USE OF MULTICOMPONENT FLUID FOR WASTE HEAT RECOVERY USING KALINA CYCLE

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FOR THE DEGREE OF BACHELOR OF TECHNOLOGY

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BY

KAUSHAL NATH
ROLL NO. 110CH0601

UNDER THE GUIDANCE
OF

PROF. P. RATH

DEPARTMENT OF CHEMICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA
ORISSA -769 008, INDIA 2013

CERTIFICATE

This is to certify that the thesis entitled "**use of multicomponent fluids for waste heat recovery using Kalina cycle"** being submitted by **Kaushal Nath (110ch0601)** as an academic project in the department of chemical engineering, national institute of technology, Rourkela is a record of bonafide work carried out by him under my guidance and supervision.

Prof. P. Rath
Department of Chemical Engineering
National Institute of Technology
Rourkela - 769008
India

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KAUSHAL NATH

110CH0601

Abstract

Heat recovery from moderate temperature heat source and convert into electricity is very difficult task. In order to make this task possible, we must go for some modern method, conventional method will not work in this case. In an industrial scale large amount of moderate temperature heat is simply wasted. To recover waste heat, researcher come-up with the idea of use of multicomponent fluid as working fluid, rather than conventional single fluid. Various thermodynamic cycle such as the "Organic Rankine cycle, Super critical Rankine cycle, Kalina cycle, Goswami cycle, and Trilateral flash cycle" have been proposed and studied for the conversion of low grade heat source into electricity. In this context we are trying to recover some waste heat coming out from the industry. Most of the heat is wasted around the boiler of the steam power plant, or around the exothermic reactor, or through 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 this task can be perform and a reliable result would be obtained. For this case it is proposed to use only the equipment available in the Aspen simulation engine. Heat recovery from flue gases coming out from chimney of any industry will be studied using Aspen plus. Composition of Ammonia and Water mixture will be 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 is listed in the table, at various input pressure to the turbine. Efficiency of the process is calculated and listed in a table.

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CHAPTER 1

Introduction

1.1 What is Kalina Cycle?

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 increase. It is therefore of great interest to improve the efficiency of power generating processes, i.e. converting more of the energy in the heat source to power. This can also be favourable from an 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. Since then, several Kalina cycle have been proposed based on different application. Kalina cycle uses a working fluid comprised of at least two different component, typically Water and Ammonia. The ratio between those components varies in different section or parts of system to decrease thermodynamic irreversibility and therefore 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. In a Carnot engine heat addition and rejection happen at uniform temperature.

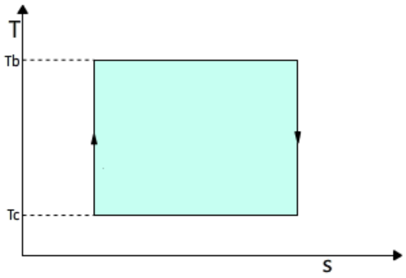


Fig.1 Carnot cycle

Efficiency of such an engine can easily be calculated as

$$\text{Efficiency } \eta = 1 - \frac{Tc}{Tb}$$

The century-old Rankine cycle which uses water as working fluid is the real-world approach to the Carnot cycle, and it has been widely used to generate electrical power throughout the world. In various novel thermodynamic cycles, the Kalina cycle is the most significant improvement in thermal power plant design since the advent of the Rankine cycle in the mid 1800’s and it has been considered as an ambitious competitor against the Organic Rankine cycle. Kalina cycle is basically a modified Rankine cycle. The modification that completes the transformation of cycle from Rankine to Kalina consists of proprietary system design that specially exploit the virtues of the ammonia-water working fluid.

