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Thermodynamic Analysis of Combined Power and Cooling Cycle Using Process Heat from a Passout Turbine as a Heating Source

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Abstract

A combined thermal power and cooling cycle is the combination a Rankine cycle and an absorption refrigeration cycle. It can provide power output as well as refrigeration with power generation as a primary goal. The new cycle uses very high concentration ammonia vapor in the turbine which can be expanded to a very low temperature in the turbine without condensation. This cycle uses an absorption condensation process instead of the conventional condensation process. In this paper combined thermal power and cooling cycle is analyzed for different fraction of steam from a passout turbine as heat input to run Goswami cycle. The proposed heating sources are the waste heat at the exit of back pressure turbine and extracted steam from pass-out turbine. The main parameters that can be varied to influence the cycle are the heat source temperature, system high pressure, basic solution ammonia mass fraction, ratio ofworking and heating fluid flow rates, and absorber pressure and temperature. Rectifier and superheater temperatures can also be modified, and the conditions of heat transfer from the source to the ammonia-water mixture as well. The combined power and cooling cycle is optimized for the maximum thermal efficiency.

Keywords: Passout turbine, Goswami cycle, rectifier, superheater, combined cycle.

Introduction

Recently alternative power cycles employing multicomponent working fluids have been studied intensively. The motivation for using mixtures is that heat transfer occurs at variable temperatures thus providing a better thermal match between a sensible heat source and the working fluid. A well-known thermodynamic power cycle using ammonia-water mixture as the working fluid is Kalina cycle [1]. A comparison of the Kalina cycle to the Rankine cycle byEl-Sayed and Tribus shows a 10% to 20% improvement in thermal efficiency [2]. Marston [3], Park and Sonntag [4], and Ibrahim and Klein [5] also analyzed the Kalina cycle and showed advantages of the Kalina cycle over the conventional Rankine cycle under certain conditions.

The cycle can be driven by different heat sources including solar, geothermal, and low temperature waste heat. The use of mid- and low-temperature solar collectors to drive the combined cycle was investigated by Goswami and Xu (1999) [6], while using geothermal energy as a heat source was analyzed by Lu (2001) and Tamm et al. (2001) [7].
Typical working conditions of a 400 K boiler superheated to 410 K, and an ambient at 280 K yield a first law efficiency of 23.5% if work and cooling are added as the net output. In comparison, the equivalent Carnot efficiency is 31.7%. Conventional power cycles operating between the same temperatures have lower first law efficiencies than the proposed cycle, as no cooling output is included. At higher temperatures, however, their thermal efficiencies are better. The thermal efficiency is deceiving though, and the strength of this cycle lies rather in the heat source utilization. It exhibits much higher second law efficiencies than conventional power cycles at the same temperatures. For utilization of low temperature resources, the proposed cycle offers several advantages in comparison to other thermal energy conversion methods.

A substantial improvement in the performance of combined power and cooling cycles can be achieved by utilizing the waste heat from the exit of the back pressure turbine of Rankine based power plant and also by extracting a fraction of steam from the passout turbine to run Goswami cycle.

1.1 System description

A schematic of the combined power and cooling cycle (Goswami cycle) is shown in Fig.1 The relatively strong basic solution of ammonia-water leaves the absorber as saturated liquid at the cycle low pressure. It is pumped to the system high pressure and is preheated before entering the boiler by recovering heat from the weak solution returning to the absorber. As the boiler operatesbetween the bubble and dew point temperatures of the mixture at the system high pressure, partial boiling produces a high concentration saturated vapor and relatively low concentration saturated liquid. The liquid weak solution gives up heat in the recovery unit and throttles into the absorber. The rectifier condenses out water to further purify the vapor, by rejecting heat to a secondary strong solution stream, before entering the boiler.The vapor is superheated and expanded through the turbine to produce work. Due to the low boiling point of ammonia the vapor expands to low temperatures yielding the potential for refrigeration. The vapor is finally absorbed back into the liquid, giving off heat that is rejected as the cycle heat output. The main parameters that can be varied to influence the cycle are the heat source temperature, system high pressure, basic solution ammonia mass fraction, ratio of working and heating fluid flow rates, and absorber pressure and temperature. Rectifier and superheater temperatures can also be modified, and the conditions of heat transfer from the source to the ammonia-water mixture as well.

