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Modelling and simulation of multi-generation systems based on a biogas operated IC Engine

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ABSTRACT

World is facing an impending energy crisis. With oil and gas production set to decline in next decade and greenhouse gas emissions at their all-time high, it is necessary to look for efficient and sustainable energy systems. Co-generation and tri-generation utilize waste heat of prime movers to produce more useful energy from same fuel input. In this paper efficient multi-generation systems based on biogas run IC Engine have been designed and simulated in TRNSYS and energy analysis has been conducted on them. Energy efficiency of our designed system was 83.40% for co-generation and 75.20% for tri-generation mode.

Keywords: TRNSYS, Modelling, Tri-generation, Simulation, Energy efficiency

Nomenclature	Meaning of subscripts
E = Energy	fl = Fuel
CV = Calorific value	ex = Exhaust

ṁ = Mass flow rate	hw = Hot water
Cp = Specific heat capacity	w = Water
T = Temperature	jw = Jacket water
T_0 = Environmental temperature	oc = Oil cooler
ɳ = Efficiency	ac = After cooler
	ref = Refrigeration
	p = Power

1. INTRODUCTION

Oil and gas supplies are set to dry in the next 35-37 years, while the demand for energy is at all-time high [1]. Price of oil is expected to rise steadily over next decade [2]. In addition to this, greenhouse gases emitted from using petroleum products as fuel are a cause of major concern. Hence, Focus should be on using our current reserves efficiently. Co-generation and tri-generation are ways to extract more useful energy output from same fuel input. Co-generation is production of Combined Cooling and Power (CCP) or Combined Heating and Power (CHP). Whereas, tri-generation is production of Combined Cooling Heating and Power (CCHP). Tri-generation systems are made by integrating co-generation systems with absorption or adsorption chilling devices such as LiBr absorption chillers. In conventional methods for energy production, waste heat produced by prime movers is lost to the environment. As a result only 25-40% of total thermal energy input by the fuel is converted to useful energy. Multi-generation systems such as co-generation and tri-generation use the waste heat of prime movers to produce more useful energy hence raising the thermal efficiencies to over 70% [4].Co-generation and tri-generation systems today find numerous uses in food, chemical, ice and cold storage industries. Such systems also find widespread application in hotel, hospitals and supermarkets [5].Modelling and simulation play key role in design of energy systems. Optimization of parameters can be done before even building the system. This saves cost and helps in increasing overall efficiency by identifying weak points in the system. TRNSYS or Transient System Simulation is highly validated and industry level software used for simulating thermal and energy systems [6, 7]. Experimentally determined parameters are fed into TRNSYS to model systems for achieving optimum outputs [8].

2. EXPERIMENTAL SETUP

This multi-generation system was developed for a Biogas plant at LNMIIT. Capacity of the biogas plant is 1 Tonne. Waste fed to the anaerobic digester included mess reject, sewage sludge from Waste Water Treatment Plant (WWTP) as well as biodegradable waste produced in the campus. The producer gas or the biogas (mostly methane) was then used as fuel for a 10 KW IC Engine made by Prakash Diesels which acted as a prime mover. The waste heat produced by this engine was then supplied to waste heat recovery devices which will be described in coming sections.

3. TRNSYS SIMULATION

The system described in [Section 2] was simulated in TRNSYS software components. The model developed in TRNSYS was dependent upon the parameters determined experimentally from the plant. Various components used for simulation are as follows:

3.1. Parts of TRNSYS model

3.1.1. IC Engine

This was a type 907 IC Engine used from the co-generation library of TRNSYS. It had 3 type of engine coolants namely jacket water, oil cooler and after cooler. Different parameters of the engine are given Table 1. Fuel consumption was determined by simulating a generic diesel engine (Type 120a) of same capacity.

Table 1 Parameters of IC Engine

Parameter	Value
Rated power	10 KW
Specific heat of engine coolant	4180 J/KG.K
Specific of exhaust gas	1007 J/KG.K
Flow rate of exhaust gas	50 KG/hr

Engine intake air temperature	35 °C
Jacket water flow rate	70 KG/hr
Oil cooler flow rate	70 KG/hr
After cooler flow rate	70 KG/hr

3.1.2. Hot water generator

This was a type626 hot water generator used from waste heat recovery section in TRNSYS. It used exhaust gas as source side fluid and water as load side fluid.

3.1.3 Absorption chiller

This was a type 107 hot water fired absorption chiller. The engine coolant (Jacket water) was used as hot water for the chiller while water was used as chilled water and cooling fluid. The input parameters of absorption chiller are given in Table 2.

Table 2 Absorption chiller parameters

Parameter	Value
Rated capacity	1.5 KW
Hot water fluid specific heat	4180 J/KG.K
Chilled water fluid specific heat	4180 J/KG.K
Chilled water flow rate	40 KG/hr
Chilled water inlet temperature	35 °C
COP	0.4460

3.1.4. Variable volume thermal storage tank

A variable volume thermal storage tank was used to store the hot water generated by hot water generator, oil cooler, after cooler and hot water coming from outlet of the absorption chiller. The parameters of thermal storage tank are given in Table 3.