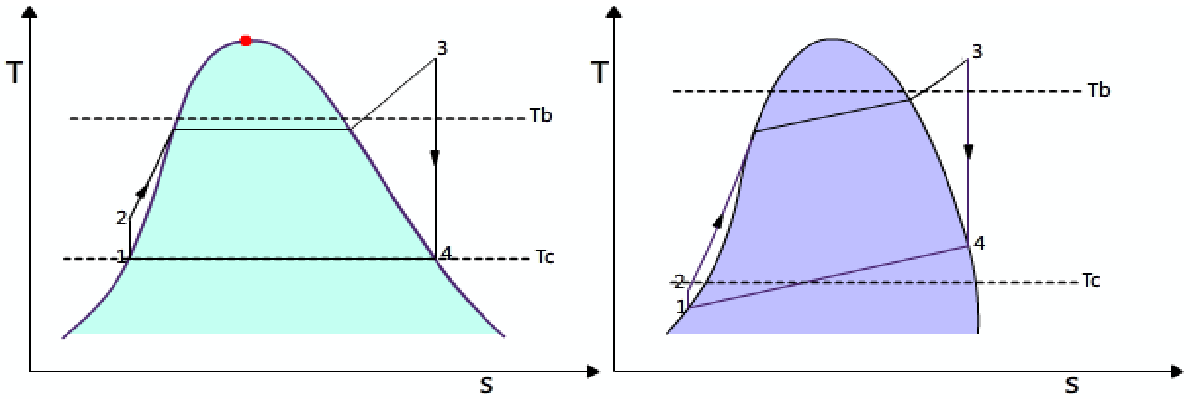


Fig.2 **Rankine cycle** **Kalina cycle**

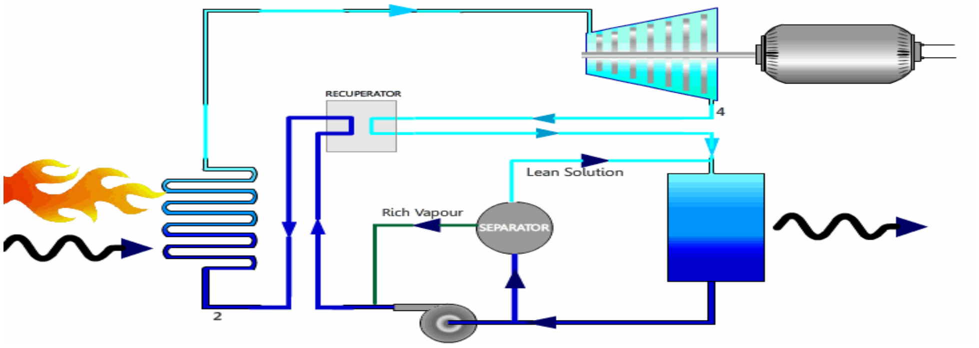
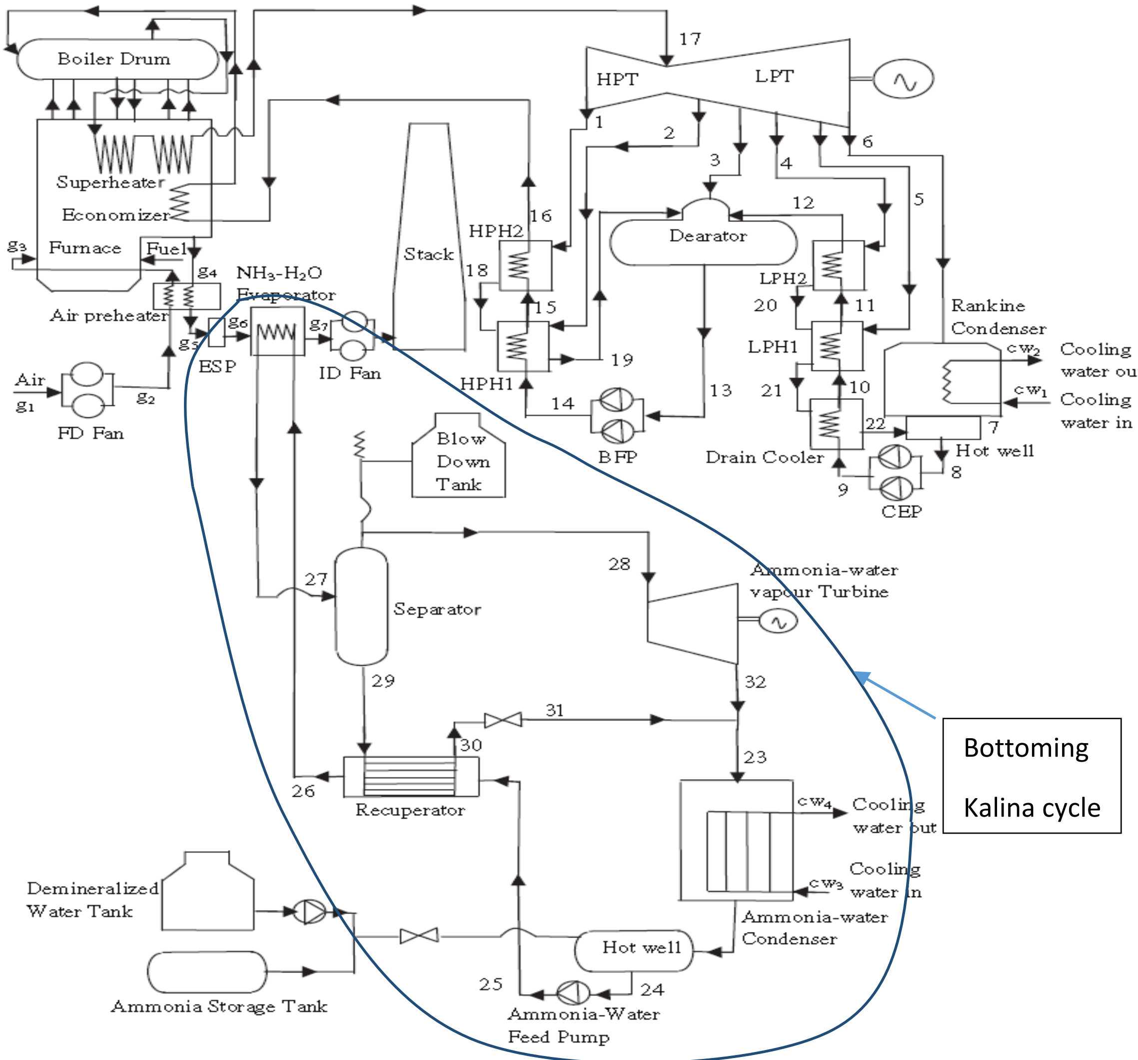


