

Optimizing the Fuel Consumption and Providing the Environmental Indicators in Green Architecture by using the Exergy Analysis

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Abstract: This study aims to evaluate the reduced consumption of fossil fuels which lead to the environmental pollution, high costs and intensified fuel crisis in global markets. This research is applied based on the objective, has a type of library research and is among the survey research based on the method. The method of library studies with the document branch is applied in order to collect the required data; and the information related to the variables of research is extracted by referring to the scientific sources and accessible documents of relevant organizations. Providing the consumed electric power in this article has been classified into three sections of manufacturing, distribution and consumption. As noted in the theoretical studies, the library studies and review of Ministry of Energy statistics indicate that about 80% of fuel of industry sector is consumed in power plants and refineries and the power plants play the highest role in the environmental pollution after the transportation sector. Therefore, by using the exergy and pinch technologies and developing the thermodynamic laws, it has been tried to provide the computational methods to reduce the energy consumption.

Keywords: Exergy, fossil fuels, Green architecture, pinch

INTRODUCTION

Green Architecture or Sustainable Architecture is one of the new trends and approaches to architecture and has been considered by a large number of designers and architects around the world in recent years. This trend, which is derived from the concepts of sustainable development, is as the result of consistency and balance of human life way with the environment. The concept of sustainable development in the energy sector (fossil fuel) dates back to the energy crisis in the 1970s. During this decade, the tendency towards building the houses with optimized energy consumption has been increased in America and simultaneously the motivation for reducing the energy costs, dependency on the fossil fuels, respecting for the environment, etc were created (Mao *et al.*, 2009).

The main objectives and indicators in the green architecture are in line with reducing the damages and destruction of architectural monuments in the environment. This trend of architecture emphasizes on the use of renewable resources. Hence, the main indicators of green architecture are based on the amount of using the technologies which utilize the consumption of restorable energies such as the sunlight through inactivate solar energy, active solar energy, photovoltaic techniques with using the plants and trees through the green roofs, rain gardens for reducing the rain water and numerous other techniques such as using the packed gravel or permeable concrete instead of conventional concrete or asphalt for accelerating the cycle of filing the underground water, etc in designing

the houses and industrial sites. These indicators can be measured and compared with the traditional designs by using the amount of energy saving, cost of rebuilding and mending, costs of maintaining the green space and other costs (U.S. Environmental Protection Agency, 2009).

Green architecture is defined as optimization in implementing or applying these indicators in construction. On the other hand, according to the features of green architecture, the applied viewpoint in designing the structure is in line with the features of nature surrounding the structure and utilizing the environmental sources of that structure (WBDG Sustainable Committee, 2009).

Exergy is one of the ways of energy analysis, which includes all energies of fluid flow. This energy can also be caused by the movement of reaction or anything else. The equation "Energy= exergy + anergy" is the basis of exergy analysis. Exergy is called the section of energy which is consumed usefully. For instance, for vehicle movement, the wasted part of energy is called the anergy. In recent decades, the topics of process integration have been proposed. It was thought previously that the best conditions of system performance can only be achieved by making all processes of a system efficient, but evaluating the interaction of processes and their impact on each other and on the whole system will lead to the efficiency of system. This method has two parts, the analytical tool or Exergy and the applied tool or pinch.

Exergy is based on the second law of thermodynamics and the pinch is based on the first law

of thermodynamics. The exergy method is strategy for thermodynamic analysis of processes and is defined approximately as the world measurement of work potential or the quality of or other forms of energy associated with an environment. A balance application of exergy expresses that how much potential of used (useful) work entered into the process has been consumed by the process. This amount of loss is the irreversibility which was mentioned previously (Hasan *et al.*, 2002).

In fact, pinch is a practical tool in the industry which uses the first law of thermodynamics. According to the theory of energy well and spring, the Pinch analyst seeks to send the energy from spring, in where the energy is generated, to the place, where needs the energy (well), thus the existing energy in the system is used for fulfilling the need. Obviously, this method will reduce the energy waste. By considering a set of flows and calculations, the Pinch analyst reaches a temperature which is called the pinch point. This point shows the optimized temperature of interchanging the system flows.

