Exergetic and Energetic Analysis of Power Generation from Geothermal Resources in Pakistan

Ahsan Mustaqeem SYED, Shafiq R. QURESHI and Waqar A. KHAN

Pakistan Navy Engineering College, National University of Science & Technology (NUST), Pakistan

SYED.AHSAN.MUSTAQEEM@pnec.nust.edu.pk

Keywords: geothermal energy, Organic Rankine Cycle, exergy analysis, Pakistan

ABSTRACT

World is presently facing an unprecedented energy challenge. This situation is even graver in developing and under developed countries like Pakistan. Future solution of this challenge lies in harnessing renewable and other sustainable energy resources. Geothermal energy is one of such options. This paper presents an analysis of possibilities of exploiting this resource in Pakistan. Geological research underlines presence of several geothermal resources in country. Most of the geothermal resources of the world lie near the seismic belts and Pakistan too is situated in the western rifted margin of Indo-Pakistan sub continental plate. The presence of geothermal resources is strengthened by the development of alteration zones and fumaroles in different regions of the country, presence of hot springs and indication of quaternary volcanism. There exist several medium and low temperature geothermal sources up to temperatures of 200°C in different areas of Pakistan. The present work addresses the idea of power generation from geothermal energy sources in Pakistan. The work encompasses the review of geothermal resources in Pakistan and the application of engineering principles for the exploitation of these resources. The work includes a comparative Energetic and Exergetic study of different geothermal power plant concepts, based on the source temperature. Cycles incorporated in this study are simple Organic Rankine Cycle (ORC), Organic Rankine Cycle with an Internal Heat Exchanger, and Regenerative Organic Rankine Cycle & Regenerative Organic Rankine Cycle with an Internal Heat Exchanger. A thermodynamic model is developed for ORC and validated using available data from literature. Numerical and analytical analysis is carried out for finding the optimum working conditions and working fluid. The performance of each configuration of cycle has been analyzed in terms of energetic &exergetic efficiency, exergy destruction rate, fuel depletion ratio, relative irreversibility and productivity lack. It is observed that the increase in geothermal source temperature results in an exponential increase in maximum cycle output and a linear increase in turbine inlet temperature. It is also proposed to use internal heat exchanger and regeneration to increase the effectiveness of cycle.

1. INTRODUCTION

The world is facing an unprecedented energy challenge, rapid industrialization, urbanization and exponential growth in population are the key drivers behind the ever increasing demand for energy. The Global Primary Energy supply had been 13113 MTOE in 2011 and the demand is projected to increase by more than one third in 2035[1]. The global Electricity consumption has been 20407 TWh in 2011 of which residential, commercial and agricultural sector consumed 55.8%, Transportation sector consumed 1.6% and Industrial Sector consumed 42.6% electricity [1]. Still in 2011 Fossil fuels have been the major source of generation of electricity with Coal, Natural gas and Oil producing 41.3%, 21.9% and 4.8% of electricity respectively, while the remaining electricity is generated by Hydro 15.8%, Nuclear 11.7% and Renewable Sources 4.5%. The carbon emissions from fossil fuels pose a serious threat to eco system and is culpable for global warming crisis [1]. It is projected that, by 2035 the energy related Carbon Emissions alone will rise to 37.2Gt from 32.34 Gt in 2011 consequently resulting in a long term global temperature increase of 3.6°C which is far above the international allowable limit of 2°C. This increase in Carbon Emissions which is contributed majorly by the excessive use of fossil fuels, can be quelled by the use of alternate energy resources [2].
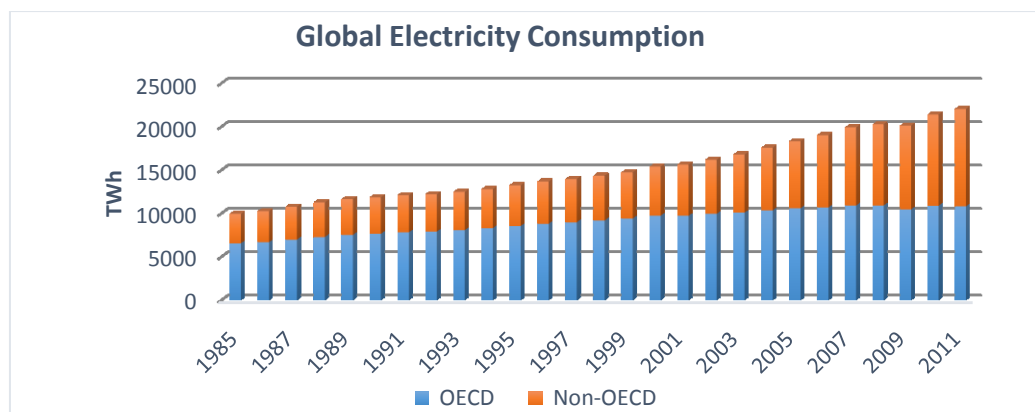

Figure 1: Global Electricity Consumption 1985-2011 [1]

