Combined Cooling Heating and Power Systems – A review

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***Abstract*— Combined cooling, heating and power (CCHP) systems, including various technologies, provide an alternative for the world to meet and solve energy-related problems, such as energy shortages, energy supply security, emission control, the economy and conservation of energy, etc. this has been discussed in the paper and a detailed review of CCHP technologies and its comparison with the individual separate(SP) technologies has been shown through various graphs. Also focused has been made on using the solar light for the generation of steam in the CCHP system which could immensely effect the energy shortages-a challenge that world is facing today. In order to have this technology running it would be necessary to have a greater know-how and working towards increasing its efficiency is also required.**

Key words: Combined Cooling Heating and Power, Separate Technologies, Distributed Integrated Systems, TCO2ER-Trigeneration Carbon-di-oxide Reduction, TPES- Trigeneration Percentage Emission Standards.

I. INTRODUCTION

Combined cooling, heating and power (CCHP), is derived from combined heat and power (CHP, also called cogeneration1)—a proven and reliable technology on which applications for its commercialization has been done for past 30 and more years, which was utilized mainly in large-scale centralized power plants and industrial applications. The conventional way to provide electricity and heat is to purchase electricity from the local grid and generate heat by burning fuel in a boiler. But in a CHP system, by-product heat, which can be as much as 60–80% of total primary energy in combustion-based electricity generation, is recycled for different uses. Typically, CHP is defined as the combined production of electrical (or mechanical), and useful thermal energy from the same primary energy source. A slight difference between CCHP and CHP is that thermal or electrical/mechanical energy is further utilized to provide space or process cooling capacity in a CCHP application. In some literature, CCHP systems are also referred to as trigeneration and building cooling heating and power (BCHP) systems . CCHP can be defined as a more extensive concept than CHP is. In winter, many CCHP systems can be seen as CHP units, when there is no cooling demand of building air-conditioning. In other words, CHP system is CCHP without any thermally activated equipments for generating cooling power, though this difference will change the structure of systems to some extent. In general, recent development of CCHP systems is related to the emergence of DER (distributed/decentralized energy resources)—a novel technical concept in energy supply**[1]** DER is defined as an electricity-generation system located in or near user facilities, which provides electrical and thermal energy simultaneously to meet local users in top-priority. Certain factors, such as various rated capacities, ownership of systems, technologies employed and types of connection with utility grids, are not critical in a consensus definition of DER. According to some reports, DER can be divided into two major sections. The first section is high-efficiency CHP or CCHP systems in industry and buildings throughout the world, using prime mover technologies as reciprocating engines, gas turbines, micro-turbines, steam turbines, Stirling engines and fuel cells. The second major area of DER is on-site renewable energy systems with energy recycling technologies, including photovoltaic and biomass systems, on-site wind and water turbine generators, plus systems powered by gas pressure reduction, exhaust heat from industrial processes, and other low energy content combustibles from various processes. Due to the relationship between traditional CHP and novel DER , CCHP systems are classified into two categories:

1. Traditional large-scale CCHP applications (predominantly CHP systems without in centralized power plants or large industries;
2. Relatively small capacity distributed CCHP units with advanced prime mover and thermally activated technologies to meet multiple energy demands in commercial, institutional, residential and small industrial sections. There is no clear borderline between two categories. A theoretical calculation of prime energy utilization based on traditional energy supply mode and typical CCHP system as Fig. 2 can be seen in Figs. 3 and 4. If end user needs 33 units of electrical power, 40 units of cooling power and 15 units of heating power in a summer day, 148 units of prime energy are consumed in a traditional way. Centralized power plant runs at the efficiency of 33% and 100 units of prime energy are used to generate 33 units of electrical power. Traditional boiler burns 18 units fuel to heat 15 units of domestic hot water at the efficiency of 85%. Electrical air-conditioner driven by 10 units of electrical power can generate 40 units of cooling power at COP of 4. However, consider the efficiency of electricity generation in power plant, 30 units of prime energy is needed in all for space cooling. Based on a typical CCHP system shown in Fig. 2, only 100 units of prime energy are needed for 33 units of electrical power, 40 units of cooling power and 15 units of heating power in a summer day. Compared with the energy supply mode of large centralized power plant and local air-conditioning system, distributed CCHP systems will receive more attention, because—along with the developing tendency and promising prospects—they possess some advantages, which traditional energy supplies do not share**[2]**

