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Thermodynamics analysis of ORC for heat recovery from decomposition of phosphogypsum

M.Alla[a*], M.L. El Hafyani[a],S.Zouggar[a],E.K. Gharibi[b]

[a]Laboratory of Electrical Engineering and maintenance, Higher School of Technology, University Mohammed First Oujda, Morocco. P.O Box 60000.

[b] Laboratory of Solid Minerals and Analytical Chemistry, Faculty of Sciences, Mohammed first University, Oujda, Morocco

m.alla@ump.ac.ma, m.elhafyani@gmail.com, szouggar@gmail.com

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Abstract:

This paper examine the thermodynamic and physical properties of some fluids used in organic Rankine-cycles (ORC) supplied by waste energy sources. Then Energy requirement and recovery system performances are analyzed using realistic design operating conditions. Thermodynamic efficiencies and alternative results are calculated by varied some recovery system operational parameters at numerous reference temperatures. With relevancy projected application, equations and graphs area unit only if interrelate the recovery system operational parameters for a couple of getable operational fluids with computation results. An analysis of a ORC cycle was performed to determine the increase in power output that would be achieved by adding a bottoming ORC to the utility-scale steam Rankine cycle, and confirm the impact of close conditions (heat sink temperature) on power increase. For the chosen station location, the massive distinction between the winter and summer temperatures encompasses a sizeable impact on the ORC power output. The recovery of the fatal heat leads to two axes of complementary thermal valorization: a valorization in house, to answer to the needs of heat specific to the company; an external valuation. In this study, we will valorize the thermal energy released by the phosphogypsum desulfurization system and protect the environment.

Keyword: *organic Rankine-cycles (ORC), waste heat, phosphogypsum (PG) ,desulfurization.*

1. Introduction

With the increasing development of science and technology, the demand for energy is stormy at Associate in Nursing unprecedented pace. Considering the growing consumption of typical primary energy (coal, petroleum, natural gas) and environment-related considerations, ill low grade heat sources has become Associate in Nursing inevitable choice to solve the energy and atmosphere drawback. n plant power generation has recently become in style, particularly once the utility value becomes high. However, standard electricity generation isn't perpetually economically possible for personal business thanks to its cost of capital and supply of high priced fuels. this case is even additional eminent for nations with un abundant natural resources, like Taiwan. underneath this circumstance, power generation mistreatment organic fluids in convalescent waste heat has attracted additional and additional attention [1] .The temperatures of the exhaust from most industrial processes and power plants square measure 370 C °(643.15 K). If this sort of waste heat is let into the surroundings directly, it might not solely waste heat however additionally build heat pollution to the surroundings. victimization standard ways to recover energy from this sort of exhaust is economically unfeasible. The organic temperature unit cycle (ORC) system exhibits nice flexibility, high safety and low maintenance necessities in ill this grade of waste heat. Integrating the ORC to the energy system, like power plants, may win victimization low grade energy (waste heat) to come up with high grade energy (power), easing the facility burden and enhancing system potency [2]. Since ,the ORC consumes just about no extra fuel, for identical another power, the emission of environmental pollutants like greenhouse gas (CO2), gas (SO2) so on would be faded. What's additional, in step with the native demand, the exhaust heat exiting from the ORC can be additional used to drive chillers like absorption chillers to provide cooling capability.