Fig.3 Basic configuration of Kalina cycle Fig. 1, 2&3 are taken from the web page

http://www.learnengineering.org/2013/01/kalina-cycle-power-plant.html

All simulated Kalina cycle configurations generated more power than the steam cycle, except for one simple Kalina cycle configuration compared with a dual-pressure steam cycle. The best Kalina bottoming cycle could generate 40-50% more power than single pressure steam cycle and 20-24% more power than a dual-pressure steam cycle. The adoption of the Kalina cycle to certain heat source and a certain cooling fluid sink has one degree of freedom more than the Organic Rankine cycle, as ammonia-water composition can be adjusted as well as the system high and low pressure levels.[14]

In order to obtain high thermodynamic performance, Kalina cycle requires a very high maximum pressure. Taking temperature range into consideration, a combination of high heat transfer efficiency of the heat source and the low heat losses to the heat sink gives the Kalina cycle much higher overall efficiency. Typical Kalina cycle coupled with Rankine cycle in a coal fired power plant is shown in fig.4.



Bottoming

Kalina cycle

. Kalina cycle system 11 (KCS11) coupled with a coal fired steam power plant.

Fig.4 Rankine cycle coupled with Kalina cycle.(figure is taken from Omendra Kumar Singh, S.C. Kaushik 2013) [11]

1.2 Different Kalina cycle and its uses

The prototype of the Kalina cycle was proposed in early 1980s. The cycle published in1984 was later designated as Kalina Cycle System1 (KCS1).In order to attain a significant improvement in matching of the working fluid and the heat- source heat-temperature curves in the boiler ,a new, improved variant which provides a 10% efficiency improvement over the initial KCS1, has been developed and was designated as KCS6. KCS1 would be preferable for small units (below 20MW total output; about an 8MW bottoming cycle), while the more complicated KCS6 would be preferable for larger units [5]. Generally speaking, each Kalina

Cycle System in the family of designs has a specific application and is identified by a unique system number. KCS 6, intended as the bottoming cycle for a gas turbine based combined cycle, provides the highest efficiency of all the Kalina cycles.

KCS 5 is particularly applicable to direct (fuel) fired plants. KCS 5n is similar to KCS 5, except the water loop has been removed. Because the incoming gases are not at as high temperature as in a combustion system, there is not as much heat available at the high end of the system. As in KSC 5, the hot gases are used primarily for superheating and not for boiling. KCS 2 is intended for the applications where the sources are generally below 375 ^{0}F [12].

One of the most important applications of the Kalina cycle is power generation from low temperature geothermal energy. Kalina cycle geothermal plants offer significant efficiency, cost, safety and environmental advantages over geo- thermal binary power plants using Organic Rankine Cycle (ORC) technology. A Kalina plant generates 30 to 50% more power than an ORC plant. There are many different Kalina system designs for geothermal applications. .KCS11 is most applicable for geothermal temperatures from about 250 to 400 ^{0}F [9].

1.3 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. The boiling process for an ammonia-water mixture is shown in Fig.6. 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. As can be seen in Fig.9, the difference in mass fraction of ammonia between the coexisting liquid and vapour is large. At the dew point, the mixture is completely vaporized and the mass fraction of ammonia in the vapour is 0.5. By changing the composition of the working fluid throughout the cycle a more efficient internal heat exchange can be achieved. Introducing one or more separators in the cycle accomplishes this. The new aspect in the cycle design presented by Dr. Kalina in [1] was this ability to change the composition of the working fluid in order to achieve better internal heat exchange. In this thesis the term Kalina cycle is used for ammonia-water power cycles presented by Dr. Kalina. Fig.3 shows the configuration of the simplest possible Kalina cycle. The working fluid is vaporized and superheated in the vapour generator and then expanded through the turbine. The stream from the turbine is cooled in the recuperator and the heat is used to partly vaporize the stream to the separator. After the recuperator the working mixture is mixed with the ammonia lean liquid from the separator. The resulting stream, called the basic mixture, is condensed in the absorber. By lowering the mass fraction of ammonia of the working fluid before the absorber the turbine can be expanded to a lower pressure. This results from the fact that a mixture with low mass fraction of ammonia has a lower condensing pressure than a mixture with high mass fraction of ammonia. After the absorber the basic mixture is pressurized and then the working mixture is condensed before it enters the vapour generator [4].

1.4 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 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 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].

Jonsson & Yan [8] have studied the differences between Kalina-type bottoming cycle configuration designed for different types of gas engines and gas diesel engines. One of their key focuses was to demonstrate the potential of the Kalina cycle to produce more power than the Rankine cycle as an engine bottoming cycle.

