LOW TEMPERATURE SOLAR THERMAL POWER GENERATION BASED ON KALINA CYCLE

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Abstract:

Recently, with decreasing oil resources and environmental issues associated to use of fossil fuels, solar thermal power plants have attracted much attention mainly due to zero emission and huge fuel savings they bring about .Efficient utilization of the low temperature heat is a challenge. Kalina cycle was proposed to exploit the opportunity of extracting this low grade energy as the conventional Rankine is very inefficient for low temperature applications. The Kalina cycle has recently seen increased interest as a replacement for the more traditional steam Rankine cycle for geothermal, solar, ocean thermal energy conversion and waste heat recovery applications. The Kalina cycle uses a mixture of ammonia and water as the working fluid. The ammonia-water mixture evaporates and condenses with a temperature glide, thus providing a better match with the heat source/sink temperature profile. This better match results in reduced thermal irreversibility, but at the cost of relatively larger heat exchanger areas. The parabolic trough collector is the most mature technology for the conversion of solar thermal energy into electricity. In this paper preliminary thermal design calculations are performed for a low temperature Kalina cycle based solar parabolic trough power plant with storage along with basic economic analysis.

1.INTRODUCTION

In today's world, with the increasing population, the energy demands are rising but the resources (fossil fuels) are limited and depleting drastically. It is only a matter of time we run out of the major fuels namely oil, gas, and coal. Therefore we need to switch to some other source of energy. The other forms of energy available to us are solar, geothermal, wind, etc. Out of these solar and geothermal forms a source of heat, but there is a problem with them that they are low grade source of heat and possess low quality.

Heat is itself a low grade form of energy. But low grade heat implies heat that is extracted from low- and mid- temperature sources that has less exergy density and cannot be converted efficiently to work. The main low-grade heat sources are from: Solar thermal, Geothermal, and industrial waste thermal. These days the focus is majorly on the benefits of capturing and utilising low grade thermal energy which are highly dependent on the qualities and properties of the heat in the waste streams. The temperature of the low grade heat stream is the most important parameter, as the effective use of the residual heat or efficiency of energy recovery from the low grade heat sources will mainly depend on the temperature difference between the source and a suitable sink.

2. KALINA CYCLE

Kalina cycle uses an ammonia-water mixture to get over the two main drawbacks of the conventional Rankine steam cycle :-

1.) At any given pressure, much of the heat has to be taken in at the temperature at which water boils.

2.) Secondly the waste heat in the steam, after it has done its work in the turbine, has to be rejected at one temperature.

One shot temperature changes are thermodynamically inefficient.They are the antithesis of Monsieur Carnot's dictum that there should be infinitesimal differences in temperature, in an energy conversion process,for achieving perfect heat engine conditions. Kalina gets over the boiling problem by using a solution of ammonia in water, which evaporates over a range of temperatures.

The exhaust pressure of the mixture turbine in the Kalina cycle is above atmospheric pressure .Hence no vacuum needs to be maintained in the condenser during operation, or stand-by periods. Therefore, the start-up procedure can be performed within a much shorter time. This is also beneficial with respect to steam turbine size and cost. Fig 1 demonstrates Kalina cycle on T-s (Temperature Entropy) diagram Kalina cycle has got lower average heat rejection temperature(T_c) and higher average heat addition temperature(T_b) compared to Rankine cycle. This leads to high thermal efficiency. Expansion in mixture turbine results nearly a saturated vapor at exit compared to wet steam in Rankine cycle, which requires protection of blades in the last few stages. Due to this reason,reheater is not essential for Kalina power turbine.

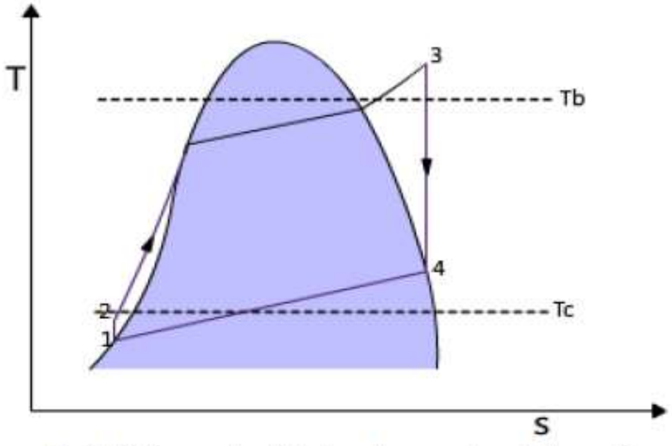

Fig 1. Kalina cycle plotted on Temperature Entropy diagram

Without any problems, ammonia can be used in thermal power installations in a mixture with water. It is cheap and readily available, has no corrosive effect on iron and its alloys, and is soluble in water in any concentration . Conventional axial flow steam turbines can be used in Kalina cycle plants. This is possible because the molecular weights of ammonia and water are at the same scale (ammonia 17 g/mol and water 18 g/mol).

