Preliminary Design and Piping Diagram for a Combined Heat and Power System

For the College of Engineering at the University of Louisiana Lafayette Using Donated Equipment

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ABSTRACT

Combined heat and power (CHP) systems have many different factors in design procedures. The configuration of a CHP system can be changed to affect different factors of the design and to meet specific needs of the system. Before the design process can begin, product specifications, such as steam or water pressures and temperatures, and equipment, such as absorption chillers and heat exchangers, need to be identified and defined. The objective of this paper is to lay out a preliminary design of the CHP system at the College of Engineering at the University of Louisiana, Lafayette. First, a flow chart is presented depicting a broad scope model of the whole system. Then, the specifications of the absorption chiller and the heat exchanger to be used in the system are calculated by working out the flow rates of the water circuits and the temperature of the exhaust gas. Once these are determined, a piping and instrumentation diagram is shown, based on these calculations. Most of the equipment was donated to the University for work in the Energy Engineering Laboratory of the Mechanical Engineering Department and the Industrial Assessment Center. Our design work involves connecting all of the donated and other equipment to make our CHP system.

Keywords: Combined heat and power, absorption chiller, heat exchanger, piping and instrumentation diagram

Nomenclature

HWI = Hot water inlet
HWO = Hot water outlet
CHWI = Chilled water outlet
CHWO = Chilled water inlet
COWI = Cooling water inlet
COWO = Cooling water outlet
Tw, o = Water outlet temperature
Tw, i = Water inlet temperature
Tex, o = Exhaust outlet temperature

INTRODUCTION

Combined heat and power (CHP), also known as cogeneration, is a simultaneous process of using waste heat and at the same time, generating power. The waste heat is generally used to run many cogeneration related equipment, such as heat recovery steam generators, duct burners, or direct- and indirect-fired absorption chillers, while the power, typically in the form of mechanical or electrical energy, may be totally used in the industrial plant that serves the cogeneration system, or may be partially exported to a utility grid [1]. CHP is not a new concept but rather has been in the United States since the late nineteenth century. In 1884, the Del Coronado Hotel located in San Diego was the first company to utilize a CHP system [2].

A CHP system utilizes waste heat which increases the system's efficiency up to 90 percent compared to power plants, which have an efficiency of about 40 percent. Besides being efficient, CHP reduces fuel costs by about 27% [3] and is beneficial to the environment because it decreases the emissions of NO_x, SO_x, mercury and CO released into the atmosphere.

BACKGROUND

The University of Louisiana at Lafayette has been given the major equipment needed to set up a combined heat and power system. This includes an 800-kW gas turbine from Solar Turbines, a 100-ton Thermax absorption chiller and a 100-ton cooling tower from Coastal Engines. The plant is being set up in New Iberia, Louisiana, where cooling is needed over a longer period of the year than heating. The primary goal of setting up a CHP system in the University is to improve the current air conditioning by supplementing the existing air-conditioning unit with additional chilled water supply. By doing so, the University will be able to reduce its dependence on external utilities' systems, therefore reducing utility cost. Other uses for the system could include providing power in the event of a major emergency, such as a hurricane or a flood, when grid power will not be available. The University may also seek to sell excess power to the Lafayette utilities system. Figure 1 illustrates a schematic of the CHP system.

SYSTEM DESCRIPTION

The task that was set this summer was to link together the various components and develop a piping and instrumentation diagram for the CHP system. A flow chart is presented in Figure 2 explaining the different water circuits flowing in and out of the chiller unit. In addition to this, it shows how the turbine exhaust is connected to the chiller through a heat exchanger.

Exhaust gas at 800°F comes out of the turbine at a flow rate of 48,880 lbs/hr [4]. The important parameter in designing the CHP system was to control the final temperature of this exhaust gas. After running different iterations on temperature calculations, it was decided to divert 35% of the exhaust air to the heat exchanger, while the remaining 65% is directed up the stack. In addition, this relieved the problem of back pressure build-up at the end of the turbine. In the heat exchanger, the exhaust gas heats the water, which goes to the absorption chiller. An absorption chiller is a machine that uses heat in any form to produce chilled water or hot water. The basic principle of an absorption chiller, which makes it different from the more familiar vapor compressor mechanical refrigerator, is that the refrigeration effect is produced through the use of two fluids and some quantity of heat input rather than electrical input [5]. A continuous water circuit is made to run through the chiller to take away heat from the heat input source and also from the chilled water. These chillers run on either steam or hot water. The absorption chiller donated to the University runs on hot water and supplies chilled water. The chilled water is then transferred to the existing University air-conditioning unit.

