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Minimization of Irreversibilities in Vapour Absorption system by placing Organic Rankine Cycle at Condenser

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Abstract:- *The main objective vapour absorption refrigeration system(VAR) is to produce cooling effect by utilizing low grade energy(Heat). It contains Evaporator, Absorber, Condenser, Generator, Pump, Expansion valve, Solution Heat exchanger as main components. Water-lithium bromide is a system in which water is used as refrigerant. Lithium Bromide(LiBr) salt is used as absorbent. To analyze availability destruction in components of VAR a 6.18kW Water-LiBr system is designed by first law analysis(care should be taken while taking temperature limits so that system must not enters into crystallization zone). The analysis going to be done on a VAR system which contains both internal and external irreversibilities. Second law analysis is carried out in each component to identify the component having maximum irreversibilities. Since condenser involves heat transfer with more finite temperature difference irreveribilities are occurring higher at condenser. To decrease irreversibilities the idea of placing a heat engine is bring forward and after placing organic rankine cycle at condenser. By performance evaluation of both systems New Proposed System(which is having organic rankine cycle is performing more efficiently than single-stage vapour absorption refrigeration system with identical temperature limits and equal evaporator loads. The whole analysis is written in MAT LAB script file. MAT LAB script identifies and compares irreversibilities among each components. And asks user to enter input parameters of organic rankine cycle with in VAR condenser temperature limits with R-134a as working fluid*

Keywords:-mat lab, second law, irreversibility's, crystallization zone, Organic Rankine Cycle.

1.INTRODUCTION

The continuous increase in the cost and demand for energy has led to move research and development to utilize available energy resources efficiently by minimizing waste energy. A better understanding of second law revealed that entropy generation minimization is important technique in achieving optimal system configurations and/or better operating conditions. The vapour Absorption refrigeration system becoming more important because it can produce higher cooling capacity than vapour compression systems. And it can be powered by low grade heat sources like flue gases from boiler, geothermal, biomass other than electricity. The absorption cycle uses a heat driven concentration difference to move refrigerant vapour from evaporator to condenser.

In recent years, global warming and ozone depletion have stimulated the researchers to focus their interest in absorption based cooling systems. These systems utilize such absorbent and refrigerant pairs, which have very low or negligible ozone depleting effect. However it's COP is comparatively low from that of vapour compression refrigeration system (VCRS). This limitation can be over looked, as vapour absorption refrigeration systems (VAR) are operated on low grade thermal energies and most importantly it allows avoiding use of chlorofluorocarbons (CFCs) that possess high degree of ozone depletion and a major source of electricity consumer, which causes high demand of electricity during peak summer. It is crucial to promote absorption based cooling system to meet the cooling demand in place of VCRS. A number of researchers have investigated the performance a VAR with aqua-ammonia and lithium bromide (LiBr) – water as absorbent refrigerant pair, with cooling capacity ranges from 5 to 50 kW. Small scale cooling system gives very low COP with slow cooling rate, which require a focus for improvement of its COP with compact designing. Additionally the small scale system must be operating on low temperature driving source. Most of the researchers inclined their work towards aqua-ammonia pair because of the low boiling temperature of ammonia (-33˚ C), which allows to go for cooling effect below 0˚ C. Ammonia is corrosive to copper tubings, toxic and flammable in nature. In addition to these limitations, water as absorbent is reasonably volatile which leads to presence of appreciable amount of water vapour in ammonia vapour leaving the generator. This may result in clogging of evaporator tubing due to which an analyzer and a rectifier is used in aqua-ammonia system, which increases the system complexity. Based on these restrictions of aqua ammonia system, LiBr-water absorption system is more suitable to study.

It is important to note that system performance can be enhanced by reducing the irreversible losses in the system by using the principles of the second law of thermodynamics. A better understanding of the second law of thermodynamics [1] has revealed that entropy generation minimization is an important technique in achieving optimal system configurations and/or better operating conditions. Some researchers [2,3,4] have used the principles of entropy generation minimization to analyze different systems and to improve the systems performance. Theoretical and experimental studies on the performance and thermodynamic analysis of ARSs are available in the literature. Chen and Schouten [5] conducted an optimal performance study of an irreversible ARS.

an irreversibility factor and optimized the expression for COP with respect to a number of system parameters. Chua et al. [6] modeled an irreversible ammonia–water absorption chiller by considering the internal entropy production and thermal conductance of the heat exchangers. The model was applied to a single-stage chiller, and the results showed that the highest heat dissipation occurred in the rectifier. Kececiler et al. [7] performed an experimental study on the thermodynamic analysis of a reversible lithium bromide–water ARS.

