Modelling the Concept of Waste-Heat Recovery System for Generating Electricity in Holcim Cement Factory, Kien Giang,Vietnam

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Abstract

Salvaging waste-heat from system's kilns and boilers in Waste-Heat Recovery System (WHRS) for generating electricity is being a potential opportunity in Vietnam. This paper aims at building a model for simulating the WHRS of Holcim cement factory in Kien Giang. The model then will be implemented as an available scientific base for other factories in Vietnam. The existing WHRS of factory is simulated in order to demonstrate the accuracy of model so that the results can be used for modelling a new solution which salvages waste-heat from water-boiler of system. Results of the simulation are closely similar to parameters obtained from the existing system. The new suggestion of waste-heat salvaging shows impressive results with 34.5% increase of generator power and 33.3% raise of electricity energy in comparison with the existing system; 1.32 million USD is saved, and 10.3 tons of CO_2 is mitigated annually by implementing the new WHRS one. For its positive results, the system then will be implemented commercially for other cement factories in Vietnam.

Keywords: Modelling, cement, waste-heat recovery system, Vietnam

1. Introduction

Due to the three facts that: (1) there is a huge potential in cement industry to generate power to meet its increasing demand in building and constructions; (2) cement industry is the largest energy consumer compared to other industries; and (3) cement industry is one of the least efficient in terms of energy efficiency [1], it is urgently required to figure out solutions to overcome these issues

Recent studies show the result that the energy consumption for each ton of cement is from 4 to 5 GJ/ton. It leads to the energy share of the cement industry in the industrial sector is from 12% to 15% [2]. However, about 35% of the input energy is being lost as waste-heat streams [1]. For this reason, considerations and studies have focused on how to optimise the cement manufacturing process, reduce energy consumption, mitigate the issue of power shortage, reduce greenhouse gas emissions, and recover the waste-heat from the cement manufacturing process in recent years.

WHRS are already in operation in various industries with success. Söğüt et al [3] showed a mathematical examination of heat recovery from rotary kiln for a cement plant in Turkey. Results indicated the presence of 217.31 GJ of waste-heat, which is 51% of the overall heat of the process. Some prototypes of heat exchanger was introduced in numerous studies [4]-[8]. Karamarkovíc et al [9] studied on the improvement of energy efficiency of a rotary kiln by the use of heat loss from its mantle. Results showed that the exchanger decreases fuel consumption of the kiln for 12% and increases its energy and energy efficiency for 7.35% and 3.81% respectively [9]. Karellas et al [10] has examined and compared energetically, energetically, and economically for the two different WHRS: (1) a Water-steam Rankine Cycle (WRC), and (2) an Organic Rankine Cycle (ORC). Results are conducted to the conclusion that installing WHRS in cement industry can contribute significantly in the reduction of the power consumptions, investment cost could be refunded with a payback period up to 5 years. In Canada, the Gold Creek Power Plant has installed a 6.5 MW power WHRS using ORC technology [10].

In Vietnam, the cement manufacturing industry, which annually consumes approximately 5.7% of total national power productivity [12]. In line with the worldwide tendency on optimizing the cement

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manufacturing process, WHRS have been studied with significant attention. One of the successful study-cases in salvaging the waste-heat obtained from the cement manufacturing process to generate electricity is at Holcim Cement Plant-Kien Giang. Research and simulations on this system are significantly meaningful, and is the premise, scientific base for computing and implementing the model at commercial scale in Vietnam.

This article aims to build a simulation model for the salvaging process of exhaust-air and waste-heat collected from incinerator to generate power at Holcim Cement Plant-Kien Giang. Results of the stimulation will be verified by comparing installation parameters and operating measured data at the plant. A new opportunity of salvaging the remain waste-heat to generate electricity is founded and computed in the model.

