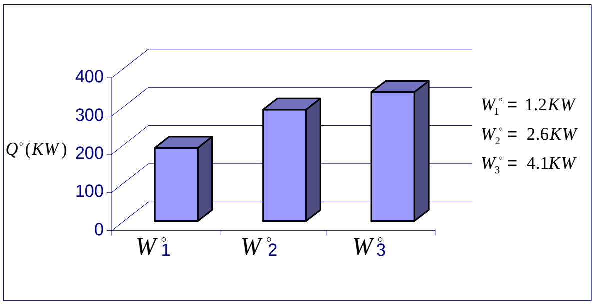


FIGURE 8. Heat absorbed by water in boiler in different out put works

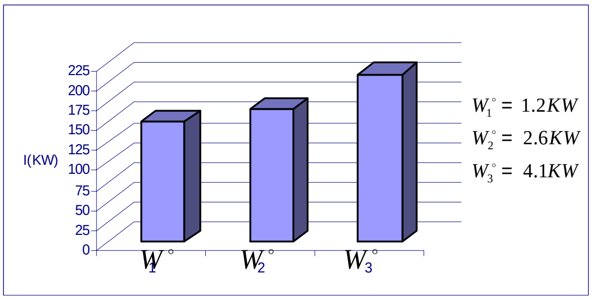


FIGURE 9. Irreversibility of boiler in operation pressure of 6 bar and in different outputs

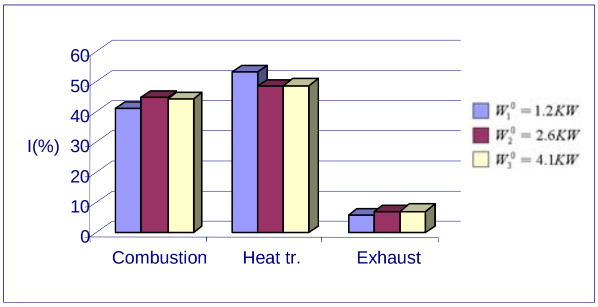


FIGURE 10. The percentage of irreversibilties in regions of boiler in operation pressure of 6 bar and different output works

12. Results and Conclusions

1) All experiments show that the percentage of irreversibility of heat transfer to water or steam is the maximum one.
2) As the output power of cycle increases in fixed boiler pressure, the amount of irreversibility of regions increases.
3)As the output power of cycle increases in fixed boiler pressure ,the percentage of irreversibilites in first and third regions (combustion and exhaust) increases very little and for second region decreases very little

13. References

[1] A.Bejan,G.Tsatsaonis,and M.moran”Thermal Design and optimization”,Wiley,New york,1996
[2] Wark,k”AdvancedThermodynamics forengineers” McGraw-Hill ,singapore,1995
[3] YunusA.Cengel,MichaelA.Boles”Thermodynamic an engineering approch” McGraw-Hill,1989
[4]A.Bejan,EngineeringThermodynamics,inM.kutz,ed.Mechanical egineers Hand book,wiley, Newyork,1986
[5]Kotas,T.J”the Exergy Analysis of Thermal Plants”Krieger Publishing company,Florida, 1985