IJE TRANSACTIONS A: Basics Vol. 31, No. 10, (October 2018) 1789-1795

International Journal of Engineering

Journal Homepage: www.ije.ir

Improvement of Efficiency of Coal-fired Steam Power Plant by Reducing Heat Rejection Temperature at Condenser Using Kalina Cycle

G. Khankari*, S. Karmakar

Department of Mechanical Engineering, National Institute of Technology Durgapur, West Bengal, India

PAPER INFO

Paper history:
Received 16 November 2017
Received in revised form 20 May 2018
Accepted 17 August 2018

Keywords:
Condenser waste heat
Energy
Exergy
Environment
Kalina Cycle

ABSTRACT

This paper proposes an approach for improving the plant efficiency by reducing the heat rejection temperature of power cycle using Kalina Cycle System 11 (KCS11) which is integrated at the steam condenser of a 500 MW_e SubC (subcritical) coal-fired power plant. It is modelled by using power plant simulation software 'Cycle Tempo' at different plant operating conditions. Results show that the additional net electric power of 5.14 MW_e from KCS11 improves the net energy and exergy efficiencies of the power plant by about 0.302 % point and 0.27 % point, respectively at full load over the stand-alone coal-fired steam power plant. Thereby, the carbon dioxide (CO_2) emission is reduced by about 2.02 t/h at full load. Combined plant efficiencies decrease with decrease in evaporator outlet temperature due to decrease in vapour quality of binary mixture at turbine inlet and higher steam turbine back pressure. Levelized Cost of Electricity (LCoE) generation and payback period of the combined cycle power plant are about Rs 1.734 and 4.237 years, respectively and the cost of fuel saving is about Rs 0.685 per kg of coal which is lower than the fuel cost.

***doi**: 10.5829/ije.2018.31.10a.23*

1. INTRODUCTION

The global energy concerns due to depleting fossil fuels and drastic climate change put the researcher to a great challenge. Efficient use of energy and waste heat recovery becoming the suitable option for mitigating rising problems comes from coal-fired power plant. The low graded waste heat recovery at condenser may be an attempt towards improving plant efficiency as about 50-60% of the total input energy is lost in the condenser. Turbo-generator (TG) cycle efficiency of steam power plant can be improved by reducing the heat rejection temperature at condenser. For which, condenser loss can be reduced. Reduction of heat rejection temperature at condenser side causes lower condenser back pressure and thereby, the exit loss of low pressure steam turbine (LPT) and the moisture content at the later stage of turbine blades increases. This will in turn decrease the TG cycle efficiency and thereby, the modern coal-fired steam power plant is designed at optimum condenser back pressure of 0.103 bar to run the plant efficiently. By considering this matter in view, the latent heat of steam exhausted from steam turbine can be used for additional electric power generation by using KCS11 where, ammonia-water mixture is used as working fluid. Thereby, it reduces the heat rejection temperature at the condenser of combined cycle power plant due to further expansion of binary vapour mixture in the turbine. As a result, it improves the plant efficiency and reduces the fuel consumption for the plant. The use of conventional steam power cycle is not economically feasible to recover low-grade waste heat [1]. K. Matsuda developed and implemented a Low Heat Power Generation (LHPG) system based on Kalina cycle in Japan by utilizing low-grade waste heat of the overhead vapor from the fractionators and achieved electric power generation of 3.3 MW_e with gross thermal efficiency of 8% at heat source temperature of 120 ˚C [2]. Last few decades, various combined cycle system have been proposed by several researchers and analyzed the system by varying working fluids to optimize the system performance [3, 4]. Kim et al. [5] designed a scroll expander of 45% efficiency which was lower in

---

*Corresponding Author Email: *goutam_khankari@yahoo.co.in* (G. Khankari)

Please cite this article as: G. Khankari, S. Karmakar, Improvement of Efficiency of Coal-fired Steam Power Plant by Reducing Heat Rejection Temperature at Condenser Using Kalina Cycle, International Journal of Engineering (IJE), IJE TRANSACTIONS A: Basics Vol. 31, No. 10, (October 2018) 1789-1795

size compared to conventional involutes scroll and tested the prototype in a R134a Rankine cycle with heat source of 20 kW. As far as power generation is concerned, Kalina cycle is more suitable efficient technology for power generation from low grade waste heat [6]. Nami et al. [7] performed a parametric optimization of a combined system whcich is combination of methane fired gas turbine with supercritical CO_2 and Organic Rankine Cycle. Parametric optimization for performance improvement of ORC have been done by using different working media for waste heat recovery from the low graded heat sources and results show that R123 has higher cycle efficiency compared to R12, R1341 etc. [8, 9]. Khankari and Karmakar [10] utilized coal mill reject particles for additional electric power generation using Kalina cycle which was modelled in the MS Excel macros.