2. Vietnam Cement Industry

Joining international commercial and trading market had made Vietnamese economy develop rapidly (~6% annually) for over about 20 years. This is the major motivation for the development of cement industry. Vietnam had produced 78 Mt of productivity (2014) from 116 rotary-kiln-based facilities and 75 vertical-kiln-based manufacturing lines. The energy consumption per product for these technologies is shown in Table 1.

Strategies to ensure the balance and sustainable development for cement manufacturing industry up to 2020 are listed as: (1) using advance technologies, especially, implementing the WHRS for existing facilities; (2) research and develop diversifically for ranges of cements; (3) integrate crushing stations into cement manufacturing facilities to meet local consumption requirement, reduce costs and transportation duration; (4) planning technological development scheme, enhance the design – management - manufacturing – executive ability, improve equipment; (5) analyzing – evaluating sufficiently the impacts of the cement industry on the environment, mitigate greenhouse gases emission and climate change.

Table. 1. Energy consumption per product of current cement manufacturing technologies [13]

Technology	**Capacity (Tons Clinker/Day)**	**Heat consumption (kcal/kg Clinker)**	**Electricity consumption (kWh/Ton)**
Vertical kiln	240	980	≤ 100
Wet rotary kiln	3,000 – 3,600	1,450 – 1,750	120 – 130
Dry rotary kiln	4,000 – 5,500	730	90 - 100

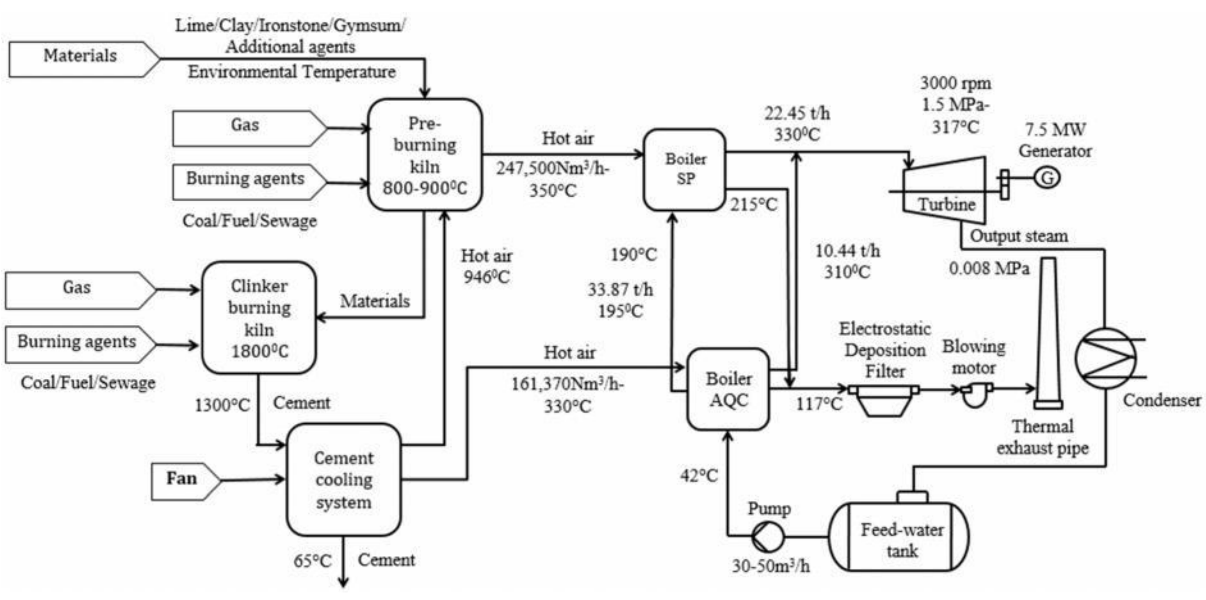

Fig. 1. Block diagram of a cement manufacturing line and waste-heat salvaging system (Source: Documents of Holcim Kien Giang [15], [16]).

