# 에너지 대역분석 기법을 이용한 생산플랜트에서 에너지절감 잠재량 산정

논 문
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## Estimation of the Energy Saving Potential using Energy Bandwidth Analysis in Manufacturing Plant

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**Abstract** - Currently one of the most importance issues in industrial sector is energy cost and energy efficiency. The manufacturing plants especially have made many efforts to reduce energy cost by implementing maintenances. But in many cases, they are not aware that how much energy could be saved more. If we know the best energy consumption, which signifies energy baseline, we can control the intensity of maintenances. One way to obtain the baseline is using proper statistics from a specific plant, a sector of industry. Energy bandwidth signifies the gap between actual Specific Energy Consumption(SEC) of a certain plant and minimum SEC of the best plant, and estimate energy saving potential(ESP) is a result of bandwidth analysis. We chose a model plant and implemented some maintenance for a year, and then we obtained ESP. Additionally we could determine the decreased amount of carbon emissions from the plant using Carbon Emissions Factor(CEF) by Intergovernmental Panel on Climate Change(IPCC).

**Key Words** : Bandwidth Analysis, Carbon Emissions Factor(CEF), Energy Baseline, Energy Saving Potential(ESP), Manufacturing Plant, Specific Energy Consumption(SEC).

### 1. Introduction

Fossil fuel price has increasing trend again since global economic crisis in 2008, caused not only economic cause but also industrial causes especially in energy intensive industry. Energy intensive industries such as (petro) chemical, iron and steel, cement, and pulp and paper, glass industries are especially very sensitive to energy price and energy efficiency because the energy-cost portion of their products is considerably larger than that of other industries. Thus those industries have been tried to do the energy effective operation of the plant. The first step toward the effective operation of industrial plants is executed by maintenance including energy efficiency analysis through field diagnosis for the plants[1-2].

In the energy diagnosis, Energy Intensity(EI) is a very important criterion to evaluate the energy efficiency of a plant or a sector of industry or even a nation[3]. In this research, we chose a model industrial plant which belongs to energy intensive industry, then we did energy analysis and maintenance to the model plant for a year. During the energy maintenance in the model plant, annual average specific energy consumption(SEC) decreased, and this signifies that the energy saving potential(ESP), which was obtained by comparing actual SEC and 'best SEC' from the same sector of industry, is decreased. Thus we can evaluate the effect of maintenance, and make maintenance plan to achieve 'best SEC'.

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### 2. Energy and Efficiency[3]

Energy sources in the industrial plant are usually divided into two broad categories; one is electric energy and the other is heat energy.

Electric energy is used to operate electric facilities in the plant. There are many kinds of electric facilities, but the most widely used electric facility is the electric motor or more precisely 3 phase induction motor(IM). Electric motor driven systems are estimated to consume over 70[%] of all electricity in many industrial plants and over half of all electricity from the U.S. estimation[4]. Thus, in some cases, electric energy consumption and the efficiency of electricity can be simplified to those of IMs.

Heat energy is widely used in industrial plants as well. One of the most important purposes of heat energy is for heating process such as drying or melting. In drying process, for example, form of heat energy is usually steam because of its large energy capacity and convenience of transfer along steam pipes etc. The efficiency for heat energy can be obtained by the ratio of supplied calories and necessary calories supplied calories by steam and necessary calories which are used to evaporate water contents and to heat the products as well.

### 2.1 Specific Energy Consumption

There are two categories of energy efficiency indicator, one is energy intensity(EI) from the economic point of view, and the other is specific energy consumption(SEC) which is sometimes called as physical energy intensity from the physical point of view. Sometimes these two terms are simply called EI without classification. EI is widely used for an individual plant, industrial sector or national economy but not typically used for some manufacturing processes.

On the other hand, SEC is the physical indicator which is used for individual plants or industrial sectors but generally not used for the national economy. the SEC is energy consumption divided by physical production in units such as ton, $m^3$ etc. as industrial activity. In this indicator, the unit of energy consumption is usually a ton of oil equivalent(toe) and the unit of products is usually a ton of the products of the plants. In this paper, we use the SEC as energy efficiency indicator. It is clear that EI(or SEC) is inverse proportion to energy efficiency. The equation of the SEC is below;

$$Specific\,Eenrgy\,Consumption\,(SEC) = \frac{Energy\,Consumption\,(toe)}{Industrial\,Activity\,as\,Physical\,Production\,(ton)} \quad (1)$$

The unit of energy is Joule in International System of Unit, but the unit of calorie is widely used as well. Thus we should convert the unit of SEC sometimes. By unit conversion rate, 1[J] = 0.2389[cal], The calories of BC(bunker C) oil 1 liter is equivalent to 9900[kcal/liter], so we can obtain SEC in calorie unit and then the unit converted into the unit of toe again. Electric energy of 1[kWh] is equivalent to 860[kcal], the unit of electric energy likewise converted into toe for the unit consistency.

