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ORC power plant for electricity production from forest and agriculture biomass

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ABSTRACT

The paper presents the calculation results for three variants of CHP plant fuelled by sawmill biomass. The plant shall produce electricity and heat for a drying chamber. An analysis of the system efficiency for four different working fluids was conducted: octamethyltrisiloxane, methylcyclohexane, methanol and water. The highest electric power was obtained for the system with internal regeneration and methylcyclohexane applied as the "dry" working fluid, the highest temperature to supply the drying chamber was obtained for the system with external regeneration and octamethyltrisiloxane applied as the working fluid. The results of the analysis indicate that, by proper choice of the working fluid and of the regeneration variant (internal or external), it is possible to "adjust" the work of the system to the needs and expectations of the plant investor (user).

1. Introduction

For many years, the West Pomeranian University of Technology in Szczecin, Poland, has conducted research aimed at developing technologies for distributed generation of electricity by using the ORC technology, with a particular focus having been placed on utilization of geothermal energy [1] and low temperature waste heat [2]. This paper presents proposals of the ORC power plant solutions to be applied for utilization of sawmill waste and other types of wood waste.

Currently, in Poland, plants of this kind utilize sawmill waste for heating and drying only. On the other hand, as shown in [3], both generation and utilization of the respective source heat can be optimized. Effectiveness of the wood dryers performance is there analyzed for various drying technologies (such with air heat exchangers or with standard or absorption heat pumps), and electricity and heat consumption are for those processes presented and referenced to the cumulative sawmill production in Sweden.

Sawmill waste, as well as other types of biomass (straw, corn stalks) can be converted into some intermediate fuel, e.g. in the form of pellets, if the plant possesses a suitable production line and marketing ability. Examples of respective energy conversion systems are presented in [4]. However, the trends in the energy developments are to produce electricity "on site", that is without a need to transport biomass waste to power plants, which also fits in perfectly with the idea of distributed generation. In addition, the combined production of electricity and heat (i.e. not only of heat as it is usually done now) is one of the best ways to increase the efficiency of energy conversion processes. At present, there are principally two technologies of the distributed combined heat and power generation that are considered in respect to the biomass utilization:

– internal combustion piston engine (IC Engine) fuelled with syngas generated in a biomass gasification system,
– turbine based CHP plant with either steam turbine or vapour turbine working with organic fluids (ORC plant), with energy input from appropriate biomass boilers. Such plant can be also driven with heat from the biogas fired boilers.

Other CHP technologies, such as those based on fuel cells, gas turbines, Stirling engines and others are still in the developing phase and are expected to be commercially available in the next few years.

The techno-economic analysis of the ORC system with input from a gasification system is presented in [5] for the case of bioenergy applications. It results from that analysis that, in respect to the proportion of generation of electricity versus heat, the high temperature system incorporating biomass gasification and biogas fired piston engine appears as more advantageous. On the other hand, biomass combustion and the resulting heat conversion by means of the ORC system is technologically more matured and burdened with less risk, and is applied more frequently. A comparative analysis of the

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Nomenclature

c_p	specific heat at constant pressure, kJ/kg K
h	specific enthalpy, kJ/kg
$\dot{m}$	mass flow rate, kg/s
p	pressure, MPa
P	power, kW
S	entropy, kJ/kg K
T	temperature, °C
$T_{d,max}$	maximum temperature value of air supplied to the drying chamber, °C
$\dot{Q}$	heat flow rate, kW
ΔT	temperature difference in pinch point, K
η	efficiency, %

Subscripts

a	air
cr	critical
d	drying
el	electric
o	heat carrier (thermal oil)
th	thermal
wf	working fluid
1, 2, 2d, 2r, 2s, 3, 4, 4s, 4r 5, 6	characteristic points of cycle

Abbreviations (also used as subscripts)

B	boiler
C	condenser
D	drying chamber
G	generator
HE	heat exchanger
ORC	organic Rankine cycle
P	pump
R	internal regenerator
T	turbine

relevant systems (i.e. those based on ORC and IC Engine) is given in [6]. In that case, the economic effectiveness for systems with varying power outputs is made with account of Polish and German support schemes for conversion of energy from renewable energy sources. A sawmill integration with a pellet plant and a CHP plant (biomass waste combustion in dedicated steam power plant) is investigated in [7]. The results show that up to 18% of the biomass by-products of the sawmill can be saved in case of the integrated production process. The energy-economic analysis for biomass based CHP plants working according to various technologies: Stirling engine, ORC, steam engine, steam turbine and gas engine is presented in [8]. The analysis yields that, for Serbian conditions, the installation of CHP plants in small capacity sawmills (about 10,000 m^3/year) is not justified economically.