3. Modelling the WHRS using for Generating Electricity in Holcim Cement Factory-Kien Giang

3.1. Cement Manufacturing System

Technology currently used in the Kien Giang Holcim cement factory is a combination system of a dry-rotary-kiln, a WHRS and a copper furnace system for waste treatment [14].

The manufacturing process showed in Fig. 1 is divided into 3 steps: (1) material preparation, (2) Clinker manufacturing, and (3) cement manufacturing. Dust sedimentation compartment technology, cyclone technology, cloth dust filter, and electrostatic filter are technologies applied for treating exhaust dusts. Waste-heat collected from Clinker cooling system and excessive heat collected from pre-burn tower will be transferred to boiler to create superheated-steam to run the turbines for generator afterward.

The 4.500 tone/day furnace, using DO fuel, HFO, coals and waste; is a consist of 2 kilns: (1) Pre-burning kiln with the temperature of 800^0C to 900^0C, and (2) Clinker burning kiln with the temperature of $1{,}330^0$C – $1{,}800^0$C. The boilers system includes (1) boiler SP (Suspension Pre-heater) receives excessive heat from the pre-burning kiln and (2) boiler AQC (Air Quenching Cooler) obtains waste-heat from the cement cooling system. Boiler SP and AQC have the same construction and operation principle; however, the only difference is that the boiler SP receives water and steam from the boiler AQC instead of having its own component of heating intake water. The superheated steam from SP and AQC boilers will be used to run a turbine at the speed of 3,000 rpm and connected to a 7.5 MW Generator.

3.2. Modelling the Existing WHRS

The research diagram for the WHRS is illustrated in Fig. 2, boiler AQC takes the waste-heat from cement kiln which is installed on the exhaust-air-pipelines uses to cool clinker after going through the dust collector device. Water will be delivered into the water heater at the flow rate of 33.83t/h, then will be heated to the temperature of 195^0C before delivering to ejector with the flow rate of 12.5t/h. After being heated, the mix of steam and water will be delivered into the steam-drum, the saturated steam will be separated, delivered to superheated-device to be heated to become superheated-steam under high pressure. Boiler SP recovers waste-heat from the pre-burning kiln which is installed in the middle of the outlet-air conducting pipeline of the heat exchange tower and the high temperature exhaust-air conducting pipeline at the end of the furnace. The designed inlet-temperature of exhaust air of the boiler is 350^0C and decreases to approximately 215^0C after passing through vaporizing devices.

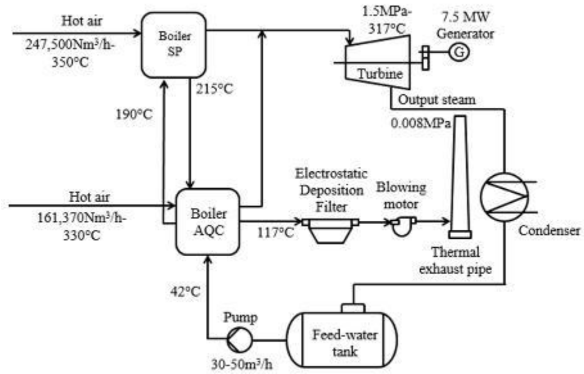

Fig. 2. The WHRS (Source: Holcim [15], [16]).

Exhaust air will go through the dust filter to collect dust at the end of boiler afterward. The research diagram for the WHRS is illustrated in Fig. 2, boiler AQC takes the waste-heat from cement kiln which is installed on the exhaust-air-pipelines uses to cool clinker after going through the dust collector device. Water will be delivered into the water heater at the flow rate of 33.83t/h, then will be heated to the temperature of 195^0C before delivering to ejector with the flow rate of 12.5t/h. After being heated, the mix of steam and water will be delivered into the steam-drum, the saturated steam will be separated, delivered to superheated-device to be heated to become superheated-steam under high pressure. Boiler SP recovers waste-heat from the pre-burning kiln which is installed in the middle of the outlet-air conducting pipeline of the heat exchange tower and the high temperature exhaust-air conducting pipeline at the end of the furnace. The designed inlet-temperature of exhaust air of the boiler is 350^0C and decreases to approximately 215^0C after passing through vaporizing devices. Exhaust air will go through the dust filter to collect dust at the end of boiler afterward.