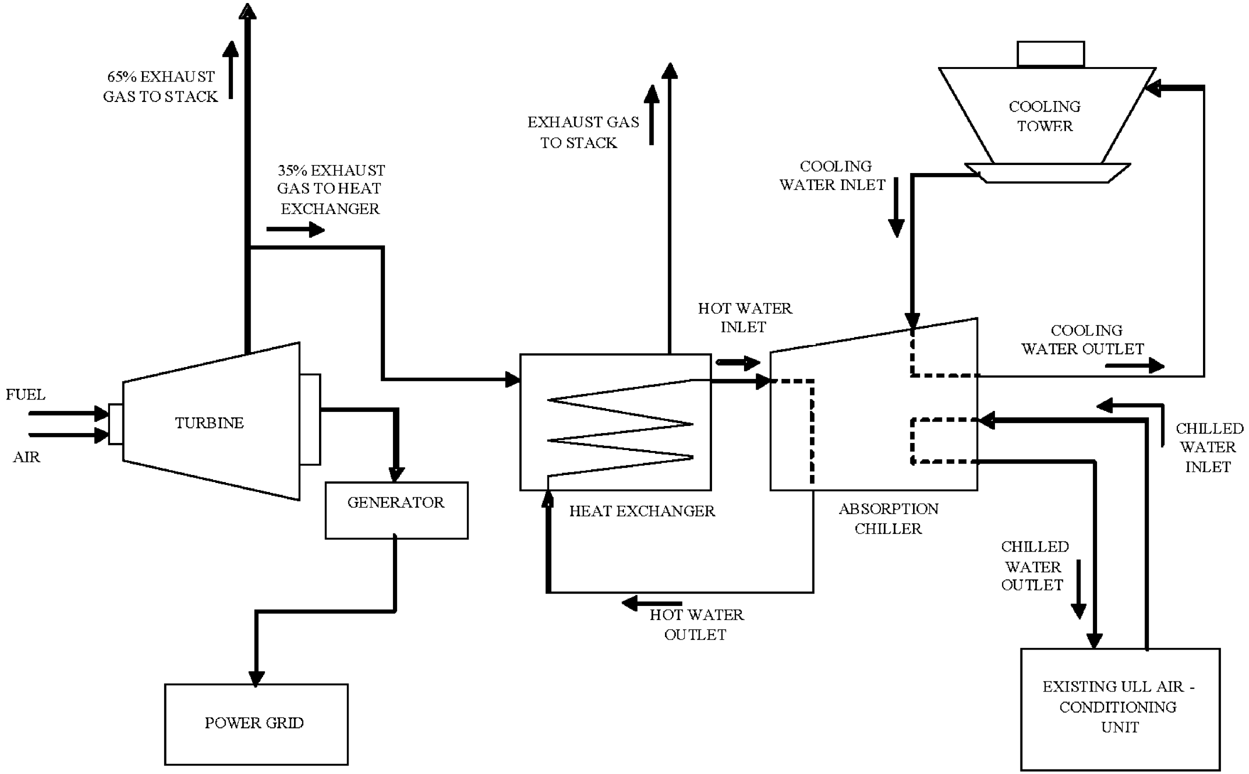

Figure 1. Flow chart for the CHP System

Calculations

Absorption Chiller: The chiller used in the system is a single-stage unit with a refrigeration capacity of 100 tons. For the Thermax unit, the temperatures for the three water circuits are: hot water entering at 195°F, leaving at 175°F, cooling water entering at 85°F, leaving at 95°F and chilled water entering at 54°F, leaving at 44°F [6]. Under these conditions, a coefficient of performance (COP) of approximately 0.65 to 0.70 can be expected [7]. The COP is considered as an index to determine the efficiency of the machine. It is calculated by dividing the cooling output by the required heat input.

