Advanced Energy Systems and Energy Conservation Measures to Meet the Growing Energy Demand in a Sustainable Approach

Bale V. Reddy, *Fellow Member, IACSIT*

***Abstract*—To meet the growing energy demand, there is a need to develop advanced energy systems to utilize coal, natural gas and biomass with higher energy conversion efficiency. On the other hand we need to conserve the energy resources in an efficient manner. There is also growing interest to develop renewable energy sources such as wind, solar, biomass on one side and on the other side to develop efficient and sustainable energy technologies to utilize coal and natural gas in an environmentally sustainable approach. In the present paper the developments in advanced energy systems and energy management measures are discussed.**

***Index Terms*—Combined cycle, efficiency, energy conversion, waste heat.**

I. Introduction

The demand for energy is growing worldwide due to industrialization and economic development in many countries on side and the growth in population on the other side. This has to be met with in an environmentally friendly manner. There is a growing attention to develop advanced coal, natural gas and biomass based power generation systems. Given the current global situation, there is a need to utilize all energy sources, to meet the energy requirement. In the present paper the role of coal, natural gas, biomass based advanced power generation systems and the role of energy conservation and energy management measures are discussed.

II. Coal, Natural Gas, Biomass Based Energy Systems

A. Natural Gas Combined cycle power generation systems

Combined cycle power generation systems are receiving great deal of attention due to their high energy conversion efficiency which results in higher power output and reduced pollutants and greenhouse gas emissions. Natural gas based combined cycle power generation systems [1] are being employed for power generation due to the clean burning of natural gas. The arrangement of gas turbine and steam turbine cycles through a heat recovery steam generator results in higher energy conversion efficiency. This is due to the recovery of waste heat from gas turbine exhaust gases in the heat recovery steam generator. Currently there are many natural gas based combined cycle power generation systems operating world wide with high energy conversion efficiencies compared to only gas turbine and steam turbine power plants. Research investigations are conducted on natural gas based combined cycle power generation systems to improve their performance further. The exergy analysis is also receiving a great deal of attention in recent years to identify the irreversibilities in power system components which in turn will aid for further improvement. Reddy and Mohammed [2] reported the exergy analysis for natural gas fired combined cycle power generation systems with various operating conditions. With advances in gas turbine blade materials and higher gas inlet temperatures to the gas turbines, the combined cycles will operate with higher energy conversion efficiencies resulting reduced greenhouse gas emissions and better economy. Natural gas and biomass hybrid combined cycle power generation systems are also receiving attention due to the ability to utilize biomass and to reduce carbon dioxide emissions and research investigations are conducted in this direction. The natural gas and biomass supplementary fired hybrid combined cycle power generation scheme as proposed by Gnanapragasam et al., [3] is represented in Figure 1. The analysis and the role of biomass supplementary firing and the effect of operating parameters on plant performance and carbon dioxide emissions are reported by Gnanapragasam et al., [3].

B. Coal, Biomass Gasification and Combined Cycle Power Generation

There is also a growing interest to use coal, biomass in a combined cycle mode for power generation through gasification due to its high energy conversion efficiency. In an integrated gasification combined cycle (IGCC) the coal is gasified in a gasifier and the fuel gas is cleaned and is burnt in a gas turbine combustion chamber and the unit is operated in a combined cycle mode [4]. There are coal based IGCC technology power plants operating worldwide. Research investigations are conducted on IGCC systems to further improve their performance. Gnanapragasam et al., [5] reported the performance analysis for a coal gasification combined cycle power generation system as shown in Figure 2. There is also growing interest to develop IGCC systems with carbon capture and also with hydrogen production [6, 7]. This is a growing area to utilize coal and biomass for power generation with high energy conversion efficiency approach to reduce carbon dioxide emissions.

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Bale V. Reddy is with Department of Mechanical Engineering, UOIT, Oshawa, ON, Canada(email: Bale.Reddy@uoit.ca).

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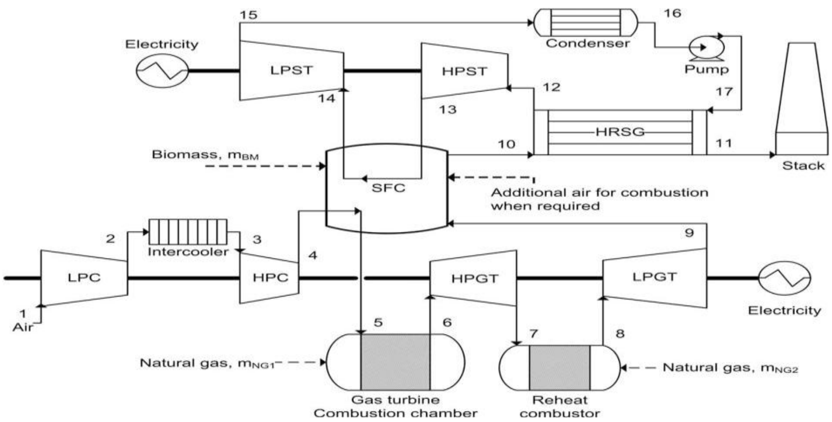

Fig. 1. Natural gas fired combined cycle plant with biomass as supplementary fuel [3].