Energy bandwidth is that the gap between actual SEC of a certain plant and minimum SEC of the best plant which reliable statistics, Energy bandwidth analysis is efficiency analysis method using energy bandwidth.

$$Energy\,Bandwidth = SEC\,of\,actual\,plant - SEC\,of\,best\,plant \quad (2)$$

### 2.2 Green House Gases Emissions

In the past time, the objective of energy efficiency improvement was strongly related with energy security, whereas energy efficiency improvement in recent time is related not only with energy security but also with reducing Green House Gases(GHG) emissions; the most dominant emissions is carbon dioxide($CO_2$).

The most simple method to calculate the $CO_2$ emissions from the used fossil fuel is by using carbon emissions factor(CEF) which is suggested by Intergovernmental Panel on Climate Change(IPCC). Table 1 shows some samples of CEF from IPCC[5].

Table 1 Carbon Emissions Factors From IPCC.

| Fuel Types | toe | CEF [ton/toe] | Carbon emissions [C ton] | $CO_2$ emissions [$CO_2$ ton] |
|---|---|---|---|---|
| Crude Oil | 1.00 | 0.829 | 0.829 | 3.0397 |
| Gasoline | 0.83 | 0.783 | 0.650 | 2.3829 |
| Bunker C oil | 0.99 | 0.783 | 0.775 | 2.8423 |
| LNG | 1.05 | 0.637 | 0.669 | 2.4525 |

Another energy source is the electricity. Carbon emissions from electricity are indirectly generated and its quantity depends on the structure of electric power generation. If power grids do not use fossil fuel, such as nuclear or hydro power etc., carbon emission approximately do not generated. Thus every electric power grid has their own carbon emissions factor. The CEF of electricity in Korea is known to 0.4448[kgCO2e/kWh] in 2007[5]. Thus we can estimate $CO_2$ emissions from electricity consumption. Equation (3) shows the $CO_2$ emissions from electricity.

$$CO2\,emission\,of\,electricity = Purchasing\,Electricity\,[MWh] \times Emission\,factor\,[ton/MWh] \quad (3)$$

## 3. Case Study

### 3.1 Paper Industry

The model plant is a paper manufacturing plant. Paper manufacturing is composed of several processes. Fig.1 shows the key processes in paper and pulp making procedure. Usually the term 'pulp and paper industry' is more general than just 'paper industry' because all paper comes from pulp which is made first from wood. Most paper plants in Korea import pulp from pulp producing countries. Thus generally the most important procedure in paper manufacturing plant is the paper making procedure. The most energy consuming process in the paper making plant is drying process. In a certain statistics, heat demand for paper drying process accounts for 68[%] of total heat demand on the paper machine[7].

There are four production lines in the model plant. In order to do mainteanace, we chose the most energy intensive process in every production lines and calculate electric and heat efficiency of the process; for electric efficiency by means of efficiency of electric motors using load factor, for heat efficiency by calculating the ratio of supplied and necessary calories.

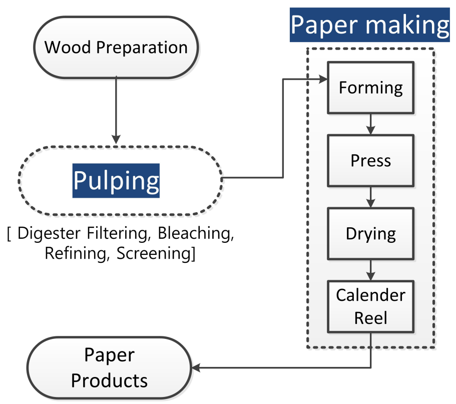


Fig. 1 Paper making Process.

In the period of maintenance for a year, we suggested many proposals for maintenance to improve efficiency and to reduce energy loss. For example, adapting efficient motor, to improve the efficiency of electric energy, we could save electric energy about 3[%]. For heat energy, there was much heat loss through exhaust air system in the drying process, thus we suggested the new installing or maintenance of heat exchangers and many other energy saving proposals. As a result of the maintenance, we could verify energy efficiency is improved step by step.

