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THERMODYNAMICS ANALYSIS FOR WASTE HEAT RECOVERY SYSTEMS IN A CEMENT INDUSTRY

(ÇİMENTO SEKTÖRÜNDE ATIK ISI GERİ KAZANIM SİSTEMİNİN TERMODİNAMİK İNCELEMESİ)

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ABSTRACT

Recently, application of energy and exergy analyses to new projects presents most important data in terms of first design of systems and economic analyses. Evaluation and interpretation of analyses reports make determine the place, size and reasons of energy losses, therefore enhances the efficiency of systems. This project aims to thermodynamically inspect and develop the effects of Waste Heat Recovery (WHR) system on energy efficiency in cement factories. According to results, for all system, exergy losses value and totally exergy efficiency are founded 5038.61 kW and 55.69%, respectively. These results will constitute important data in terms of design and economical while building and operating waste heat recycling power plants. Thus energy saving and effective energy usage, which have great importance today, will be possible.

Keywords: Energy efficiency for industry, Waste heat, WHR, Cement industry

ÖZ

Son yıllarda enerji ve ekserji analizinin yeni projelerde uygulanması, sistemlerin ilk dizaynı ve ekonomik analizlerinin yapılması açısından önemli veriler sunmaktadır. Analiz sonuçlarının değerlendirilmesi ve getirilen yorumlarla enerji kayıplarının yeri, büyüklüğü ve nedenleri saptanabilmekte, dolayısıyla sistemlerin verimleri arttırılabilmektedir. Bu proje ile çimento fabrikalarında WHR sisteminin enerji verimliliği üzerine olan etkisi ve bu sistemin termodinamik olarak incelenmesi, geliştirilmesi amaçlanmaktadır. Elde edilen sonuçlara göre tüm sistem için ekserji kaybı 5038,61 kW ve ekserji verimliliği ise % 55.69 olarak bulunmuştur. Elde edilen sonuçlar atık ısı geri kazanım santrallerin kurulmasında ve işletilmesinde dizayn ve ekonomik açıdan önemli bir veri teşkil edecektir. Böylece günümüzde çok büyük önem teşkil eden enerji tasarrufu ve enerjinin en verimli şekilde kullanılması sağlanabilecektir.

Anahtar kelimeler: *Sanayide enerji verimliliği, Atık ısı, WHR, Çimento sanayisi*

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1. INTRODUCTION

Societies energy demand also grows continuously in parallel with global competition, economic and social developments. Increasing energy demand and rising of energy costs daily have led societies to search alternative energy sources [1]. WHR system is a method to generate electricity by using warm gases released from chimneys to the atmosphere, in other words the fact that it's fuel is free makes this method highly economical [2]. The first step to implement this brand new system for Turkey was first initiated to be applied for a cement plant in late 2009 [3].

In this study, thermodynamic efficiencies of systems that generates electricity with some special equipments, using hot gas ejected from chimney's of current system cement factories, which might even have the most intensive energy consumption in heavy industry [4, 5]. Moreover, WHR system is the main focus point rather than cement production system and system's thermodynamic efficiency was evaluated. Although there are many studies regarding cement sector in the literature, there are limited studies focusing on WHR to generate electricity. This project, discusses a sample situation regarding evaluation of thermodynamic performances of WHR plants to generate electricity, which was implemented or planned to be implemented in cement plants, dissimilarly from literature.

The situation study in hand is planned to be implemented on the second clinker production line which is a cement producer placed in Aegean Region. In line with the design information of this to be implemented project, analyses about energy and exergy were evaluated and optimum performance conditions, energy and exergy analyses results were included. Considering contemporary cement plants in our country, 420 MW electrical power is expected to be generated with thanks to WHR systems. The business will not only enhance its energy efficiency but also indirectly contribute the reduction of CO_2 release.

2. DESCRIPTION OF CASE STUDIES

The project activity is a WHR and utilization for power generation project located at the cement plant in Turkey. The foundations of facility were laid in 1955 and it started its activities as wet system with a clinker capacity of 85.000 tons/year. Technological developments and continuous improvement activities has increased its clinker production capacity to 1.000.000 tons/year and cement grinding capacity to 1.375.000 tons/year. Product range are included Portland Clinker, Portland Cements, Blended Cements as well as White Cement and Sulfate Resisting Cement that requires compelling and special work.

The main objectives of the project activity are developed the auxiliary WHR generation project of 2100 ton/day clinker production lines. The recovery and use of waste heat from the rotating kiln of the clinker production lines. Therefore, it’s built to meet the electrical supply needs of cement plant beside of reduce greenhouse gas emissions. The scale of construction is 5.5 MW and the project proposes to build two heat recovery boilers with one set of mixed pressure admission condensing turbine-generator unit. The facilities established by the project activity are commissioned in April 2012. The annual design power generation of the set of turbine generator unit above amounts to 42,240 MWh and yearly power supply to cement production facilities is 35,000 MWh. The designed annual operation time of the facilities is about 7,680 hours.

The WHR system will efficiently utilize the waste heat from the clinker production process to generate electricity. [6, 7]. Normally, the factories are supplied to electricity from Turkish power grid so electricity price is app. 0,16 USD/kWh in Turkey. We are considered to annual profit app. 7 million USD by only WHR system. The project is lead to indirect reduction of CO_2 emission from plant electricity consumption. The volume of reduction is defined by the plants net electricity generation (42,240 MWh) and the respective grid emission factor of the Turkish power grid. The WHR project is reduce greenhouse gas emissions (CO_2) versus the baseline scenario, which is the continued supply from the regional power grid to meet the demand for power of the cement.