To reach this point, the appropriate heat exchangers are used and it is determined that which flows enter which exchangers. When the cycle of a thermal car is investigated, the energy balance is written by the first law and the second law determines that how much heat can be converted to the work; and then we use Carnot efficiency. For instance, about contacting two hot and cold objects, the first law states that the total energy, which hot object loses, is get by the cold object, but the exergy analysis expresses that just a part of that energy can be transferred. Thus it can be stated that the Exergy determines the energy exchange ability and pinch determines its method and both of these two methods are used together for integration of process energy (Yumrutas *et al.*, 2002).

This study seeks to present the suggestions for reducing the energy consumption (fossil) in green architecture by using the environmental indicators and exergy analysis and its concepts.

Theoretical principles: Library studies and review of Ministry of Energy statistics indicate that about 80 percent of fuel of industry sector is consumed in power plants and refineries and the power plants play the highest role in the environmental pollution after the transportation sector. Therefore, the main task of this article is based on the methods of reducing the fossil fuel consumption in power plants. Given the statistics of consumed fuel cost, study of power plants according to the economic savings is much important than the sector of houses.

Exergy is one of the ways of energy analysis, which includes all energies of fluid flow. This energy can also be caused by the movement of reaction or anything else. In recent decades, the topics of process

integration have been proposed. It was thought previously that the best conditions of system performance can only be achieved by making all processes of a system efficient, but evaluating the interaction of processes and their impact on each other and on the whole system will lead to the efficiency of system. This method has two parts, the analytical tool or Exergy and the applied tool or pinch. Exergy is based on the second law of thermodynamics and Pinch based on the First law of thermodynamics.

Laws of thermodynamics:

- **First law of thermodynamics:** The internal energy of an isolated system is constant. First Law of Thermodynamics, which is also known as the law of conservation of energy states that the change of internal energy in a system is equal to the amount of heat supplied to the system and the work done by the system on its surroundings. First law of thermodynamics is presented in the form of mathematical equation as follows:

$$\frac{dE}{dT} = \sum_{i=0}^n \dot{Q} - \dot{W} + \sum_{in} \dot{m}h - \sum_{out} \dot{m}h$$

In which, Metalpy is equal to

$$h = h + \frac{V^2}{2} + gz$$

T_0 : Ambient temperature

E : Internal energy

S : Entropy

W, Q : Heat and Work transfer rate

- **Second law of thermodynamics:** It is impossible to build a cyclic engine which has no effect except continuous heat transfer from the warm to cold temperatures. According to Kelvin- Planck viewpoint, it is impossible to build a device which operates in a cycle and also has only a heat exchange reservoir; in other words, the work of a heat engine is impossible without losing heat in Q_c . According to Clausius statement, Heat can never pass from a colder to a warmer body in a refrigerator; it means that it is impossible to build a refrigerator which works without the input. It can be stated that the balance of energy, conservation of energy and exergy is the balance of energy quality or energy quality degradation. Energy quality degradation is equal to irreversible waste associated with all real processes. Second law of thermodynamics is expressed as the following equation in terms of mathematics (Winter Bone, 1997).

$$\dot{S}_{gen} = \frac{ds}{dt} - \sum_{i=0}^n \frac{Q_i}{T_i} - \sum_{in} \dot{m}s - \sum_{out} \dot{m}s \geq 0$$

$$\dot{W} = \dot{W}_{rev} - T_0 \dot{S}_{gen}$$

MATERIALS AND METHODS

In this section, the technologies of exergy and pinch are introduced and the computational strategies for reducing the fuel consumption through the efficiency of first and second Newton's laws are provided by the expansion of formulas derived from laws of thermodynamics, calculations of work and heat of exergy in the plant sector and also the technology of pinch.

- Energy technology:** The quality of exergy can be measured through balancing the amount of exergy to the energy. In this case, various forms of energy including the kinetic microscopic energy, electrical energy, and Gibbs free energy ($G = U + PV - TS$) can be restored. The exact ratio of exergy in a material depends on the relative amount of entropy in an environment under the concept of second law of thermodynamics. Exergy is useful when the efficiency of a restored energy process can be measurable. According to the second law of thermodynamics, the efficiency is the ratio of output to input exergy. In this relative comparison, the quality of energy is considered. According to the standard definitions, the energy is defined as the ability to do work (Smith, 1995).

The work can be defined as the movement by the flow caused by the energy transfer power. Thus if there is energy transfer in doing a work, the second article of energy transfer expresses that this process should include the waste of an amount of energy as heat. Measuring the amount of released heat is one way of determining the quantity of energy, ability to perform the work, and applying the force over a distance (Dincer and Rosen, 2004).