Boiler SP receives exhaust-air which has the temperature of 350^0C from the pre-burning kiln with the flow rate of 247,500 Nm^3/h. Boiler AQC receives heat from the clinker cooling component of the kiln with the flow rate of 161,370 Nm^3/h and the temperature of 330^0C. Superheated-steam from boiler SP (22.45 t/h, 330^0C) in combination with superheated-steam from boiler AQC (10.44 t/h, 310^0C) to release steam of 317C and 1.5 Mpa before being transferred to the turbine. The steam after going out of the turbine has the value of pressure of 0.008 Mpa, will be delivered to the chiller to condense back to water and bring back to the feed-water tank afterward. Water from the feed-water tank which has the temperature of 42^0C will be delivered to boiler AQC to be re-heated. Then, the key diagram of system is re-drawn as Fig. 3, the calculation flow chart is shown as Fig. 4.

The heat-cycle of system is described as Fig. 5. The Law 1 and 2 of Thermodynamic are applied to build the energy balance equations and weight in the Rankine cycle for calculating parameters of the WHRS [10]. Computed results are simulated and compared to practical operating measured data at the plant. Suggestions for improving system's efficiency are given afterward.

The value of inlet enthalpy at each node matched with the actual pressure value (ii) is referred from the Enthalpy value table of water, and steam with pressure.

Work energy created by steam (turbine work) is calculated for node 1 and 2 as Eq.1:

$$l = i_1 - i_2 \quad \text{[kJ/kg]} \quad (1)$$

Heat load required for the constant pressure (isobaric) process along 3-4-5-1:

$$q_n = q_1 + q_2 + q_3 \quad \text{[kJ/kg]} \quad (2)$$

The thermal efficiency of the process:

$$\eta = \frac{l}{q_n} \quad (3)$$

Heat of exhaust-air required for water evaporation in boiler SP and AQC:

$$Q_{k1} = G_{k1}(c_{p\ \ 1} \times t_{k\ 1} - c_{p\ \ 1} \times t_{k\ 1}) \quad \text{[kJ/s]} \quad (4)$$

$$Q_{k2} = G_{k2}(c_{p\ \ 2} \times t_{k\ 2} - c_{p\ \ 2} \times t_{k\ 2}) \quad \text{[kJ/s]} \quad (5)$$

where:

G_{ki}: the mass flow rate of exhaust-air at boiler SP and AQC.

$$G_{k1} = m_k \times \rho_k \quad \text{[kg/s]} \quad (6)$$

m_{ki}: the volume flow rate of exhaust-air at boiler SP and AQC [m^3/s].

ρ_{ki}: the density of exhaust-air at boiler SP and AQC [kg/m^3].

c_{pkvi}: the specific heat capacity of air entering the boiler SP and AQC [kJ/kg.K].

c_{pkri}: the specific heat capacity of air existing the boiler SP and AQC [kJ/kg.K].

t_{kvi}: temperature of air entering the boiler SP and AQC [K].

t_{kri}: temperature of air existing the boiler SP and AQC [K].

Total heat load required to steam water in boilers:

$$Q_k = \sum_{i=1}^{n} Q_k \quad \text{[kJ/s]} \quad (7)$$

Inlet mass flow rate for turbine:

$$G_n = \frac{Q_k}{q_n} \quad \text{[kg/s]} \quad (8)$$

Turbine power:

$$P_t = G_n \times l \quad \text{[kW]} \quad (9)$$

3.3. Modelling the suggested innovative WHRS from boiler SP to heat water in boiler AQC

The waste-heat from boiler SP is assumed to be delivered to boiler AQC to heat water. The assumed diagram is drawn as Fig. 6. When the WHRS is applied to recover waste-heat from boiler SP, the steam's temperature and pressure to turbine are constants, it means that the mass flow rate *Gn* will increase; then one more combined turbine - generator will be needed.