To the best of authors' knowledge, there is hardly any research work carried out for reducing the heat rejection temperature of working fluid at condenser for efficiency improvement of coal-fired steam power plant. In the present study, the condenser of main steam power cycle (Rankine cycle) is replaced by the evaporator of Kalina cycle system 11 (KCS 11) for condensing the expanded steam and simultaneously, generate the ammonia-water vapour mixture for generating additional electric power through expanding vapour mixture in a binary mixture turbine.Thermodynamic performance study of the proposed combined Rankine-Kalina power cycle is carried out to measure and optimise the plant performance by varying different operating conditions through energy and exergy analysis.

2. SYSTEM DESCRIPTION

Figure 1 shows the 500 MW_e standalone SubC coal-fired steam power plant and Figure 2 shows the flow diagram of 500 MW_e combined Rankine-Kalina cycle power plant. In Figure 2, main plant condenser is replaced by the evaporator of KCS11 for exchanging heat in between working fluids of Rankine cycle and KCS11. In the evaporator, phase change of ammonia-water mixture occurs at different quality and separated saturated vapour binary mixture is supplied to the binary mixture turbine for expansion and it is condensed in the condenser of KCS11 by cooling water flow. Cooling water is circulated by cooling water (CW) pump. Saturated hot liquid binary mixture from the separator is used as extraction fluid for binary mixture heating and then it is discharged into the condenser. Saturated ammonia-water liquid binary mixture is again fed to the evaporator by running feed pump after heating in the heater. The generator of KCS11 is directly coupled with the binary mixture turbine.

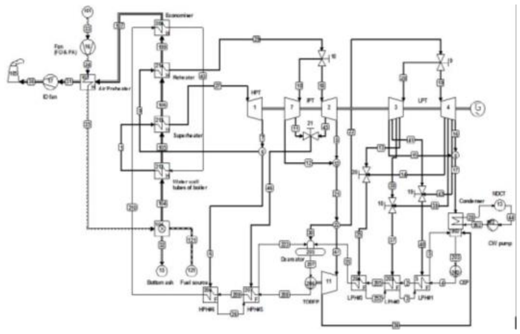

Figure 1. Schematic diagram of 500 MW_e Stand-alone SubC coal-fired steam power plant

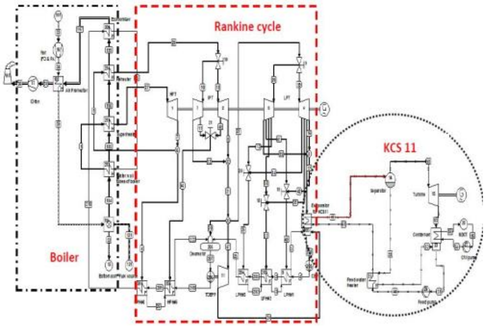

Figure 2. Schematic diagram of 500 MW_e combined Rankine-Kalina cycle coal-fired power plant

3. METHODOLOGY

Thermodynamic performance analysis of 500 MW_e combined Rankine-Kalina cycle coal-fired thermal power plant is done by 'Cycle-Tempo' modeling software which constitutes a flow-sheet computer program [11]. System input parameter at different operating conditions of the equipments and process path are specified like pressure, temperature, coal quality and efficiency of the pumps, fans and turbines. System modeling has been done based on following steady state equations.

Mass balance:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{1}$$

Energy balance:

$$\sum \dot{m}_{in}\ h_{in} + \dot{q}_k = \sum \dot{m}_{out}\ h_{out} + \dot{W} \tag{2}$$

where, $\dot{q}_k$: heat transfer rate to the system at temperature T_k.