Both Bombarda et al. [2] and Valdimarsson [13] have compared the Kalina cycles and ORC. Isopentane is used as the working fluid for ORC. A saturated vapour of ammonia-water mixture Kalina cycle is used. As a result, the maximum power generated for a given source is greater for the Kalina cycle. The Kalina is better than the ORC when the heat source stream has finite heat capacity, but similar when the source is condensing steam (constant temperature).

Bombarda et al.[2] compared the thermodynamic performance of the Kalina cycle and ORC (hexa-methyl-disiloxane as working fluid) in the case of heat recovery from two Wärtsilä 20V32 8.9 MW diesel engines with exhaust gas mass flow of 35 kg/s for both engines, at 346ºC. In order to facilitate the comparison, only the heat recovery from the exhaust gases was considered. An almost equal net electric power of 1615 kW (with a cycle efficiency of 19.7 %) and of 1603 kW (with cycle efficiency of 21.5 %) for the Kalina and ORC cycles was calculated, respectively. In this case, the Kalina cycle requires a very high maximum pressure in order to obtain high thermodynamic performances: 100 bar against the about 10 bar of the ORC cycle. The turbine design also favours the ORC cycle, as the isentropic enthalpy drop is definitely higher for the Kalina (575 kJ) than for the ORC (92 kJ). For the Kalina cycle, the required turbine rotational speed is very high (> 60000 rpm) thus requiring a gear box, and therefore adding gearbox losses. The use of the Kalina cycle for medium and high temperature thermal sources seems unjustified because there is no gain in performance. Instead, a complicated plant scheme comprising of large surface heat exchangers and corrosion resistant materials, such as titanium in the turbine, results.

Chapter 2

Literature review

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 modelling and a detailed study of energy and exergy losses for the considered plant has been presented. In his study he found that Energy losses mainly occurred in the condenser of 134MW is lost to the environment while only 13 MW is lost from the boiler system. The percentage ratio of the exergy destruction to the total exergy destruction is found to be maximum in the boiler system (77%) followed by the turbine (13%), and then the forced draft fan condenser (9%). The thermal efficiency is calculated based on the lower heating value of fuel i.e 26% while the exergy efficiency of the power cycle is 25%. For the change in the environmental conditions like pressure and temperature no effect was noticed on the performance of major components. The boiler is the major source of irreversibility in the power plant.

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 indicates, there exists an optimal turbine inlet pressure under given conditions to maximize the net power output and the modified system efficiency. Turbine inlet temperature does not affect the net power output and the modified system efficiency. An optimum conditions for ammonia fraction in the liquid mixture can be identified that yields maximum net power output and 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.

In his paper, 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). Two cycle is compared for economic analysis with the fluid that offers the best performance for each thermal cycle which are R-290 for ORC and for Kalina cycle a composition of the mixture of 84% of ammonia mass fraction and 16% of water mass fraction. For this conditions the Kalina cycle produce 18% more net power than the ORC. A levelized electricity costs (LCOE) of 0.22€/kWh is reached for ORC and 0.18 €/kWh for Kalina cycle.

A. Kalina, H. Leibowitz[1]**,** aims at a very large increase of the efficiency while keeping costs basically at the same level of other geothermal 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 25 bar 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 (typically in the 100 to 200 KJ/Kg/s of working fluid) limiting the pumping parasitic, with beneficial effects on the total net efficiency. Another interesting feature of Kalina cycle is the total absence of vacuum sections which results in high power density in terms of kW of production per Kg/s of working fluid. Similar cycle have a power density less than 70kW/Kg/s but in case of Kalina cycle it is 100-200 kW/Kg/s noticed.

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. Increasing the turbine inlet pressure, increases the maximum cycle efficiency further corresponding to a much richer ammonia-water mixture. With a moderate pressure of 4000 kPa at ammonia turbine inlet and an ammonia fraction of 0.8, when the exhaust gas temperature is reduced from existing 407.3 K to 363.15 K, the bottoming cycle efficiency reaches a maximum value of 12.95% and a net bottoming cycle output of 605.48 kW is obtained thereby increasing the overall energy efficiency of the plant by 0.277% and the overall exergy efficiency by 0.255%.

In the study of waste heat recovery from the cement kiln, 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. Both these component is desirable for the trees to grow healthy. During the process if some leaks occur in the system then this leak does not create any potential hazard. Heat is recovered mainly from the kiln and calcination process. Heat recovery typically depends on, flow rate of exhaust gases and it’s temperature. For 3000 ton/day of kiln operation, expected power generation is ranges from 6-9MW.

Chapter 3

Flow sheet and process description

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 (entire process unit, one piece of equipment, etc.). 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. Because the Kalina cycle power plant exist in reality, coupled with steam power plant, or in other words it exist coupled with Rankine cycle in the same power generation system. It is not economical to fabricate the Kalina system at laboratory scale. 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.