Referring to this figure, the ammonia-water strong solution is pumped from the absorber to a high pressure at state 2. At this point, the solution is split into two streams. One stream goes through a heat exchanger (state 2') to recover heat from the weak solution exiting from the boiler. The second stream goes to the rectifier (state 2") to cool the ammonia vapor exiting the boiler to condense the water vapor in it. The two streams are combined again (state 3) before entering the boiler. In the boiler, the mixture is heated to boil off ammonia vapor (state 4). In order to get high concentration ammonia vapor (state 6), the vapor goes through the rectifier to condense some water in it. The condensate is rich in water and returns to the boiler (state 5). The enriched ammonia vapor is then superheated in a superheater (state 7). After expansion in the turbine, ammonia vapor drops to a very low temperature (state 8). The low temperature ammonia vapor provides cooling by passing through the refrigeration heat exchanger (state 9). Ammonia vapor is then absorbed into the weak solution in the absorber to regenerate the ammonia-water strong solution (state1). Weak solution leaving the boiler (state 10) goes through a heat recovery heat exchanger (state 11) to transfer heat to the strong solution. After passing through a pressure-reducing valve (state 12), the weak solution returns to the absorber.

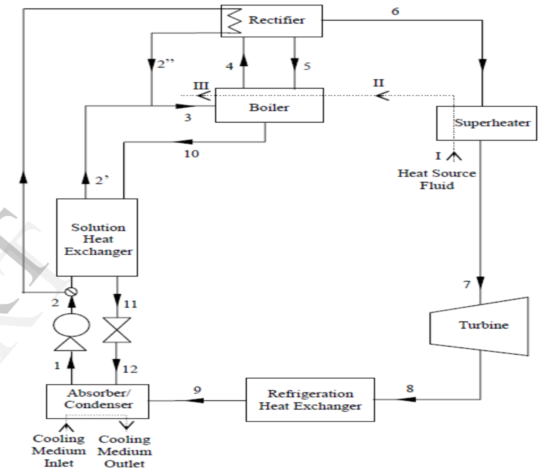

Fig. 1 Ammonia-Based Combined Power /Refrigeration Cycle

1.2 Nomenclature

COP = coefficient of performance
X = Dry-nessfraction
h = enthalpy (kJ/kg)
$\dot{m}$ = mass flow rate (kg/s)
P = pressure (kPa)
T = temperature (^{0}C)
S = entropy (kJ/kgK
w = the amount of steam extracted per second to run goswami cycle
w_s = flow rate of steam (kg/s) entering the turbine
Q_{in} = total heat input
W_R = work output from Rankine
W_G = work output from Goswami
Q_{cool} = refrigeration output from Goswami
$W_{equivalent}$ = equivalent work
η_T = efficiency of turbine
η_{th} = combined thermal efficiency
$W_{equivalent} = W_R + W_G + Q_{cool} / COP$

$Q_{in} = w_s(h_1 - h_7)$
$Q_H = w(h_2 - h_5)$

Energy balance at state 6 in fig 3.
$(w_s - w)h_4 + wh_5 = w_s h_6$
$W_R = w_s(h_1 - h_2) + (w_s - w)(h_2 - h_3)$
$\eta_{th} = \frac{W_{equivalent}}{Q_{in}}$

2. Research Method

Thermodynamic analysis of Rankine cycle using back pressure turbine

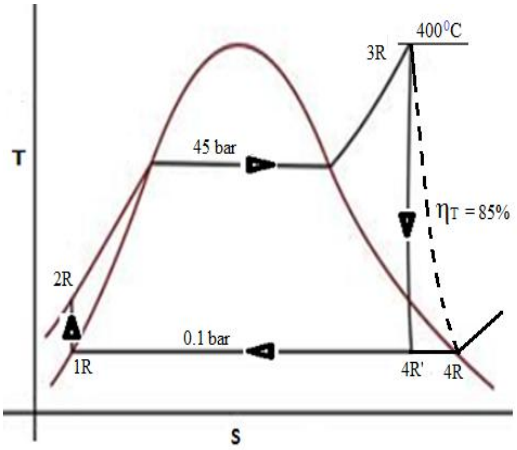

Fig 2. Thermodynamic analysis of rankine cycle operating between pressure range of 0.1bar to 45bar using back pressure turbine.

Table 1. Cycle Performance Parameter for Rankine Cycle using back pressure turbine.