Exergy balance:

$$\sum \dot{m}_{in}\ \varepsilon_{x\,in} + \dot{q}_k\left(1 - \frac{T_0}{T_K}\right) = \sum \dot{m}_{out}\ \varepsilon_{x\,out} + \dot{W} + \dot{Ex}_D \tag{3}$$

where, $\dot{Ex}_D = T_0\ [\dot{S}_{gen}]$ and $\varepsilon_x = [(h - h_0) - T_0(s - s_0)]$ which, ε_x indicates specific exergy of energy carrier, $\dot{Ex}_D$ indicates the exergy destruction in the system and subscript '0' indicates the environment condition of the system.

3. 1. Assumptions

i. NH_3-H_2O binary mixture temperature at evaporator inlet is considered as 30 ˚C with temperature rise of 10 ˚C.
ii. Dry saturated vapour at binary mixture turbine inlet is considered.
iii. Cooling water pressure and temperature at condenser inlet is 2 bar and 25 ˚C, respectively.
iv. The ammonia-water mixture temperature at condenser outlet is saturated liquid.
v. Isentropic efficiencies of turbine and pumps are considered as 95 and 85%, respectively.
vi. Ambient pressure (P_0) and temperature (T_0) of environment are 1.013 bar and 25 ˚C, respectively.
vii. Lower heating value of coal (LHV): 17162.60 kJ/kg and coal analysis is given in Table 1.
viii. Excess air of 20% is supplied for complete combustion.
ix. Evaporator shell pressure (Steam turbine back pressure) is considered as 0.103 bar.

3. 2. Performance Parameters for KCS11

Net energy efficiency of Kalina Cycle System 11 (KCS11):

$$\eta_{kcs11}^{net} = \frac{(\dot{W}_{kcs11}^{TG} - \dot{W}_{kcs11}^{FP} - \dot{W}_{kcs11}^{CWP})}{\dot{E}_{kcs11}^{in}} \tag{4}$$

where,
$\dot{W}_{kcs11}^{TG}$: indicates TG output of KCS11;
$\dot{W}_{kcs11}^{FP}$: indicates power consumed by feed pump of KCS11;
$\dot{W}_{kcs11}^{CWP}$: indicates power consumed by condenser cooling water pump of KCS11.

Net exergy efficiency of Kalina Cycle System 11 (KCS11):

$$\psi_{kcs11}^{net} = \frac{\dot{W}_{kcs11}^{net}}{\dot{Ex}_{kcs11}^{in}} \tag{5}$$

3. 3. Performance Parameters for 500 MW$_e$ Combined Cycle Power Plant

Net combined power plant energy efficiency:

$$\eta_{plant}^{comb.} = \frac{\dot{W}_{mp}^{TG} + \dot{W}_{kcs11}^{TG} - \dot{\mathrm{p}}_{\mathrm{aux.}}^{\mathrm{comb.}}}{\text{Energy supplied by coal}} \tag{6}$$

$\dot{\mathrm{p}}_{\mathrm{aux.}}^{\mathrm{comb.}}$ indicates the auxiliary power consumption for combined power plant. It includes power consumed by fans, pumps ($\dot{W}_{CEP}$, $\dot{W}_{kcs11}^{FP}$ and $\dot{W}_{kcs11}^{CWP}$) and others (about 2.93% of total generation) of the combined plant.

$$Energy\ supplied\ by\ coal\ =\ m_{coal}\,LHV \tag{7}$$

Net energy efficiency of combined Rankine-Kalina cycle system:

$$\eta_{comb.cycle}^{net} = \frac{\dot{W}_{net}^{comb.}}{\dot{E}_{int.}^{comb.}} \tag{8}$$

$$E_{comb.}^{rej} = \dot{\mathrm{m}}_{kcs11}^{cw}\left(h_{kcs11}^{cwout} - h_{kcs11}^{cw\ in}\right) \tag{9}$$

TABLE 1. Proximate analysis of coal

Proximate analysis of coal				Unburnt carbon	
TM (%)	ASH (%)	VM (%)	C (%)	Bottom ash (%)	Fly ash (%)
6	40	16	38	2.5	1.5

Net combined power plant exergy efficiency:

$$\psi_{plant} = \frac{\dot{W}_{mp}^{TG} + \dot{W}_{kcs11}^{TG} - \dot{\mathrm{p}}_{\mathrm{aux.}}^{\mathrm{comb.}}}{\text{Exergy supplied by coal}} \tag{10}$$

$$Exergy\ supplied\ by\ coal\ =\ \dot{m}_{coal}\,\varepsilon_{coal} \tag{11}$$

Specific exergy of coal (ε_{coal}) is calculated as follows:

$$\varepsilon_{coal} = (0.9775LHV_{coal} + 2.416) \pm (0.0065LHV_{coal} + 0.054) \tag{12}$$