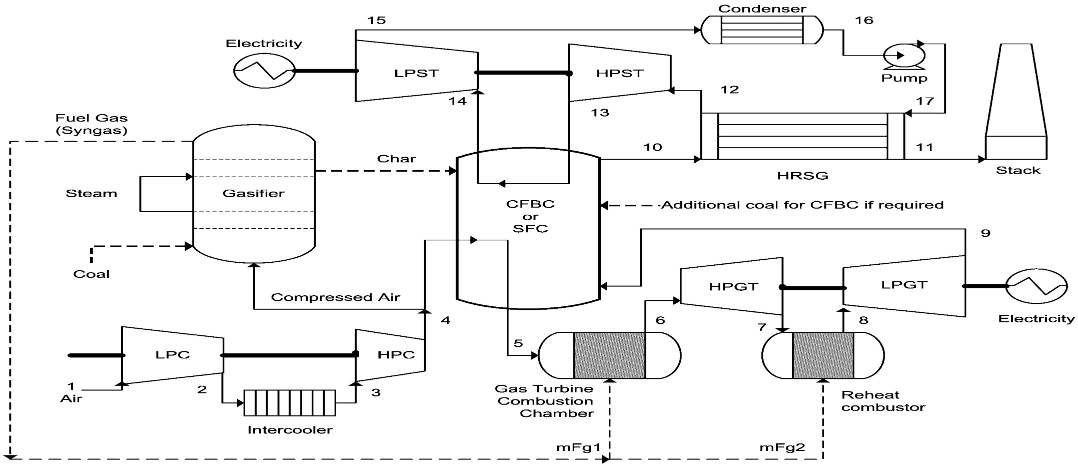

Fig. 2. IGCC power plant configuration with CFB combustor or supplementary firing combustor (SFC) [4].

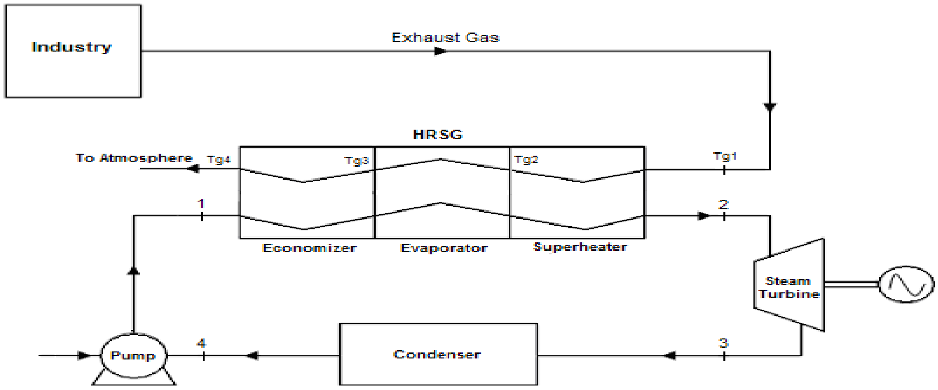

Fig. 3. Waste heat recovery based power generation system [8].

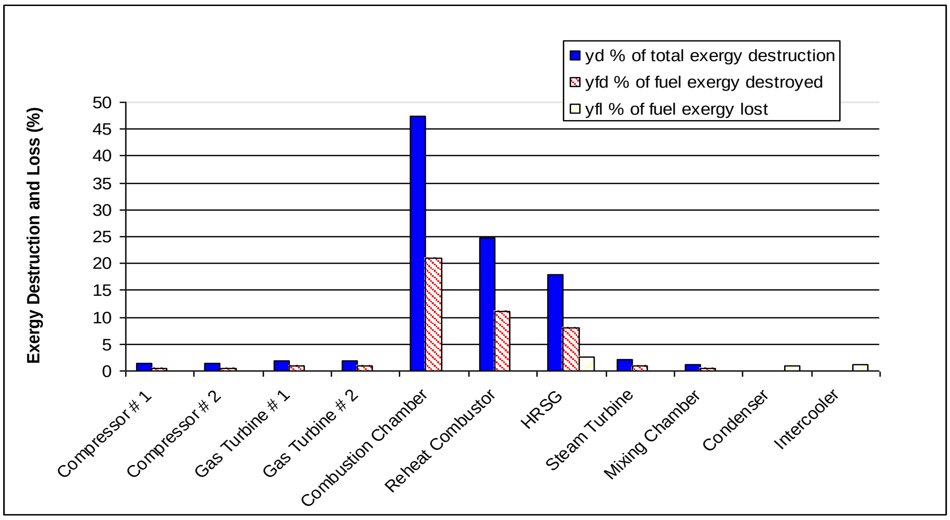

Fig. 4. Exergy destruction and loss of all system components, TIT = 1600K, r_p = 25 [10].

