POWER GENERATION BASED ON WASTE HEAT RECOVERY

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Abstract - *Production of electricity from low or moderate temperatures is very difficult. To make it possible we need modern techniques. In every industry, power plants and process plants lot of low grade energy is wasted into the atmosphere. To recover this low grade energy, we propose Kalina cycle as a modern tool of thermodynamics. This Kalina cycle consists of multi component fluids as thermodynamic working fluid. Most of the heat is wasted near the boiler of the steam power plant, or at the flue gases coming out from chimney or stack. Using Kalina cycle we perform heat recovery task quite easily. Kalina cycle uses Ammonia and Water as working fluid. Using Aspen plus simulation tool the simulation work was performed and a reliable result was obtained. The Heat recovery from flue gases coming out from chimney of any industry may be studied using Aspen plus. Composition of Ammonia and Water mixture was varied from 0.5 to 0.9 mass fraction of Ammonia. Flow rate of hot gases is kept constant, assuming that there is constant burning of fuel in the boiler. Power generated in this process was tabulated and efficiency of the process is also calculated.*

Key Words: Kalina Cycle, Flue gas, Heat Recovery, Power

1. INTRODUCTION

The energy demand in the world is expected to increase continuously. In order to minimize the negative environmental impact from utilizing energy resources, more efficient energy conversion processes are necessary. The electrical power demand is also expected to be very high in future. It is therefore a great interest to be taken to improve the efficiency of power generating processes and power plants. This can also be very good from for the national economic point of view. There are many possible ways in which these improvements can be achieved [4]. Kalina cycle was first developed by Alexandr I. Kalina [1] in the late 1970's and early 1980's. Based on this, several Kalina cycle have been proposed for differentapplications. Kalina cycle uses a working fluid comprised of at least two different components, typically Water and Ammonia. The ratio between those components varies in different section or parts of system to decrease thermodynamic irreversibility and thereby to increase the overall thermodynamic efficiency [1]. In thermodynamics, the Carnot cycle has been described as being the most efficient thermal cycle possible, wherein there are no heat losses, and consisting of four reversible processes, two isothermal and two adiabatic processes. But In a Carnot engine heat addition and rejection happen at uniform temperature.

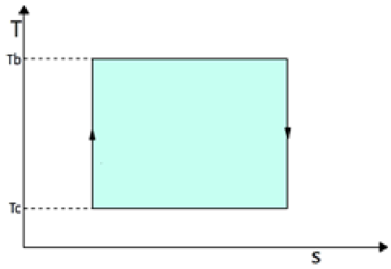

Fig.1 Carnot cycle

1.1 Ammonia-water power cycle principle

The ammonia and water mixture is non-azeotropic. The characteristic for non-azeotropic mixtures is that the composition and temperature changes during boiling at all possible compositions of the mixture. When the mixture starts boiling, a separation of the components takes place. The vapour is richer in ammonia fraction than the liquid. The starting point for the boiling is called the bubble point and the end point is called the dew point. The bubble point temperature for a mixture with a mass fraction of ammonia of 0.5 at a pressure of 11 MPa is 204 °C. During the boiling the temperature of the mixture increases as the composition changes. When the temperature of the boiling mixture has reached 230°C, the mass fraction of ammonia in the liquid phase is 0.37, while in vapour phase it is 0.70.

1.2 Comparison between Kalina cycle, Rankine cycle and ORC

The Kalina cycle is principally a "modified" Rankine cycle. These special designs, either applied individually or integrated together in a number of different combinations, comprise a family of unique Kalina cycle system. In theory, the Kalina cycle can help to convert approximately 45% of direct-fired system's heat input to electricity and up to 52% for a combined-cycle plant. Moreover, Kalina cycle can give up to 32% more power in the industrial waste heat application compared to a conventional Rankine steam cycle. However, the Kalina cycle in small direct-fired biomass fuelled cogeneration plant do not show better performance than a conventional Rankine steam cycle. When both cycle are used together in a same power generation system with same thermal boundary conditions, it can be found that when the heat source is 1100 ^{0}F (537^{0}C), Kalina cycle shows 10-20% higher second law efficiency than the simple Rankine cycle [14].

2. Literature Review

A. Kalina, H. Leibowitz [1], aims at a very large increase of the efficiency while keeping costs basically at the same level of other applications. Author suggested that, for the better performance of the cycle ammonia mass fraction in the cycle varies from 0.7 to 0.9 with mass flow rate of 25kg/s, and inlet pressure to the turbine should be between 25bar to 40 bar with outlet pressure to the turbine as 7-10 bar. It should also be mentioned that the use of a water ammonia mixture allows the total flow of the fluid to remain within reasonable limits.