HEAT INPUT OR HOT WATER FLOW RATE:

Cooling capacity = 100 RT
1 RT = 12,000 Btu/hr
Cooling output = 100 × 12,000 = 1,200,000 Btu/hr
Heat input = Cooling Output/COP
Heat input = 1,200,000/0.7 Btu/hr
Q_1 = 1,714,286 Btu/hr
$m = Q_1/(c \times \Delta T)$
Specific heat for water, c = 1 Btu/lbm-°F
ΔT = HWI temperature – HWO temperature
ΔT = 195 – 175°F = 20°F
$m = 1{,}714{,}286/(1\times 20)$
m = 85,714.3 lbm/h
Mass flow rate of hot water = 171.3 gpm (1)

COOLING OUTPUT OR CHILLED WATER FLOW RATE:

Cooling output = 100 × 12,000 Btu/hr
Q_2 = 1,200,000 Btu/hr
$m = Q_2/(c \times \Delta T)$
ΔT = CHWI temperature – CHWO temperature
ΔT = 54 – 44°F = 10°F
$m = 1{,}200{,}000/(1\times 10) = 120{,}000$ lbm/hr
Mass flow rate of chilled water = 239.8 gpm (2)

COOLING WATER FLOW RATE:

Cooling water takes heat from the hot water and also the heat rejected by the chilled water.

$Q_3 = Q_1 + Q_2$

Q_3 = 1,714,286 +1,200,000
Q_3 = 2,914,286 Btu/hr
$m = Q_3/(c \times \Delta T)$
ΔT = COWO temperature – COWI temperature
ΔT = 95 – 85°F = 10°F
m = 2,914,286/(1×10) = 291,428.6 lbm/hr
Mass flow rate of cooling water = 582.4 gpm (3)

Heat Exchanger: A shell-and-tube heat exchanger with a generic efficiency of 0.8 is considered for temperature calculations. The exhaust gas will pass in the shell side and water in the tube side. The hot water coming out of the chiller at 175°F is the inlet temperature of water in the heat exchanger.

HEAT TRANSFER:
$Q = m \times c \times \Delta T$
From (1), mass flow rate of water = 171.3 gpm
= 85,714.3 lbm/hr
$\Delta T = T_{w,\ o} - T_{w,\ i}$
ΔT = 195 - 175°F = 20°F
Q_1 = 85,714.3×1×20 = 1,714,286 Btu/hr
Efficiency of heat exchanger = 80%
Therefore, $Q = Q_1/0.8$ = 1,714,286/0.8
Net Heat Transfer = 2,142,857 Btu/h (4)

EXIT TEMPERATURE OF EXHAUST GAS:
Flow rate = 48,880 lbm/hr
As 35% is diverted to the heat exchanger,
Flow rate = 0.35 × 48,880 =17,108 lbm/hr
$\Delta T = Q/(m \times c)$
Specific heat of exhaust air at 800°F, c = 0.2667 Btu/lbm-°F [4]
ΔT = 2,142,857/(17,108 × 0.2667)
ΔT = 470°F
$T_{ex,\ o} = 800 - \Delta T$
Outlet temperature of exhaust gas = 330°F (5)

Piping and Instrumentation Diagram

A piping and instrumentation diagram (PI&D) is a diagram that uses process symbols to describe a process unit. It is a complex drawing and includes the graphic representation of the equipment, piping and instrumentation. P&IDs are used as a detailed design guide for construction and installation purposes. They are also a principle form of communication between those who design the system and those who will later operate it, so it is very important that they be complete and clear [8].

The P&ID presented in Figure 2 includes the flow rates, temperatures, instrumentation data and the connections between the various equipment.