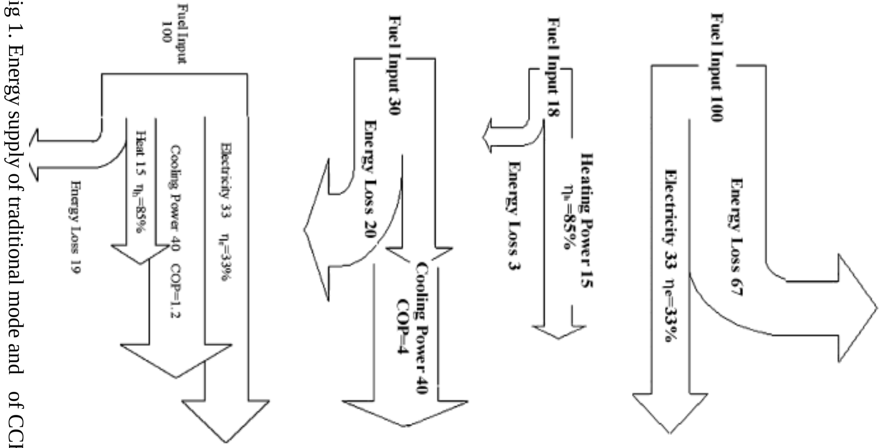

Fig 1. Energy supply of traditional mode and of CCHP

Table II Characteristics and Parameters of Prime Movers in CCHP

	Steam turbines	Diesel engines	Spark ignition engines	Combustion turbines	Micro-turbines	Stirling engines	Fuel cells
Capacity range	50 kW–500 MW	5 kW–20 MW	3 kW–6 MW	250 kW –50 MW	15–300 kW	1 kW–1.5 MW	5 kW–2 MW
Fuel used	Any	Gas, propane, distillate oils, biogas	Gas, biogas, liquid fuels, propane	Gas, propane, distillate oils, biogas	Gas, propane, distillate oils, biogas	Any (gas, alcohol, butane, biogas)	Hydrogen and fuels containing hydrocarbons
Efficiency electrical (%)	7–20	35–45	25–43	25–42	15–30	~40	37–60
Efficiency overall (%)	60–80	65–90	70–92	65–87	60–85	65–85	85–90
Power to heat ratio	0.1–0.5	0.8–2.4	0.5–0.7	0.2–0.8	1.2–1.7	1.2–1.7	0.8–1.1
Output heat temperature (°C)	Up to 540	[a]	[a]	Up to 540	200–350[b]	60–200	260–370
Noise	Loud	Loud	Loud	Loud	Fair	Fair	Quiet
CO_2 emissions (kg/MWh)	[c]	650	500–620	580–680	720	672[d]	430–490
NO_x emissions (kg/MWh)	[c]	10	0.2–1.0	0.3–0.5	0.1	0.23[d]	0.005–0.01
Availability (%)	90–95	95	95	96–98	98	N/A	90–95
Part load performance	Poor	Good	Good	Fair	Fair	Good	Good
Life cycle (year)	25–35	20	20	20	10	10	10–20
Average cost investment ($/kW)	1000–2000	340–1000	800–1600	450–950	900–1500	1300–2000	2500–3500
Operating and maintenances costs ($/kWh)	0.004	0.0075–0.015	0.0075–0.015	0.0045–0.0105	0.01–0.02	N/A	0.007–0.05