Apart from other studies this paper deals with maximizing system performance by doing second law analysis on the system and running simulation of VAR system with Organic Rankine Cycle. And proposing a new model to increase COP and to Decrease irreversibilities. The properties for calculations various state points for solutions at different concentration are taken from R. Gonzales3 and S. A. Nebra2[8].

2.SYSTEM DESCRIPTION AND WORKING

Fig.1 shows main components of Vapour Absorption Refrigeration system Qg is the heat input rate from source rejecting by fluid entering at point 15 and leaving at 16.The Weak solution from the solution heat

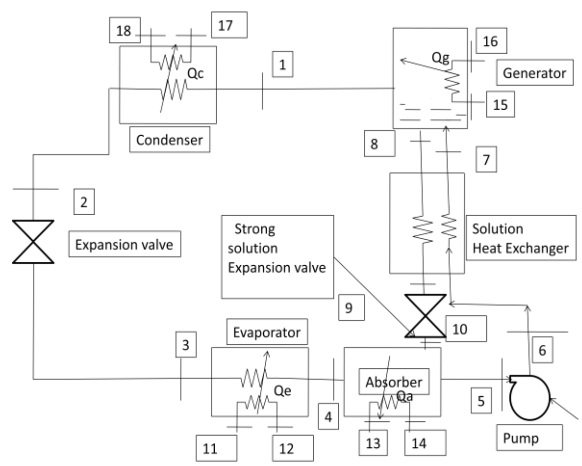


Figure1:- Designed Vapour Absorption Refrigeration system

Exchanger enters into generator by gaining heat water vapour at state1 enters into condenser and rejects heat to external circuit. Which flows at cooler temperature (T17) by gaining heat it gets heated taking Qc from the water vapour at Point 1 and converting it into high pressure liquid at Point 2.After the Expansion valve the pressure of refrigerant is decreased to point 3(saturated liquid).After getting Qe heat load from Evaporator circuit refrigerant gains latent heat and becomes saturated vapour at point4, Circulating Water is cooled from Point 11(T11) to Point(12) (T12).In the absorber strong solution absorbs water vapour from the evaporator and becomes weak solution at point 5.pump pressurizes weak solution up to generator pressure at point 6.After entering into solution heat exchanger Weak solution at point 6 is heated to point 7 by taking heat from strong solution coming from generator at point 8(which is equals to generator temperature). The strong solution is cooled to point 9 after heat exchanger and expanded to point 10 after strong solution expansion valve.

3.DESIGNING OF 2 TR VAPOUR ABSORPTION SYSTEM

Generator Temperature = 90ºc

Absorber Temperature = 35 ºc

Condenser Temperature = 35 ºc

Evaporator Temperature = 10 ºc

Generator source Temperature = 150 ºc (Isothermal heat addition)

Absorber cooling water entering Temperature = 20 ºc

Absorber cooling water leaving Temperature = 25 ºc

Condenser cooling water entering Temperature = 30 ºc

Condenser cooling water leaving Temperature = 35 ºc

Refrigerating load = 6.18 kW

3.1.First Law & Second law Steady State analysis on Designed Vapour Absorption system:-

Mass conservation:-

$(\Sigma m)in = (\Sigma m)out$

$ʒ = m_{libr}/(m_{libr}+m_w)$

Energy conservation:-

$(\Sigma m*e)in = ((\Sigma m*e)out$

Irreversibility generation rate:-

$I = T0*[m_R*(S_{system\ out}-S_{system\ in})+m_{surroundings}*(S_{surr\ out} - S_{surr\ in})]$

Coefficient Of Performance:- $Q_e/(Q_g + W_p)$

3.2.Assumptions:-

1. The system is operated under steady state conditions.
2. Pressure drops and heat transfer losses in the pipelines are neglected.
3. Expansion of the LiBr- water mixture through throttle valves is isenthalpic in nature.
4. The solution pump is isentropic in nature.
5. The refrigerant states at outlet of condenser and evaporator are saturated liquid and saturated vapour respectively.