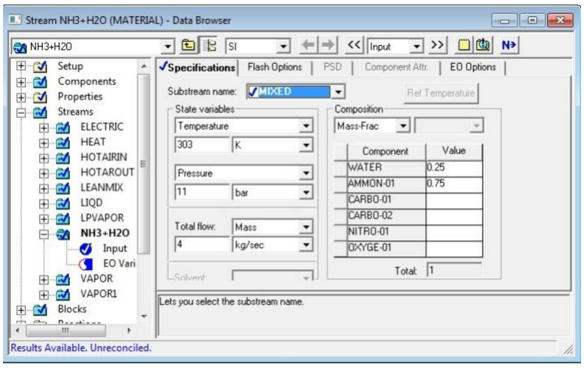
3.2 The process flow sheet

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 require. By following the same procedure for each piece of equipment, we can add as many numbers of equipments as we require. After placing the equipments at it proper place, equipments are connected with the suitable material stream. Aspens has a feature that indicates the required stream and optional stream for the equipments (required stream with red arrow and optional stream with blue arrow). Aspen also has feature to rotate, resize, and rename the equipments and streams.

3.4 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 and may cause problems in getting simulations to converge successfully. 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 bottom it is indicated by “Required inputs completes”.

Data entry for the Ammonia-water is shown in Fig.5


Stream NH3+H2O (MATERIAL) - Data Browser

Substream name: MIXED

State variables

Temperature: 303 K

Pressure: 11 bar

Total flow: Mass 4 kg/sec

Composition: Mass-Frac

Component	Value
WATER	0.25
AMMON-01	0.75
CARBO-01	
CARBO-02	
NITRO-01	
OXYGE-01	

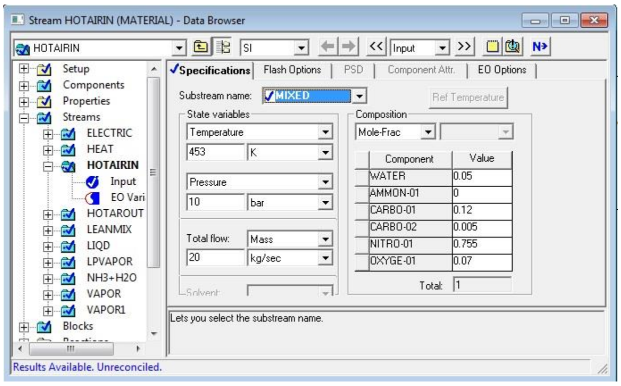
Total: 1

Lets you select the substream name.

Results Available. Unreconciled.

Fig.5 NH_3+H_2O data input

Data entry for the hot air and its composition is shown in Fig. 6


Stream HOTAIRIN (MATERIAL) - Data Browser

Substream name: MIXED

State variables

Temperature: 453 K

Pressure: 10 bar

Total flow: Mass 20 kg/sec

Composition: Mole-Frac

Component	Value
WATER	0.05
AMMON-01	0
CARBO-01	0.12
CARBO-02	0.005
NITRO-01	0.755
OXYGE-01	0.07

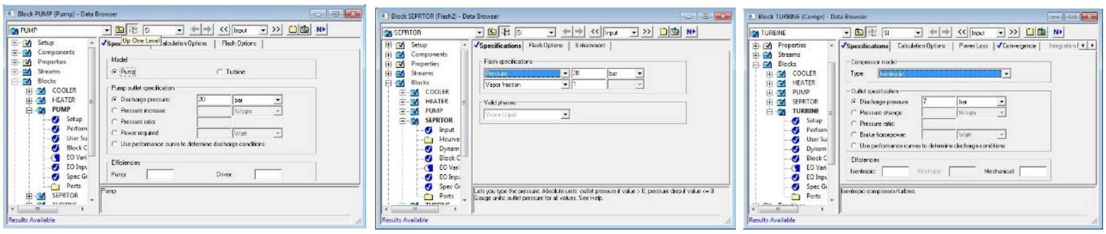
Total: 1

Lets you select the substream name.

Results Available. Unreconciled.

Fig.6 Hot air data input

Specification for pump, separator, and turbine is also shown in the followin figure


Block PUMP (Pump) - Data Browser

Model: ● Pump ○ Turbine

Pump outlet specification

● Discharge pressure: 20 bar

○ Pressure increase: N/sqm

○ Pressure ratio:

○ Power required: Watt

○ Use performance curve to determine discharge conditions

Efficiencies

Pump:

Driver:

Pump

Results Available

Block SEPRTOR (Flash2) - Data Browser

Flash specifications

Pressure: 20 bar

Vapor fraction: 1

Valid phases: Vapor-Liquid

Lets you type the pressure. Absolute units: outlet pressure if value > 0; pressure drop if value <= 0. Gauge units: outlet pressure for all values. See Help.