Exergy calculations (work, heat): The amount of heat transfer rate should be considered constant and be eliminated from both thermodynamics laws in order to combine the first and second laws and access to an equation for calculating the work transfer rate. Then the rate work transfer rate will be equal to:

$$\dot{W} = -\frac{d}{dt}(E - T_0 S) + \sum_{i=1}^n \left(1 - \frac{T_0}{T_i}\right) \dot{Q}_i + \sum_{in} \dot{m}(\dot{h} - T_0 S) - \sum_{out} \dot{m}(\dot{h} - T_0 S) - T_0 \dot{S}_{gen}$$

The above equation has been obtained from combining the first and second laws of thermodynamics in which the work is lost with a rate in accordance with the rate of entropy. In the case of reversible process, the transmission rate of work will be maximized (Kotas, 1995). Therefore, it can be written:

Lost work is called the accessible lost work due to the thermodynamic irreversibility of work. The ratio of accessible lost work and the entropy generation creates the law of lost work (Szargut *et al.*, 1988). Thus it can be written:

$$\dot{W}_{lost} = T_0 \dot{S}_{gen}$$

As we stated, the work is the improved transferring energy and every amount of work (in the lack of Atmosphere work) will be equal to the amount of its Exergy (El-wakil, 1998). Thus it can be written:

$$\dot{E}_w = \dot{W} - p_0 \frac{dv}{dt}$$

There is not the atmosphere work ($P_0 \cdot dv/dt$) in most of the systems with the engineering importance and with the input and output flows and each amount of work is equal to the value of its exergy (Sciubba, 2001). Thus it can be written for maximizing the exergy related to the work transfer that:

$$(\dot{E}_w)_{rev} = \dot{W}_{rev} - p_0 \frac{dv}{dt}$$

On the other hand:

$$(\dot{E}_w)_{rev} = -\frac{d}{dt}[E + P_0 V - T_0 S] + \sum_{i=1}^n \left(1 - \frac{T_0}{T_i}\right) \dot{Q}_i + \sum_{in} \dot{m}(\dot{h} - T_0 S) - \sum_{out} \dot{m}(\dot{h} - T_0 S)$$

In above equation, the terms on the right of equality are the total static exergy, exergy transfer through the heat transfer, exergy of input flow through the mass transfer, output flow exergy through the mass transfer, respectively.

For maximizing, the exergy related to the heat transfer from a control volume is equal to the work which can be obtained by the interaction of heat and the outside environment. For the heat transfer rate (Q) in the transfer temperature (T), the maximum accessible work is as follows:

$$\dot{E}_Q = \dot{Q} \tau$$

In above equation, τ is called the temperature of exergy without dimension and it converted to Carnot efficiency in the case that there is the heat transfer between the system and environment with temperature T_0 . Thus $\tau = 1 - (T_0 / T)$. Using this equation, the equation related to the flow access (b) and exergy of flow (ex) can be written as follows:

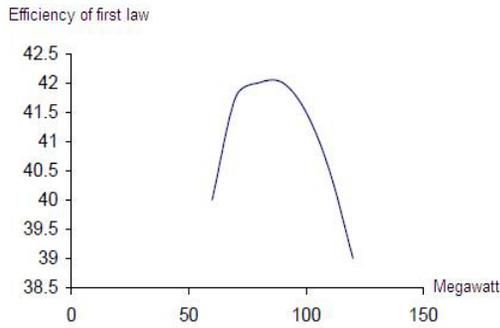


Fig. 1: Diagram of the efficiency of first law in different loads

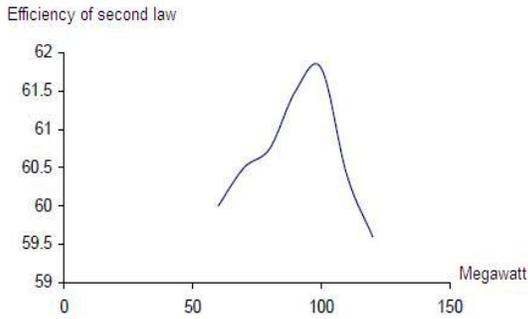


Fig. 2: Diagram of the efficiency of second law in different loads

$$b = \dot{h} - T_0 S$$

And the equation of flow exergy will be equal to

$$ex = b - b_0 = \dot{h} - \dot{h}_0 - T_0(S - S_0)$$

By considering changes of static exergy term during the time equal to zero (in the systems with uniform performance) and considering the equations of flow access (b) and flow exergy (ex), the equation can be provided as follows:

$$\dot{E}_w = \sum_{i=1}^n (\dot{E}Q)_i + \sum_{in} \dot{m} e_x - \sum_{out} \dot{m} e_x - T_0 \dot{S}_{gen}$$

The above equation is used as the balance exergy in the systems of uniform flow. Thus, the efficiency of first and second laws of thermodynamics can be written as follows (Bafekrpour *et al.*, 2008),

The efficiency of first law, energy rates (η_1) is equal to the rate of net produced work divided by the input. Diagram of the efficiency of first law is shown in Fig. 1.

