



# Investigating steam turbine feasibility to improve the sustainability of a biomass boiler using TRNSYS

Marc Compton, Behnaz Rezaie\*

Applied Energy Research Laboratory (AERL), Department of Mechanical Engineering, College of Engineering, University of Idaho, 875 Perimeter Dr., Moscow, ID 83844-0902, USA

## ARTICLE INFO

### Keywords:

Biomass Boiler  
Steam Turbine Feasibility  
District Energy Sustainability  
District Energy Feasibility  
District Energy Turbine  
Wood Chips Electricity  
Exergy Efficiency

## ABSTRACT

Adding a turbine to a steam generator plant of a district energy system increases the efficiency of the plant by generating some electricity. This is the method of turning a heating and cooling plant into a combined heating, cooling, and power plant. The district energy plant at University of Idaho, Moscow, Idaho, USA is modeled by using TRNSYS modeling software. Simulation of different models is made to compare the current system configuration to the current plus a small backpressure steam turbine, and adding a double effect absorption chiller. Operating costs, energy, and exergy efficiencies are evaluated at current and maximum steam pressure levels through the boiler and turbine. Primary components in the system include a wood chip fired boiler, steam turbine, 2100 kW single effect and 4100 kW double effect absorption chillers, and campus with associated pumping needs. Results show that installing a turbine and increasing pressure to maximum possible levels improve energy and exergy efficiency by 3–4% and 5%, respectively over current levels. Bringing a double effect chiller in addition to the turbine increases energy and exergy efficiencies further to 20% and 7%. Economic savings are substantial if power can be sold back to the utility at a higher rate.

## 1. Introduction

Modern society's demand for more energy has been one of its biggest challenges, a trend that has shown no signs of stopping. In recent centuries, this demand has been satisfied by extracting fossil fuel resources such as coal, oil, and natural gas. These resources cannot be replenished on a time scale that is sustainable and will eventually run out. Renewable energy resources have the potential to replace fossil fuels as the dominant source of energy. However, while extensive work has been done to harness solar, wind, biomass, and many other energy sources, the technology is not yet at a point where it can reliably replace our dependence on fossil fuels. It is for this reason that we must utilize the energy resources available, no matter their origin, as efficiently as possible.

One of the ways energy resources can be used efficiently is in district energy (DE) applications. DE systems can produce heating, cooling, and electricity in a central location, where it is then distributed for use in buildings. By using a central plant, less efficient equipment is eliminated from the individual buildings. These systems have been shown to meet energy demands with reduced greenhouse gas emissions compared to more traditional systems (Rezaie & Rosen, 2012). DE systems using non fossil fuels have also been shown to be economically advantageous

compared to fossil fuels after considering taxes associated with CO<sub>2</sub> emissions (Rezaie, Reddy, & Rosen, 2014).

The energy plant at the University of Idaho (UI) has been operating for over ninety years, with many expansions and upgrades throughout its life. Originally using coal as the primary fuel source, UI eventually switched to natural gas and today uses biomass in the form of wood chips, resulting in significant economic savings without relying on fossil fuels (Compton & Rezaie, 2017a). Recently, to increase the cooling capacity a 7500 m<sup>3</sup> cold thermal energy storage (TES) tank was added to the UI district heating and cooling in the Moscow, ID campus. The UI energy plant has capacity for more advancement by integrating a turbine for generating electricity. Combined heat and power (CHP) plants, also known as cogeneration plants, have been in use for decades. During warm summer periods, traditional CHP plants have difficulty discharging sufficient heat. This limits the amount of power than can be produced and presents an opportunity to utilize waste heat to produce cooling in what is referred to as combined heating, cooling, and power (CHCOP), or trigeneration. Szega and Żymelka presented a thermo-economic analysis of producing cold through the use of single effect absorption chillers in a trigeneration plant (Szega & Żymelka, 2017). They concluded that producing cold allowed for increased electricity production at the cost of increased fuel consumption. There has been

\* Corresponding author.

E-mail addresses: [comp8033@vandals.uidaho.edu](mailto:comp8033@vandals.uidaho.edu) (M. Compton), [Rezaie@uidaho.edu](mailto:Rezaie@uidaho.edu) (B. Rezaie).

<https://doi.org/10.1016/j.scs.2018.08.032>

Received 27 February 2018; Received in revised form 23 August 2018; Accepted 23 August 2018

Available online 25 August 2018

2210-6707/ © 2018 Published by Elsevier Ltd.

**Nomenclature**

|       |                                      |
|-------|--------------------------------------|
| BDMT  | Bone dry metric ton                  |
| BDT   | Bone dry ton                         |
| Boost | Booster                              |
| C     | Cost (\$)                            |
| CHCP  | Combined heating, cooling, and power |
| CHP   | Combined heating and power           |
| Cond  | Condensate                           |
| CT    | Condensate tank                      |
| DA    | De-aerator                           |
| DE    | District energy                      |
| H     | Efficiency                           |
| econ  | economizer                           |
| FD    | Forced draft                         |
| Feed  | Feed water                           |
| GHG   | Greenhouse gas                       |
| H     | Specific enthalpy (kJ/kg)            |
| HLS   | Hot lime softener                    |

|           |                              |
|-----------|------------------------------|
| HHV       | Higher heating value (MJ/kg) |
| ID        | Induced draft                |
| $\dot{m}$ | Mass flow rate (kg/s)        |
| P         | Pressure (kPa)               |
| PH        | Air preheater                |
| PRV       | Pressure reducing valve      |
| $\dot{Q}$ | Heat transfer rate (kW)      |
| RT        | Refrigeration ton            |
| T         | Temperature (K)              |
| TES       | Thermal energy storage       |
| UF        | Under-fire                   |
| $\dot{X}$ | Exergy rate (kW)             |