3. Concentrated Solar Power (CSP) with storage

Concentrated solar thermal power (also called concentrating solar power and CSP) systems use mirrors to concentrate sunlight from a large area to a small area where it is absorbed and converted to heat at high temperatures. The high temperature heat is then used to drive a power block (usually a steam turbine connected to an electrical power generator) similar to the power block of a conventional thermal power plant. A major advantage of CSP plants over solar photovoltaic (PV) power plants is that CSP plants may be coupled with conventional fuels and can utilize thermal energy storage (TES) to overcome the intermittency of solar energy. TES systems can collect energy during sunshine hours and store it in order to shift its delivery to a later time or to smooth out plant output during cloudy weather conditions. Hence, the operation of a solar thermal power plant can be extended beyond periods of no solar radiation without the need to burn fossil fuels. . By extending the hours of usage of the power block beyond the sunshine hours a TES system can reduce the Levelized Cost of Energy (LCOE) for the plant.

CSP with thermal storage enhances the grid flexibility to accommodate infirm or intermittent power. The power which can be produced from the thermal storage capacity can be ramped up and down quickly and on demand. Therefore, depending upon variability of renewable power, CSP plant can minimise grid shocks .For a given a solar field size and the units of electricity required to be generated, the CSP plant with thermal storage can be configured differently based on the time of day and rate at which power is required

An indirect system with two tanks uses different fluids for heat-transfer and storage. The storage fluid from the low-temperature tank flows through an extra heat exchanger, where it is heated by the high-temperature heat-transfer fluid. The high-temperature storage fluid then flows back to the high-temperature storage tank. The fluid exits this heat exchanger at a low temperature and returns to the solar collector or receiver, where it is heated back to a high temperature. Storage fluid from the high-temperature tank is used to generate steam in the same manner as the two-tank direct system. The indirect system requires an extra heat exchanger, which increases system cost.

4. System Layout

The complete layout of system consists of two modules :-

1.) Solar plant module with indirect storage

2.) Kalina power cycle module

The working of solar plant with indirect storage (Fig 2) is as follows:-

1.) During sunshine hours the heat transfer fluid (HTF) is heated in the four parabolic trough shaped mirrors.

2.) Part of it goes to kalina power cycle module while remaining is used for heating the molten salt . Molten salt from the cold salt tank moves to hot salt tank after absorbing heat in the heat exchanger from heat transfer fluid (HTF).

3.) During night hours , the heat transfer fluid (HTF) can be heated in the heat exchanger by the reverse movement of molten salt from hot to cold tank.

The schematic flow diagram of the Kalina cycle with HTF (heat transfer fluid) as heat source coming from solar concentrating collectors is shown in Fig 3.The various steps of cycle are :-

STEP 1.:- The heat from the hot fluid (14) coming from solar plant module is recovered in the superheater and boiler.

STEP 2:- In separator (SEP) the working fluid is separated into rich ammonia water vapor (10) and weak liquid mixture (11).

STEP 3:- The rich ammonia water vapor's temperature is increased in the superheater (SH 10-1) before entering the inlet of the turbine (1).

STEP 4:- The vapor (1) is expanded in mixture turbine (MXT 1-2) to generate power and it is diluted with a weak solution (13) in mixer (MXR).The liquid weak solution coming from separator has been throttled (12–13) after rejecting heat (11–12) at high temperature regenerator and mixed with turbine exit fluid (2).

High concentration ammonia solution used at turbine inlet has very low condensation temperature. Mixing with weak solution increases the condensation temperature allowing use of ordinary temperature cooling water in condenser

STEP 5: -The mixture (3) again rejects heat (3–4) at low temperature regenerator and condenses to a saturated liquid state (5).

STEP 6:- The condensate is pumped to separator pressure (6) and heated in a low temperature regenerator (6–7) and high temperature regenerator (7–8).

STEP 7:- The preheated liquid mixture (8) is converted into liquid vapor mixture (9) in the evaporator of the boiler.

STEP 8 :- The saturated vapor (10) is again heated in a superheater before entering into the mixture turbine at state 1. This cycle repeats for continuous power generation.