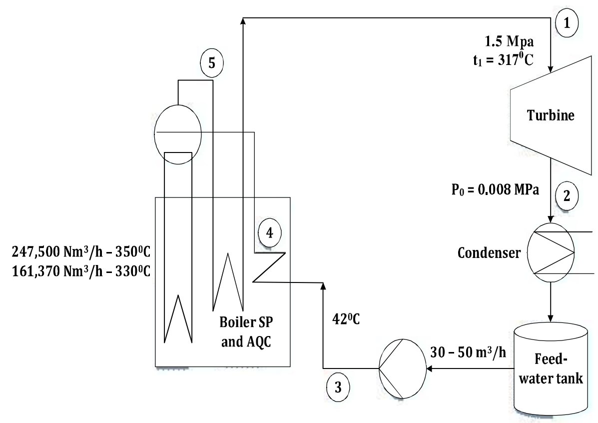

Fig. 3. Key diagram of WHRS of the power plant.

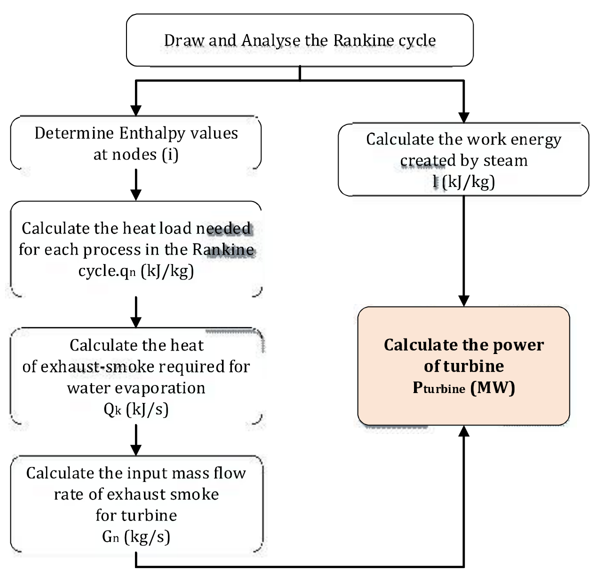

Fig. 4. Calculation flow chart of the WHRS.

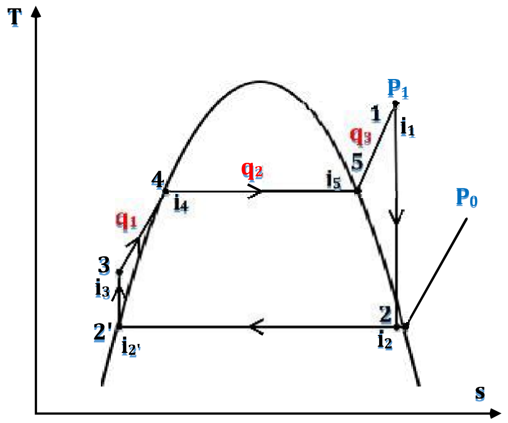

Fig. 5. Boiler's T-s diagram.

The basic principle and the calculation procedure for system's parameters will not change. When the waste heat from boiler SP is recovered to provide additional heat to boiler AQC, then the total heat load required to steam water in boilers will be calculated as:

$$Q_k = Q_{k1} + Q_{k2} + Q_{k3} \quad \text{[kJ/s]} \quad (10)$$

Where Q_{k3} is the salvaged heat taken from boiler SP:

$$Q_{k3} = G_{k3}\left(c_{p\ \ 3} \times t_{k\ \ 3} - c_{p\ \ 3} \times t_{k\ \ 3}\right) \quad \text{[kJ/s]} \quad (11)$$

Where $G_{k3} = G_{k1}$; $c_{pkv3} = c_{pkr1}$; and $t_{kv3} = t_{kr1}$

The model of WHRS is calculated in Excel software. Results of the simulation include: (1) generator power of the existing system to verify the accuracy of the model; (2) The power of the additional turbine – generator combination as suggested.