Additionally the project activity are significantly reduce harmful emissions (including SOx, NOx and floating particles), and thus improve the local environment reduction in the temperature of the vented hot air from about 380 °C to 90 °C . The project activity makes use of advanced heat recovery technology and the power generation of clinker per ton amounts to 37.9 kWh which comes up to the advanced international standard with the clear superiority of high efficiency of heat recovery and good effect of energy conservation. The project will not impact on the existing production process of cement [8].

It entails the installation as follows;

- One 5.5 MW türbine,
- One 6 MW generator,
- One AQC boiler,
- One SP boiler.

AQC boiler is installed next to the kiln head of the cement line, producing superheated steam and hot water. Dedusting chamber like a cyclone is to be set up to alleviate the boiler abrasion. Also, SP boiler is connected to the pre-heater outlet, producing a superheated steam.

On the basis of existing clinker production lines, the project are utilized feed water to recover the heat energy of low-temperature waste heat exhausted by cement clinker production lines [9, 10]. The feed water is converted into superheated steam by SP heat recovery boilers and AQC heat recovery boilers. This steam has been fed into a steam turbine through a steam pipe. The heat energy is converted into kinetic energy in the steam turbine by rotating the turbine blades. This rotation is caused the energy to be converted into mechanical energy which is caused the generator rotate. The rotating generator is produced electricity. The model numbers and performance characteristics of the main equipment relating to the project can be seen from Figure 1 (the energy mass flow diagram).

Water is heated by the boiler and turn to vapor phase and transfer to steam turbine. The steam is conveyed to condenser through the steam turbine and then cooled into condensed water which is sent by the condensed water pump to the low-pressure heater and then to the deaerator. The deaerated water is sent to the high-pressure heater by pump then complete the water cycle. The flow sheet of a system is shown in Figure 2.

As can be seen thermodynamic node points in Figure 2, major energy and exergy loses are defined that heat transfer between fluids and gases. Also that node points are shown inlet-outlet gas and fluid thermodynamic conditions for each equipment. For example; Node 2:

Inlet SP boiler (fluid), Node 4: outlet SP boiler (fluid), Node 16: outlet of the SP Boiler (hot gas).