II. COMBINED COOLING HEATING AND POWER GENERATION SYSTEMS

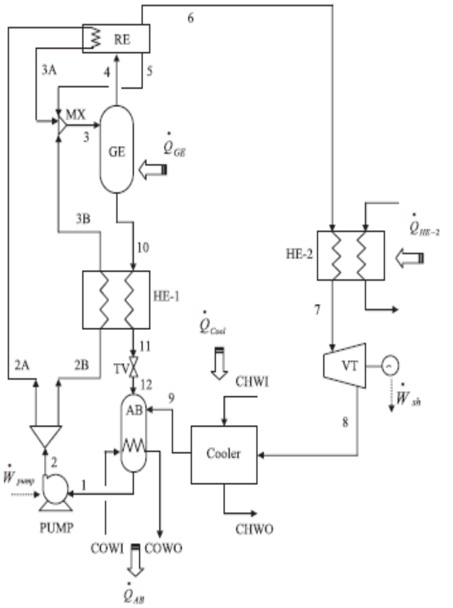

Fig2. Schematic of combined cooling and power generation systems

The proposed cycle combines the Rankine cycle and the absorption refrigeration cycle, which can produce both power and refrigeration simultaneously with only one heat source. This cycle uses ammonia–water mixtures as a working fluid, which reduces the heat transfer irreversibility, especially for low temperature heat sources such as solar energy and geothermal heat. As shown in Fig. 1, the basic concentration saturated solution which leaves the absorber is pumped to a high pressure. After being heated in a heat exchanger, it is sent to the rectifier, where the basic solution is separated into ammonia-rich vapor and a weak solution. The bottom of the rectifier is boiler, where weak solution absorbs heat and becomes saturated vapor. The weak saturated solution is superheated through the superheater and then expanded through the turbine to produce power. The ammonia-rich vapor is condensed to liquid in the condenser. The liquid ammonia passes through a valve, and is throttled to a low pressure. This stream which is almost pure ammonia, evaporates completely to vapor in the evaporator for refrigeration. It is then absorbed by the weak solution which is brought to absorber after expansion through the turbine, to form the basic ammonia–water saturated liquid solution to complete the cycle. The heat source passes through superheater firstly, and then flows into boiler, and finally exhausts into environment through heat exchanger.**[21]**

Table II PARAMETERS FOR CCHP

Stream	T°C	P bar	M [kg/s]	X, kgNH_3/kg H_2O
1	9.72	1.50	1	43.7
2	9.87	20.50	1	43.7
2A	9.87	20.50	0.05	43.7
2B	9.87	20.50	0.95	43.7
3	103.89	20.50	1	43.7
3A	110.00	20.50	0.05	43.7
3B	103.48	20.50	0.95	43.7
4	125	20.50	0.18	92.3
5	108	20.50	0.01	40.42
6	108	20.50	0.17	96.30
7	108	20.50	0.17	96.30
8	6.74	1.50	0.17	96.30
9	12	1.50	0.17	96.30
10	125	20.50	0.83	32.83
11	14.87	20.50	0.83	32.83
12	15.30	1.50	0.83	32.83
CHWI	17	1.50	0.18	0.00
CHWO	11.73	1.50	0.18	0.00
COWI	4.72	1.50	13.19	0.00
COWO	9.72	1.50	13.19	0.00

III. CALCULATIONS [9]-[13]-[14]-[22][23]-[24]

As far as evaluation of the system is concerned, it is based on the energy efficiency and exergy efficiency of the system. A. vidal et.al, B.Zheng, Y.W.Zengh, O.Balli et.al, J.Wang et.al,jk H. Hazi et al, C.Cou et al, J.Xu. et al, Hony et.al have described the system using ammonia- water mixtures based on the energy and exergy efficiency which are calcuted as per the below mentioned equations. Some of the reported efficiencies are listed here in table

Energy

$$E = Wnet + Qeva / Qin \qquad (1)$$

Where

W_{net} : Turbine work – Pump work

Q_{eva} : Refrigeration output

Q_{in} : Total heat added to the cycle from heat source

Exergy

Exergy of the heat source fluid

$Ein = mg (hg - ho) - To (Sg-So)$ (2)

Exergy associated with refrigeration output

$Eeva = meva [heva,i - heva,o] - To(Seva,i - Seva,o]$ (3)

Where
Eeva = Exergy associated with the evaporator
heva,i= Enthalpy of the evaporator inlet
heva,o= Enthalpy of the evaporator outlet
Seva,i= Entropy of the evaporator inlet
Seva,o=Entropy of the evaporator outlet

Table III REPORTED EFFICIENCIES

Energy efficiency (%)	Exergy efficiency (%)	Ref.
-	53	8
34.1	56.8	13
58.2	15.2	15
-	43.06	20
58.0	15.2	21
58.97	36.13	22
35	60.7	24