In 2011, Renewable Energy resources met 13% of the global primary energy demands. The primary Renewable Energy Demand is forecasted to increase to 18% in 2035[3]. This projected increase in primary Renewable Energy Demand is induced by the advancement in Renewable Energy technologies, achievement of Economics of scale, enforcement of Carbon Pricing, Depletion of fossil fuels resources and increase in prices of fossil fuels. Very steadily, Renewable Energy resources are becoming a part of global power generation mix and are projected to grow strongly. The global primary Renewable Energy power generation is projected to increase by over 7000 TWh between 2011 and 2035 from 4482 TWh to 11612 TWh [3]. The share of renewable energy resources in global power generation stands at 20% in 2011 and is projected to rise to 26% in 2020 and 31% by 2035 [3].

The energy policy of Pakistan is characterized by overreliance on fossil fuel. Out of 95,365 GWh produced in FY 2011-12 35.2%, 29.03%, 0.1%,29.9%, 5.8% of the electricity has been produced from Oil, Gas, Coal, Hydro Electric and Nuclear Power resources respectively. 4720 MW of State run Water & Power Development Authority(WAPDA), 2381 MW of Karachi Electric and 8353 MW of 27 Independent Producers' installed capacities are fossil fuel based. [4] The burgeoning energy crisis that the beleaguered country is battling with has been one of the major hurdles in the economic growth during the current fiscal year. The energy crisis has aptly complemented the prevalent structural problems like escalating security issues, ever rising inflation, precipitously declining investments, and low tax revenues, thus declining the GDP growth. The hefty amount of subsidy government has to bear on power and losses in the state run enterprises have further exacerbated the economic situation. The energy crisis that seems to have engulfed the whole country, is neither an aberration nor an unexpected phenomenon, rather it is an outcome of years of neglect and lack of proper planning, which is likely to intensify in the years to come. However, Pakistan has been blessed with several renewable energy resources which can exploit to alleviate the power crisis. Geothermal Energy is one of these viable Renewable Power generation options.
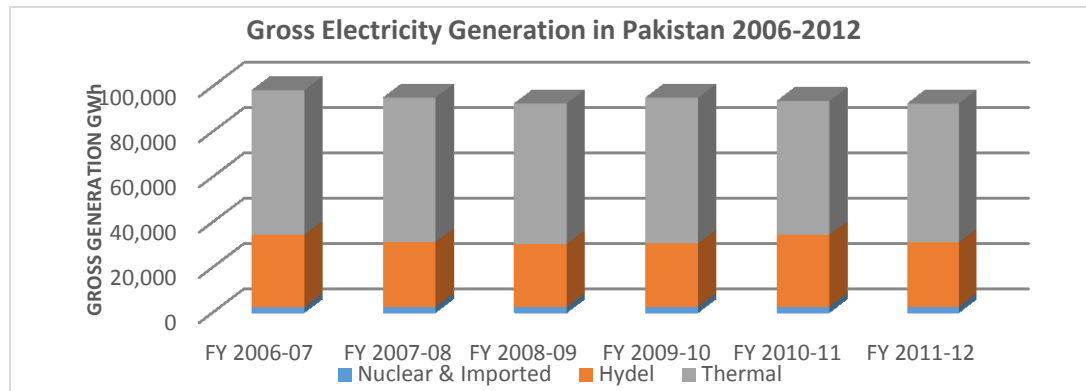

Figure 2: Global Electricity Consumption 2006-2012[4]

2. GEOTHERMAL ENERGY RESOURCES IN PAKISTAN

Geological research underlines presence of several geothermal resources in Pakistan. The energy mix of the country can be enhanced by exploiting these geothermal resources. Most of the geothermal resources of the world lie near the seismic belts and Pakistan too is situated in the western rifted margin of Indo-Pakistan sub continental plate.

The presence of geo thermal resources in Pakistan is strengthened by the development of alteration zones and fumaroles, presence of hot springs and indication of quaternary volcanism in different regions of the country. [5-10]
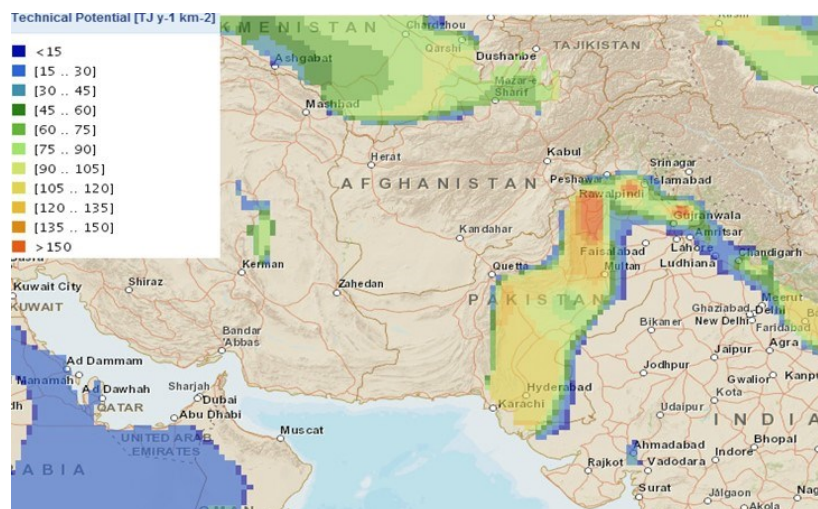