3.4. Financial Analysis for the suggested innovative WHRS.

A short financial analysis for the suggested innovative WHRS is released to demonstrate the feasibility of the suggested system. The input data are provided with average tariff of the national electricity-2016, capacity factor, capital cost, and O&M (see Table 4).

Vietnamese electricity tariff is classified as three levels corresponding to different rush demands of consumer. However, in order to conduct a feasible financial analysis, an average tariff is generated by balancing the weight of each level as following equation:

$$P_{av} = \frac{\sum_{i=1}^{n} P_i \times D_i}{2} \quad \text{[USD/kWhe]} \quad (12)$$

Where P_{ave} (USD/kWhe) is the average tariff for each electricity power consumed; P_i (USD/kWhe) is the classified tariff corresponding to the three levels of prices; and D_i is the total duration in which the consuming demand has a similar characteristic.

A payback period estimation (see eq.12) is employed to calculate the financial feasibility of the new innovative technology.

$$\sum_{t=0}^{T} \frac{R_t}{1+i^{-t}} = \sum_{t=0}^{T} \frac{C_t}{1+i^{-t}} \quad \text{[yr]} \quad (13)$$

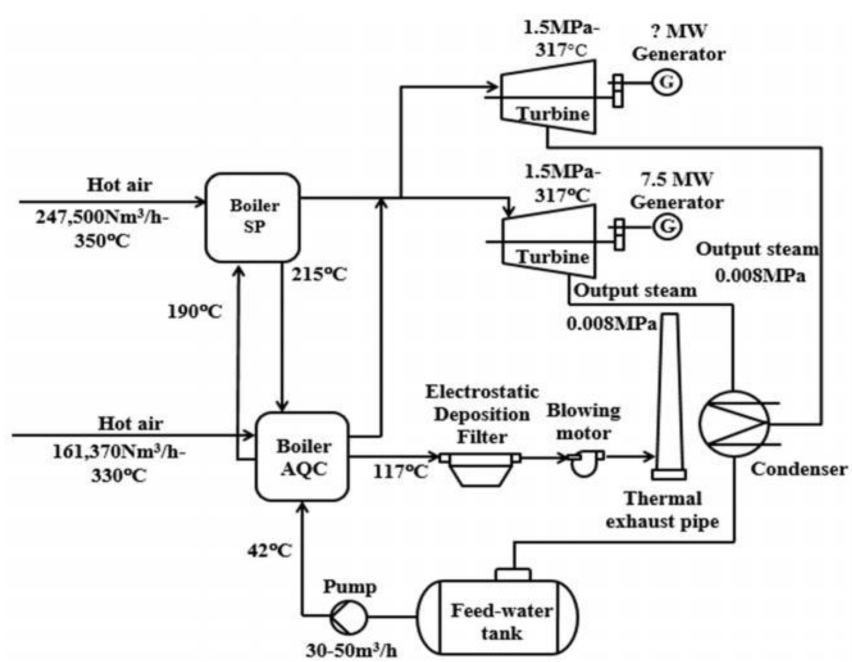

Fig. 6. Diagram of the new WHRS, recovers waste-heat from boiler SP to reheat water in boiler AQC.

Where i (%/yr) is defined as local bank interest rate; T (yr) is the lifetime of technology or project; t (yr) is the considered moment; C_t (USD) is the investment of the year t; and R_t (USD) is the net saving of the year t.

