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Straw Energy saving Solution: Power Plant based on a hot Air Turbine

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Abstract

Straw is an agricultural byproduct of the harvest of crop plants and one of the most significant biomass resources. It is considered a non-hazardous material, environmentally harmless and not dangerous for human health. In spite of this, straw still represents a big problem because requires disposal solutions. Nowadays, traditional field burning is no longer accepted, so other solutions must be found. The most attractive is the recovery of the straw energetic potential. In this view, an interesting solution consisting in a straw fueled power system with hot air turbine and based on a semi-closed cycle is presented in the paper. The study is focused on parametric optimization of the system in order to get maximum performance, which is described by output power, thermal efficiency, fuel consumption and specific fuel consumption. Influence of the compression ratio and air mass flow distribution over the performance of the power system is analyzed.

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Keywords: Straw; energy recovery; hot air; turbine; semi-closed cycle; performance; output power; efficiency; fuel consumption.

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1. Introduction

One of the most significant biomass resources is straw [1], an agricultural byproduct of the harvest of crop plants (e.g. wheat, barley, rice, oats or rye). According the directive 2008/98/EC, straw is considered a non-hazardous material, environmentally harmless and not dangerous for human health. Straw represents a big problem for agriculture, because requires a practical disposal solution. The traditional method of field burning is no longer acceptable nowadays, so other solutions must be found and investigated. The most attractive one is the recovery of

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straw energy potential. Consequently, several studies referring to gasification [2], fermentation [3], hydrolysis, pyrolysis [4] or direct combustion of straw [5] had been developed so far in order to get power and/or heat from straw. In this context, the Biomass Master Plan, developed by the Romania's Ministry of Economy, Trade and Business Environment, stipulates that solid biomass CHP units of 1 – 5 MWe are needed to fulfil the requirements of the 2020 scenario. Obviously, power generation is the main objective while heat is a byproduct energy form in many cases since implies the heat demand to exists. However, there are situations when only heat is required but they are typically simply solved by using a hot water boiler.

The usual solution for power generation from straw (or other form of biomass) is a steam power plant. But there are many cases when this solution cannot be implemented because there is no any water source. Besides, another restrictive requirement may be the possibility to change the power plant location as easy as possible in order to get the optimum position relative to the fuel (straw) provider. An interesting solution in this case is a Hot Air Turbine Power Plant (HATPP) – a particular case of the externally fired gas turbine (EFGT) systems, usually operating in closed cycle (i.e. with helium); after a long period of abandon, EFGT capture now much attention due to their potential of using renewable energy sources such as concentrated solar power or biomass [6].

Currently, there are available on the market only micro-scale units (but they can't be classified as Power Plants) based on the hot air turbine, such as HLT-100 model produced by Schmidt Energy Solutions. In fact, this is a CHP unit with 95 kWe (maximum), 350 kWt and just 15% electrical efficiency. In what concerns Power Plants of 1 – 5 MWe, they are not available yet. The theoretical studies developed so far [7], [8] refer to SIEMENS AG concept, which means CHP plant based on Pebble-Heater technology (a regenerative heat exchanger with radial flow) and hot air turbine. By taking into consideration TIT = 870°C and a $\pi_c = 4.5$, the power generation efficiency is estimated to be in the range of 30%. Unlike these studies, a HATPP based on a simpler heat exchanger type (conventional counter-flow configuration, with tubes) and operating in semi-closed cycle is analyzed.

Nomenclature

a_f	fly ash fraction
FC_{PP}	fuel consumption of the power plant (kg/h)
h_{PTin}, h_E	power turbine air inlet / outlet enthalpy (kJ/kg)
h_{ina}, h_{outa}	compressed air enthalpy at heater inlet / outlet (kJ/kg)
H_{0a}, H_{fg}	ambient air / flue gas enthalpy (kJ/kg fuel)
H_{af}	enthalpy of air entering the furnace of the compressed air heater (kJ/kg fuel)
H_{ash}	ash enthalpy (kJ/kg fuel)
$\dot{m}_{ad}$	air mass flow fraction diverted to the stack (kg/s)
$\dot{m}_{af}$	air mass flow entering the furnace of the compressed air heater (kg/s)
P_{PT}	output power of the power plant (kW)
$\dot{m}_{w1}$, $\dot{m}_{w2}$	water flow in the flue gas / air section of the heat recovery unit
SFC_{PP}	specific fuel consumption of the power plant (kg/kWh)
t_{as}, t_{gs}	bypass air / flue gas temperature at stack (°C)
t_E	power turbine air outlet temperature (°C)
t_{fl}, t_{fg}	temperature of gases in CAH, before the heat exchanger / CAH flue gas temperature (°C)
t_{ina}, t_{outa}	compressed air temperature at heater inlet / outlet (°C)
t_{wi}, t_{wo}	inlet / outlet water temperature in heat recovery unit (°C)
q_{sh}, q_{as}	heat loss by sensible heat of the flue gas / ash and slag (%)
$\dot{Q}_a$	heat output of the compressed air in heater [kW]
$\dot{Q}_{in}$	heat input of the compressed air heater [kW]
$\dot{Q}_w$	heat output of the heat recovery unit [kW]
Δt_i, Δt_e	temperature difference in CAH at the entrance / exit of the combustion gases in / from heat exchanger (°C)
λ	air excess coefficient in compressed air heater
π_C	compression ratio
η_{CAH}	efficiency of the compressed air heater (%)
η_{GTE}	thermal efficiency of conventional gas turbine engine (%)