Net exergy efficiency of combined cycle system:

$$\psi_{comb.cycle}^{net} = \frac{\dot{W}_{net}^{comb.}}{\dot{Ex}_{int.}^{comb.}} \tag{13}$$

$$\dot{Ex}_{comb.}^{rej} = \dot{\mathrm{m}}_{kcs11}^{cw}\left(\varepsilon_{kcs11}^{cwout} - \varepsilon_{kcs11}^{cw\ in}\right) \tag{14}$$

CO_2 emission can be reduced by saving coal under same load condition and calculated as follows:

$$CO_2^{reduction} = \frac{\dot{m}_{coal}^{saving}\{\%C - \%Ash(0.80\frac{\%UC_{FA}}{100} + 0.20\frac{\%UC_{BA}}{100})\}}{100} \tag{15}$$

Relative energy/exergy (R_{en}/R_{ex}): It can be defined as the ratio of energy or exergy of a system to unit gross generation.

4. RESULTS AND DISCUSSION

4. 1. Model Validation and Parametric Analysis of 500 MW$_e$ Combined Cycle Power Plant

Simulation results of 500 MW$_e$ main steam power plant and KCS11 are closely matched with the performance data of published research papers [12] and [6], respectively. Energy and exergy balance of 500 MW$_e$ stand-alone SubC coal-fired power plant and 500 MW$_e$ combined Rankine-Kalina cycle power plant are carried out at 100% of rated load which is given in Tables 2 and 3, respectively. From Tables 2 and 3, it is observed that the condenser energy and exergy losses are reduced by about 0.424% point and 0.876% point, respectively. Thereby, energy and exergy efficiencies of combined cycle power plant is more than Rankine cycle power plant by about 0.302% point and 0.27% point, respectively at full load due to additional electric power generation of about 5.14 MW$_e$ from the KCS11. For which, heat rejection temperature is reduced to about 30 ˚C, Improvement of efficiency is very less due to high condenser back pressure of KCS11 which causes less enthalpy drop across the turbine. The priority is given more importance in the conversion of low graded waste heat energy into high graded mechanical works rather than the less thermal efficiency.

From Figure 3, it is also found that relative energy rejection and relative exergy destruction of the combined power cycle reduces due to less relative energy and exergy input. The proposed combined Rankine-Kalina power cycle is one of the suitable technologies for converting condenser waste heat into electricity.

4. 2. Effect of Load Variation on the Plant Performance Parameters

Plant performance analyses are done at different plant load condition. For this instance, analysis results are given at 60, 80 and 100% of rated load condition. From Figure 4, it is observed that the net plant energy and exergy efficiencies increase with increase in load and increment slope reduces after 80% of rated load due to less throttling effect of control valves. It is also observed that the gap in between energy and exergy efficiencies of both the plants are reduced towards higher load due to less exergy destruction associated with large opening of control valves. As a result, relative energy and exergy input to the cycle of both the plants are reduced (Table 4).

TABLE 2. Energy balance (%) at 100% load

Components	500 MW Stand-alone coal-fired power plant	500 MW Combined cycle power plant
Power plant gross efficiency (%)	39.676	40.500
Condenser loss (%)	51.900	51.476
Heat rejected through stack (%)	5.954	5.954
Heat rejected in bottom ash (%)	0.813	0.822
Other losses (by difference) (%)	1.657	1.247

TABLE 3. Exergy balance (%) at 100% load

Components	500 MW Stand-alone coal-fired power plant	500 MW Combined cycle power plant
Power plant gross efficiency (%)	35.460	36.200
Condenser loss (%)	1.184	0.307
Turbine losses (%)	4.902	4.946
Heaters losses (%)	0.238	0.260
Boiler loss (%)	54.980	55.538
Others losses (by difference) (%)	3.237	2.750

It is also observed from Figure 5 that the improvement of net energy efficiency of combined Rankine-Kalina cycle power plant over stand alone steam power plant is higher at higher load due to less energy rejection and less exergy destruction of the cycle (Table 4). Through this combined Rankine-Kalina power cycle approach, maximum net plant energy efficiency improvement is achieved as about 0.302% point at full load and this improvement reduces the CO_2 emission by about 2.02 t/h.