Results Available

Block TURBINE (Compr) - Data Browser

Compressor model

Type: Isentropic

Outlet specification

● Discharge pressure: 7 bar

○ Pressure change: N/sqm

○ Pressure ratio:

○ Brake horsepower: Watt

○ Use performance curves to determine discharge conditions

Efficiencies

Isentropic:

Polytropic:

Mechanical:

Isentropic compressor/turbine.

Results Available

Fig.7 a) Pump b) Separator c) Turbine

3.5 Flow sheet description

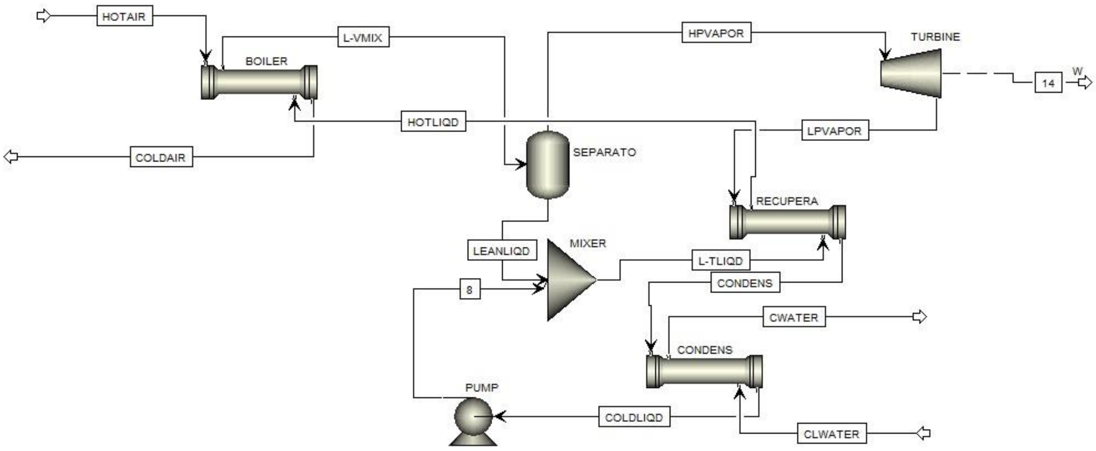


Fig.8 Kalina cycle flow sheet in Aspen plus

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 as shown in figure8. Hot flue gases is 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. High pressure vapour expanded and cooled in the turbine, mechanical work is done on turbine blade which tends to rotate the blade at very high speed (50Hz). Low pressure vapour coming out from the turbine and lean liquid from the separator is mixed in a mixer unit, and passes through the recuperator where primary heat exchange takes place. This exchange also helps in condensation of ammonia-water mixture coming out from the turbine. Pump pressurized the cold fluid to the desire pressure, and pumped into to heat exchanger called evaporator.

3.5.1 Difficulty in the condensation

Kalina cycle uses high concentration ammonia mixture (around 70% ammonia) at turbine part but such a mixture has got very low condensing temperature.

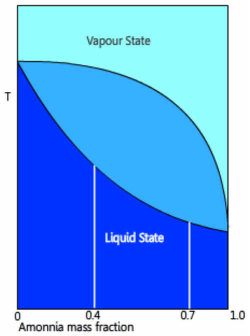


Fig. 9 Ammonia-Water vapour-liquid equilibrium diagram.

Means we have to supply a very low temperature cooling water at condenser for this purpose. Production of such low temperature cooling water is not economical. It is shown in Fig.9 that condensation temperature of ammonia-water mixture increases drastically with decrease in ammonia concentration. So in a Kalina cycle power plant, we will decrease ammonia concentration at condenser side. An equipment called separator will produce two streams of fluid from condenser outlet, one with high concentration (vapour) and other with low concentration lean liquid mixture (30% ammonia). Low concentration ammonia mixture will get mixed with high concentration fluid at turbine and will produce a medium concentration (40% ammonia) ammonia mixture. This mixture will have fairly high condensing temperature and can be condensed with supply of ordinary cooling water, this rendering the process economical.

3.5.2 **Use of recuperator**

It is clear from T-S diagram of Kalina cycle (Fig.2) that temperature at exit of turbine is greater than temperature at inlet of boiler. So there exists a chance of heating up boiler liquid by virtue of this high temperature turbine output. This is accomplished with help of a heat exchanger called recuperator (shown in figure 3 & 4). Thus with use of recuperator one need not supply the same amount of heat to the boiler side as supplied in case of Rankine cycle system. This will further increase efficiency of Kalina cycle power plant. But this opportunity of heat transfer is not there in Rankine cycle based power plant. We can notice that in Rankine cycle, temperature at turbine outlet is always less than temperature at boiler inlet, thus there is no chance of heat transfer from steam turbine outlet to boiler inlet.

3.5.3 Use of separator

Separator is to be used to separate the liquid-vapour mixture, from the evaporator into two streams. One stream rich in ammonia fraction that comes out as vapour from the top section of the separator. Where as another stream in the form of liquid is coming out from the bottom part of the separator. This helps to improve the turbine performance. Gas turbine can’t handle the liquid phase fraction more than 0.001%. Separator ensures the flow through turbine is only of vapour phase but no liquid phase flow through turbine is possible in this case. This also helps to improve the corrosion resistance of turbine and life period of the system. When only vapour phase flows through the turbine then its efficiency reached to maximum value.