Carlos Eymel Campos Rodríguez .et.al [3] deals with the thermodynamic analysis, of first and second law of thermodynamic of two different technologies, (ORC and Kalina cycle) for power production through an enhanced geothermal system (EGS). In order to determine the performance of both thermal cycles, he evaluated 15 different working fluids for ORC and three different composition of ammonia-water mixture for the Kalina cycle. For this purpose, the Aspen-HYSYS software is used by the author to simulate both thermal cycles and they calculated thermodynamic properties of organic and ammonia-water solution based on Penge-Robinson Stryjeke-Vera (PRSV) Equation of State (EoS).

Isam H. Aljundi [6] studied, the energy and Exergy analysis of Al-Hussein power plant in Jordan. His primary objectives was to analyse the system components separately and to identify and quantify the sites having largest energy and Exergy losses. In addition, the effect of variation of environmental conditions, on this analysis will also be represented. The performance of the plant is estimated by a component wise modeling and a detailed study of energy and Exergy losses for the considered plant has been presented.

Jiangfeng Wang et.al [7] studied the solar-driven Kalina cycle to utilize solar energy effectively using ammonia-water, due to its varied temperature vaporizing characteristic. In order to ensure a continuous and stable operation for the system, a thermal storage system is introduced to store the collected solar energy and provide stable power when solar radiation is insufficient. A mathematical model was developed for the simulation of the solar-driven Kalina cycle under steady-state conditions and also a modified system efficiency were defined to evaluate the system performance over a period of time. He found the results that indicate, there exists an optimal turbine inlet pressure under given conditions to maximize the net power output and the modified system efficiency. The optimized modified system efficiency is 8.54% under the given conditions. The Kalina cycle, which utilizes ammonia-water as its working fluid, was originally proposed by Alexander Kalina in 1983.

Mark D. Mirolli [10], suggested that, cement production consumes large quantity of heat, for kiln, calcination and drying process. Also lot of energy is consumed by the electrical motors for grinding, fans, conveyers and other motor driven processes. By assembling the Kalina cycle which utilizes the waste heat from the various parts of the cement production process, it is possible to generate electricity without consuming fuel. This reduces the cost of cement production. Author noticed that, thermal efficiency using Kalina cycle improves 20-40%, in comparison with the conventional hot gas power plant. Kalina cycle power plant is more environment friendly than any other power generation plant because of utilization of ammonia-water as working fluid.

Omendra kumar singh, S.C. kaushik [11], did a computer simulation of a Kalina cycle coupled with a coal fired steam power plant with the aim of examining the possibility of exploiting low-temperature heat of exhaust gases for conversion into electricity. They described the numerical model, to find the optimum operating conditions for the Kalina cycle. The effect of key parameters namely ammonia mass fraction in the mixture and ammonia turbine inlet pressure on the cycle performance has been investigated. Results indicate that, for a given turbine inlet pressure, there is an optimum value of ammonia fraction that yields the maximum cycle efficiency.

3. PROCESS DESCRIPTION AND SIMULATION

3.1 Simulation of Kalina cycle using Aspen plus

In industry complicated problems are often not solved by hand for two reasons: human error and time constraints. There are many different simulation programs used in industry depending on the field, application and desired simulation products. When used to its full capabilities, Aspen can be a very powerful tool for a Chemical Engineer in a variety of fields including oil and gas production, refining, chemical processing, environmental studies and power generation etc. Kalina cycle can also be simulated through Aspen plus. As we all know that Aspen provides a very handy tools for simulation. Aspen considered all the real and ideal method in the property tab which provides a reliable result of simulation. This result may be treated as a result found by direct experiment in the laboratory. Flow sheet of Kalina cycle is drown in the Aspen plus using the equipment available with Aspen plus. No equipment entry is taken from outside of Aspen for the simulation purpose.

3.2 Beginning of simulation

Step-1, Aspen program started in the computer by clicking on the Aspen plus user interface.

Step-2, what type of simulation is to be performed, that is chosen from the simulation menu. For my purpose, general simulation with English unit is chosen. There are 26 different options of simulation with Aspen plus is available.

Step-3, by clicking on OK button, Aspen redirect to another page. On this page we can create our flow sheet as per our requirement.

3.2 The process flow sheet

A piece of equipment is selected from the equipment model library by clicking once on the flow sheet window, we can place this equipment where it is required. By following the same procedure for each piece of equipment, we can add as many numbers of equipment's as we require. After placing the equipment's at it proper place, equipment's are connected with the suitable material stream. Aspens has a feature that indicates the required stream and optional stream for the equipment's. Aspen also has feature to rotate, resize, and rename the equipment's and streams.