A solution for these issues is to recover low temperature waste heat to come up with electricity with the utilization of environmentally-friendly technologies, one among that is that the organic temperature unit cycle (ORC) technology. The ORC systems square measure used for ill waste heat throughout industrial processes, and therefore the scale of ORC systems is typically lots of kilowatt-level, that is kind of smaller than typical steam power cycles. Possible operating fluids to be used in Rankine cycle power systems area unit virtually innumerable.
Basically, smart physics properties would lead to high efficiency, low value systems. Further, a operating fluid is taken into account fascinating once it exhibits (a) low toxicity, explosion and manageable flammability characteristics and (b) smart material compatibility and fluid stability limits . A substance could also be deadly if it's eaten, inhaled or absorbed through the skin . The leasttoxic fluids area unit the refrigerants. Basically, the flammability hazard expose by every of the fluids is manageable. Special vapor detection, fireplace detection and suppression systems could also be needed for those fluids exhibiting the best potential hazard. The fluid ought to be noncorrosive to common engineering materials [3].The temporary review conferred on top of clearly shows that the choice of an acceptable operating fluid is incredibly vital for max waste heat recovery in actual thermal power plants. With this aim in sight, constant quantity optimization and performance analysis of an ORC victimization R-11, R-123,R-245ca and R-245fa are investigated within the gift work [4]and also the results square measure examined for the information of four 1.2 MW .in most of the literatures, the analyses of the ORC area unit in light-weight of mounted saturated or superheated temperature within the evaporator, condensation or sub-cooling temperature within the condenser and recess temperature of the rotary engine. However, the influence of the running conditions on system performance isn't terribly clear. This paper studies the ORC from the outer running conditions and tries to urge some helpful conclusions.

1. **System description:**

2.1. Organic Rankine Cycle

The basic parts that compose associate degree ORC ar just like the traditional temperature unit cycle. The layout of the parts of a system performing on ORC utilizing exhaust flue heat as thermal supply is shown in Fig. 1[5].

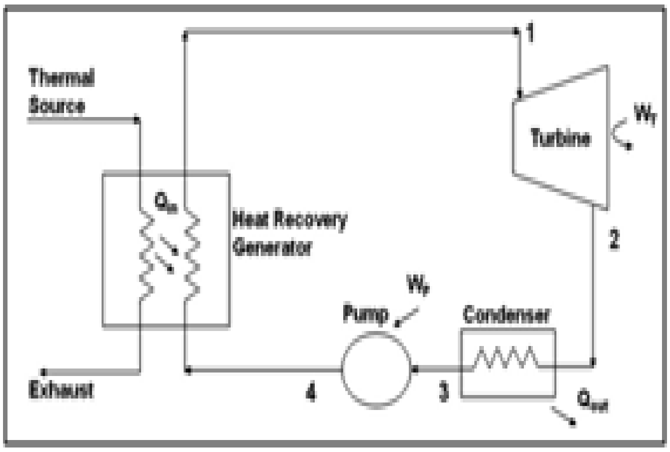

Fig. 1. Basic components of a system working on ORC

2.2. Effect of working fluid on the environment:

Ozone Depletion Potential (ODP) and warming Potential (GWP) of the refrigerants live result of unleash of those elect fluids within the surroundings. The ODP is that the potential for one molecule of the refrigerant to destroy the layer. All refrigerants use R-11 as a data point reference wherever R-11 has AN ODP ¼ one.The less the worth of the ODP e the higher the refrigerant is for the layer and also the surroundings. Because the Chlorine is dissipated

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at lower altitudes, The HFCs are the family of compounds accustomed replace CFC as refrigerants. R-123 being a CFC refrigerant could also be replaced by fluorocarbon R-134a in close to future [6].

2.2. Waste heat recovery power plant model

The solid fuel is reacted with an acidic medium of direct tangential combustion. in our phosphogypsum decomposition system[7] , the phophogypsum is used as a reagent. This plant works on the Rankine cycle with steam as a working fluid.

For the utilization of this waste heat for the generation of power the data were collected and tabulated in Table 1. shows a schematic diagram of the proposed waste heat recovery power plant The results for power generation, pinch point,1st and 2nd law efficiencies of the proposed system through waste heat recovery are presented here. The results obtained through above parametric optimizations are also applicable for other systems like distributed generation but it is not taken up under this study.