Chapter 4

Result

4.1 Running the simulation and results obtained

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.

Table1. Hot air composition and condition

Input data		
Flow rate of hot air :	20 kg/s	
Composition Mass % :	H_2O	0.05
	CO_2	0.12
	CO	0.005
	N_2	0.755
	O_2	0.07
Temperature	453 K	
Pressure	10 bar	
Flow rate of hot air	20 Kg/s	

Flow rate of Ammonia-Water through the heat exchanger is 3Kg/s, power generated is listed in table 2.

Table.2 Power generated

Ammonia mass fraction	Power (KW) At 2000 KPa	Power (KW) At 3000 KPa	Power (KW) At 3500 KPa	Power (KW) At 4000 KPa
0.5	403.3	540.6	588.9	628.6
0.55	401.4	538.0	586.1	625.5
0.6	399.2	534.9	582.7	621.8
0.65	396.5	531.2	578.6	617.4
0.7	393.2	526.7	573.5	611.9
0.75	389.2	520.9	567.1	604.9
0.8	384.1	513.6	558.9	595.9
0.85	377.3	503.8	547.9	583.7
0.9	367.5	489.7	531.9	566.1

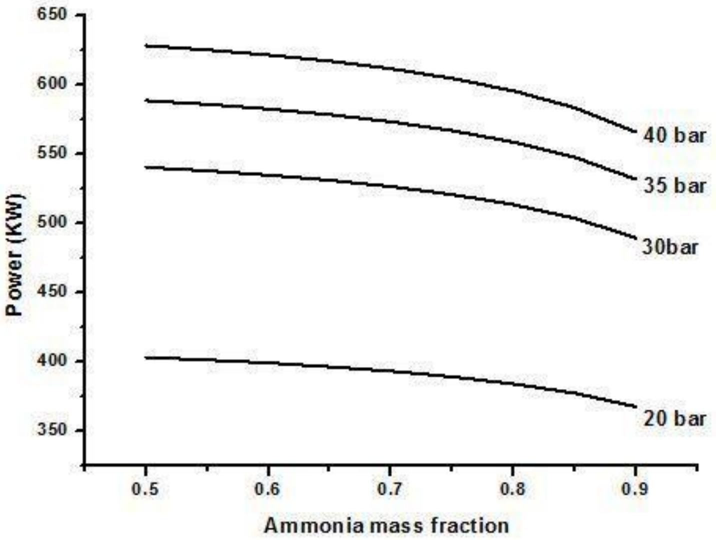


Fig.10 plot between Ammonia mass fraction and power generated (KW), at Ammonia-Water flow rate of 3 Kg/s.

Flow rate of Ammonia-Water through the heat exchanger is 4Kg/s; power generated is listed in table 3

Table3. Power generated

Ammonia mass fraction	Power (KW) At 2000 KPa	Power (KW) At 3000 KPa	Power (KW) At 3500 KPa	Power (KW) At 4000 KPa
0.5	537.8	720.8	785.2	838.1
0.55	535.3	717.4	781.4	834.0
0.6	532.3	713.3	776.9	829.1
0.65	528.6	708.3	771.4	823.2
0.7	524.3	702.2	764.7	815.8
0.75	518.9	694.6	756.2	806.6
0.8	512.1	684.9	745.3	794.6
0.85	503.0	671.8	730.5	778.4
0.9	490.0	652.9	709.2	754.7

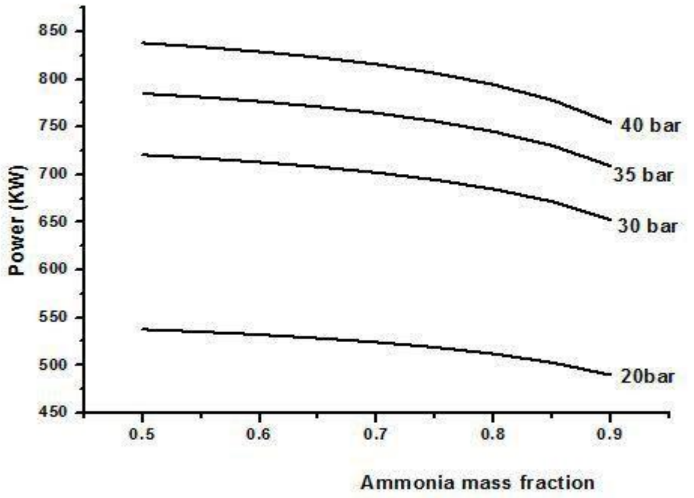


Fig.11 plot between Ammonia mass fraction and power generated (KW), at Ammonia-Water flow rate of 4 Kg/s

Power input to the turbine in watt, at different pressure, for the feed rate of 3Kg/s.