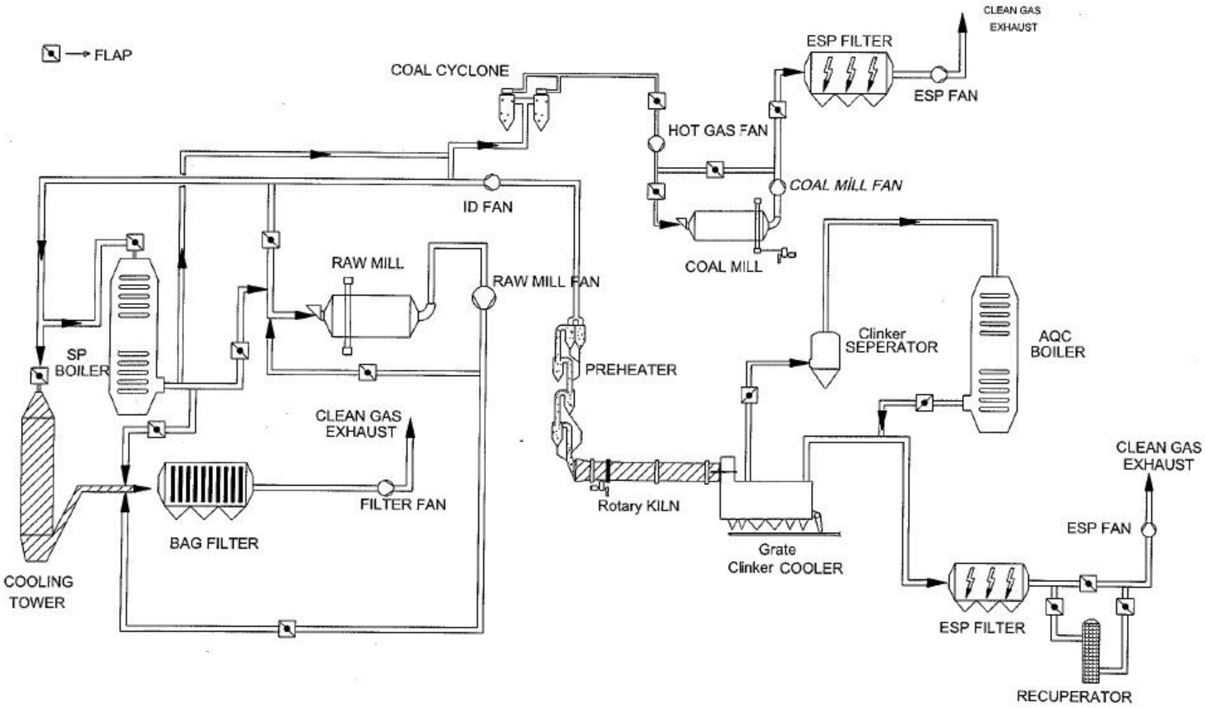

Figure 1. Energy Flow diagram in cement production system

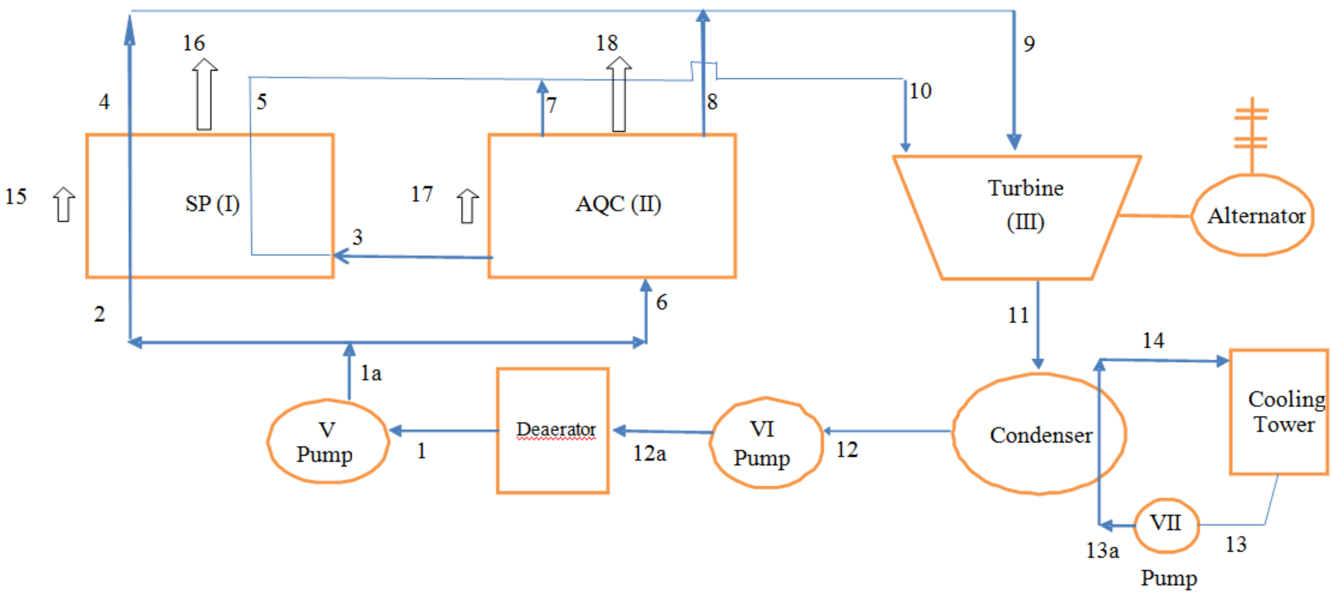

Figure 2. Schematic representation of the WHR system

3. MAIN EQUIPMENTS OF WHR SYSTEM

3.1. SP and AQC Boilers

The main body of this system consists of two WHR boilers and one set of condensing steam türbine & generator. Function of waste heat boiler is utilizing waste flue gas released from cement kiln to produce superheated steam in compliance with stated temperature and pressure. Boiler system consists of its body and auxiliary equipments, including water feeding equipments, pipeline, dust cleaning, transporting devices, sewage water drainage device, dosing device etc; there is one kiln outlet boiler (AQC boiler) at the outlet of kiln and one kiln outlet boiler (SP boiler) at the inlet of kiln.

This exhaust heat boiler is major equipment mainly for power generation by exhaust heat recovered from cement kiln [12]. This boiler installed in the gas outlet of the preheater. Thus called "SP" Exhaust Heat Boiler. The design temperature at the exhaust gas inlet of the SP boiler is 360 °C. The exhaust gas temperature drops down to about 170 °C after the exhaust gas passes the MP superheated, generator and economizer. And then the gas is drafted to the raw material drying system and the dust collecting system of the kiln by the high temperature fan at the cement kiln back end. The design parameters are shown in Table 1.

Table 1. Specification of suspension preheated (SP) boiler

Specification of SP Boiler	
Inlet gas temperature	360 °C
Inlet gas amount	135,000 Nm^3/h
Outlet gas temperature	170 °C
Inlet dust content in gas	80 g/ Nm^3
Circulation type	Natural Circulation
Main Steam Stage Parameters	
Superheated steam output	13.4 t/h
Superheated steam pressure	1.25 MPa
Superheated steam temperature	345 °C
Feed water temperature	125 °C
Low pressure steam Stage Parameters	
Steam output	1.8 t/h
Steam pressure	0.25 MPa
Steam temperature	170 °C
Feed water temperature	39 °C

Air quenching cooler (AQC) boiler is installed on the cement kiln pipeline between the exhaust gas outlet of the clinker cooler and the dust collector, thus called AQC waste heat boiler. The design temperature at the exhaust gas inlet of the boiler is 380 °C. The exhaust gas temperature will drop down to 80 °C after the gas passes the superheater, evaporator, economizer and water heater. The gas then enters the dust collectors installed on the clinker cooler where a fan discharges the gas into the atmosphere. The detail design parameters are given as Table 2.

Table 2. Specification of air queching cooler (AQC) boiler

Specification of AQC Boiler	
Inlet gas temperature	380 °C
Inlet gas amount	106,400 Nm^3/h
Outlet gas temperature	80 °C
Inlet dust content in gas	15 g/ Nm^3
Circulation type	Natural Circulation
Main Steam Stage Parameters	
Superheated steam output	10.5 t/h
Superheated steam pressure	1.35 MPa
Superheated steam temperature	365 °C
Feed water temperature	130 °C
Low pressure steam Stage Parameters	
Steam output	1.8 t/h
Steam pressure	0.35 MPa
Steam temperature	170 °C
Feed water temperature	39 °C
Hot Water Stage Parameters	
Feed water temperature	39 °C
Output water temperature	140 °C
Mass flow rate of hot water	32.54 t/h

3.2. Turbine and Generator

Featuring a function of cogeneration, this steam turbine is applicable to the communal thermal plant as well as the self-sustained power stations. After entering into turbine, the steam shall drive rotor of turbine to rotate; meanwhile, the rotor of generator shall rotate with that of turbine, namely, the energy transferring process of hot energy of steam to mechanical energy [13]. This is the process of hot energy turned into mechanical energy by turbine. The specifications of steam turbine is shown in Table 3.