Table 3 Parameters of variable storage tank

Letter name	Uppercase
Overall tank volume	300 Ltr
Minimum tank volume	50 Ltr
Maximum tank volume	300 Ltr
Cross sectional area	3.14 m^2
Flow rate to load	40 KG/hr

The model was developed in TRNSYS keeping in mind the requirements of LNMIIT which included Electricity, chilled water at mess timings in the nearby mess and heat for keeping the food warm during mess timings. Based on the timings of mess absorption chiller remained functional only between 12 PM – 2 PM and 7:30 PM – 9:30 PM, hence there were two modes of operation in this system.

3.2. Co-generation mode

In this mode IC Engine was used along with a hot water generator and the hot water as shown in Fig. 1. In this mode the exhaust gas was passed through source side of hot water generator and water at room temperature was given as load side inlet input parameter. This hot water was then mixed with Jacket water, oil cooler and after cooler. Together they were then stored in a variable volume thermal storage tank.

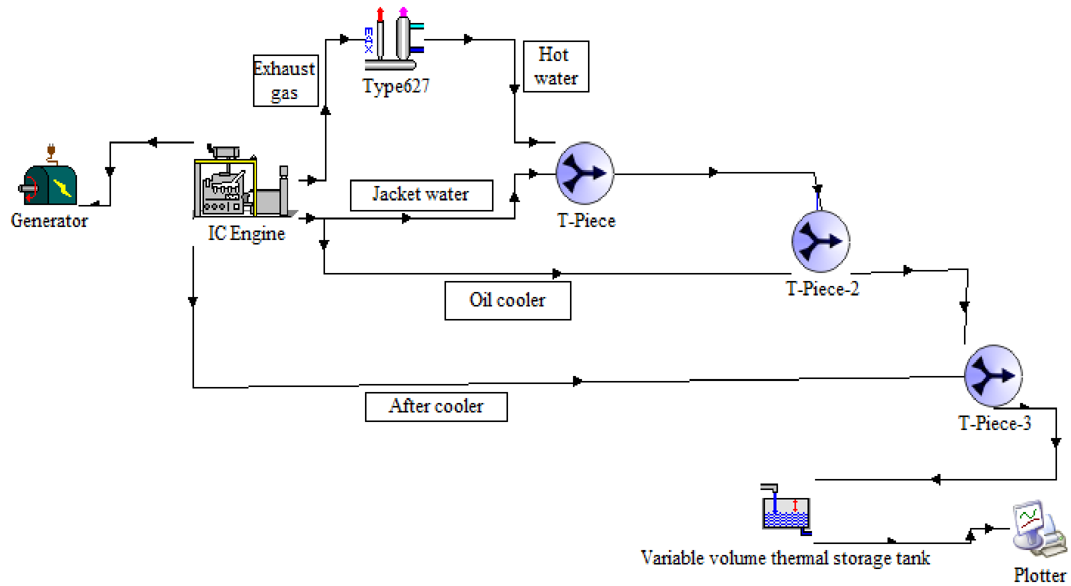

Figure 1 TRNSYS model of co-generation mode

3.3. Tri-generation mode

In addition to equipment of co-generation mode, this also included an absorption chiller of 1.5 KW capacity. The jacket water was given as hot water to the chiller. Even after doing net work to cool the water in the chiller, some energy remained in the jacket water. Hence this along with hot water from other sources was stored in the variable volume storage tank as shown in Fig.2.

