The effect of concurrent thermal and power production system in reduction of air pollution

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Abstract—Development of cities and increase of the population in recent years and need to energy and as a result increase of economic cost of providing energy and also harmful environmental effects of pollutants resulted from combustion of the urban and nonurban consumers fossil fuels in the future will lead to challenges for the governments. It is necessary to find solutions to prevent social crises resulted from these problems. The developed countries have sought solutions for sloving similar problems and they have produced energies for different users in the cities and country and developed concurrent thermal and cooling systems. Due to economic and technical advantages like high thermal output relative to other thermal power plants (up to 90%) and as result significant saving in fuel consumption, development of such power plants reduces urban electricity transferring and distribution networks burden and investment costs and also decreases losses and improves cities environmental conditions. This action is aligned with implementation of Kyoto protocol regarding to sustainable development and reduction of greenhouse gases production. Expansion of commercial, residential and administrative spaces will lead to increase 47% in fuel consumption until 2020. This enhancement will add trillions environmental pollutants on the earth and air. In this article the environmental effects of air pollution are investigated. According to this fact the next century will be the century of energy and attention to energy crises and necessity of saving on energy consumption and considering air pollution and as result greenhouse effect and other environmental and commercial impacts so it is necessary to use concurrent thermal and power production systems in order to reduce electricity and thermal production process pollutants and study feasibility of employing this technology in power industry.

Key words— micro turbine, air pollution, concurrent thermal and power production

Indeed, these industrial units were the first concurrent producers. The main drivers were reciprocating steam motors that steam was used by low pressure for heating.

Between early years of decades 20 and 70 industries progressed rapidly due to increase in electrical power demand. Concurrent to this rapid progress, electricity production cost was reduced mainly due to economic issues resulted from dimensions, sizes, efficient technology and reduced cost of fuel. In this period, most of the industries forgot their electrical power due to following reasons:

1-the power plants reduced produced electrical rate.
2- The buyers were benefited by the income tax rules instead of supporting investors.
3-Salaries and wages were increased.
4-The industries were interested in productions instead of lateral issues like electrical power production.

The estimation on concurrent electrical energy production showed that between 1954 -1976, the USA industrial concurrent electricity production reached to 9 % from 25% in total production.

From middle of eightieth century this value was constant in 5%. For example, at the end of 1992, 5.1% of total electrical energy production capacity was attributed to concurrent production systems in USA.

During decades 60 and 70, natural gas industry offered new total energy as a concurrent production. This effort was unsuccessful due to economic relative weakness (like electricity relative cheapness and expensiveness of the fuels) and lack of governmental regulations for coordination with large power plants.

In late 1973 and again in 1979, USA experienced crisis in energy that mainly it was resulted from reduction of imported oil.

Between 1973 and 1983, fuel and electricity price increased fivefold. At that time, all electrical power buyers investigated economic savings of concurrent production.

In other hand, these investigations were synchronous with governmental regulations for reducing or eliminating barriers on concurrent production. In 1978, USA approved National Energy Act (NEA) that consisted several important rules. Indeed, NEA involved fuel consumption law, natural gas policy and power plants and public utility regulatory act (PURPA). Every regulation had direct impact on concurrent production and PURPA defined concurrent thermal and
power production systems so that it consisted power plants that provide defined percentage of input energy ad useful thermal energy output (in addition to electrical and mechanical energy output).

Other regulation approved in late 1950 to early 1995 helped to installation of the concurrent production systems. Particularly, regulation regarding to quality of water and air that impacted significantly on concurrent production systems. In order to control air pollution, the main regulation of quality of air 1967 was implemented that amendments were added into it in 1970, 1977 and 1990.

The main principle of water pollution control is water pollution control regulation in 1956 that it was amended in 1965 by quality of regulation and water pollution control act in 1972 and clean water regulation in 1977. These regulations were effective in progress of concurrent production projects.

In early 21st century, the world experienced concurrent production accompanied by ever growing progress by financial and energy savings. At present new technologies and new regulations are approved in this regard.

1-CHP and environmental pollutants

CHP is a process with high energy output that reduces combustion products significantly in consumed energy unit compared to thermal and power generators. Decrease of these products impacts significantly on reduction of air pollution and resulted consequences. The performance of CHP usually increases local fuel consumption but reduces the central power plants consumed fuels considerably by decrease on electricity buy. Compared to a thermal generator like boiler with the similar output and fuel consumption of the thermal and electrical generators separately 35% saving is achieved. It is obvious that the size and type of CHP system impact on environment. The main impacts are dispersion of combustion products, noise and wastage. In addition it can be referd to building landscape and maintenance and preservation of consumed fuels.