Table 4. Turbine input in watt.

Ammonia mass fraction	Power (W) At 2000 KPa	Power (W) At 3000 KPa	Power (W) At 3500 KPa	Power (W) At 4000 KPa
0.5	2.3343 x10^7	2.3323x10^7	2.3312x10^7	2.3305x10^7
0.55	2.1703x10^7	2.1732x10^7	2.1720x10^7	2.1714x10^7
0.6	2.0181x10^7	2.0140x10^7	2.0131x10^7	2.0125x10^7
0.65	1.8590x10^7	1.8556x10^7	1.8546x10^7	1.8540x10^7
0.7	1.7010x10^7	1.6975x10^7	1.6965x10^7	1.6960x10^7
0.75	1.5436x10^7	1.5399x10^7	1.5391x10^7	1.5386x10^7
0.8	1.3863x10^7	1.3831x10^7	1.3824x10^7	1.3821x10^7
0.85	1.2310x10^7	1.2276x10^7	1.2243x10^7	1.2268x10^7
0.9	1.0760x10^7	1.0741x10^7	1.0738x10^7	1.0739x10^7

Power input to the turbine in watt, at different pressure, for the feed rate of 4Kg/s.

Table 5. Turbine input in watt

Ammonia mass fraction	Power (W) At 2000 KPa	Power (W) At 3000 KPa	Power (W) At 3500 KPa	Power (W) At 4000 KPa
0.5	3.1156x10^7	3.1098x10^7	3.1083x10^7	3.1074x10^7
0.55	2.9033x10^7	2.8975x10^7	2.8960x10^7	2.8952x10^7
0.6	2.6912x10^7	2.6856x10^7	2.6842x10^7	2.6834x10^7
0.65	2.4796x10^7	2.4741x10^7	2.4728x10^7	2.4721x10^7
0.7	2.2685x10^7	2.2633x10^7	2.2620x10^7	2.2613x10^7
0.75	2.0582x10^7	2.0532x10^7	2.0520x10^7	2.0515x10^7
0.8	1.8488x10^7	1.8441x10^7	1.8431x10^7	1.8427x10^7
0.85	1.6409x10^7	1.6367x10^7	1.6360x10^7	1.6358x10^7
0.9	1.4535x10^7	1.4321x10^7	1.4317x10^7	1.4310x10^7

Efficiency calculated using the formula

$$\eta = \frac{power\ recovered}{power\ input}$$

Table 6 Percentage of efficiency calculated at various pressure inputs.

Ammonia mass fraction	η at 20bar (%)	η at 30bar (%)	η at 35bar (%)	η at 40bar (%)
0.5	1.73	2.31	2.53	2.70
0.55	1.85	2.47	2.70	2.88
0.6	1.97	2.65	2.89	3.08
0.65	2.14	2.86	3.12	3.33
0.7	2.31	3.10	3.38	3.60
0.75	2.52	3.38	3.68	3.93
0.8	2.77	3.71	4.04	4.31
0.85	3.06	4.11	4.47	4.75
0.9	3.41	4.55	4.95	5.27

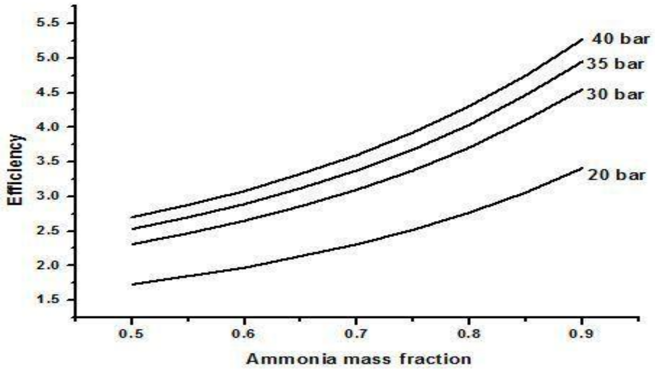


Fig.12 Plot between Ammonia mass fraction and cycle efficiency in percentage.

Chapter 5

5.1 Discussion

In the figure 12, it has been shown that, efficiency of the process is increasing as the ammonia mass fraction increases. At the input pressure of 20 bar the slope of graph is increasing slowly, which indicates that the rate of change of efficiency with the ammonia mass fraction is slow. While at 40 bar input pressure rate of change of efficiency is substantially high with the ammonia mass fraction, especially in the region closer to the ammonia fraction between 0.8 to 0.9. But at the same time power generation is decreasing, which is shown in figure 10 and 11 (for the two different feed rate of ammonia-water mixture). Power generation at 40 bar input pressure is maximum which is highly desirable. Also the power recovered during the process giving the value between 100-200 KW/kg/s, which is expected. Similar result was published by the A.I. Kalina [1] in his research paper.

In this case, when power generation is decreasing with the ammonia mass fraction and efficiency is increasing at the same. There must be an optimum value of ammonia mass fraction which is highly desirable for the process to be economically feasible.

5.2 Conclusion

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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