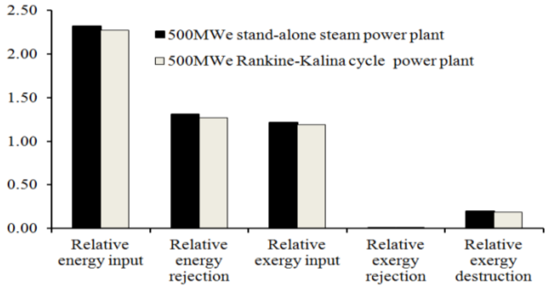

Figure 3. Energy and exergy analysis of the plants

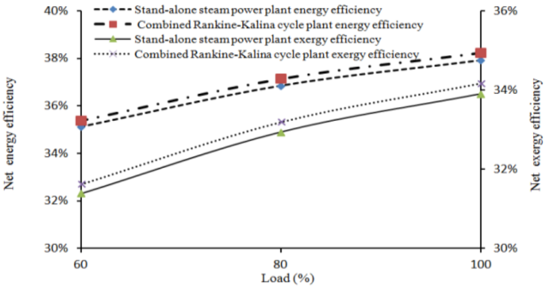

Figure 4. Effect of part load on plant performance

TABLE 4. Energy and exergy analysis of the main and combined power plant at different part loads

% of load	500 MW$_e$ Stand-alone steam power plant					500 MW$_e$ Combined Cycle Power Plant				
	R^{int}_{en}	R^{rej}_{en}	R^{int}_{ex}	R^{rej}_{ex}	R^{dest}_{ex}	R^{int}_{en}	R^{rej}_{en}	R^{int}_{ex}	R^{rej}_{ex}	R^{dest}_{ex}
100	2.321	1.308	1.217	0.006	0.198	2.273	1.271	1.192	0.0085	0.185
80	2.361	1.347	1.239	0.006	0.219	2.312	1.310	1.212	0.0087	0.204
60	2.429	1.416	1.272	0.007	0.253	2.377	1.376	1.245	0.0092	0.237

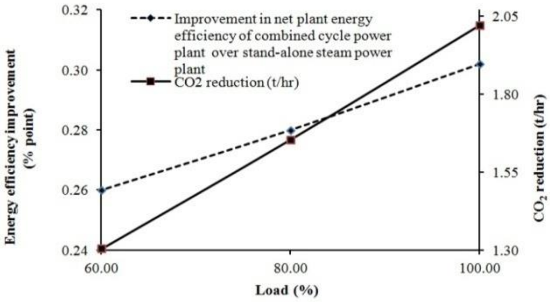

Figure 5. Efficiency improvement at different part loads

TABLE 5. Energy and exergy analyses of KCS11 of combined cycle power plant at different NH_3 mass fraction

Condition	**100% of rated load**			
Ammonia mass fraction	0.860	0.880	0.900	0.920
Net TG output (kW)	4864.420	5008.420	5139.910	5264.490
Net energy input to KCS11 cycle (kW)	640416.592	640217.232	640040.025	639870.783
Energy rejected from KCS11 cycle (kW)	625292.231	631260.669	635535.688	638719.862
Exergy input to KCS11 cycle (kW)	38072.415	34156.989	29125.861	23171.589
Exergy rejected from KCS11 cycle (kW)	4168.615	4208.404	4236.905	4258.132
Exergy destructed in KC11 cycle (kW)	29039.380	24940.164	19749.046	13648.967
Net cycle energy efficiency of KC11 (%)	0.760	0.782	0.803	0.823
Net cycle exergy efficiency of KC11 (%)	12.777	14.663	17.647	22.720
Net combined plant energy efficiency (%)	38.425	38.437	38.447	38.458
Net combined plant exergy efficiency (%)	34.342	34.352	34.362	34.371

4. 3. Effect of Ammonia Mass Fraction Variation on the Performance of KCS11 and Combined Cycle Power Plant

Ammonia mass fraction variation in NH_3-H_2O binary mixture of KCS11 is studied and the results of ammonia mass fraction at 0.86, 0.88, 0.90 and 0.92 are given in Table 5. From Figure 6, it is observed that net energy and exergy efficiencies of KCS11 increases with ammonia mass fraction due to increase the input energy through KCS11 turbine which causes more TG output from KCS11. This improvement increases the energy and exergy efficiencies of combined Rankine-Kalina cycle power plant (Table 5). Higher vapour mass fraction is caused by the lower saturation temperature at higher ammonia mass fraction. As a consequence, amount of vapour mass flow rate through the turbine increases and the amount of saturated liquid mixture for the feed heater of KCS11 also reduces. It is also analyzed that the energy rejection increases and exergy destruction rate decreases with increase in ammonia mass fraction.