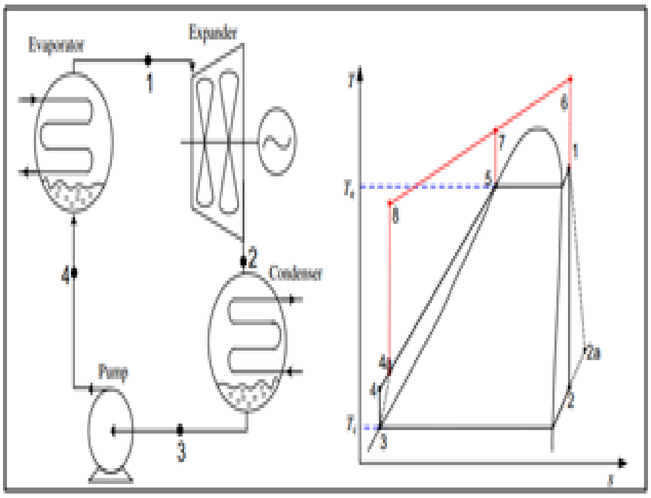
Table.1:Flue gas characteristics and pressure loss across proposed

parameters	values
load	1.2MW
Flue gas temperature	135 C°
Mass flow rate (M)	0.2341Kg/s
Composition	SO_2
Molecular Wight	64,066 g/mol
Density	2.6288 kg m^{-3}

2. thermodynamic analysis of systems:

ORC systems accommodates a minimum of 5 principal components: evaporator, turbine, condenser, pump and dealing fluid [6]. during this study, the performances of ORC systems is examined exploitation totally different organic operating fluids by using the primary and Second Law of natural philosophy. The system layout and cycle Tes chart for every ORC system area unit shown in Figs. 2[8].

Fig. 2. System layout and cycle T-S chart of the basic ORC system.



As shown in Fig. 2 there are four different processes in the ORCsystem [9]:
Process 1e2 (actual process is 1e2a): expansion process;
Process 2e3: constant pressure cooling process;
Process 3e4 (actual process is 3e4a): pumping process;
Process 4e1 (actual process is 4ae1): constant pressure heat addition process.
The pump power can be expressed as:

$$W_p = m(h_{4a} - h_3) = m(h_4 - h_3)/\eta_p \quad (1)$$

The turbine power is given by:

$$W_{exp} = m(h_1 - h_{2a}) = m(h_1 - h_2)/\eta_{exp} \quad (2)$$

The heat transfer rate from the evaporator is given by:

$$Q = m(h_1 - h_{4a}) \quad (3)$$

For ORC with internal device, an indoor device is superimposed to recover heat of operating fluid before the condenser to heat the operating fluid before the evaporator. the inner device acts as a preheater before the evaporator and a precooler before the condenser at the same time.

3. Results and discussion :

The thermodynamic calculations are show Fig.3, were carried out by the software DWSIM . Practically, thanks to the unchangeability during a real

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world natural philosophy system, it's not possible to convert all the accessible thermal energy into helpful work. supported the primary and second laws of physical science of a basic temperature unit cycle,the potency of as sociate ORC is obtained
beneath numerous operating conditions for a selected operating fluid. For simplicity, the inner unchangeability and, consequently, the pressure drops within the parts aside from the rotary engine, like the evaporator, condenser and pipes, square measure unheeded. so as to optimize energy conversion, the operating fluid has to be selected rigorously, and also the operation conditions ought to match with the fluid of alternative.