The efficiency of second law (η_2) is equal to the input exergy rate divided by the exergy output rate.

Diagram of the efficiency of second law is shown in Fig. 2.

The second law is based on this law that two forms of equal energy quantity may have complete different types of exergy. The energy is measured according to the relevant and the efficiency of second law is used instead of efficiency of first law in calculating the loss of ability to perform the work in a process.

Exergy has the feature under which can be conserved if all processes of system and environment are reversible. When the irreversible process is occurred, the exergy will be lost. When the exergy analysis is performed on a complex such a plant, the thermodynamic defects can become numerical as the exergy destruction and these are the lost work or potential for generating the work. For instance, the energy and exergy can pass the the boundaries of a system or can be sent. There is a transfer or emission for every kinds of transfer or emission of related exergy energy. Exergy associated with the work-orientation is equal to the work-orientation. But the exergy transfer by the heat transfer depends on the level of temperature which this indicates about the ambient temperature (Sadik and Hongtan, 2002).

- Pinch technology:** Pinch technology is a tool for calculating the energy and targeting in order to optimize its conduction. Cycle efficiency of a thermal power plant depends on the applied operating temperature and pressure in the cycle. So that the more the operating temperature and pressure is increased, the more the cycle efficiency will be increased. This case can easily be proved by the laws of thermodynamics. According to the laws of thermodynamics, heating the recharge water leaving the condenser by the steam extracted from different levels of turbines can improve the cycle efficiency. This method is called the restoration or the amount of restored heat. Nowadays, this method is used in all modern thermal plants. The method of using the extracted steam for heating the recharge water optimally is a complex issue. In the conventional method, it is proposed to select the extracted steam in a way that the increased recharge water temperature while passing the middle heaters is the same for all heaters and is equal to the difference of saturation temperature in the boiler minus the condenser temperature divided by one more than the number of available heaters.

$$\omega = (\Theta - \kappa) \div (N + 1)$$

In which, ω is the increased temperature, θ Difference of saturation temperature in the boiler, κ

Table 1: Specifications of private plant

Name	Location	Capacity	Type	Start-up
Aliabad katool power plant	Golestan Province	1000 MW	Natural gas	2010

Table 2: Values of efficiencies of first and second laws corresponding to different generated loads

MW	$\eta I\%$	$\eta II\%$
120	49	70
140	53.5	71
160	54	71.5
180	63	73
200	52	73.6
220	51	70.8
240	42	69.2

Table 3: Results of calculating the exergy of Aliabad Katool power plant

Name of part/machine	$E_{in}(kw)$	$E_{out}(kw)$	$W_{lost}(kw)$	$\eta 2\%$
Turbine	470397	83760	47093	89.6
Condenser	32305	1425	28152	11.9
Gland	3331	2055	1276	61.3
Heater 1	1882	1472	410	81.3
Heater 2	7972	6902	1070	88.2
Heater 3	11108	10691	417	92.7
Boiler	778039	490257	287782	65
Valve 1	284	256	28	91.2
Valve 2	533	473	60	89.5
Valve 3	3218	3109	109	88.9
Boiler Feed Pump	19650	19983	1998	93
Condensate Pump	1327	1144	183	82

Condenser temperature and N Number of available heaters.

However, this method has the drawbacks in terms of optimal use of energy. During the past two decades, the technology of optimized use of energy called the pinch technology has been introduced by providing the practical methods based on laws of thermodynamic for targeting and designing the processes and its has shown its effectiveness in designing the processing units. Therefore, it is better to study the way of using this tool in appropriate design of cycle in a thermal power plant. According to one of the combined cycle power plants as the case study in this paper, it has been observed that this technology has been used about the case study power plant and a new cycle has been designed. The results of this study indicate that the network proposed by pinch technology has worked in a way that the possibility to increase the efficiency of a cycle has been increased to more than 5 times from 97.41% of studied power plants. This amount of increased efficiency has created the effect equal to 3.3% of reduction in fuel consumption. This issue is important in the case of generalizing to other plants and according to the energy crisis in the world and also the green architecture and its fundamental principles (reduced consumption of fossil fuel).