3.3 Data Input

All of the data input for Aspen is entered in the Data Browser window. This window can be opened by clicking on the eyeglass icon or by going to Data/Data Browser in the Menu Bar. Aspen has two features in the Data Browser window that can both help and hurt the user. The first of these can be seen on the right hand side. Aspen highlights the areas where the input has been completed and has not been completed with the use of either a blue check mark or a half filled red circle. However, it is not always necessary that all the required input are entered, especially if we are simulating a more complex problem. This feature will only track the minimal data input required to run a simulation. If one required data is entered, by clicking the blue N button to go to the next required inputs. When all the required inputs are completed, in the right most bottoms it is indicated by "Required inputs completes".

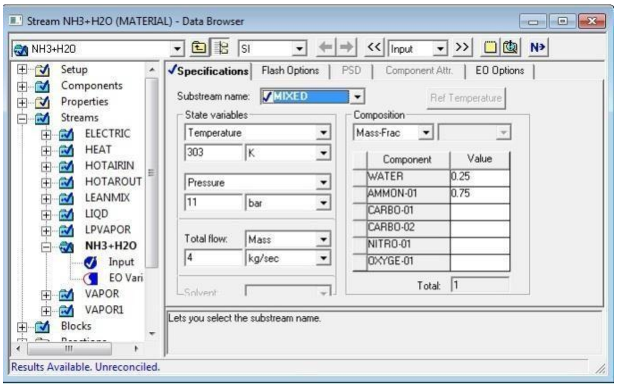

Fig.2 NH3+H2O data input

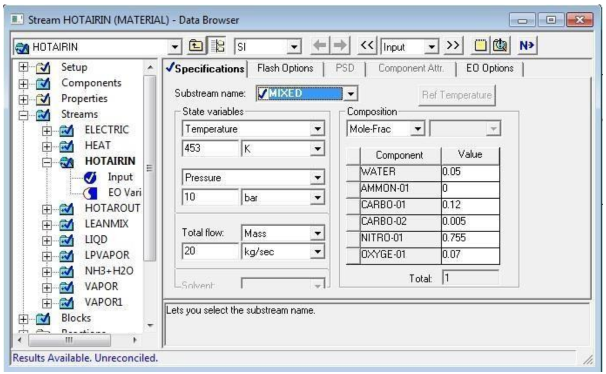

Fig.3 Hot air data input

3.4 The process flow sheet Description

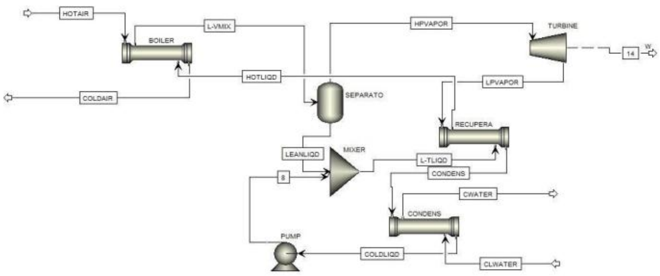

Fig.4 Kalina cycle flow sheet in Aspen plus

Hot exhaust gases coming out from the industry is passed through a heat exchanger in order to exchange heat with ammonia-water mixture flowing in the same heat exchanger in the shell side. Hot flue gases are flowing in the tube side. Because the vapour holdup of shell side is much higher than the tube side. That's why ammonia-water mixture is allowed to pass through shell side. If the liquid flows in the tube side, the possible vapour generation will create difficulty in flow. After heat exchange ammonia-water, liquid-vapour mixture passes through a separator, where vapour and liquid get separated into their respective streams (vapour and liquid stream). From the top of the separator vapour comes out as top stream and bottom releases liquid which is a lean ammonia-water mixture. Top stream or vapour stream which is high pressure and high temperature vapour, is feed into the turbine, where its enthalpy is utilised to generate electricity.

4. RESULT AND GRAPHS

When all the data are entered into the corresponding data space in the Aspen plus. The software indicates all the required input is complete. That means we can run our simulation by clicking the N button. After completion of calculation, the software indicates the completion of given process through indication of results. Result corresponding to the stream and block can be obtained by clicking the on stream or block.

Input data		
Flow rate of hot air	25 Kg/s	
Composition in Mass %	H_2O	0.05
	CO_2	0.12
	CO	0.005
	N_2	0.755
	O_2	0.07
Temperature	463 K	
Pressure	12 bar	

Table1. Hot air composition and condition

5. CONCLUSIONS

Based on the data input from a power plant as reported earlier using a Kalina cycle for waste heat recovery at low temperature condition using Ammonia-Water system. It is concluded that the process generates substantial amount of energy for improving the thermal efficiency of the given power plant. Aspen was said to be a very powerful tool (software) to simulate the result and arrive at a satisfactory result. It is also suggested that, the process can also be extended to other energy intensive industries like cement, steel and glass etc. To find an economical solution to the excessive power consumption through application of Kalina cycle by way recovering energy from waste stream.

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