The forest biomass and other biomass waste can be also utilized in distributed hybrid energy conversion systems. A proposal of the hybrid biomass-solar power plant is presented in [9], with utilization of various biomass types (wood chips, urban wood waste) and parabolic trough collectors. A hybrid CHP plant with direct solar supply and biomass energy is discussed in [10]. Biomass is combusted in a fluidized bed boiler and solar energy is collected via a concentrated receiver, with thermal energy being converted into electricity by using Stirling engine. The thermo-economic analysis of a micro gas turbine supplied with externally fired natural gas and biomass is presented in [11].

2. Description of the CHP plant systems fuelled with sawmill biomass

In the present work, three variants of the CHP plant based on organic Rankine cycle and fuelled with sawmill waste have been analysed. The CHP plants are to produce electricity and to supply heat for drying processes. The variants of CHP plant systems result from the type of the working fluid used in the system: wet or dry [12]. Selected parameters of the working fluids chosen for the calculation are shown in Table 1, and the shapes of the saturation curves, determining the type of the fluid (dry, wet) are shown in Fig. 1.

2.1. CHP plant with wet working fluid – variant A

The thermodynamic conversion cycle for the CHP plant with wet working fluids (water or methanol) is shown in Fig. 2, while the scheme of the plant system is given in Fig. 3.

The boiler (B) with a capacity of $\dot{Q}_B = 250$ kW, in which the combustion of biomass waste from sawmill occurs, is the source of energy for the CHP plant. The heat $\dot{Q}_B$ generated by combustion is, via a heat carrier – thermal oil, transferred in the heat exchanger (HE) to the working fluid in the power plant:

$$\dot{Q}_B = \dot{m}_o c_{p,o}(T_{o1} - T_{o2}) = \dot{m}_{wf}(h_1 - h_4) \quad (1)$$

It was assumed that the thermal oil temperature at the boiler outlet is $T_{o1} = 300$ °C, and at the boiler return tap it is $T_{o2} = 240$ °C. Thermal oil supplied from the boiler to the heat exchanger HE causes: preheating (process 4-5), evaporation (process 5-6) and superheating (process 6-1) of the working fluid. Next, the vapour of the working fluid is directed to the turbine (T) where vapour expansion (process 1-2) follows. The expanded working fluid vapour from the turbine is directed to the condenser (C) that is cooled by air. The heat flux removed from the condenser

$$\dot{Q}_C = \dot{m}_{wf}(h_2 - h_3) \quad (2)$$

Table 1
Selected properties of the working fluids adopted in the calculations.

Working fluid	Critical temperature (°C)	Pressure (MPa @ T = 25 °C)	Type of fluid
Methylcyclohexane	299.05	0.006177	Dry
MDM octamethyltrisiloxane	290.94	0.000498	Dry
Methanol	239.45	0.016981	Wet
Water	373.95	0.003170	Wet

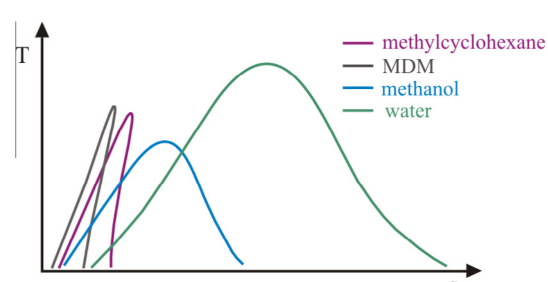

Fig. 1. Shapes of the saturation curves of the selected working fluids.