Table 3. Specification of steam turbine

Steam Turbine		
Model		BN5.5-1.25/0.25
Rated power	kW	5,500
Rated speed	rev/min	3,000
Rated inlet pressure	MPa	1.25
Rated inlet temperature	°C	348
Injection pressure	MPa	0.25
Injection temperature	°C	160
Rated exhaust pressure	MPa	0.007

4. ENERGY AND EXERGY ANALYSIS

4.1. Assumptions

In order to analyze the WHR thermodynamically, the following assumptions are made:

(a) The system is assumed as a steady state and steady flow process,
(b) Kinetic and potential energy changes of input and output materials are ignored,
(c) No heat is transferred to the system from the outside,
(d) The change in the ambient temperature is neglected,
(e) It is assumed that only physical exergy is used for flue gas and steam flows,
(f) Flue gas which use that SP and AQC boilers is ideal gases.

Under the above mentioned conditions and using the design data of the project, energy and exergy balance are applied to the WHR.

4.2. Mass, Energy and Exergy Balance Equations

For a general steady-state,steady-flow process, the three balance equations as follows.

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (1)$$

$$\dot{E}_{in} - \dot{E}_{out} = dE_{sys}/dt \rightarrow 0 \quad (2)$$

$$\dot{Q}_{CV} + \sum \dot{m}_{in} h_{in} = \dot{W}_{CV} + \sum \dot{m}_{out} h_{out} \quad (3)$$

where m is mass flow rate, E_{in} is inlet energy, E_{out} is outlet energy, Q is rate of heat input, W rate of net work output and h the enthalpy per unit mass [16-27]. Also, the energy efficiency is defined to other main equipments and system is given at the Table 4.

Exergy analysis of a complex system can be performed by analyzing each component of the system separately.

The general exergy balance can be expressed in the rate form as;

$$Ex = Ex^{PH} + Ex^{KN} + Ex^{PT} + Ex^{CH} \quad (8)$$

(CH: chemical; KN: kinetic; PH: physical; PT: potential)

where we were considered to only physical exergy in this study other exergy parameters were neglected. Therefore, exergy balance can be expressed in the rate form as ;

$$\dot{E}x_{heat} - \dot{E}x_{work} + \dot{E}x_{mass,in} - \dot{E}x_{mass,out} = \dot{E}x_{dest} \quad (9)$$

The last general equations is specific exergy for flue gas can be given as ‘’Webfer equations’’.

$$\psi_{gas} = c_p\left(T_1 - T_0 - T_0 \ln\frac{T_1}{T_0}\right) + RT_0 \ln\frac{P_1}{P_0} \tag{10}$$

where cp is specific heat of gas, T is the temperature of gas and P is the pressure of gas and the subscripts ‘’1’’ stands for gas and ‘’0’’ for dead state [19].

Related to main equipments of exergy equations in WHR system are shown in Table 5.

4.3. Restricted Dead State

Exergy is defined as maximum amount of work which can be produced by a system when it comes to equilibrium with a reference environment. That’s why we are accepted the reference environment pressure and temperatures, that is meaning the defined restricted dead state. In this study pressure and temperature of environment are taken average ambient conditions, such as 1 atm and 15 °C [21].

Table 4. Description of energy efficiency for main equipment

Number	Equation	Description
4	$\eta_{tur} = \dfrac{\dot{W}_{tur}}{\dot{E}_{in} - \dot{E}_{out}}$	Energy efficiency for the turbine
5	$\eta_{pump} = \dfrac{\dot{E}_{out} - \dot{E}_{in}}{\dot{W}_{pump}}$	Energy efficiency for the pumps
6	$\eta_{kond} = \dfrac{\dot{E}_{out,cold} - \dot{E}_{in,cold}}{\dot{E}_{out,hot} - \dot{E}_{in,out}}$	Energy efficiency for the condenser
7	$\eta_k = \dfrac{\dot{E}_{out}}{\dot{E}_{in}}$	Energy efficiency for the overall system

4.4. Environmental Impact Analysis

ACM0012 is a consolidated baseline methodology for greenhouse gas emission reductions from waste energy recovery projects. This methodology is also applicable to projects which use waste pressure to generate electricity.

Table 5 Generally balance and exergy equations and thermodynamically description for the equipment