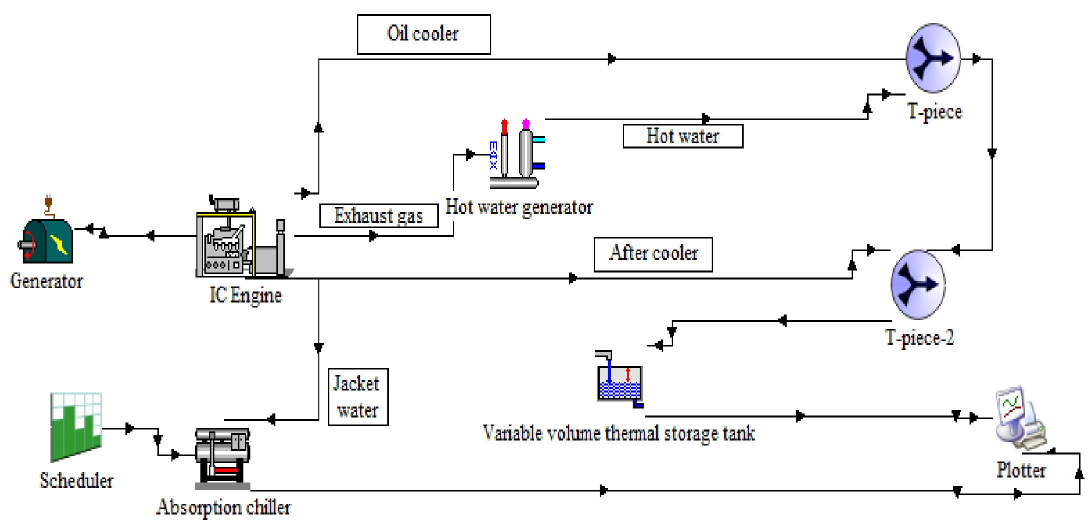

Figure 2 TRNSYS model of tri-generation mode

4. ENERGY ANALYSIS

Energy analysis for the co-generation and tri-generation systems is described in this section. Everywhere environmental temperature (T_0) has been taken as 35 °C.

Total energy given through fuel:

$$E_{fl} = \dot{m}_{fl} * CV \quad (1)$$

Energy recovered by exhaust gas:

$$E_{ex} = \dot{m}_{hw} * Cp_w (T_{hw} - T_0) \quad (2)$$

Energy recovered by engine coolant, after cooler and oil cooler:

For cogeneration:

$$E_{coolants\text{-}co\text{-}gen} = \dot{m}_{jw} * Cp_{jw} * (T_{jw} - T_0) + \dot{m}_{ac} * Cp_{ac} * (T_{ac} - T_0) + \dot{m}_{oc} * Cp_{oc} * (T_{oc} - T_0) \quad (3)$$

For tri-generation:

$$E_{coolants\text{-}tri\text{-}gen} = \dot{m}_{hwo}*Cp_{hwo}*(T_{hwo} - T_0) + \dot{m}_{ac}*Cp_{ac}*(T_{ac} - T_0) + \dot{m}_{oc}*Cp_{oc}*(T_{oc} - T_0) \quad (4)$$

Energy recovered in refrigeration:

$$E_{ref} = \dot{m}_{chw}*Cp_{chw}*(T_0 - T_{chw}) \quad (5)$$

Thermal efficiency of co-generation mode:

$$\eta_{co\text{-}gen} = (E_{ex} + E_{coolants} + E_p)/E_{fl} \quad (6)$$

Thermal efficiency for tri-generation mode:

$$\eta_{tri\text{-}gen} = (E_{ex} + E_{coolants} + E_{ref} + E_p)/E_{fl} \quad (7)$$

Table 4 Results of energy analysis

Parameter	Co-generation	Tri-generation
Energy supplied through fuel	29,913.51 W	29,913.51 W
Jacket water temperature	105.00 °C	105.00 °C
Oil cooler temperature	50.52 °C	50.52 °C
After cooler temperature	74.27 °C	74.27 °C
Chilled water temperature	NA	8.068 °C
Temperature of jacket water out from absorption chiller	NA	75.12
Heat recovered from jacket water	5716.66 W	3276.46 W
Heat recovered from oil cooler	1267.46 W	1267.46 W
Heat recovered from after cooler	1208.31 W	1208.31 W
Heat recovered from exhaust gas	6755.99 W	6755.99 W
Heat recovered by absorption chiller	NA	1256.82 W
COP of chiller	NA	0.4460
Energy efficiency	83.40%	75.20%
Water outlet temperature from storage tank for flow rate of 40 KG/hr	69.22 °C	74.32 °C

5. RESULT AND DISCUSSIONS

The TRNSYS model was simulated using parameters given in [Table 1,2, and 3]. The results of energy analysis are given in [Table 4]. Total energy provided to the system through biogas was 29,913.51 W. 22.58% of total energy provided through fuel was recovered from the exhaust gas coming out from the engine. For co-generation energy recovered from jacket water was 19.11% and for tri-generation it was 10.95%. Energy recovered from jacket water was lesser in case of tri-generation because jacket water was first passed through generator of the absorption chiller where it lost a part of its energy. Energy recovered from oil cooler and after cooler was 4.23% and 4.03% respectively. In case of tri-generation energy recovered by absorption chiller was 4.20% of the total energy supplied through fuel. Hence total energy efficiency for co-generation system was 83.4% and for tri-generation system it was 75.20%.

6. CONCLUSION

A biogas operated IC Engine based Tri-generation system was simulated with satisfactory results. From the above results we made following conclusions:

- Most of the waste heat is lost in form of exhaust gases hence major focus should be given to exhaust heat recovery systems.
- It was observed that COP of chiller was significantly lesser than the rated COP, hence there is a scope of improvement in model for the absorption chiller.
- We also concluded that tri-generation systems using an absorption chiller with a COP<1 will have lesser energy efficiency than a corresponding co-generation system. This is because only a part of heat consumed by the generator of absorption chiller is converted into cooling energy.
- Overall we concluded that amount of useful energy extracted for same fuel input for multi-generation systems was significantly higher than single generation.

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