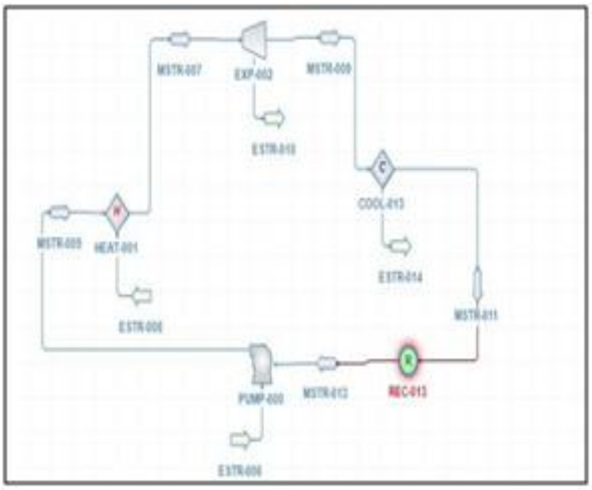

Fig.3: DWSIM simulation result

Thermodynamic analysis is done following literature . The analysis is based on the following assumptions: (1) the system is operating under steady-state condition, (2) no undesired pressure drop and heat loss occur in the system, (3) working fluid at the evaporator and condenser exits is saturated, and (4) isentropic efficiencies for the turbine and pump.

Optimizations for the ORC system are performed and various working fluids are tested, including R123, R11, R245ca, and R245fa. According to the results, the thermodynamic parameters in each optimal operating condition for each fluid are listed in Table 2.

Table.2: Optimal performance of the ORC system for different working fluids.

	R123	R11	R245ca	R245fa
chemical formula	$C_2HCl_2F_3$	CCl_3F	$CHCl_3$	$CHCl_3$
T(k)	407.4	407.68	405.6	394.391
P(Kpa)	1560.4	1617.05	1820.690	1957.820
Tout(k)	411.576	412.041	408.236	390.039
Ƞ(%)	15.88	16.21	15.3	13.98
Wp(Kw)	0.423	0.480	0.874	0.298
Wt(Kw)	16.323	15.418	24.124	64.198
m(kg/s)	0.645	0.536	0.840	2.453
Wnet(Kw)	15.511	14.720	22.818	59.998

Table.2:Optimal performance of the ORC system for different working fluids.

Figure 4 shows the output temperatures of the heat source fluid under optimal ORC operating conditions using various working fluids. It can be seen that (R11) ORC systems have higher heat source fluid outlet temperatures than the system.

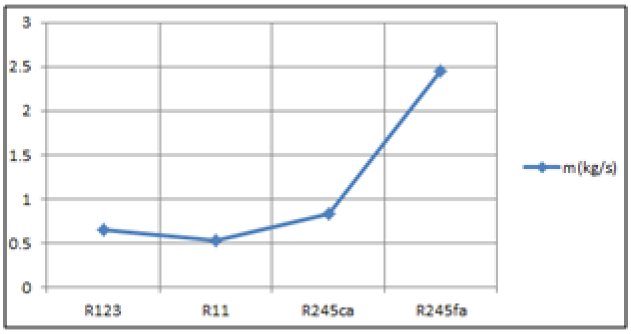

Fig.4: Temperature of the water flower in the optimized of system, ORCusing different fluides of work.

ORC systems adopt specific methods to improve the inlet temperature of the stent. According to the thermal balance of the evaporator, under the same thermal conditions and with certain working fluids ,. With respect to different working fluids, the use of R245fa provides the lowest heat source fluid outlet temperatures, which is significantly lower than other working fluids. We can also conclude that, for optimal working conditions for different working fluids, the outlet temperature is inversely proportional to the boiling point when it is used optimal working conditions.

Figure 5shows the mass flow of ORC working fluid using different working fluids under optimal operating conditions. It can be seen that R245fa always requires maximum mass flow rates that are significantly higher than those of other selected working fluids. As we know, working fluids act as energetic vectors of ORC systems. As the specific heat varies in a relatively small range for different working fluids under the same working conditions, the outstanding mass flow rates of R245fa allow a greater energy transfer of the coolant to the working fluid, which is the reason the more likely of its lower output temperatures, the R245fa.

