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# COMPARISON BETWEEN COGENERATION AND SEPARATE PRODUCTION OF HEAT AND ELECTRICITY

Conventional power plant usually convert one third of fuel use to utilize power and the rest of fuel loss as heat to the atmosphere. Even the most advanced technologies do convert more than 55% of fuel into useful energy. Cogeneration known as Combined Heat and Power, or CHP, is the production of electricity and heat in one single process for dual output streams. Cogeneration uses both electricity and heat and therefore can achieve an efficiency of up to 90%, giving energy savings between 15-40% when compared with the separate production of electricity from conventional power stations and of heat from boilers. It is the most efficient way to use fuel. CHP also helps save energy costs, improves energy security of supply. The paper considers two examples to explain difference between separate production of heat and electricity and cogeneration.

## 1. INTRODUCTION

Thermal power plants are one of the main sources of electricity in both industrialized and developing countries. Typical use as big central power station and use wide of fuels usually fossil fuel (Coal, heavy and light oil, natural gas, etc) to generate electricity, thermal power plant has poor efficiency (35%).

Cogeneration is the simultaneous production of electricity and useful heat, usually in the form of either hot water or steam, from one primary fuel, such as natural gas.

In cogeneration systems, the efficiency of energy conversion increases to over 80% as compared to an average of 30–35%for conventional electricity generation systems. This increase in energy efficiency can result in lower costs and reduction in greenhouse gas emissions when compared to the conventional methods of generating heat and electricity separately.

Cogeneration products are aimed for meeting the electrical and thermal demands of a building for space and domestic hot water heating.

## 2. CONVENTIONAL SYSTEM

Conventional power plants are highly complex and custom designed on a large scale for continuous operation. By-products of power thermal plant operation need

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to be considered in both the design and operation. Waste heat due to the finite efficiency of the power cycle must be released to the atmosphere, using a cooling tower, or river or lake water as a cooling medium.

The energy efficiency of a conventional thermal power station, considered as salable energy as a percent of the heating value of the fuel consumed, is typically 33% to 48 %. This efficiency is limited as all heat engines are governed by the laws of thermodynamics. The rest of the energy must leave the plant in the form of heat. This waste heat can go through a condenser and be disposed of with cooling water or in cooling towers. If the waste heat is instead utilized for district heating, it is called co-generation.

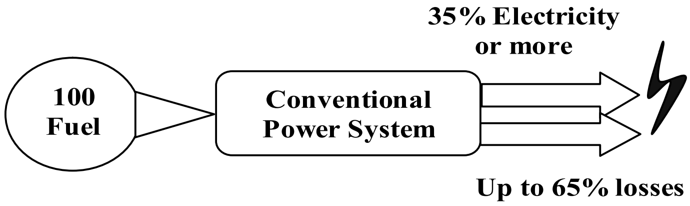


Fig. 1. Conventional system

## 3. COGENERATION (CHP)

Combined heat and power (CHP) is the production of electricity and heat in one single process for dual output streams. Natural gas is often selected as the fuel for CHP systems.

There are two common ways to define the energy content of fuel: higher heating value (HHV) and lower heating value (LHV).

Turbine, microturbine, engine, and fuel cell manufacturers typically rate their equipment using lower heating value (LHV), which accurately measures combustion efficiency; however, LHV neglects the energy in water vapor formed by combustion of hydrogen in the fuel. This water vapor typically represents about 10% of the energy content. LHVs for natural gas are typically ($33.53\times10^{6}$ to $35.37\times10^{6}$ J/m$^{3}$)

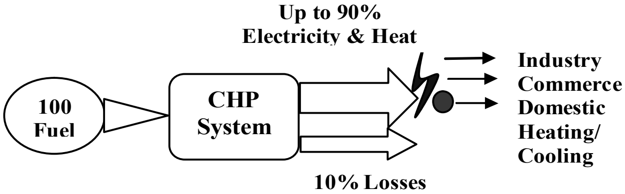


Fig. 2. Combined CHP system

Consumers purchase natural gas in terms of its HHV; therefore, performances of CHP systems as well as the electric grid for comparison are calculated in HHV. The net electric efficiency ($\eta_E$) of a generator can be defined by the first law of thermodynamics as net electrical output ($W_E$) divided by fuel consumed ($Q_{Fuel}$) in terms of kilowatt hours of thermal energy content.

$$\eta_E = \frac{W_E}{Q_{Fuel}} \quad (1)$$

A CHP system, by definition, produces useful thermal energy as well as electricity. If the first law is applied, adding the useful thermal energy ($Q_{TH}$) to the net electrical output and dividing by the fuel consumed (which is how virtually all CHP system efficiencies are reported), the resulting overall efficiency (ηo) does not account for the relative value of the two different energy streams

$$\eta_O = \frac{W_E + \sum Q_{TH}}{Q_{Fuel}} \quad (2)$$

According to the second law of thermodynamics, the two different energy streams have different relative values; heat and electricity are not interchangeable. The first law describes the quantity of the two energy streams, whereas the second law describes their quality or value (exergy). The theoretical maximum efficiency at which thermal energy can be converted to work is the Carnot efficiency, which is a function of the quality, or temperature, of the thermal energy and is defined as $(T_{Hight} - T_{low}) / T_{High}$

## 4. CHP ELECTRIC EFFECTIVENESS

The current methodology of using net electric efficiency $\eta_E$ and overall efficiency ηo either separately or in combination does not adequately describe CHP performance because

- $\eta_E$ gives no value to thermal output.
- ηo is an accurate measure of fuel use but does not differentiate the relative values of the energy outputs, and is not directly comparable to any performance metric representing separate power and thermal generation.