CASE ANALYSIS

Data related to one of the private power plants of Iran has been used for doing the calculations of exergy.

Relevant data has been provided in Table 1. It is noted that the data has been adjusted by a specified coefficient.

Data related to the plant has been presented in Table 2.

The results of calculating the above data, which its measuring method is presented in previous sections, are provided in Table 3.

As it is observed, the highest amount of energy loss for first four cases of critical energy loss is related to the boiler, turbine, condenser and boiler feed pump.

CONCLUSION

This paper seeks to study and evaluate the reduction of fossil fuel consumption which leads to the environmental pollution, high costs and fuel crisis in the global markets by using the green architecture approach. Providing the consumed electric power in this article has been classified into three sections of manufacturing, distribution and consumption. As noted in the theoretical studies, the library studies and review of Ministry of Energy statistics indicate that about 80% of fuel of industry sector is consumed in power plants and refineries and the power plants play the highest role in the environmental pollution after the transportation sector. Therefore, by using the exergy and pinch technologies and developing the thermodynamic laws, it has been tried to re-test the computational methods for reducing the energy consumption.

The specifications of private power plant Aliabad Katool is presented in Table 1; the values of efficiencies of the first and second laws corresponding to different generated loads in Table 2 and the results of calculating the exergy of Aliabad Katool power plant are presented in Table 3. Figure 1 and 2 have shown the efficiency of the first and second laws in different loads.

The results of exergy destruction and efficiency of power plant cycle components are presented in Table 3 by using the energy balance, which is required for exergy balance, and by applying the mentioned computational methods.

As mentioned in the section of Materials and Methods, the following results are obtained in a case study of project of implementing the exergy in a combined cycle power plant.

- Increased cycle efficiency from 97.41% to more than 5 times the capacity
- Reduced 3.3% of fuel consumption

Given the main mechanisms of entropy generation and losing the exergy (Friction, Heat transfer, Throttling, integration), it is proposed to pay attention to eliminating or reducing the effect of these

mechanisms in designing and rebuilding the production lines of power plants (Bafekrpour *et al.*, 2008).

Friction: Fluid Friction is much more similar to the Mechanical Friction. Expansion of the fluid behind a column or within a turbine in the form of internal friction leads to the dissipation of a part of energy to the internal heat which could be changed to the useful work. This leads to the reduced work of fluid and it will come out in a higher temperature.

Heat transfer: Heat transfer reduces the ability of performing the work because no work has been done between the object with high temperature and the object with low temperature. Moreover, this matter follows this rule that the difference of higher temperature between two objects will lead to the lost ability of doing higher work. Thus it is important to minimize the difference of temperatures between the sources within a heat exchanger in order to minimize the irreversibility caused by the heat transfer.

Throttling: Throttling is an uncontrolled expansion process for fluid and in this process the fluid goes from a high pressure to low pressure area. No kinds of work or heat transfer are considered during this process. Throttling process is an irreversible process because no work is done as the result of flow between the two high and low pressure areas in this case and it will reduce the ability to do the work. In fact, the higher pressure difference in the throttling process will lead to the creation of a larger irreversibility.

Integration: When two or more separated fluid are combined together or splashing inside each other, they cannot be integrated without external losses. Thus, the integration is an irreversible process and reduces the ability to do work. Integration is unavoidable in numerous processes such as the combustion. However, it should be noted that the calculations indicate that the integration is not as important as the heat transfer and fluid friction in the power systems in terms of irreversibility.

The suggestions for increasing the capacity of efficiency in power plants and also reducing the fossil fuel consumption have been provided as follows,

- Increasing the efficiency of combustion systems in the power plants boilers by the method of fuel evaluation
- Increasing the efficiency of power plants by using the methods of Pinch and Exergy
- Developing the regional heating and cooling systems DHC through establishing the heat distribution and sale companies

- Increasing the output power of gas turbines by cooling the input air
- Developing the use of expansion turbines in the input pressure reducing machines in cities and power plants
- Changing the diesel engines in the industry to the gas-fuel engines and utilizing this capacity in peak hours of consumption.

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