4. 4. Effect of Temperature Rise of Binary Mixture Across the Evaporator on the Plant Performance

Temperature rise at the evaporator may deviate from its design value due to different real problems in the heat exchanger. This effect is studied by varying evaporator outlet temperature and results are shown in Figures 7 and 8. From Figure 7, it is observed that the net energy and exergy efficiencies of combined cycle power plant decreases with decrease in temperature rise at evaporator outlet. The lower temperature rise across the evaporator increase the steam turbine exhausts pressure and reduces the specific work output from the steam and binary mixture turbines (Figure 8). Specific work output is reduced due to less enthalpy drop across the steam and binary mixture turbines due to higher evaporator back pressure (shell pressure) at steam turbine exhaust and low quality of vapour mixture at binary mixture turbine inlet.

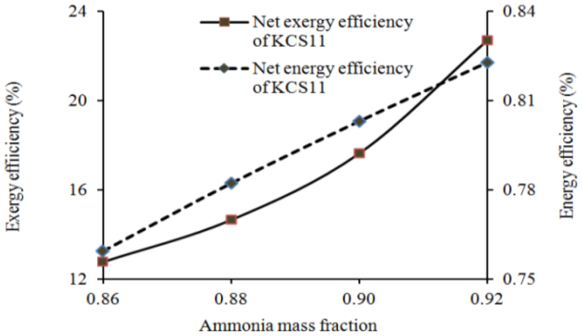

Figure 6. Effect of NH_3 mass fraction on KCS11 performance

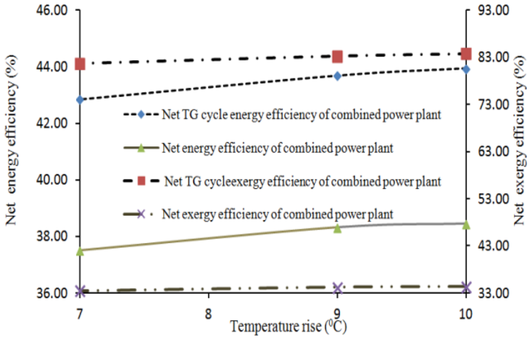

Figure 7. Effect of temperature rise on plant performance

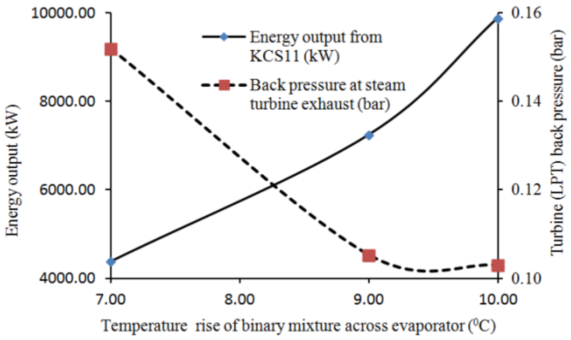

Figure 8. Effect of temperature rise on KCS11performance

TABLE 6. Economic comparison of the plants

Description	Unit	500 MW$_e$ Coal-fired power plant	500 MW$_e$ Combined cycle power plant
Capital cost (C_C)	Rs./kW	50800.000	51021.760
Life of the power plant (n)	Year	25.000	25.000
Discount rate (d)	fraction	0.120	0.120
Capital recovery factor (RF_C)	fraction	0.127	0.127
Annualized capital cost (CC_A)	Rs./kW	6476.998	6505.273
Plant capacity factor (PCF)	fraction	0.900	0.900
Auxiliary power consumption (P_{aux})	fraction	0.044	0.051
Net energy generated annualy (P_{net})	kWh/kW	7537.892	7485.070
Fixed capital cost per unit (FC_C)	Rs./kWh	0.859	0.869
Fixed O&M cost (FOM)	Rs./kW	971.550	975.791
Fixed O&M cost per unit($FC_{O\&M}$)	Rs./kWh	0.129	0.130
Fuel cost (C_{fuel})	Rs./kg	0.750	0.750
Lower heating value of fuel (LHV)	kJ/kg	17162.600	17162.600
Net heat rate(NHR)	kJ/kWh	9490.169	9363.079
Fuel cost per unit (FC_{fuel})	Rs./kWh	0.415	0.409
variable O&M cost per unit (FC_{VOM})	Rs./kWh	0.200	0.200
Total variable cost per unit (C_V)	Rs./kWh	0.615	0.609
Annualized cost of electricity generation (AC_OE)	Rs./kWh	1.603	1.609
Excalation rate (fuel/O&M- fixed and variable) (e)	fraction	0.031	0.031
Equiavalent discount rate with escalation (d')	fraction	0.087	0.087
Levelizing factor (L_F)	fraction	1.170	1.170