2-POLLUTANTS TYPES

2-1-1-CO2

CO2 is the main product of combustion that impacts on greenhouse phenomenon and weather change. CO2 production depends on the consumed fuel so by CHP utilization and reduction of fuel consumption CO2 level is reduced.

CO2 is the highest combustion process product. Conversion of all carbons accessible to CO 2 is the goal of any combustion process that significant amount of energy is released. By burning fuels with carbon oxygen is combined with carbon and CO2 is produced. Dioxide carbon is a null gas as the part of the earth carbon natural cycle. But increase in dioxide carbon level as a greenhouse effect increases probability of global warming and climate changes. CO2 level depends on the fuel carbon level and fuel type. By less burning of carbon the CO2 level can be reduced. Any method that have more output in fuel releasing energy reduces CO2 level.

2-1-2-SO2

SO2 is produced in combustion of sulfuric fuels and constitutes corrosive acids by attendance of water, so high dispersion of SO2 in the air causes to acid rain and if the gas leaving CHP is distilled causes to sever corrosion in chimney and exhausts. Sulfur level is trivial in natural gas but it is considerable in diesel and bio gas and it is necessary to take required actions.

SO2 is produced from combustion of sulfur in the fuel. One kilogram sulfur in a fuel produces two kilogram sulfur. Chemical reactions in the air produce acid substance like H2SO2 and finally, acid rain and impact on the earth. Following table summarizes SO2 percentage produced by fuel.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>sulfur %</th>
<th>SO2 ton/fuel</th>
<th>SO2 kg/GJ(GCV)</th>
<th>SO2 kg/Mwh(GCV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>2.0</td>
<td>40</td>
<td>1.15</td>
<td>4.14</td>
</tr>
<tr>
<td>Kerosene</td>
<td>2.5</td>
<td>50</td>
<td>1.17</td>
<td>4.21</td>
</tr>
<tr>
<td>Oil</td>
<td>0.3</td>
<td>6</td>
<td>0.13</td>
<td>0.47</td>
</tr>
<tr>
<td>Natural gas</td>
<td>Trivial</td>
<td>Trivial</td>
<td>Trivial</td>
<td>Trivial</td>
</tr>
</tbody>
</table>

The main method for reduction of SO2 is reduction of of the burnt sulfur in combustion process. There are many methods for decreasing pollution and FGD could remove SO2 in combustion process.

UHC: they are organic molecules with high chain carbon that produced due to weak control of combustion process with suspended particles and CO. In normal condition, the output of these compounds is not considered as important issue. Unlimited dispersion of SO2 causes to air pollution and greenhouse effect.

Suspension particles: these solid particles are dispersed in the air due to incomplete combustion as colored smoke and in addition to imbalance in animals breathe and they cause to general reactions.

2-1-3-CO

CO is a toxic and fetal gas that it is formed by incomplete combustion and they can be eliminated by correct control. CO is formed by incomplete carbon combustion and different factors influence on formation of CO in a combustion process. The production level of this gas is trivial and it is part of million dispersed gases. But, it should be pointed that when combustion process is weakly controlled its amount is increased. CO is a toxic gas and its high amount causes to respiratory problems and air pollution. CO dispersion can be limited by replacement, maintenance and control of the equipments.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Carbon %</th>
<th>CO2 ton/fuel</th>
<th>CO2 kg/GJ(GCV)</th>
<th>CO2 kg/Mwh(GCV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>87</td>
<td>3.2</td>
<td>91</td>
<td>327.6</td>
</tr>
<tr>
<td>Kerosene</td>
<td>86</td>
<td>3.1</td>
<td>74</td>
<td>266.4</td>
</tr>
<tr>
<td>Oil</td>
<td>86</td>
<td>3.1</td>
<td>69</td>
<td>248.4</td>
</tr>
<tr>
<td>Natural gas</td>
<td>73</td>
<td>2.8</td>
<td>50</td>
<td>180</td>
</tr>
</tbody>
</table>
2-1-4- NOx

Oxide nitrogen is produced by combination of any fuels. But its production level depends on combustion temperature, combustion pressure, combustion chamber geometry and fuel to air ratio. Unlimited dispersion of NOx causes to smog, ozone decomposition and acid rain. For this reason, many researchers have been conducted on this gas.