4. Results of simulation

4.1. For the existing WHRS

Table 2 presents the results of existing WHRS's parameters which leads to some comments regarding: the temperature of water from feed-water pump is 42^0C; boiling temperature to evaporate water into steam at the pressure of 1.5 Mpa is 198.3^0C; the temperature of exhaust air from boiler SP is 215^0C. The mechanical power of turbine resulted from the calculation are 8.86 MW. However, due to the efficiency of generator is commonly at 85%, then it results to the electric power of generator at 7.53 MW. It is then chosen at 7.5 MW for actual operation in the plant [15]. This fact demonstrates the accuracy and reliability of the model.

Table.2. Results of calculation for the existing WHRS

Calculation factor	Result	Unit
Heat load needed for process 3-4, 4-5, 5-1 (2)	2.89	MJ/kg
Work energy generated by steam (1)	889.2	kJ/kg
Thermal efficiency (3)	31.9	%
Waste-heat needed for water to be steamed in boiler (4) + (5)	28.9	MJ/s
Steam weight produced (Inlet mass flow for turbine) (8)	9.96	kg/s
Turbine output power (9)	8.86	MW
Generator power	7.53	MW
Annual electricity generation with capacity factor (C_f) of 86%	56.7	GWh/ Yr

Table. 3. Results of calculation for the suggested innovative WHRS

Calculation factor	Result	Unit
Waste-heat needed for water to be steam in boiler (4), (5), (10)	38.83	MJ/s
Steam weight produced (Inlet mass flow for new system of turbine)	13.4	kg/s
Additional turbine power	3.05	MW
Additional generator power	2.59	MW
Annual additional electricity generation with C_f of 86%	19.6	GWh/yr

4.2. The suggested innovative WHRS

New results of system are shown in Table 3. When the waste-heat with a temperature of 215^0C from boiler SP is recovered to reheat water in boiler AQC, then the output capacity of turbine increases by 34.5% compared to the existing system. The power of additional turbine is calculated by computing the value of Q_{k3} then applying the same calculation process mentioned above. Additional generator power is chosen at value of 2.59 MW. The annual power productivity increases by 33.3%.

4.3. Financial Analysis for the suggested innovative WHRS

Since the suggested innovative WHRS is an upgrading solution of existing manufacturing line by installation of additional power of steam turbine and generator of 2.6 MW (increasing 34.5% capacity compared to the existing system), and replacing of new condenser and water pump of 100 m^3/h, 30 KW; other components of the existing WHRS are remained caused by 100% of capacity reservation of those components [16]. The capital cost is 1.025 million USD [17], [18].

A simple payback period (SPP) method is launched to calculate the payback ability of the WHRS investment. Results of the analysis are also presented in table 4. The annual power productivity increases by 33.3%. The net savings from implementing the new WHRS is approximately 1.32 million USD/yr. This value excludes the depreciations of turbine-generator combination investment. With the emission factor of 143 g-C/kWhe [11], the annual reduction of CO_2 is approximately 10.3 ton/year, and payback time is 0.9 year.

Table. 4. Financial analysis for the suggested innovative WHRS

Calculation factor	Result	Unit
Capital cost	1,025,000	USD
Capacity factor (C_f)	86	%
Average tariff of electricity (2016)	0.07	USD/kWh
O&M cost per year	328,947	USD/yr
Annual income by electricity productivity	1,370,628	USD/yr
Payback Period	0.98	Yr

5. Conclusion and recommendations

The article has presented the calculation and simulation for the WHRS of Holcim cement factory-Kien Giang. The calculation result for the generator power of the existing system is closely similar to the actual technical figure. The accuracy of the model, therefore, has been verified.

When applying the suggested innovative WHRS from boiler SP to reheat water in boiler AQC, the capacity the system increase 34.5%, and the annual electricity productivity increases by 33.3%. Reduction of CO_2 is 10.3 tons/yr; especially, payback time is less than 1 year. These results reflect the impression of the suggested one.