State	Pressure P(bar)	Temperature T(°C)	Enthalpy h(kJ/kg)	Entropy S(kJ/kgK)	Mass flow rate $\dot{m}$ (kg/s)	SpecificVolume V(m^3/kg)	Dry-nessfraction (X)
1R	0.1	45.8	191.8	0.649	1	0.001010	0
2R	45		196.3	0.649	1	0.001010	0
3R	45	400	3200	6.7	1		0.81
4R	0.1	45.8	2290.5	7.2	1		0.88

Pressure range = 0.1 to 45 bar
Boiler temperature = 4000C
Exhaust steam temperature = 45.830C
Efficiency of turbine = 85%
Heat input = 3003kJ/s
Turbine work = 909.5kW
Pump work = 4.5kW
Net work = 905 kW
Heat rejected = 2098 kJ/s
Efficiency of cycle = 30%

Thermodynamic analysis of Rankine cycle using passout turbine

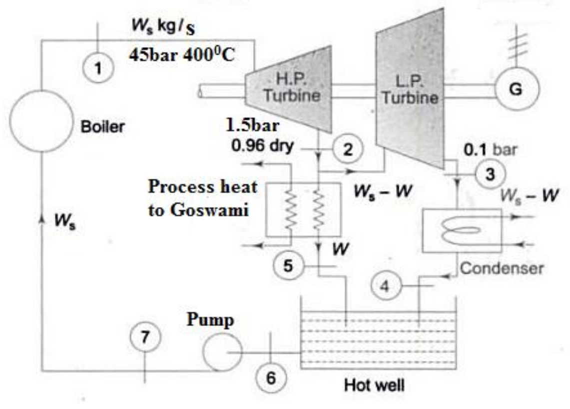

Fig 3.Rankine based power plant having a single stage extraction of steam at 1.5bar to run Goswami cycle

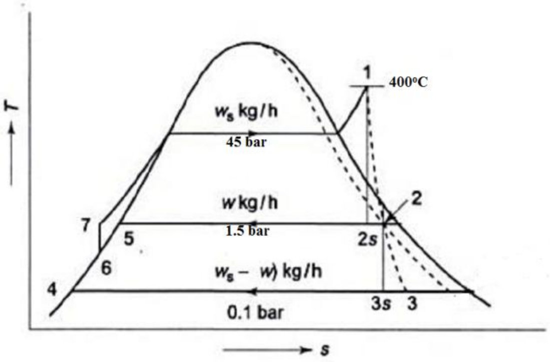

Fig 5.Thermodynamic analysis of Rankine cycle using passout turbine

Table 2.Cycle Performance Parameter for Rankine Cycle using passout turbine.

State	Pressure P(bar)	Temperature T(°C)	Enthalpy h(kJ/kg)	Entropy S(kJ/kgK)	Massflow rate(kg/s)	Dry-nessfraction(X)
1	45	400	3200	6.7	w_s=1	1
2s	1.5	111.4	2500	6.7	w_s=1	0.91
2	1.5	111.4	2605	7.0	w_s-w	0.96
3s	0.1	45.8	2220	7.0	w_s-w	x_{3s}
3	0.1	45.8	2277	7.2	w_s-w	x_3
4	0.1	45.8	191.8	0.649	w_s-w	0
5	1.5	111.4	467	1.433	w	0
6		T_6	h_6	s_6	w_s=1	0
7	45	T_7	h_7	s_7	w_s=1	0

Table 3.cycle performance parameter for condition in table 2.

SN	% of steam extracted	Total heat in Q_{in} (kJ/s)	Power out (rankine) W_R (kW)	Power out (goswami) W_G (kW)	Refrigeration (goswami)Q_{cool} (kW)	Equivalent Power out $W_{equivalent}$ (kW)	Efficiency (combined) η_{th}
1	0	3003	905.00	0	0	905.00	30.13
2	10	2980	890.00	16.23	13.87	920.10	30.87
3	20	2953	856.80	32.46	27.72	916.98	31.05
4	30	2925	824.00	49.23	42.12	915.35	31.30
5	40	2898	791.80	65.64	56.16	913.60	31.52
6	50	2870	758.60	81.87	70.20	910.67	31.73
7	60	2842	725.80	98.10	84.00	907.90	31.94
8	70	2814	693.00	114.33	97.77	905.10	32.16
9	80	2786	660.20	130.56	111.64	904.4	32.46
10	90	2760	627.40	147.70	126.40	901.50	32.66
11	100	2728	595.00	164.11	140.40	899.51	32.97

3. Result and Analysis

The analysis is done for a rankine cycle between a pressure range of 0.1bar to 45bar and superheat temperature of 400^{0}C. Using backpressure turbine steam whole mass of steam at 45bar pressure and 400^{0}C temperature is allowed to expand up to the lower pressure of 0.1bar. assuming turbine efficiency of 85% power output and the first law efficiency is calculated.

Now the backpressure turbine is replaced by passout turbine from which a fraction of steam at 1.5bar, 111^{0}C is extracted, which is used as a heating source for the combined power and cooling cycle. The simulation starts with extraction of 10% of total stem at 1.5bar and increasing it by 10% every time, until 100% steam is extracted at 1.5 bar and utilized by goswami cycle.