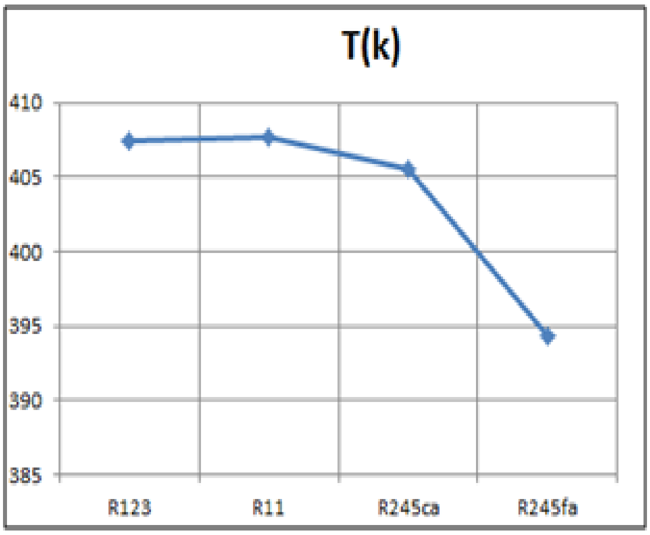

Fig.5:Required mass flow rate under the optimal working conditions of different ORC systems using different working fluids.

Different working fluids are shown in Figs. 6 Thermal efficiency and exergy efficiency have the same trend in the evolution of working fluids. For each working fluid, the ORC system always offers the best efficiency For each system, R11 offers a greater thermal efficiency than those of other working fluids. The increase in the outlet temperature of the heat source causes an increase in the average heat addition temperatures (Tm), which finally contributes to the increase in thermal efficiency with a constant heat rejection temperature. In addition, the average transfer temperature difference between the waste heat flux and the working fluid in the evaporator decreases in the ORC system.

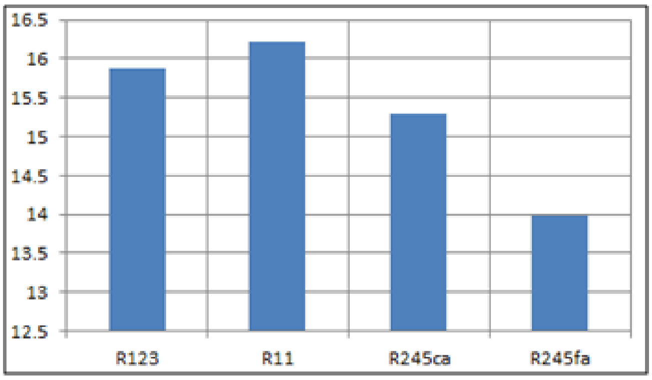

Fig.6:Thermal efficiency under the optimal working conditions of ORC system using different working fluids.

it can be concluded that the ORC system generates a net output power greater than that of the regenerative ORC systems. However, the ratio between the net output power and the total heat input (thermal efficiency) is much higher. That is, when producing the same net output power, from the point of view of use Regenerative energy, ORC systems have a higher potential for waste heat of low quality recovery.

4. Conclusion :

The objective of this study is to optimize the operating parameters of the ORC system using different working fluids under the same waste heat. Optimized thermodynamic parameters include turbine inlet pressure, turbine inlet temperature, and flow fractions of regenerative ORC systems. The first and second law of thermodynamics is used to analyze the performance of the system. The main conclusions of this work can be summarized as follows:

1) Regenerative ORC systems have a higher potential for recovering low quality residual heat for superior thermodynamic performance when operating under optimum operating conditions. It is important to note that when they produce the same net output power, regenerative ORC systems have higher efficiencies and a lower total amount of heat absorbed. Although some more real industrial conditions, such as initial investment and detailed economic analysis, need to be thorough .

2) R245fa is weeded out for its highest evaporator heat load, condenser heat load and mass flow rate requirement and its lowest exergy efficiency and thermal efficiency. R11 is recommended as suitable working fluids for ORC systems for their superior thermodynamic performances.

Nomenclature

T	temperature	(K)
P	Presure	(Kpa)
ŋ	effiency	(%)
W	Power	(KW)
H	enthalpie	(KJ/Kg)
M	mass flow rate	(Kg/s)
Q	heat of working fluid (KJ/s)	

Subscripts

A	actual
P	pump
1,2,3,4	states in system
Exp	expander
T	thermal
Out	output system

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