CHP electric effectiveness $\varepsilon_{EE}$ is a new, single metric that recognizes and adequately values the multiple outputs of CHP systems and allows direct comparison of system performance to the conventional electric grid and competing technologies. This more closely balances the output values of CHP systems and allows CHP system development to be evaluated over time.

## 5. POWER AND HEATING SYSTEM

For CHP systems delivering power and heating (steam and/or hot water, or direct heating), the CHP electric effectiveness is defined as

$$\varepsilon_{EE} = \frac{W_E}{Q_{Fuel} - \Sigma(Q_{TH} / \alpha)} \tag{3}$$

where α is the efficiency of the conventional technology that otherwise would be used to provide the useful thermal energy output of the system; see Table 1.

Table 1. Values of $\alpha$ for Conventional Technology

| FUEL | $\alpha$ |
|---|---|
| Natural gas Boiler | 0.80 |
| Biomass Boiler | 0.65 |
| Direct Exhaust* | 1.0 |

Examples 1&2 demonstrate how to apply this metric. The basis for comparison is a 25% HHV efficient electric power source. Performance values for larger combustion turbines, reciprocating engines, and fuel cells vary significantly.

Example 1. Separate Power and Conventional Thermal Generation. A facility supplies its power and thermal requirements by two separate systems: a conventional boiler for its thermal needs and a power-only generator for electricity. Conventional Boiler: 100 units of fuel are converted into 80 units of heat and 20 units of exhaust energy as shown in Figure 3.

Power-Only Generator: A 25% HHV efficient electric generator consumes 160 units of fuel and produces 40 units of electricity and 120 units of exhaust energy (Figure 4).

The performance metrics for this separate approach to energy supply are as follows:

$$\eta_E = \frac{W_E}{Q_{Fuel}} = \frac{40}{160} = 0.25$$

$$\eta_O = \frac{W_E + \Sigma Q_{TH}}{Q_{Fuel}} = \frac{40 + 80}{160 + 100} = 0.46$$

$$\varepsilon_{EE} = \frac{W_E}{Q_{Fuel} - \Sigma(Q_{TH} / \alpha)} = \frac{40}{260 - (80 / 0.80)} = 0.25$$

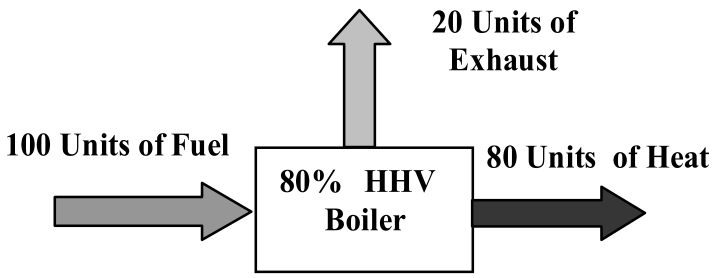


Fig. 3. Conventional boiler for example one

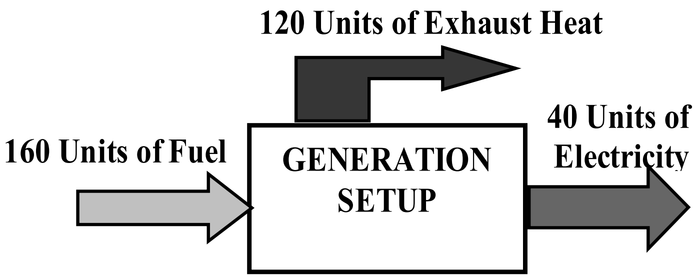


Fig. 4. Power-only generator for example one

Example 2. Combined Power and Thermal Generation (Hot Water/Steam). A CHP system is used to meet the same power and thermal requirements as in Example 1, with a 25% HHV efficient generator and a 67 % efficient heat recovery heat exchanger (e.g, 315°C air stream reduced to 115°C exhaust and yielding 93°C hot water). The performance parameters for this combined system are shown in Figure 5.

$$\eta_E = \frac{W_E}{Q_{fuel}} = \frac{40}{160} = 0.25$$

$$\eta_O = \frac{W_E + \sum Q_{TH}}{Q_{Fuel}} = \frac{40 + 80}{160} = 0.75$$

$$\varepsilon_{EE} = \frac{W_E}{Q_{Fuel} - \sum(Q_{TH} / \alpha)} = \frac{40}{160 - (80 / 0.80)} = 0.67$$

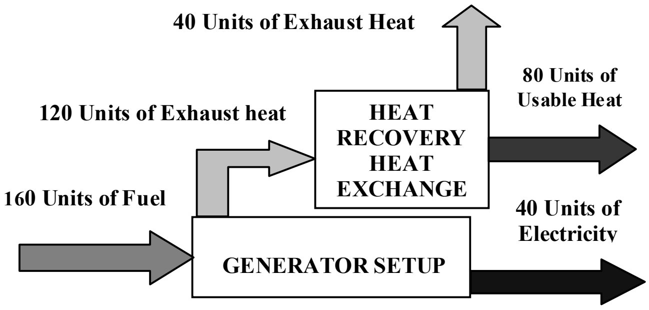


Fig. 5. Performance parameters for combined system

## 6. CONCLUSION

- $\eta_E$ For both systems (Example 1's separate generation and Example 2's CHP) is the same, but the CHP system uses less fuel to produce the required output, as shown by the differences in overall efficiency (ηo = 75% for CHP versus ηo = 46% for separate systems)
- Cogeneration is the most efficient way of generating electricity, heat and cooling from a given amount of fuel. It saves between 15-40% of energy when compared with the separate production of electricity and heat.
- Cogeneration helps reduce $CO_2$ emissions significantly. It also reduces investments into electricity transmission capacity, avoids transmission losses, and ensures security of high quality power supply.
- A concurrent need for heat, electricity and possibly cooling indicates suitable sites for cogeneration.

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