NO and NO2 is produced from reaction of oxygen with nitrogen in high temperature. The production of NOx in contrary to CO2 and SO2 does not depend only on consumed fuel. Formation of NOx is affected by several factors like combustion heat, pause time in combustion area and concentration of oxygen and nitrogen. NOx is produced by two methods:

Thermal NOx is produced due to reaction between oxygen and nitrogen in the air and this heat is produced in all combustion processes.

Fuel NOx is formed by reaction of nitrogen. Production of NOx by combustion of solid and oil fuels with nitrogen in chemical combination is proper.

NOx produced in a combustion process usually contains more than 90% NO and less than 10% NO2. In cold weather NO reacts with O3 and forms NO2. These reactions cause to desertion of O3 layer in higher levels and formation of fog. NO2 is harmful for respiratory system and climatic reactions involving NO leads to formation of HNO3 and acid rain.

Fuels and pollutants

In general, NOx causes to most of the environmental pollutions and the countries pollutants regulations are set accordingly. In next step CO and UHC levels are investigated.

Except SO2 emission that depends on consumed fuel, other pollutants emission depend on the combustion condition and the main condition is fuel to air λ ratio. There are three combustion types:

<table>
<thead>
<tr>
<th>Table 1-3- combustion type according to λ</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stochiometric</td>
<td>Petroleum and gas(SI)</td>
</tr>
<tr>
<td>run rich</td>
<td>Extra fuel and higher combustion temperature like CI</td>
</tr>
<tr>
<td>lean burn</td>
<td>Extra air and less combustion temperature like gaseous turbine</td>
</tr>
</tbody>
</table>

The fuel to air ratio impacts on output and emission of pollutants particularly on NOx.

Figure 1 depicts fuel to air ratio impacts on emission of pollutants like UHC, CO and NOx.

![Figure 1: the effect of fuel to air ratio on emission of pollutants](image)

The highest motor output by air to fuel ratio ranges 0.9 to 1. NOx increases significantly and λ reduces insignificantly and by trivial increase of λ the emission of CO and UHC is increased and the output is reduced.

The motors regulated in lean burn (1.2<λ<1.4) in spite of losing power and output and reduction in NOx emission, the pollutants CO and UHC are produced in optimal level. But performance of the most motors by air to fuel ratio (1.5<λ and λ<1.6) is high in spite of rapid reduction of NOx and increase of CO and UHC. In this case, using Turbo-change components power loss.

NOx

NOx is emitted in a combustion process usually with more than 90% NO and less than 10% NO2. Emission of this pollutant in old motors by ratio of stochiometric fuel is about 1800gr/GJ and it is 140 gr/GJ in new motors and even half of this amount.

METHODS FOR REDUCTION OF NOX

- Using lean burn motor with control of λ
- Using stochiometric motors with 3 ways catalytic convertor
- Using selective catalytic reduction

In the first method the high amount emission is prevented and in other methods NOx is converted into oxygen and nitrogen.

ACOUSTIC POLLUTION

One of the environmental effects on human being is noise of CHP system about 100 dB in distance of one meter that it reaches to 65-75 dB by acoustic insulator and in standard state it should be less than 85 dB. Acoustic chambers have dampers in inlets and outlets and the panels are removed easily for maintenance and oscillation is reduced. This issue is important in units that are placed on roof or foundation.
special cases the chambers are used that the noise of system reaches to 30 decibels in distance of 60 meter.

Due to burning fossil energies like gasoline and natural gas SO2, NO2, CO and CO2 are emitted. The concentration of emitted gases from power plants that use different fuels is shown in table 4-1.

Table 4-1: concentration of emitted gases from power plants

<table>
<thead>
<tr>
<th>Emission</th>
<th>SO2 ton/gwh</th>
<th>NO2 ton/gwh</th>
<th>CO2 ton/gwh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil</td>
<td>63.1370</td>
<td>63.1560</td>
<td>1240</td>
</tr>
<tr>
<td>Synthetic cycle</td>
<td>45.140</td>
<td>650-810</td>
<td>450</td>
</tr>
<tr>
<td>Large hydraulic</td>
<td>18.21</td>
<td>34-40</td>
<td>7-8</td>
</tr>
<tr>
<td>Micro header</td>
<td>38-46</td>
<td>71-86</td>
<td>-</td>
</tr>
<tr>
<td>Small hydraulics</td>
<td>24-29</td>
<td>46-54</td>
<td>2</td>
</tr>
<tr>
<td>Wind turbine</td>
<td>10-32</td>
<td>14-34</td>
<td>11</td>
</tr>
<tr>
<td>PV</td>
<td>330-135</td>
<td>160-340</td>
<td>228</td>
</tr>
<tr>
<td>Micro turbine</td>
<td>-</td>
<td>PPM15&lt;</td>
<td>PPM12&lt;</td>
</tr>
</tbody>
</table>

Environmental resources are valuable deserving preservation. These resources are destructing due to pollutions of industrial activities wastages. Production of energy damages the environment. Most of the external factors that impose perils in different stages. Air pollutants produce problems like increase green house gases also emission of pollutants causes to side effects in the patients. In other hand, they impact on agricultural products and plant and animal species and lead to significant economic losses.