III. Energy Conservation

There is a growing need to conserve coal, natural gas and other energy resources with higher efficiency. Also the power that is generated should be used with reduced losses. There is also growing interest to utilize waste heat from various industrial applications for power generation, process heat and to other applications. The industries and power plants are constantly working to improve their performance thereby leading to better economic and reduced pollution and greenhouse gas emissions. There is also growing interest to utilize municipal solid waste for process heat and power generation applications. Where ever there is a scope energy conservation and management measures should be taken to reduce energy wastage and increase the availability of fuels for a longer period. There should also serious effort on the part of government and other energy related organizations to educate the people on the need to conserve the energy resources.

A. Waste Heat Recovery and Utilization

There are many industrial applications (ex: Cement, Steel), where there is huge amount of waste heat gases available at relatively high temperature. If the waste heat is not utilized, it will be lost into the atmosphere. In recent years, attention is paid to recover part of the waste heat from industrial waste gases to generate electric power. If the waste heat gases from the industry are at higher temperature, then the gases could be used to generate superheated steam in a heat recovery steam generator and the steam could be expanded in a steam turbine to generate power as shown in Figure 3 [8]. Research investigations are reported in the literature [8] on the analysis of waste heat recovery based power generation systems. If the waste heat gas temperature is in medium to low temperature range, Kalina cycle could be employed where ammonia and water mixture is the working fluid. The waste heat from the gases is used in a heat recovery vapor generator, to generate ammonia vapor. The ammonia vapor is expanded in a vapor turbine and power is produced. There are power plants in operation based on this concept and lot of research is conducted on medium to low temperature waste heat recovery power generation systems.

IV. Second Law (Exergy Analysis) and Its Role on Energy Systems

The second law analysis or exergy analysis is receiving a great attention from the last decade due to the ability to analyze a power generation system on a component basis and also as a whole system. Unlike the first law of thermodynamics which talks about energy balance for components or for the whole system, the second law provides insight into the performance of the energy system components and the whole energy system with quality point of view by analyzing the irreversibilities. Bejan [9] provided important details on the exergy analysis. The exergy analysis for a natural gas fired combined cycle power generation system is reported by Law and Reddy [10]. The irreversibilities, exergy losses and destructions in various components are shown in Figure 4 for a natural gas combined cycle power generation system and more details are reported in the paper [10]. The basic details of exergy analysis are given below.

Exergy Analysis

Once the temperature, enthalpy, and entropy are calculated, the availability is computed using:

$$av_i = h_i - h_o - T_o(s_i - s_o) \tag{1}$$

The physical exergy rate at each state is the product of the availability at that state, and the corresponding mass flow rate:

$$\dot{Ex}_{ph,i} = \dot{m}_i \, av_i \tag{2}$$

The chemical exergy rate of the fuel (ex: methane) is calculated using the relations reported in the literature. The total exergy rate at each state is the sum of the physical and chemical exergy rates, neglecting the potential and kinetic exergy effects:

$$\dot{Ex}_i = \dot{Ex}_{ph,i} + \dot{Ex}_{ch,i} \tag{3}$$

V. Conclusion

Natural gas, coal and biomass combined cycle power generation systems provide the opportunity to generate power with higher efficiencies and with reduced greenhouse gas emissions. Research investigations are conducted to further improve them.

1) Energy conservation and waste heat recovery is receiving attention to utilize the energy resources and to reduce greenhouse gas emissions.

2) The exergy analysis identifies the performance of components and provides details to improve the performance of power plant components and the overall system.

3) There is a serious need to educate people on the need to conserve energy resources and to reduce energy wastage.

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Dr. Bale Viswanadha Reddy is a Professor in Department of Mechanical Engineering in Faculty of Engineering and Applied Science, University of Ontario Institute of Technology (UOIT), Oshawa, Ontario, Canada. Prior to this Dr. Reddy also worked as an Associate Professor in Mechanical Engineering Department, University of New Brunswick (UNB), Fredericton, Canada. Dr. Reddy received his MTech and PhD degrees in Mechanical Engineering from IIT, Kharagpur, India.

Dr. Reddy research interests are in the area of simulation of advanced and sustainable energy systems, energy management and alternative energy sources. He has led funded research projects in the area of energy systems. Dr. Reddy has published 175 papers in refereed journals and refereed conference proceedings. He is also involved in the organization of many international conferences as conference chair, track chair, organizing committee member, advisory committee member etc. He has delivered keynote and invited presentations in various international conferences and has also chaired technical sessions in international conferences.

Dr. Reddy has also contributed ten book chapters along with his research collaborators in energy systems area. Dr. Reddy has also received best professor award for teaching excellence five times both in India (VIT, Vellore) and in Canada (UNB, Fredericton; UOIT, Oshawa).