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Assessment of Waste Heat Recovery Potential, a Case Study in a Textile Mill †

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Abstract: The world is facing an energy crisis due to globalization and the depletion of conventional energy sources. Fossil fuels are the primary energy source used to fulfill the energy demands in industries, transportation, and residential sectors. The industrial sector consumes one third of the world's total energy, and around 50% of the energy is eventually wasted as heat. The textile industry is one of the most energy-intensive sectors. Therefore, a lot of research has been conducted on the reduction of energy costs and associated environmental effects. The main reason for energy inefficiency is the generation of waste heat and its utilization being ignored in the developing countries. The purpose of this research is to conduct a quantitative analysis of waste heat recovery from onsite electrical power generators in a textile mill. The investigated results indicate that an annual energy saving of 90,741 MWh and 10,936 MWh can be achieved with the installation of waste heat recovery boilers and economizers at the exhaust gases ducts of internal combustion engines, respectively. Utilization of the hot water from an engine's jacket was estimated to save 30,095 MWh of energy annually. The recovered waste heat energy can be utilized in the processing unit and in the chiller section within the textile facility. The total energy saving is 131,772 MWh with a reduction of 52,708.8 tons in CO_2 emissions.

Keywords: waste heat recovery; internal combustion engine; energy balance; exhaust gas recovery

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1. Introduction

Energy is considered the backbone for a country's industrial sector's development, modernization, and economic growth, and therefore the demands are increasing worldwide. Around 32–35% of the world's total energy is used by the industrial sector and approximately half of that energy is ultimately wasted as heat [1]. Energy saving is one of the key issues, not only from the point of view of fuel consumption but also for the security of the global environment. Currently, developing countries are facing the problem of a shortage of energy, e.g., in Pakistan, the balancing of supply against demand has remained unresolved. At the present time, the country is categorized as an energy deficient state and greatly depends on imported fossil fuels, and about 88% of its energy demands are being met by non-conventional sources [2]. Textile industry is one of the most energy-intensive industries. Due to the low energy conversion efficiencies of engines, a lot of fuel energy is wasted in the form of hot exhaust gases and hot water. Various studies have been carried out for the recovery of waste heat. The exhaust from a diesel engine contains about 30% of the total input energy with an additional 16% of power improvements, and it is dependent on the part-load ratio. Heat exchangers have been modified which increases additional power from 16% to 23.6% [3]. Hoang, Anh Tuan et al. reviewed the latest technologies of engine waste heat recovery and concluded that conventional diesel engine efficiency is around 25% and that the engine wasted more than 60% of fuel energy, which makes it the biggest CO2 emission contributor [4]. Waste heat recovery from exhaust gas and jacket water simultaneously runs a 16 kW mixed effect absorption chiller with a cooling output of about 34.4 kW and a COP of 0.96 [5].

In this work, a case study was carried out in a textile mill located in Faisalabad, Pakistan. It was a vertically integrated state-of-the-art textile manufacturing mill with the production capacity of 28.8 million meters of processed dyed printed fabric per month. It is well known for the manufacturing of supreme-quality yarn, processed fabrics, home textiles, and institutional garments [6]. Energy consumption is the main concern for every industry. Here, a detailed study of power generation units was carried out for energy balance and the analysis of the recoverable potential in the whole unit. Three internal combustion engines were considered for the energy balance purpose. Each engine was analyzed for waste heat recovery potential. It was seen that about 80% of the input fuel energy could be utilized by recovering waste heat.

2. Methodology

The textile mill has its own in-house captive power plant. The total installed capacity is 26 MW, and about 80% of the total electricity demand is generated by their own in-house PG unit. The backup generation includes two dedicated feeders with a combined capacity of 6 MW from FESCO, and furnace oil generators with a combined capacity of 4.8 MW.

Two natural gas-fired Wärtsilä engines, i.e., engines 1 and 2, are identical and have almost the same trends for their continuous operation. Engine 3 is a Wärtsilä dual fuel combustion engine. The details and specifications of engines are given in the Table 1.

Table 1. Engines' specifications.

Manufacturer	Wärtsilä Gas Fired	Wärtsilä Dual Fuel
RPM	1800	720–750
Fuel type	Natural Gas	Dual Fuel
Ignition System	WECS-3000	SVOICE
Cooling system	Cooling tower	Cooling tower

The engines run for almost 24 h a day at constant load. The overall efficiency of engines 1, 2 and engine 3 is around 42% and 37%, respectively. Engines 1 and 2 consume about 455.45 Hm3 (228.73 Hm3 each) of gas, generate 185 MWh of electricity on average in a day, and the rest of the 264 MWh of energy is wasted. Engine 3 consumes about 194.87 Hm3 of gas, produces 69.8 MWh of electricity on average, and 120 MWh is wasted.