Number	Equations	Descriptions
11	$\dot{E}_x = \dot{m}_{trb}(\Psi_{11} - \Psi_{12}) + \dot{m}_{su}(\Psi_{13a} - \Psi_{14})$	The exergy destruction for the condenser
12	$\dot{E}_{x,kay1} = \dot{W}_{p1} - \dot{m}(\psi_{1a} - \Psi_1)$	The exergy destruction for the pump 1st
13	$\dot{E}_{x,kay2} = \dot{W}_{p2} - \dot{m}(\psi_{12a} - \Psi_{12})$	The exergy destruction for the pump 2nd
14	$\dot{E}_{x,kay3} = \dot{W}_{p3} - \dot{m}(\psi_{13a} - \Psi_{13})$	The exergy destruction for the pump 3rd
15	$\dot{E}_{xSP_{in}} - \dot{E}_{xSP_{out}} = \dot{E}_{xdest,SP}$	The exergy destruction for the SP boiler
16	$\dot{E}_{xAQCin} - \dot{E}_{xAQCout} = \dot{E}_{xdest,AQC}$	The exergy destruction for the AQC boiler
17	$\dot{E}x_{trb} = \dot{E}_{in} - \dot{E}_{out} - \dot{W}_{trb}$	The exergy destruction for the steam turbine
18	$\varepsilon_{pump} = \dfrac{\dot{E}x_{out} - \dot{E}x_{in}}{\dot{W}_{pump}}$	The exergy efficiency for pumps
19	$\varepsilon_{cond} = \dfrac{\dot{m}_{water}(\psi_{13a} - \psi_{14})}{\dot{m}_{mix}(\psi_{11} - \psi_{12})}$	The exergy efficiency for condenser
20	$\varepsilon_{pump} = \dfrac{\dot{W}_{trb}}{\dot{E}x_{in} - \dot{E}x_{out}}$	The exergy efficiency for steam turbine
21	$\varepsilon_{sys} = 1 - \dfrac{Ex_{dest}}{Ex_{in}}$	The exergy efficiency for overall systems
22	$IP = (1-\varepsilon)(\dot{E}x_{in} - \dot{E}x_{out})$	Improvement potential
23	$\chi_i = \dfrac{\dot{I}_i}{\dot{I}_{Tot}}$	Relative irreversibility

As per ACM0012 baseline emissions shall be generally calculated using the following formula.

$$BE_y = BE_{En,y} + BE_{ff,y} \tag{11}$$

where BEy is the total baseline emissions during the year y in tCO_2, BE_En,y is the baseline emissions from energy generated by the project activity during the year y in tCO_2, BEff,y is the baseline emissions from fossil fuel combustion, if any, either directly for flaring of waste gas or for steam generation that would have been used for flaring the waste gas in the absence of the project activity (tCO_2), calculated as per Equation 12. This is relevant for those project activities where in the baseline steam is used to flare the waste gas.

BEff, y is not applicable as there is no such direct/indirect utilization of fossil fuels for flaring of waste gas. Therefore the BE is identical to BE_En,y. According to project type and respective procedures and formulae in ACM00012, the following calculations apply.

For calculation of baseline emissions from energy generated by the project activity.

$$BE_{En,y} = BE_{Elec,y} + BE_{Ther,y} \tag{12}$$

where $BE_{Elec,y}$ is the baseline emissions from electricity during the year y in tCO2, $BE_{Ther,y}$ is the Baseline emissions from thermal energy (due to heat generation by elemental processes) during the year tCO_2. $BE_{Ther,y}$ is not applicable as no such utilization of baseline steam flare the waste gas.

Therefore the BE_En,y is identical to BE_Elec,y.For calculation of baseline emissions from electricity generation.

$$BE_{Elec,y} = f_{cap} \times f_{wcm} \times \sum_j \sum_i (EG_{i,j,y} \times EF_{Elec,i,j,y}) \tag{13}$$

where BEelec,y is the Baseline emissions due to displacement of electricity during the year y (tCO_2), EGi,j,y= is the quantity of electricity supplied to the recipient j by generator, which in the absence of the project activity would have been sourced from source i (the grid or an identified source) during the year y in MWh, EFelec,i,j,y is the CO_2 emission factor for the electricity source i (gr for the grid, and is for an identified source), displaced due to the project activity, during the year y (tCO_2/MWh), f_{wcm} is the fraction of total electricity generated by the project activity using waste energy. This fraction is 1 if the electricity generation is purely from use of waste energy. For a project activity using waste pressure to generate electricity, the electricity generated from waste pressure should be measurable and this fraction is 1. Also fcap is the factor that determines the energy that would have been produced in project year. The ratio is 1 if the waste energy generated in project year y is the same or less than that generated at a historical level. For greenfield facilities, fcap is 1.

5. RESULTS AND DISCUSSION

5.1. Thermomechanic Analysis Result

Based on design conditions, energy and exergy analysis are calculated for WHR system after that benchmarking to efficiency between main equipment. The results are shown in Table 6-8.

According to calculation, for all system, exergy losses value and totally exergy efficiency are founded 5038.61 kW and 55.69%, respectively.

As can be seen thermodynamic node points, major exergy loses are defined that heat transfer between fluids, expansion of gases and friction respectively. For exergy efficiency is calculated to use dead state based on meteorological conditions are 15 C and 101.325 kPa respectively. According to reference data calculated exergy destruction for each unit are done beside of exergy efficiency and potential irreversibility. Schematic representations of energy and exergy flow diagram are shown Figure 5 and Figure 6.