The highest efficiency of exergy reported by H. Hong et.al. [24]. Here the methanol decomposition with a catalyst was experimentally studied at temperatures of 150-300ºC and under atmospheric pressure. The chemical energy released by methanol fuel in this cycle consisted of two successive processes: solar energy drives the thermal decomposition of methanol in a solar receiver-reactor, and the syn gas of resulting products is combusted with air, namely, indirect combustion after methanol decomposition. As a result the net solar to electric efficiency of the cycle is 35% and exergy efficiency is 60.7%. These promising results indicate that this new solar thermal power cycle could make a significant improvement both in the efficient use of the chemical energy of clean synthetic fuel and in the middle-temperature solar thermal energy in a power system.

IV. DEVELOPMENT OF CCHP IN INDIA

With continuing economic growth, the Indian electricity system is in need of urgent investment and development. DER (mainly CCHP systems) capacity is only 4.1GW about 3.6 of total electricity capacity in India. High priced and unreliable electricity supply, government capital grants and soft loans are the key drivers for CCHP development. At the same time, some barriers exist, such as lack of adequate policy framework, lack of technical knowledge and support services, shortage of investment finance and limited natural gas network for cogeneration. In the CCHP market, there is tremendous potential in industrial sugar cane. Bagasse-based cogenerations in sugar mills are the main form of CCHP development in India. A distributed generation revolution began in India with 87 new local power projects, producing 710MW from sugar cane waste. In September 2001, the Ministry of Power estimated that there was a total potential for Some 15GW of cogeneration capacity, of which 2GW had been implemented to date.**[2]**

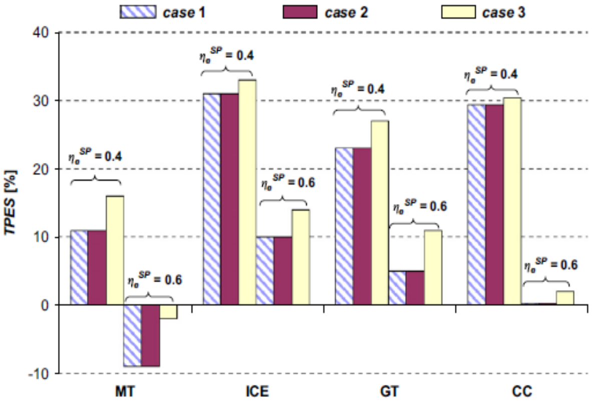

Fig3.TPES values for different separate production technologies and Combined Cycle technologies and different separate production

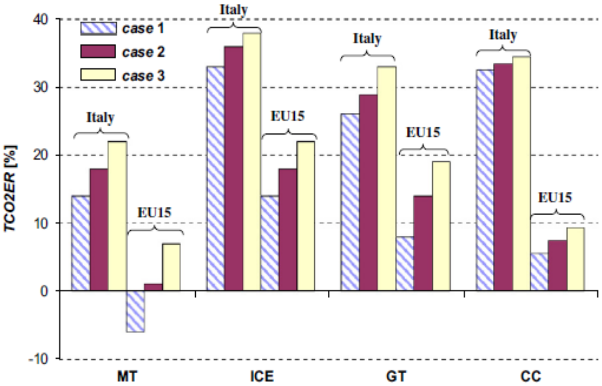

Fig.4 TCO_2ER values for different gas-fuelled CHP

V. CONCLUSION

Combined cooling, heating and power systems are derived from the CHP category, which shares some merits with CHP—especially energy conservation. Small-scale distributed CCHP applications, an important part of novel DER technologies, are the issue of CCHP recently. Existing and potential technologies of CCHP are available. These technologies contain both improved conventional approaches, like steam turbines, reciprocating engines, combustion turbines and electric chillers, as well as relatively new technologies such as fuel cells, micro turbines, Stirling engines, sorption chillers and dehumidifiers. Most prime mover technologies are still based on fossil fuel combustion, since renewable energy technologies cannot totally and economically replace traditional technologies in the near future. Therefore, CCHP technologies provide the world with a transitional system of reliable and stable energy supply.

Better understanding of user demands, careful selection of technologies and full consideration of revenue are the keystones to successful CCHP application

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