Levelized fuel and O&M cost(C_L)	Rs./kWh	0.870	0.865
Levelized cost of electricity generation (LC_OE)	Rs./kWh	1.729	1.734
Simple payback period (SPP)	Year	4.205	4.237
Additional cost for KCS11 integration	Rs./kWh	–	0.005
Energy saved for KCS11 integration	kJ/kWh	–	127.091
Cost of saved energy	Rs./kJ	–	0.00004
Cost of Saved fuel	Rs/kg	–	0.685

4. 5. Economic Comparison of the Plants

Techno-commercial feasibility of the proposed combined Rankine-Kalina cycle coal-fired power plant is done through economic comparison of both the plants based on Levelized Cost of Electricity (LCoE) generation as per research paper with plant life of 25 years. Capital cost of the steam power plant is taken as Rs. 50,800/- per kW [12] and capital cost of KCS11 is taken as Rs. 62,000/- per kW [10]. Capital cost of the combined cycle power plant is calculated based on load sharing in between the steam plant and KCS11. Economic analysis is done by considering plant capacity factor of 90% and coal cost of Rs. 0.75/kg.

From Table 6, it is observed that LCoE of the 500 MW$_e$ stand-alone steam power plant and 500MW$_e$ combined cycle power plant are about Rs.1.729/- and Rs. 1.734, respectively and also simple payback period of the both plants are 4.205 and 4.237 years, respectively. It is also found that cost of saved fuel for KCS11 integration with steam power cycle is about Rs. 0.685/- per kg of coal which is lower than the fuel cost (Rs.0.75/- per kg of coal).

5. CONCLUSIONS

Following are some of the major conclusions that could be drawn from the present study:

- The net energy and exergy efficiencies of 500 MW$_e$ SubC coal-fired thermal power plant is improved by about 0.302% point and 0.27% point, respectively by using KCS11 for reducing the condenser heat rejection temperature to about 30 $^{\circ}$C.

- About 2.02 t/h of CO_2 emission can be reduced by generating additional electric power of 5.14 MW_e from condenser waste heat at full load.
- Net energy and exergy efficiencies of the KCS11 increases with increase in ammonia mass fraction.
- Lower evaporator outlet temperature reduces the plant performance due to increase the steam turbine back pressure and low vapour quality at the inlet of binary mixture turbine.
- The LCoE and payback period of the proposed combined cycle plant are about Rs.1.734/- and 4.237 years, respectively. The cost of saved fuel is about Rs. 0.685/- per kg of coal which is lower than the fuel cost (Rs. 0.75/- per kg).