**Subscripts**

|   |                    |
|---|--------------------|
| O | Reference property |
| B | Boundary           |
| f | Flow               |
| X | Exergy             |

research using TRNSYS modeling software to determine the feasibility of integrating cooling into a CHP system. Pagliarini et al. performed an economic analysis and determined that there is a point where the operating costs of a CHCP system outweigh the selling cost of electricity, i.e. it eventually becomes cheaper to buy power than produce it (Pagliarini, Corradi, & Rainieri, 2012). Drake also investigated improvements in a university campus using TRNSYS (Drake, 1988). He discovered that the economic costs of additional piping to expand the system were not feasible, however upgrading the current steam network did result in reduced annual operating costs. Lake, et al. have investigated the reduction in greenhouse gases when CHP technology is integrated with CHCP (Lake, Rezaie, & Beyerlein, 2017). The potential for CHCP to reduce environmental impacts through the reduction of greenhouse gases has been shown by Schickanz et al. as well (Schickanz, Wapler, & Henning, 2011).

Exergy is defined as the maximum amount of work that can be extracted from a system in a reference environment Klein and Nellis (2012). Exergy accounting allows for the inputs, losses, and wastes of a process to be identified since exergy is not a conserved quantity like mass and energy (Ayres, Ayres, & Martinas, 1996). Sciubba and Wall have reviewed the development of exergy in recent years (Sciubba & Wall, 2007). Szargut et al. have suggested that taking an exergy approach to increase system efficiency can reduce the system's impact on the environment (Szargut, Morris, & Steward, 1987). Connections between energy, exergy, and long term sustainability have been identified by Dincer and Rosen as well (Dincer, 2002; Rosen & Dincer, 2001; Rosen, Dincer, & Kanoglu, 2008). Efforts to provide a meaningful comparison between renewable and nonrenewable building energy systems using an exergy approach have been made by Sangi and Müller (2016). The use of exergy methods to identify the most sustainable energy option for a buildings case study was investigated by Balta et al (Balta, Dincer, & Hepbasli, 2011). They showed that solar collectors and ground heat pumps had the highest exergy efficiency for the given system.

Efforts have been made to improve the energy and exergy efficiency of thermal power plants and district energy systems using TRNSYS software. Kallert et al. have demonstrated potential benefits when using an exergy approach to improve performance in low-temperature district heating networks (Kallert, Schmidt, & Bläse, 2017). Adibhatla and Kaushik investigated the energy efficiency, exergy efficiency, fuel savings, and solar contribution of a conceptual improvement to a 500 MWe coal fired power plant with TES (Adibhatla & Kaushik, 2017). They showed that a solar aided feed water heating network could improve system performance with a low payback period. Alam et al. investigated

the feasibility of using solar thermal energy to preheat feed water (Alam, Siddiqui, & ur Rehman, 2017). They developed a method for determining the economic impacts of integrating solar thermal energy with conventional power plants.

Boilers consume significant amounts of energy in any system and they must be used in the most efficient manner possible to realize economic and environmental benefits. The focus of this study is to improve the performance of the current cycle while minimizing capital investment. The impact of installing a small single stage, backpressure steam turbine to replace the pressure reducing valve (PRV) as the primary means of reducing steam pressure in the system as a solution is investigated. This could be implemented without significant modifications to the current steam cycle. Larger, more complex cogeneration systems could provide larger improvements in performance; however, their capital costs would also be much higher. Capital costs are not investigated in this paper, since they may vary between locations. The impact on system performance with the installation of a double effect absorption chiller is also investigated. Furthermore, energy and exergy efficiency is calculated, as well as the operating costs of the system during the peak heating and cooling months for each configuration. Previous research has shown that older generations of boilers can have similar performance of newer boilers with the right operating conditions and equipment selection (Compton & Rezaie, 2017b). It is important to optimize boiler operation to reduce fuel consumption and minimize their impacts on the environment.

## 2. Methodology

### 2.1. Exergy analysis

An exergy analysis allows for the environmental impact of a process to be determined, as it provides a better understanding of the magnitude and sources of losses in a system compared to an energy analysis alone (Kanoglu, Dincer, & Rosen, 2007). There is a fundamental difference between energy and exergy. In an energy balance, both heat and work have the same value, however work has a higher exergy value than heat and therefore the use of an exergy analysis can be more appropriate when investigating impacts on the environment (Gonçalves, Angrisani, Roselli, Gaspar, & Silva, 2013). The exergy rate associated with heat transfer is written as follows, where  $T_b$  is the system boundary temperature where heat is being transferred

$$\dot{X}_Q = \dot{Q} \left( 1 - \frac{T_o}{T_b} \right) \quad (1)$$

Download English Version:

<https://daneshyari.com/en/article/10132146>

Download Persian Version:

<https://daneshyari.com/article/10132146>

[Daneshyari.com](https://daneshyari.com)