There are huge amounts of statistical data from many international organizations. For example, Asia Pacific Energy Research Center provides SEC values for various sector of industry including pulp and paper industry[8]. According to another research, total energy consumption of the pulp and paper industry in 2002 in the US was 2,361[trillion Btu] including powerhouse loss in producing 99.5[million ton] of pulp and paper[9]. Table 2 shows estimated energy consumption from the same research[9]. There are four categories of energy consumption in the table 2 ; 'MECS(Manufacturing Energy Consumption Survey)' which is general energy consumption data from manufacturer from this sector of industry. The BAT stands for 'Best Available Technology' which is widely used best energy consumption data acquired from advanced producing technologies in the same manufacturing sector of industry. The practical minimum includes not only advanced producing technologies but more efficient practical operations. The last one, theoretical minimum, is the energy consumption of theoretical base level. This value is close to the data from laboratory experiment. The SEC of BAT is more close to the bast case than that of 'Practical minimum' or 'Theoretical minimum'.

Table 2 Energy Consumption of Paper Industry in US.

| Production types | | Production [Mton] | SEC [toe/ton] | | | |
|---|---|---|---|---|---|---|
| | | | MECS | BAT | Practical minimum | Theoretical minimum |
| Pulp and Paper making | with PL | 99.5 | 0.5981 | 0.4431 | 0.3666 | 0.3412 |
| | without PL | 99.5 | 0.4068 | 0.2931 | 0.2328 | 0.2156 |
| Paper making | | 89.7 | 0.2181 | 0.1481 | 0.1000 | 0.0885 |

In the table, the term 'PL' stands for 'powerhouse loss' which signifies the energy loss of power plant that is located in the field of pulp and paper making plant in US. But, generally, paper making plants in many countries do not have power station on their sites. Thus we will only use the bottom row data in table 2.

### 3.2 The Consequences of Maintenance

In the model plant, we have to check the trend of SEC for the plant, because SEC is in inverse proportion to the energy efficiency. Thus we can figure out the energy efficiency of the plant through SEC for the period of energy analysis and maintenance.

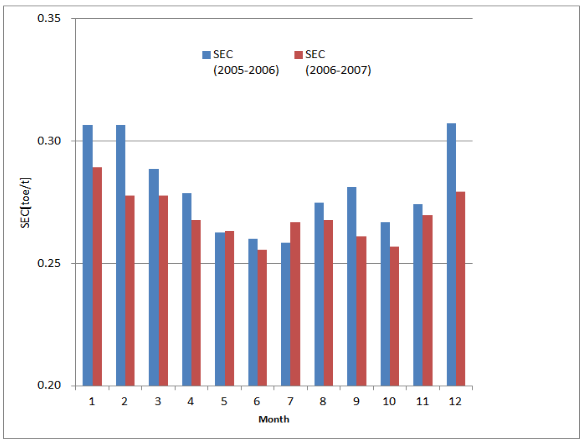


Fig. 2 Annual SEC trend of the model plant[3].

We find out that the SEC is decreased in the model plant through maintenance; The annual average SEC of electricity changed form 951[kWh/ton] to 925[kWh/ton] before and after maintenance respectively. Annual average SEC in converted unit is improved from 0.0818[toe/ton] to 0.0795[toe/ton]. Likewise, the annual average SEC of fuel is changed from 200.7[liter/ton] to 191.8[liter/ton], respectively before and after maintenance. Namely annual average SEC in converted unit is decreased from 0.1987[toe/ton] to 0.1898[toe/ton]. Fig. 2 shows the SEC trend before and after maintenance in the model plant. Blue bars mean monthly SEC before maintenance, red bars mean monthly SEC after maintenance.

Table 3 shows the annual average SEC which is analyzed from the data of fig. 2. The annual SEC is decreased by 3.94[%] from 0.2805[toe/t] to 0.2694[toe/t] during maintenance. In order to estimate energy bandwidth, we will compare total SEC of model plant in table 3 with best SEC of research statistics in table 2.

Table 3 The consequences of maintenence.

| Annual Average SEC | SEC [toe/ton] | | | Energy Saving [%] |
|---|---|---|---|---|
| | Fuel (BC Oil) | Electricity | Total | |
| Before maintenance | 0.1987 | 0.0818 | 0.2805 | 3.94 |
| After maintenance | 0.1898 | 0.0795 | 0.2694 | |

### 3.3 Energy Bandwidth Analysis and ESP

As a result of maintenance, SEC of the model plant is decreased, then we have to consider that how much SEC could be decreased more in this plant. We can call minimized energy consumption as the energy baseline or base energy consumption (or SEC of BAT in section 3.1) in this sector of industry. The energy baseline depends on calculation methods, quality of acquired data and regional characteristic etc.[6]. Thus It can be usually executed by global organizations, research institutes.

As we considered in section 3.1, we can obtain some of best practice energy consumption for some industries from global organizations such as the International Energy Agency(IEA), U.S. Department of Energy(DOE) or other organizations which have high reputation and authority. Then we compared the actual SEC with best SEC from the research statistics; this method is called as energy bandwidth analysis. Namely the energy bandwidth signifies the gap between actual SEC of a certain manufacturing plant and SEC of ideal plant[9].