CONCLUSION

The P&ID presented in this paper is based on groundwork research and has to be analyzed before making a general layout of the system. The design needs to be evaluated based on parameters such as energy balances, investment costs and economic benefits. The investment costs include cost of equipment not donated to the University, such as the heat exchanger, as well as the installation of the various units. Fuel availability and present day cost also need to be considered as future running costs. Presently, more than half of the exhaust gas is still being wasted so, a heat recovery steam generator can be added in the design to utilize the waste heat. Furthermore, a method is needed to control the amount of exhaust gas being diverted to the heat exchanger. Finally, the design and specifications of the heat exchanger need to be finalized. These design factors still remain to be determined. Subsequent to resolving these issues, the University's cooling and power demands need to be identified so that energy balance calculations can be performed.

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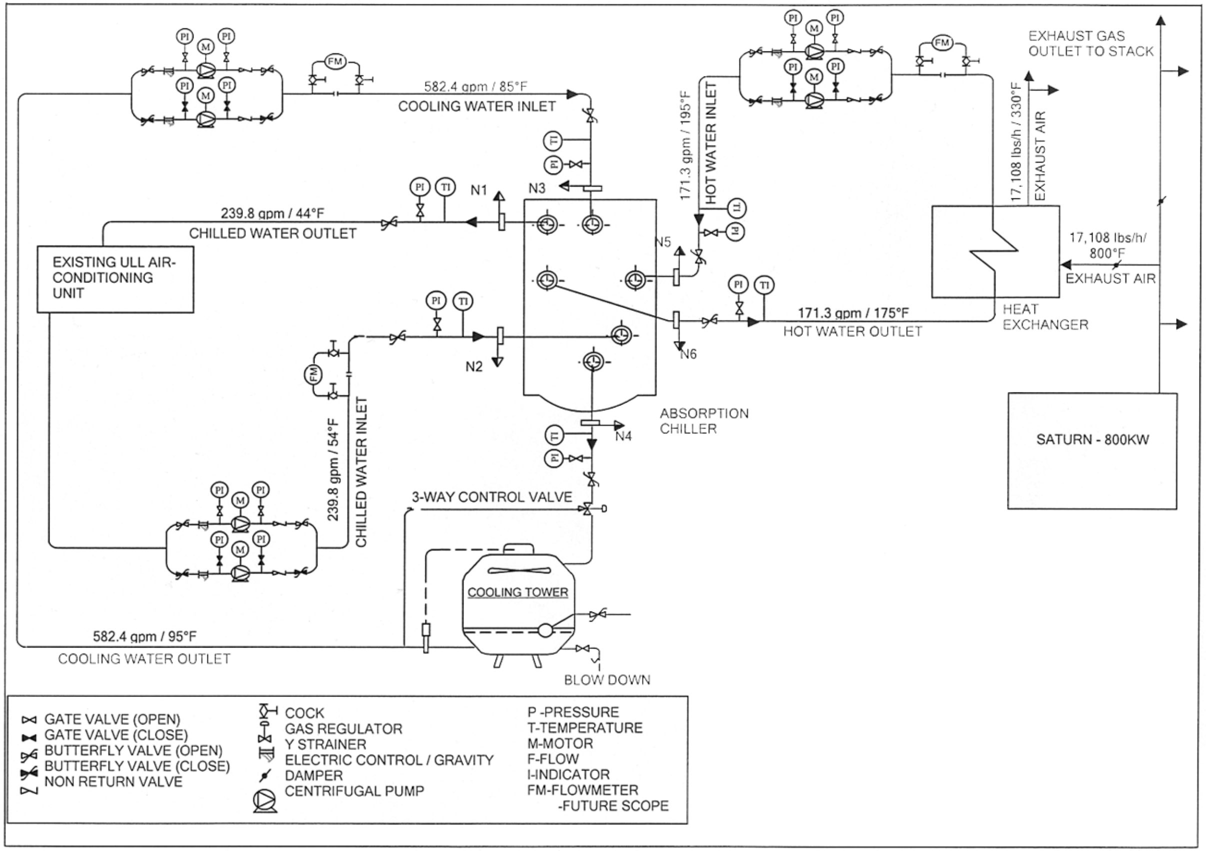

Figure 2. P&ID for a Solar Saturn 20-1600 and a Thermax THWLT10H Absorption Chiller-based CHP System

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