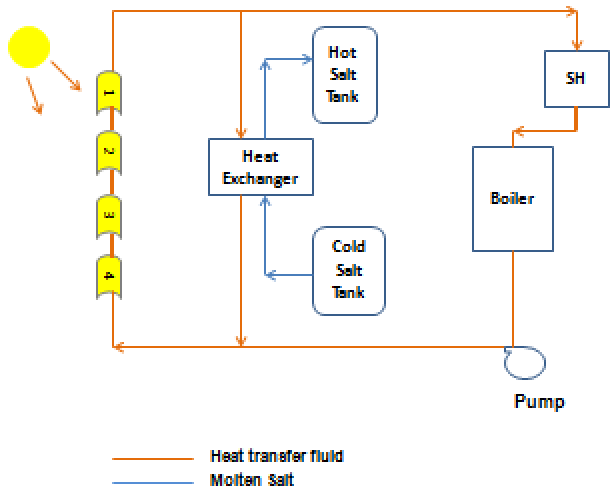

Fig 2: Solar plant module with indirect storage

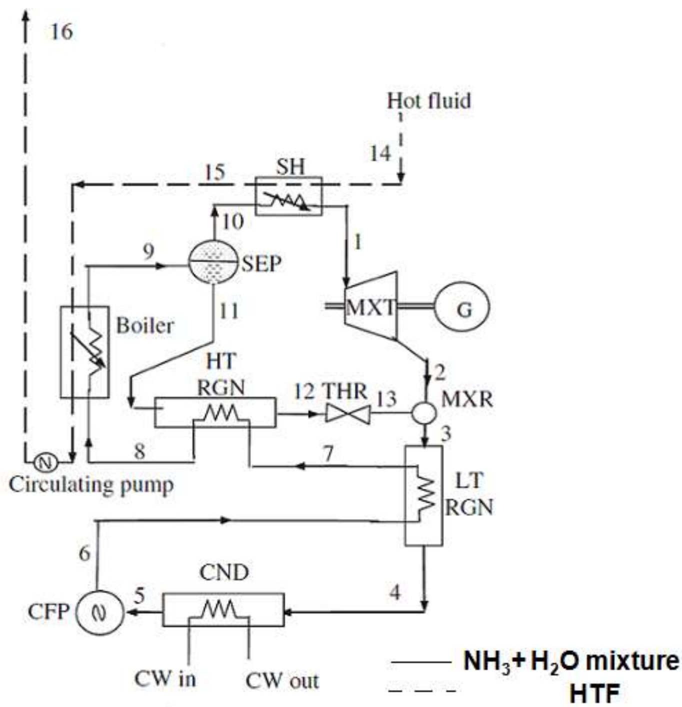

Fig 3. KALINA POWER CYCLE MODULE

5. TECHNICAL SPECIFCATIONS

a) Solar plant module

S.No	Component	Specifications
1.)	Solar parabolic Collectors	a) EUROTROUGH b) Dimensions = 150 * 100 m^2 (Standard Size). c) Four such modules are installed in series.
2.)	Heat transfer Fluid (HTF)	a) Therminol VP-1 b) Composition : Diphenyl Ether= 73.5% , Biphenyl = 26.5%
3.)	Molten salt	Mixture of inorganic nitrate salts such as $NaNO_3$, KNO_3, $LiNO_3$, and $Ca(NO_3)_2$.

b) Inlet Temp of HTF in Solar Field = 30 ° C (ambient temperature) , Outlet Temp of HTF from Solar Field =150 ° C (120 ° C heat jump)

c) Assuming plant established in belt with Direct Normal Irradiance (DNI) = 5 kwh /m^2 /day = 208 W/ m^2.

Total Solar Power on proposed Area= 208*150*100*4 = 9984 KW

e) Kalina cycle based concentrated solar plant energy efficiency = 11% (as per reference [4])

f) Solar electricity generated = 0.11*9984 ≈ 1 MW

6. Financial analysis

As per CERC benchmark capital cost of Solar Thermal power projects is INR 12.0 Crore / MW for 2016-17. For Solar Thermal power projects, levellised tariff is Rs.12.05 / unit,

a) Annual Electricity production = 1MW * 24hrs * 310 days =7440 MWh (assuming remaining days are cloudy)

b) Annual Coal saving (Ton) =7440 * 1000 * 0.69/1000 = 5133 Ton (Specific coal consumption = 0.69 Kg / KWh)

c) Cost of coal per Ton = Rs 2850 (for load centered plants)

d) Annual financial savings due to coal = 2850 * 5133 = 146 Lakhs approx

e) Tariff revenue from Electricity at rate of 12 Rs/KWh =12 * 7440 * 1000

= 893 lakhs

f) Net annual financial gains = Tariff revenue + coal savings

=146+893 = 1039 lakhs

g) CO_2 production saving=5133 *2.86=14,680 tons/year

7. CONCLUSION

Concentrated solar power (CSP) is expected to play an important part in future energy infrastructure .Kalina cycle based CSP plants with thermal energy storage can provide higher efficiency , power during night hours & better grid integration .They will also play a major role in reducing coal consumption and green house gas production . Low temperature solar thermal plants owing to their lower running costs and almost maintenance free operation although operating at lower efficiencies may hold a key to future wider usage of solar energy The International Energy Agency projects that with proper support, CSP could provide 11.3% of the total world electricity production by 2050 . At present, most CSP projects still rely on subsidies, but with further improvements in system and component design future CSP plants may be able to compete with fossil fuel based energy sources .

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