3.3.Evaporator:-

$\dot{m}_3 = \dot{m}_4$

$m_{11} = m_{12}$

$Qe = \dot{m}_3(h_4 - h_3)$

$\dot{I}evaporator = T_0 [\dot{m}_3 (S_4 - S_3)+ \dot{m}_{11} (S_{12}-S_{11})]$

3.4.Absorber:-

$\dot{m}_3 + \dot{m}_{10} = \dot{m}_5$

Refrigerant mass balance:-

$\dot{m}_3+ \dot{m}_{10} (ʒ_{ss}) = \dot{m}_5(ʒ_{ws})$

$\dot{m}_{13} = \dot{m}_{14}$

$Qa = \dot{m}_3 h_3+ \dot{m}_{10}h_{10}-m_5h_5$

$\dot{I}absorber = T_0[(\dot{m}_5S_5-(m_3S_4+ \dot{m}_{10}S_{10}))+ \dot{m}_{13}(S_{14}-S_{13})]$

3.5.Pump:-

$Wp = \dot{m}_5(h_6-h_5)$

3.6.Heat Exchanger:-

$\dot{I}shx = T_0[\dot{m}_{10}(S_9-S_8)+ \dot{m}_5(S_7-S_6)]$

3.7.Generator:-

$\dot{m}_7 = \dot{m}_8+ \dot{m}_1$

$\dot{m}_{15} = \dot{m}_{16}$

$Qg = \dot{m}_1h_1+m_8h_8-m_7h_7$

$\dot{I}generator = T_0[(\dot{m}_1S_1+ \dot{m}_8S_8)-(\dot{m}_7S_7)+(\dot{m}_{15}(S_{16}-S_{15})]$

3.8.Condenser:-

$Qc = \dot{m}_1(h_2-h_1)$

$\dot{m}_{17} = \dot{m}_{18}$

$\dot{I}condenser = T_0[\dot{m}_1(S_2-S_1)+ \dot{m}_{18}(S_{18}-S_{17})]$

$\dot{I}total = \dot{I}generator+ \dot{I}shx+ \dot{I}absorber+ \dot{I}condenser+ \dot{I}evaporator$

4. RESULTS & ANALYSIS:-

Table.1.State points for designed Absorption Refrigeration system:-

State points	P (kPa)	T (ºC)	ʒ	h(kJ/kg)	s (kJ/kg-k)	ṁ (kg/sec)
1	5.622	90	-	2660.1	7.480	0.01267
2	5.622	35	-	146.6	0.505	0.01267
3	1.23	10	-	42	0.151	0.01267
4	1.23	10	-	2520	8.902	0.01267
5	1.23	35	52.5	75.85	0.26	0.01267
6	5.622	35	52.5	75.85	0.26	0.0737
7	5.622	62	52.5	151.691	0.44565	0.0737
8	5.622	90	65	235.325	0.47826	0.0737
9	5.622	57	65	156.55	0.28260	0.06104
10	1.23	57	65	156.55	0.28260	0.06104
11	-	30	-	-	0.437	0.37577
12	-	10	-	-	0.151	0.37577
13	-	20	-	-	0.437	0.996164
14	-	25	-	-	0.3672	0.996164
15	-	150(v)	-	2706	7.129	0.01634
16	-	150(l)	-	376.9	1.193	0.01634
17	-	30	-	-	0.437	1.5211
18	-	35	-	-	0.505	1.5211

Table.2.Results obtained from mat lab script for above conditions:-

S.No	Out puts(kW)
Qe	6.18
Qa	7.0433
Qg	7.2547
Qc	6.269
İtotal	2.369
(COP)designed system	0.85185

Installing Organic Rankine cycle at Condenser

After evaluation of Irreversibilities in each component condenser is having maximum irreversibilities so there are chances of extracting some of Work(available energy). Because there is destruction large temperature gradient at condenser. To conserve exergy heat engine which operates between temperature limits between condenser entering temperature(90 ºC) and condenser temperature(35 ºC).

4.1.Designing of Organic Rankine Cycle

Working fluid = R-134a

Refrigerant leaving Temperature from gaining heat from condenser = 70 ºC(v)

Refrigerant Entering Temperature from pump = 35 ºC(l)

Refrigerant leaving from turbine = 35 ºC(v)

Organic Rankine cycle condenser Refrigerant leaving temperature = 35 ºC(l)

Cooling Water entering into Organic Rankine cycle condenser = 25ºC

Cooling Water leaving Organic Rankine cycle condenser = 30 ºC

4.2.Working of Organic Rankine Cycle

The designed working cycle work with heat rejected from the condenser i.e 6.29 kW as heat input and converts 0.5142kW of heat into work from isentropic expansion of turbine. And remaining heat is rejected to ORC condenser and saturated liquid enters into pump and by taking 0.10625kW from surroundings liquid rises upto Boiler pressure and enters into boiler