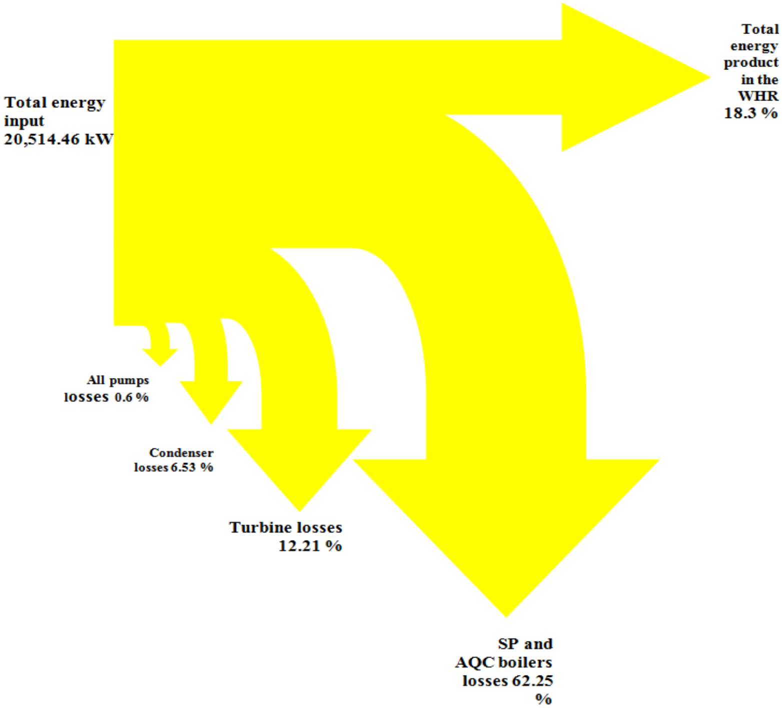

Figure 5. Energy flow diagram for the WHR system (reference state temperature and the atmospheric pressure are 15 °C and 101.32 kPa, respectively)

The fuel source mean that hot gas is accepted the ideal gas for exergy analysis that's why for during the calculation exergy efficiency that is required temperature, pressure are taken ideal gas condition.

As a Figure 7 is clearly explained that dead state temperature is effected to exergy efficiency. As we are assumed before dead state temperature is 15 C degrees, according to exergy analysis, we are calculated based on basic formula founded %55.69. As we see that inside to formula on graphics, explaining to when ambient or environment temperature is changed, how is the effect to exergy efficiency of WHR system. As shown Figure 7, if dead state temperature increases, also exergy efficiency increases at the same time.

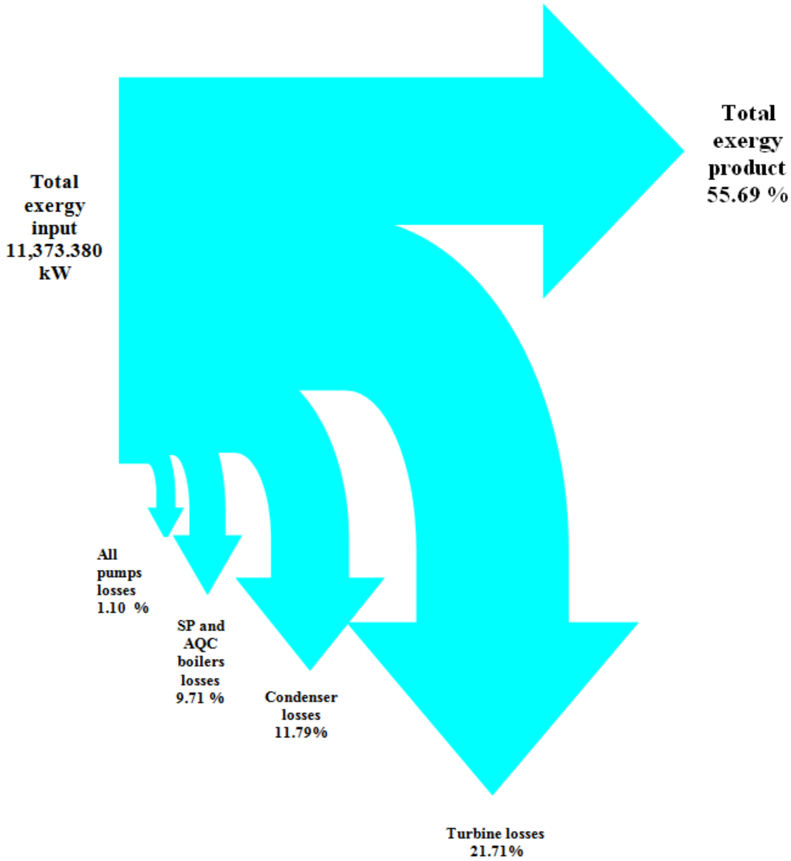

Figure 6. Exergy flow diagram for the WHR system (reference state temperature and the atmospheric pressure are 15 °C and 101.32 kPa, respectively)

Table 6. The results of exergy analysis for the waste heat recovery system

Number	Name of element	Fluid	Phase	Temperature T(°C)	Pressure P(kPa)	Specific enthalpy h(kj/kg)	Specific entropy s(kj/kgK)	Mass flow rate ṁ(kg/s)	Specific exergy Ψ (kj/kg)	Exergy rate Ėx=ṁΨ (kW)
0	-	Water	Dead state	15	101.325	62.95	0.22		0.00	0.00
1	Deaerator outlet /Pump inlet	Water	Liquid	38	600	159.02	0.54	7.638	3.63	27.79
1a	Feed pump outlet	Water	Liquid	39	2,400	163.20	0.55	7.638	3.95	30.18
2	Feed water inlet to SP boiler	Water	Liquid	39	2,400	163.20	0.55	0.5	3.95	1.97
3	AQC boiler outlet/SP boiler inlet	Water	Liquid	125	2,100	524.75	1.58	3.722	71.18	264.96
4	Low pressure steam outlet from SP boiler	Water	Saturated steam	170	250	2,767.21	6.66	0.5	849.27	424.63
5	High pressure steam outlet from SP boiler	Water	Superheated steam	345	1,250	3,141.52	7.17	3.72	1,076.04	4,005.03
6	Feed water inlet to AQC boiler	Water	Liquid	39	2,400	163.2	0.55	7.13	4.12	29.43
7	High pressure steam outlet from AQC boiler	Water	Superheated steam	360	1,250	3,173.58	7.22	2.91	1,093.40	3,188.38
8	Low pressure steam outlet from AQC boiler	Water	Saturated steam	170	250	2767.21	6.66	0.5	849.27	424.63
9	Steam inlet to turbine low pressure stage	Water	Saturated steam	160	200	2756.88	6.74	1	814.44	814.44
10	Steam inlet to turbine high pressure stage	Water	Superheated steam	340	1,150	3132.89	7.19	6.63	1,060.7	7041.49
11	Turbine outlet/Condenser inlet	Water	Water-steam Mixture	39	7	2,572.60	8.27	7.63	189.38	1446.48
12	Condenser outlet / Pump inlet	Water	Liquid	38	7	159.02	0.54	7.63	3.63	27.79
12a	Pump outlet / Deaerator inlet	Water	Liquid	39	600	163.20	0.55	7.63	3.95	30.18
13	Cooling tower outlet/pump VII inlet	Water	Liquid	26.5	30	111.01	0.38	33.00	0.89	29.66
13a	Pump VII outlet / Condenser inlet	Water	Liquid	27	250	113.10	0.39	33.00	0.97	32.00
14	Condenser outlet / Cooling tower inlet	Water	Liquid	37	250	154.85	0.53	33.00	3,326	109.74