Table 5-1 summarizes different polices in using production technology

Table 5-1: countries using different resources and related policies

<table>
<thead>
<tr>
<th>Country</th>
<th>Policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Competitive polices and optimal energy utilization</td>
</tr>
<tr>
<td>Austria</td>
<td>Meeting 30% energy needs from recycled resourced until 2015</td>
</tr>
<tr>
<td>Belgium</td>
<td>Rational utilization of energy and reduction of CO2</td>
</tr>
<tr>
<td>Republic of Cheek</td>
<td>Support of small hydraulic production</td>
</tr>
<tr>
<td>Denmark</td>
<td>Optimal utilization and reduction of CO2 and higher output</td>
</tr>
<tr>
<td>Finland</td>
<td>Privatization and restructuring</td>
</tr>
<tr>
<td>France</td>
<td>Diversity of energy resources and using CO-generation resources</td>
</tr>
<tr>
<td>German</td>
<td>Encouraging regulations in tariffs for using hydraulic, wind and solar energies in energy production</td>
</tr>
<tr>
<td>Greece</td>
<td>Reduction of CO2</td>
</tr>
<tr>
<td>India</td>
<td>Encouragement for using recycled energies</td>
</tr>
<tr>
<td>Italy</td>
<td>Reduction of destructive gases and improvement of energy output</td>
</tr>
<tr>
<td>Holland</td>
<td>Reduction of CO2 and increase of output</td>
</tr>
<tr>
<td>Poland</td>
<td>High production rate and using gas for electrical production</td>
</tr>
<tr>
<td>Portugal</td>
<td>Reduction of CO2</td>
</tr>
<tr>
<td>Spain</td>
<td>Energy saving , reduction of energy current cost and production of 12% of total energy from recycled resources until 2010</td>
</tr>
<tr>
<td>England</td>
<td>Reduction of CO2, restructuring and increase of energy output</td>
</tr>
</tbody>
</table>

RESULTS

1-If we want to demand 3% increase in electivity until 2020 for compensation of 47% surplus consumption according to output of the power plants it is necessary to increase 60% in fuel energy consumption. This means destructing sky and earth and increase air pollution and greenhouses gases. It is necessary to use production process and thermal energy by concurrent production of heat and electivity and reduction of fuel consumption in thermal power plants and a result reduction of air pollution.

2-One of the main environmental challenges is change of climate and emission of greenhouse gases that cause to flooding and increase of sea level and destruction of zoon layers and environment. The important effect of using concurrent thermal and electrical systems is reduction of NOx and CO emission.

3- As we know CO2 is an important element for increase of products and improvement of quality in the greenhouses’ that approximately when concentrated CO2 is added into a greenhouse its products increases to 20%.

In the past diesel motors were used for production of CO2 that have disadvantages that produce high amount of NOx and CO in addition to CO2. It is hazardous and damages environment and animals. SO, the owners of the greenhouses had to install expensive equipments for refining air that increases electrical consumption and lateral costs. The advantages of the micro turbines are production of heat and electricity and high amount of CO2 that require to refinery equipment.

It is concluded that according to different application of micro turbines in agriculture, domestic and commercial and industrial scopes and reduction of environment pollution and high output and less nose and necessity of reduction of fossil fuels and considering new energy resources, the application of concurrent thermal and electrical systems is justified. It can be said that the reasons for these system utilization is low pollution, thermal recycle and saving and lack of need to other thermal generator and also, using clean fuels like natural gas that plays an import role in reduction of air pollution. Concurrent production micro turbine is useful for reduction of fuel consumption and optimization of energy consumption in peak times.

<table>
<thead>
<tr>
<th>Year</th>
<th>Electrical output %</th>
<th>Totals output %</th>
<th>Installation cost(kw/eu)</th>
<th>Maintenance cost O&amp;M(kw/h/eu) Without fuel</th>
<th>Pollution NOx(PPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro turbine without re-cooperator</td>
<td>17-20</td>
<td>70-80</td>
<td>800-1000</td>
<td>0.5-1</td>
<td>&lt;9</td>
</tr>
</tbody>
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