6. REFERENCES

1. He, J., Liu, C., Xu, X., Li, Y., Wu, S. and Xu, J., "Performance research on modified KCS (Kalina cycle system) 11 without throttle valve", ***Energy***, Vol. 64, (2014), 389–397.
2. Matsuda, K., "Low heat power generation system", ***Applied Thermal Engineering***, Vol. 70, No. 2, (2014), 1056–1061.
3. Vidhi, R., Kuravi, S., Goswami, D.,Y. Stefanakos, E. and Sabau, A.S., "Organic Fluids in a Supercritical Rankine Cycle for Low Temperature Power Generation", ***Journal of Energy Resources Technology***, Vol. 135, No. 4, (2013), 042002.
4. Shokati, N., Ranjbar, F. and Mohammadkhani, F., "Comparison of Single-stage and Two-stage Tubular SOFC-GT Hybrid Cycles: Energy and Exergy Viewpoints", ***International Journal of Engineering - Transactions A: Basics***, Vol. 28, No. 4, (2015), 618–626.
5. Kim, H.J., Moon, J.H. and Kim, Y.H., "Design and testing of an algebraic scroll expander for power generation from a waste heat recovery system", ***Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy***, Vol. 229, No. 8, (2015), 1019–1031.
6. Hettiarachchi, H.M., Golubovic, M., Worek, W.M. and Ikegami, Y., "The Performance of the Kalina Cycle System 11(KCS-11) With Low-Temperature Heat Sources", ***Journal of Energy Resources Technology***, Vol. 129, No. 3, (2007), 243–247.
7. Nami, H., Mohammadkhani, F. and Ranjbar, F., "Thermodynamic Analysis and Optimization of a Novel Cogeneration System: Combination of a gas Turbine with Supercritical CO2 and Organic Rankine Cycles (TECHNICAL NOTE)", ***International Journal of Engineering - Transactions C: Aspects***, Vol. 29, No. 12, (2016), 1765–1774.
8. Roy, J.P., Mishra, M.K. and Misra, A., "Parametric optimization and performance analysis of a waste heat recovery system using Organic Rankine Cycle", ***Energy***, Vol. 35, No. 12, (2010), 5049–5062.
9. Peris, B., Navarro-Esbrí, J., Molés, F., Collado, R. and Mota-Babiloni, A., "Performance evaluation of an Organic Rankine Cycle (ORC) for power applications from low grade heat sources", ***Applied Thermal Engineering***, Vol. 75, (2015), 763–769.
10. Khankari, G., Karmakar, S., "Power generation from coal mill rejection using Kalina cycle", ***Journal of Energy Resources Technology***, Vol. 138, No. 5, (2016), 052004.
11. Delft University of Technology, Cycle-Tempo Release 5.0, software, (2008), http:// www.tudelft.nl.
12. Suresh, M.V.J.J., Reddy, K.S. and Kolar, A.K., "4-E (Energy, Exergy, Environment, and Economic) analysis of solar thermal aided coal-fired power plants", ***Energy for Sustainable Development***, Vol. 14, No. 4, (2010), 267–279.

Improvement of Efficiency of Coal-fired Steam Power Plant by Reducing Heat Rejection Temperature at Condenser Using Kalina Cycle

G. Khankari, S. Karmakar

Department of Mechanical Engineering, National Institute of Technology Durgapur, West Bengal, India

PAPER INFO

Paper history:
Received 16 November 2017
Received in revised form 20 May 2018
Accepted 17 August 2018

Keywords:
Condenser waste heat
Energy
Exergy
Environment
Kalina Cycle

چکیده

این مقاله روشی را برای بهبود کارایی نیروگاه با کاهش دمای گرما در چرخه قدرت با استفاده از سیستم چرخه کالین ۱۱ (KCS11) پیشنهاد می‌کند که در یک کندانسور بخار یک نیروگاه با سرعتی معادل ۵۰۰ مگاواتی زیر کریستال نصب شده است. این مدل با استفاده از نرم‌افزار شبیه‌سازی نیروگاه "Cycle Tempo" در شرایط مختلف نیروگاه طراحی شده است. نتایج نشان می‌دهد که توان مازاد بر برق خالص ۵/۱۴ مگاوات از KCS11 انرژی خالص و بهره‌وری اضافی نیروگاه به ترتیب در حدود ۰/۳۰۲ و ۰/۲۷۰٪ بوده است که راندمان نیروگاه بخار زغال سنگ مستقل را بهبود می‌بخشد. به این ترتیب، انتشار دی اکسید کربن (CO_2) در حدود ۰/۰۲ تن در ساعت در مصرف سوخت کاهش می‌یابد. کارایی نیروگاه سیکل ترکیبی با کاهش دمای خروجی اواپراتور، به دلیل کاهش کیفیت بخار مخلوط با سوخت باینری در ورودی توربین و فشار عقب توربین بخار بالاتر کاهش می‌یابد. هزینه تولید برق مجاز (LCoE) و دوره بازپرداخت نیروگاه ترکیبی در حدود *Rs* ۱/۷۳۴ و ۴/۲۳۷ سال است و هزینه سوخت ذخیره شده در هر کیلوگرم زغال سنگ *Rs* ۰/۶۸۵ است که کمتر از هزینه سوخت است.

doi*: 10.5829/ije.2018.31.10a.23*