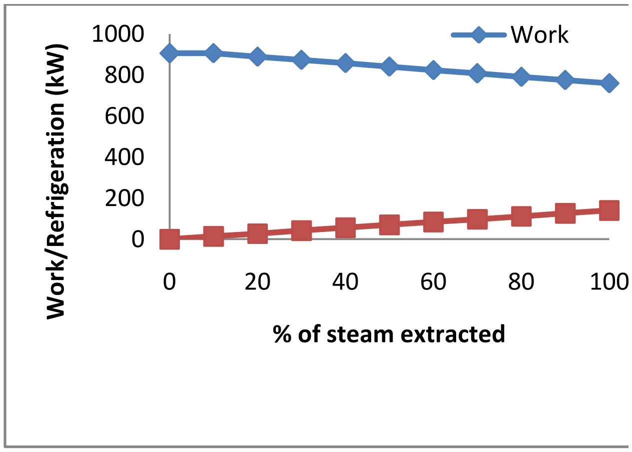

Fig 6. Optimum Work and Refrigeration Outputs at Different % of steam extracted

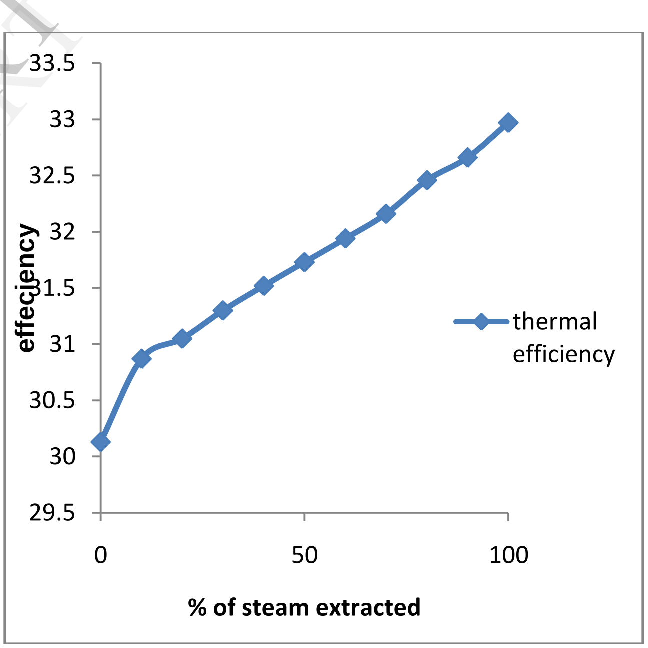

Fig 7. Optimum thermal efficiency at different mass of steam extracted from the turbine

4. Conclusions

A novel combined power/refrigeration cycle can effectively utilize low temperature steam from the exhaust of conventional power plant. For the same heat input overall efficiency of the combined system is improved in comparison to the conventional power plant because of the utilization of waste heat. When we extract a part of steam at 1.5 bar to run the Goswami cycle, net work output from the system decreases but on the other hand we get refrigeration effect and the overall thermal efficiency will increases. There is about 3% improvement in the efficiency of the combined system when whole mass of steam from the passout turbine is extracted at 1.5bar to run combined power/refrigeration cycle.

References

1. Kalina A. I., 1983, “Combined Cycle and Waste-Heat Recovery Power Systems Based on a Novel Thermodynamic Energy Cycle Utilizing Low-Temperature Heat for Power Generation,” ASME Paper 83-JPGC-GT-3.
2. El-Sayed Y. M., and Tribus M., 1985, “A Theoretical Comparison of the Rankine and Kalina Cycles,” ASME *Special Publication*, **1**, pp. 97-102.
3. Marston C. H., 1990, “A Family of Ammonia-Water Adjustable Proportion Fluid Mixture Cycles,” *Proceedings of the 25th Intersociety EnergyConversion Engineering Conference*, **2**, pp. 160-165.
4. Park Y. M., and Sonntag R. E., 1990, “A Preliminary Study of the Kalina Power Cycle in Connection with a Combined Cycle System,” *Int. J. of Energy Res.*, **14**, pp. 153-162.
5. Ibrahim O. M., and Klein S. A., 1996, “Absorption Power Cycles”, *Energy* (Oxford), **21**, pp. 21-27.
6. Xu, F., Goswami, D. Y., 1999, “Thermodynamic Properties of Ammonia Water Mixture for Use in Power Cycles,” *Energy* (Oxford), **24**, pp. 525-536.
7. Lu, S., Goswami, D. Y., 2001, “Optimization of a Novel Ammonia-Based Thermodynamic Cycle”.