Table 7. The result of exergy analysis for hot gases to the waste heat recovery system

Number	Name of element	Fluid	Phase	Temperature T(K)	Pressure P(bar)	Mass flow rate $\dot{m}$(kg/s)	Specific exergy Ψ(kj/kg)	Exergy rate $\dot{E}x=\dot{m}\Psi$(kW)
Environmental conditions for hot gases		Air	Gas	288.15	1.01		0.00	0.00
15	SP boiler inlet	Air	Gas	633.15	1.01	56.77	118.16	6707.98
16	SP boiler outlet	Air	Gas	458.15	1.01	56.77	36.38	2065.31
17	AQC boiler inlet	Air	Gas	653.15	1.01	36.11	129.19	4665.39
18	AQC boiler outlet	Air	Gas	353.15	1.01	36.11	6.38	230.63

Table 8 Exergetic, energetic and thermodynamics analysis data provided for one representative units of the WHR

Number	Name of element	Exergy destruction (kW)	Exergy efficiency (%)	Relative irreversibility χ (%)	Improvements potential IP(kW)	Energy (first law) efficiency (%)
I	SP boiler	479.94	92.85	9.53	332.17	28.90
II	AQC boiler	586.21	87.43	11.63	557.24	37.80
III	Turbine	2,505.96	68.10	49.74	2,044.55	60.90
IV	Condenser	1,340.94	9.30	26.61	1,216.19	-
V	Pump I	29.49	7.49	0.59	2.21	7.49
VI	Pump II	29.49	7.49	0.59	2.21	7.49
VII	Pump III	66.56	3.40	1.32	2.26	3.40
VIII	Overall system	5038.61	55.698	100	4,156.83	18.38

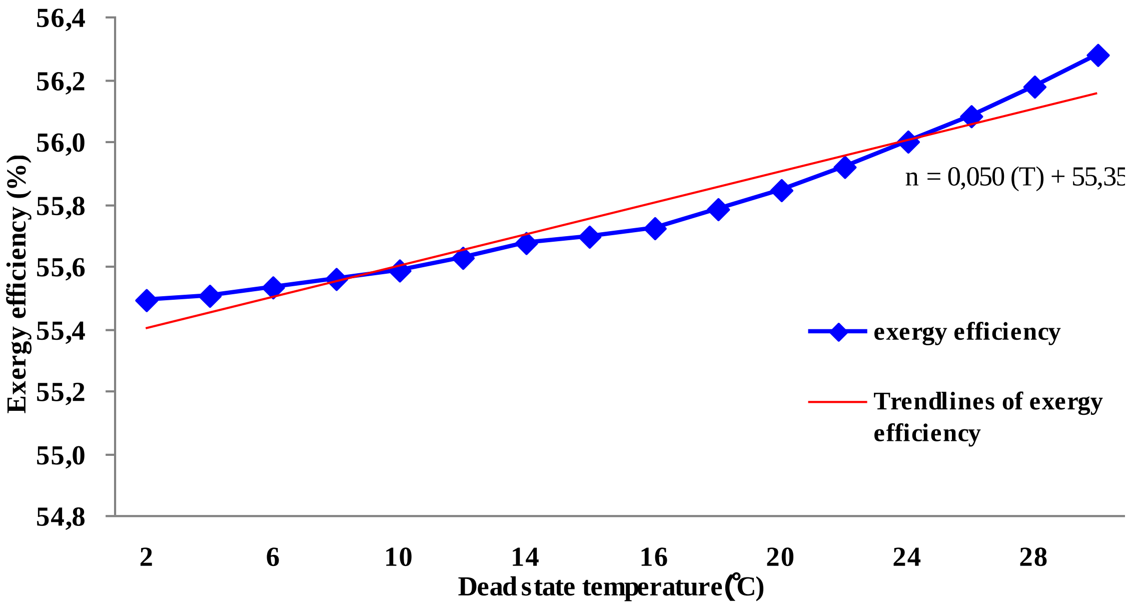

Figure 7. Variation of dead state temperature and exergy efficiency

Actually, another major parameter is inlet gas temperature of the SP boiler for exergy efficiency and also exergy destruction in the system. Based on exergy analysis and we investigated answer a simple questions 'If SP inlet gas temperature changes (increase or decrease) ,how is affected the exergy loss and efficiency of the systems?'' We have found to answer the questions from Figure 8.When temperature increase that also exergy efficiency will increase at the same time exergy loss is decreased linearly.