However, to widely apply this technology, we have to proceed these following tasks:

- Create the programs to promote the benefits of this technology to manufacturers;
- Create schemes and guidelines, consult the cement plants in selection and replacement of suitable technology to complying with technical standards to ensure the economical – technical – environmental and social benefits;
- Promote the programs to encourage, support business entities on capital and technique to re-structure manufacturing and technology acceptance; and
- Synchronize data between Ministries, Industries and Management Organization of the manufacturing plants to minimize variances of the input data.

Salvaging waste-heat to generate electricity is one of many energy saving solutions in industry generally and cement manufacturing industry in specific. Following researches might aim to the recovery of waste-heat from sewage, garbage as replacement fuel providing to cement kiln or recover hazardous waste in kilns, etc.

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References

[1] Varma, G. V. P. and T. Srinivas. Design and analysis of a cogeneration plant using heat recovery of a cement factory. Case Studies in Thermal Engineering. 2015, vol. 5, pp. 24-31.

[2] Madloola, N. A., R. Saidura, N. A. Rahim, M. R. Islama and M. S. Hossian. An energy analysis for cement industries: An overview. Renewable and Sustainable Energy Review. 2012, vol. 16, issue. 1, pp. 921-932.

[3] Söğüt Z., Z. Oktay and H. Karakoç. Mathematical modelling of heat recovery from a rotary kiln. Applied Thermal Engineering. 2010, vol.30, pp. 817-825.

[4] Sui, X., Y. Zhang, S. Shao and S. Zhang. Energetic life cycle assessment of cement production process with waste heat power generation. Energy Conversion and Management.2014, vol.88, pp. 684-692.

[5] Tan, Y., X. Li, L. Zhao, H. Li, J. Yan and Z. Yu. Study on Utilization of Waste Heat in Cement Plant. Energy Procedia. 2014, vol.61, pp. 455-458.

[6] Brückner, S., S. Liu, L. Miró, M. Radspieler, L. Cabeza and E. Lävemann. Industrial waste heat recovery technologies: An economic analysis of heat transformation technologies. Applied Energy. 2105, vol. 151, pp. 157-167.

[7] Galvez-Martos, J. L. and H. Schoenberger. An analysis of the use of life cycle assessment for waste co-incineration in cement kilns. Resources, Conservation and Recycling. 2014, vol.86, pp. 118-131.

[8] Schneider, M. Process technology for efficient and sustainable cement production. Cement and Concrete Research. 2015, vol.78, pp. 14-23.

[9] Karamarkovíc, V., M. Maraševíc, R.Karamarkovíc and M. Karamarkovíc. Recuperator for waste heat recovery from rotary kilns. Applied Thermal Engineering. 2013, vol.54, pp. 470-480.

[10] Karellas, S., A. D. Leontaritis, G. Panousis, E. Bellos and E. Kakaras. Energetic analysis of waste heat recovery systems in the cement industry. Energy. 2013, vol.58, pp. 147-156.

[11] Cuong-Vo, V.. Life Cycle CO_2 Emission Factors of Power Generation in Vietnam. Journal of Science and Technology. 2010, vol.79, pp. 102-107.

[12] INSTITUTE OF ENERGY, Electricity of Vietnam (EVN), Ministry of Industry. The Master plan on Electric Power Development in Vietnam for the period of 2010-2020 perspective to 2030. Hanoi. 2010.

[13] VIETNAM INSTITUTE FOR BUILDING MATERIALS, Ministry of Construction. Cement industry development plan of Vietnam to 2020, looking forward to 2030. Hanoi, 2011.

[14] HOLCIM VIETNAM. Sustainable development 2012 report of Holcim Vietnam - 100 years of sustainable development. Vietnam, 2013.

[15] HOLCIM VIETNAM. Documents of the Holcim Cement Factory-Kien Giang. Vietnam, 2014.

[16] Technical specifications Hon Chong Exhaust Heat Recovery Power Plant in Vietnam. 2014.

[17] http://www.alstom.com/products-services/

[18] http://vn.mhi.co.jp/