2.1. Waste Heat Recovery Boiler

WHR boilers are installed on individual unit's exhaust duct. Engines 1 and 2 and engine 3 have a capacity of 3 ton/h and 2.8 ton/h, respectively. The specifications of the boilers are given in Table 2.

Table 2. Engine specifications.

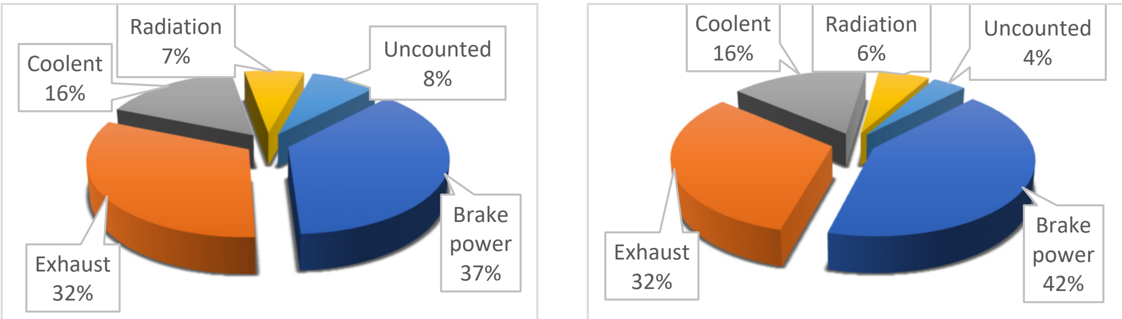
Parameters	3 TPH WHR Boiler	2.8 TPH WHR Boiler
Boiler Type	Horizontal-FireTube	Horizontal-FireTube
Efficiency	94%	93%
Economizer	Installed	Installed
Blow down	Manual	Manual

2.2. Cooling System

Two lines, i.e., LT (Low temperature) and HT (High temperature), are used for engine cooling. When fresh air passes through the turbo charger, it gets heated. The LT line is used to cool down fresh air to a specific temperature. The HT line is a closed-loop water cooling line between the engine and cooling tower.

3. Results and Discussions

The overall heat balance of the engines is given in the Figure 1a. Figure 1b is the energy balance of identical engines 1 and 2, and Figure 1b is the energy balance of engine 3.



(**a**) (**b**)

Figure 1. Heat balance of engines: (**a**) **Wärtsilä** dual fuel (**b**) **Wärtsilä** gas fired.

3.1. WHR from Exhaust

The quantity of waste heat is a function of both the temperature and the mass flow rate.

$$Q = \Updownarrow C_p \Delta T$$

where Q is the heat loss (kJ/min), $\Updownarrow$ is the exhaust gas mass flow rate (kg/min), C_p is the specific heat of exhaust gas (kJ/kg K), and ΔT is the temperature difference in K.

Heat content available and the recoverable heat from the exhaust gases of engines in Kw is given in the Table 3.

Table 3. Energy extracted from exhaust gases.

Entry	Wärtsilä Gas Fired	Wärtsilä Dual Fuel	UOM
Total Energy to Exhaust	4522	2321	*Kw*
Heat recovery in WHR boiler	1888	781	*Kw*
Heat recovery in Economizer	416	190	*Kw*
Heat rejection in chimney	1085	481	*Kw*

3.2. Energy Extracted from Jacket Water

The details of engine jacket water parameters are described in the Table 4.

Table 4. Engines jacket water parameters.

Parameters	Wärtsilä Gas Fired	Wärtsilä Dual Fuel	UOM
HT temp in	92	86	°C
HT temp out	86	79	°C
Water flow rate	180	160	m^3/h

The energy wasted in the jacket water of engines 1 and 2 and engine 3 is 1221 KW and 543 KW, respectively. This heat is rejected in the cooling towers.

4. Conclusions

The investigated results indicate that an annual energy saving of 90,741 MWh and 10,936 MWh can be achieved with the installation of waste heat recovery boilers and economizers at the exhaust gases ducts of internal combustion engines, respectively. Utilization of hot water from an engine's jacket was estimated to save 30,095 MWh of energy annually. The recovered waste heat energy is utilized in the processing unit and chiller section within the textile facility. The total energy saving is 131,772 MWh with a reduction of 52,708.8 tons in CO_2 emissions. Energy loss at blowdown of WHRB can also be minimized by the automation of the blowdown system, which can save energy. Proper monitoring of steam leakages at steam headers and control valves can also contribute to significant energy saving.

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