6. CONCLUSIONS

Feasibility of WHR systems to cement plants and system's energy and exergy analyses were performed. System's environmental effects and possible effects were discussed. Moreover environment temperature's effects on energy and exergy efficiency were inspected. General evaluation and recommendations about the system is stated below.

i. Turbine dilation and heat transfer of condenser are the major factors of exergy loss as stated clearly in Table 9. These losses can be reduced by completing cogeneration of turbine and condenser equipments.
ii. Exergy loss occurring because steam from steam turbine turns into condens, can be reduced by lowering heat difference of cooling water that procures heat transfer. Exergy loss arise from the dilation of turbine exit is related with turbine design criteria and isentropic efficiency.
iii. AQC and SP boilers, other equipments of the system, cause major exergy losses. Output exergy losses of these cauldrons don't come off as completely loss because these equipments are used for raw material drying of output exergies in the first place.
iv. In order to minimize exergy losses of SP and AQC boilers, it necessary to minimize the temperature difference of supply water heat and hot gas heat, in other words minimize the heat difference of the ones that carry out the heat transfer.
v. Constructional difference of SP boiler to AQC boiler is that SP boiler doesn't have fins on pipe coils. That causes exergy loss on SP boiler because it effects heat transfer

surface area. That's why it is a positive step to increase the surface area of pipe coils in terms of exergy efficiency but this alteration in design must be evaluated in terms of economy.

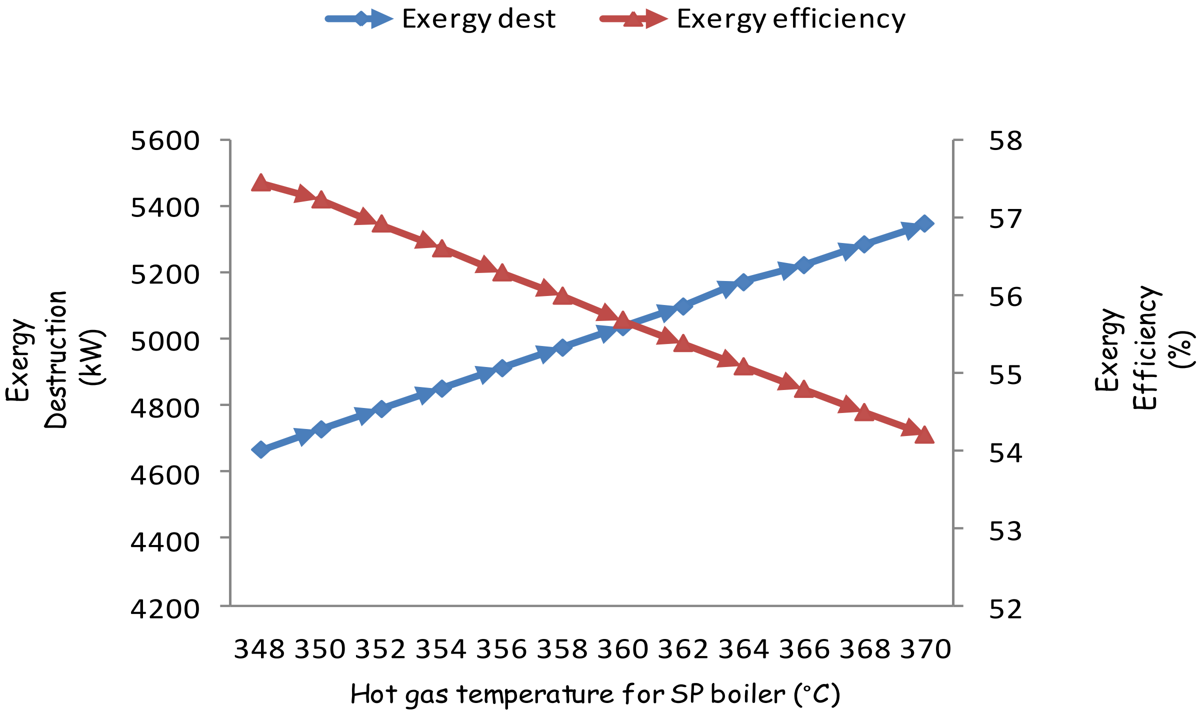

Figure 8. Variation of SP inlet gas temperature with exergy loss and efficiency of system

vi. Exergy loss of SP and AQC boilers can be reduced by applying pre-heating of supply water. Such design changes and alterations must naturally be considered with economical aspects.

Such produced power can be used on cement production line and that effects not only much more efficient usage of energy resources during production phase but also effects major increase in environmental useful effects and increases company's market share by enhancing company's production power in economical area.

Low heat technology and waste heat production have some advantages in preliminary cement production process of new dry type cement production lines, such as development, increase of efficiency during production. In other words, apart from labor division of cement production, if both systems are designed simultaneously, they can be combined with one big system. That's why usage of low temperature waste heat production technology provides a wide range for cement production lines.

In conclusion, it is verified by a third party independent institution (tuev-sued) that for WHR project, Cement plant achieved reduction of 17 thousand tons of carbon dioxide annually and 170 thousand tons of carbon dioxide for a decade. Considering 1,7 kg/kWh unit reduction between electricity generation and emission reduction, annual reduction of greenhouse gas emission is hoped to be 3.876.000 tons.

Considering the fact that a tree soaks up approximately 20 tons of CO_2 annually, this project can equally be beneficial as a forest consists of 193.800 trees.

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