In order to evaluate energy efficiency level of the industrial plant, we determined energy saving potential (ESP) which is estimated from energy bandwidth. ESP is one of the energy indicators. ESP of a certain manufacturing plant can be calculated by comparing actual SEC from the plant with the estimated 'best' SEC from the researches of global organizations[7-9]. Definitely, some improvements of energy efficiency result in decrease of $SEC_{actual}$ toward $SEC_{best}$, consequently ESP is decreased.

$$Energy\ Saving\ Potential\,(ESP)[\%] \tag{4}$$
$$= \frac{SEC_{actual} - SEC_{best}}{SEC_{real}} \times 100[\%]$$

We make a chart of fig. 3 by combining the research SEC data from table 2 with the SEC of model plant from table 3. In the fig. 3, we consider BAT as 'best' energy consumption of paper making plant. Because SEC of BAT is more close to achievable best practice case than that of 'Practical minimum' or 'Theoretical minimum'. Thus we can consider BAT as the energy baseline in paper making plant.

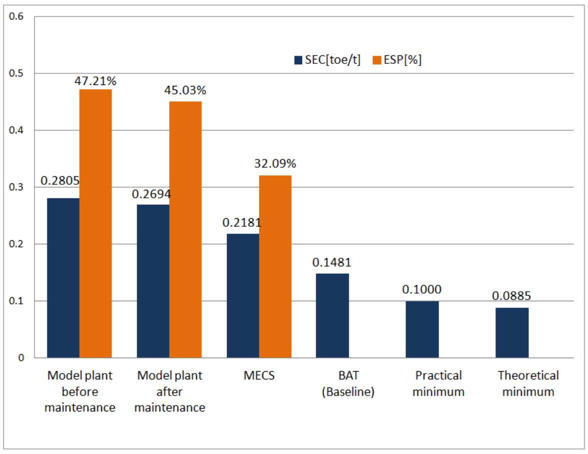


Fig. 3 Reference SEC and SEC of model plant and ESP of the model plant.

In the fig. 3, the energy bandwidth for the model plant(after maintenance) signifies the gap between 1.4181 of BAT and 0.2694 from model plant, i.e. 0.1213. The ESP is more clearly represent the current efficiency level of the model plant. The ESP(after maintenance) of 45.03[%] signifies that the energy consumption of the model plant could be decreased 45.03[%] by adapting advanced technologies in order to achieve BAT level energy efficiency. As a consequence of maintenance, ESP is decreased by 2.18[% point]; from 47.21[%] to 45.03[%].

We also convert the improvement of SEC into $CO_2$ emissions reduction to analyze another effect from efficiency improvement at the model plant. As mentioned in section 2.2, the simplest way to estimate carbon emissions is using CEF. In the model plant, annual energy consumption is about 22,590[kl/y] for Bunker-C oil, 94,380[MWh/y] for electricity.

Table 4 shows the annual $CO_2$ emissions and reduction from the model plant as a result of maintenance. The benefit of this $CO_2$ emissions reduction can be converted through the market price of Emissions Trading(ET) such as EU Emissions Trading Scheme(EU ETS), Europe Climate Exchange(ECX) etc..

Table 4 $CO_2$ emissions reduction.

| Energy types | Annual Consumption [kl/y][MWh/y] | $CO_2$ Emissions [ton/y] | $CO_2$ Reduction [ton/y] |
|---|---|---|---|
| BC Oil | 22,590 | 64,208 | 2,844 |
| Electricity | 94,380 | 41,980 | 1,142 |
| Total | - | 106,188 | 3,986 |

## 4. Conclusions

In the industrial sector, SEC is widely used energy efficiency indicators because SEC signifies the physical energy efficiency in manufacturing plant. Then we compared the actual SEC with best SEC from the research statistics; this method is called as energy bandwidth analysis. In order to evaluate energy efficiency level of the industrial plant, we determined ESP which is estimated from energy bandwidth.

In the case study, we chose a model plant. As a result of maintenance, the average SEC was decreased which signifies energy efficiency improvement. Consequently, ESP of the model plant decreased by 2.18[% point]; from 47.21[%] before the maintenance to 45.03[%] after the maintenance. The effect of energy maintenance was quite clear.

We also estimated the $CO_2$ emissions reduction from the saved energy consumption in the model plant using CEF. Estimated $CO_2$ emissions reduction of the model plant is about 3,986[ton/y]. The $CO_2$ emissions reduction results in not only financial benefit but also ultimate contribution to make sustainable society in the long term.


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