Table.3.State Points for Organic Rankine Cycle

State points	P (kPa)	T (ºC)	h(v) (kJ/kg)	h(l) (kJ/kg)	s(v) (kJ/kg-k)	s(l) (kJ/kg-k)
19	2118.2	70	427	305	0.53775	0.8977
20	863.11	35	418	247	0.36670	0.9174
21	863.11	35	418	247	0.36670	0.9174
22	2118.2	35	418	250	0.36670	0.9174

4.3.Results Obtained from Mat lab Script for above input parameters:-

Work obtained from Organic Rankine cycle = 0.5124 kW

Refrigerant Effect = 6.18 kW

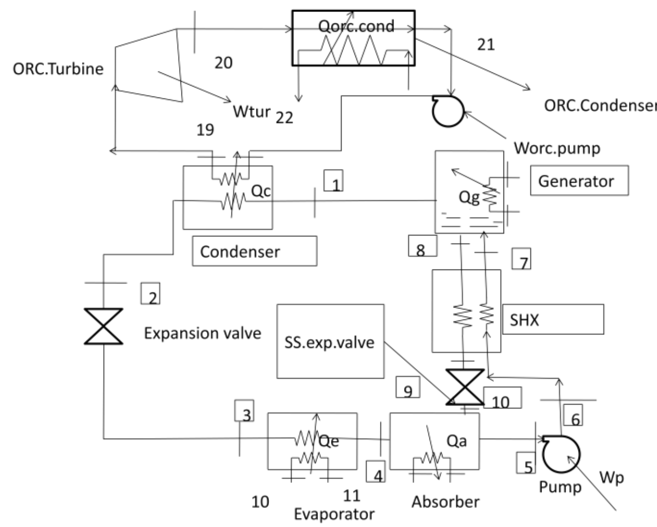
$(COP)_{VAR}$ = 0.85185

Organic Rankine Cycle Efficiency = 8.51%

Combined Performance Factor = 0.9259%

Irreversibilities associated with combined cycle = 1.77 kW

Fig.2.New Proposed System:-



5.Conclusion

The Original Vapour Absorption system is designed for constant refrigerating load for assumed temperatures that satisfy both first law and second law. But Irreversibilities at condenser are unavoidable so decrease irreversibilities at condenser organic rankine cycle is placed in between temperature limits of 70 ºC(i.e. with in the Refrigerant vapour (water vapour)entering into the condenser) and organic rankine cycle condenser temperature. Since pumps in given circuit consumes less power. The power produced from organic rankine cycle is used to run pumps that are consuming work from the external surroundings are going to get work from the turbine After installing a organic rankine cycle in vapour absorption system it is used to produce power until the system(VAR) is in use. Maintenance cost is low for Organic rankine cycle circuit. With installation of new proposed system has the Coefficient Of Performance is increased to 8% and Irreversibilities are minimized by 25%.

Nomenclature:-

P- pressure(kPa)

T- Temperature(ºC)

s – Entropy(kJ/kg-k)

$\dot{m}$ = mass flow rate(kg/sec)

in = entering into system

ʓ = concentration of lithium bromide in solution

m_w = mass of water in solution

$S_{system\ in}$ = specific entropy of working fluid entering into system in (kJ/kg-k)

$S_{system\ out}$ = specific entropy of system leaving from system(kJ/kg-k)

$m_{surroundings}$ = mass flow rate entering from external sources and sinks(kg/sec)

$S_{surr\ in}$ = specific entropy of surroundings at entry of system(kJ/kg-k)

$S_{surr\ out}$ = specific entropy of surroundings at exit of system(kJ/kg-k)

Qe = evaporator load in kW

Qg = heat supply at generator in kW

Qc = condenser heat rejection rate in kW

Qa = absorber heat rejection rate in kW

Wp = Work supplied to pump in kW

h = specific enthalpy (kJ/kg)

e = specific energy of fluid(kJ/kg)

out = leaving out of system

m_{libr} = mass of lithium bromide in solution(kg)

T_0 = surrounding temprature(k)

Wtur = Work done per unit time from turbine(kW)

Worcpump = Work giving to organic rankine cycle pump(kW)

Subscripts 1,2,3……22 = state points of working fluid at each instant

İtotal = total irreversibilities generated in cycles/sec(kW)

SHX = solution heat exchanger

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