Figure 3: Technical Potential of geothermal resources in Pakistan [11]

2.1 Geo Pressurized Sources

Geo pressurized systems are characterized by entrapment of heat flow by insulating impermeable beds, that result in a high temperature and high pressure hot connate water leakage with a temperature ranging from 19 °C to 150 °C. [12]

In Pakistan such geo pressure frames are present within the Indus River Basin which constitute south Sulaiman, South Kirthar and Lower Indus geological structures [13]

The Southeastern part of SulaimanFore deep exhibits the existence of geothermal resources which is evident by the frequent earthquakes of magnitude 3 – 7 on Richter scale in the region. [14] and prevalence of leakage of geo fluid particularly in the Giandri, Uch, GaramAab, ZindaPir, TaunsaandBakhar Regions [15, 16]

The geothermal resources in the South Kirthar Zone are characterized by frequent shallow earth quakes of magnitude 3 to 5 on Richter scale, the high thermal gradient of 3.3°C/100m at Oil and Gas wells drilled at Larkana and existence of hot springs like the ones in the Manghopir and Karsaz Regions of Karachi. [17]

The geological developments in the lower Indus geological structures strongly hint at presence of geothermal resources in region. The gradients of 4 °C/100m [18] at Damiri-1 Oil and Gas well, 3.0°C– 3.5°C/100m at Talher and Kashkeli Walls and 3.7 °C/100m at off shore well at Dabbo Creek [19] clearly exhibit the existence of geothermal resources in the region.

2.2 Seismo Tectonic and Suture Related Systems

The northern part of the Pakistan is comprised of Karakorum, Hindu Kush and Himalaya thrust mountainous belts which exhibit strong seismic activities particularly in the form of hot water springs in Chitral, Murtazabad, Budelas, Sassi, Dassu, TattaPaniandMushKhin.

In Chitral region, hot springs are present in GaramChashma Valley [20], near Pechas Glacier and in Rawat village. [16]

In the Hunza valley the geo thermal springs are present in Murtazabad Village, the geo fluid temperature ranges from 26°C to 91°C [21], whereas the reservoir temperature has been noted to be in the range of 198 °C to 212 °C. In Skardu District several springs are reported in Dassu Area with geo fluid temperature of 71 °C.

The geo thermal systems in Nanga PerbatHaramosh Massif forms hot springs near Mushkin with the geo fluid temperature of 57 °C and the reservoir temperature ranges from 86 °C to 90 °C [22].

Several geo thermal hot springs are present in the TattaPani Area spread over an area of 8 KM. Hot springs also emanate from the Rani Kot fault zone at Sassi with a geo fluid temperature of 54 °C and the reservoir temperature in the range from 40 °C to 68 °C [23]

In other parts of Indus and Baluchistan sedimentary basins, geothermal manifestation are scattered in the form of hot springs. Three hot springs are located near Sanni along the Mach and Kirthar faults [18].

In the Harnai Valley several springs are located along the Harnai and Tatra faults where earthquake of magnitudes 6 to 7 on Richter scales are frequent. [14, 24 and 25].

Furthermore two hot springs in the high seismic activity area north of Zohb valley are located.

2.3 Thermal System Related to Neo-gene Quaternary Volcanism

Geo thermal systems associated with Chagai magmatic arc manifested by thermal springs in the vicinity of Miri carter volcano region. The geo fluid temperature of these springs ranges from 25.6 °C to 32 °C [14].

The Koh-e-Sultan region has the highest geothermal potential in the country which lies in the south western part of Koh-e-Sultan volcanic are region. The reservoir temperature in the region is estimated to be in the range of 150 °C to 175 °C [22].

3. LITERATURE REVIEW

From literature survey, it is elicited that Second Law analysis (Exergy Analysis) provides the basis of design, analysis, performance evaluation and optimization of geothermal power plants. Low and Medium temperature geothermal resources in the temperature ranges that are available in Pakistan are found in various countries and literature survey suggests that an ORC is the optimum cycle configuration for power generation from these sources economically. Different researchers have carried out the study on modification of ORC by the incorporation of Regeneration, recuperation, turbine bleeding, multi pressure systems and regenerative heat exchangers and the effects on first and second law efficiency and exergy destruction. A host of working fluids are analyzed by researchers in pursuit of finding the optimum working fluid and it was found that for power generation systems binary fluids having low critical temperature in the range of geothermal source temperature provide the optimum output.

During the literature review, it was revealed that no work has yet been carried out aimed at the exploitation of geothermal resources in Pakistan, several geological investigators have however, highlighted presence of geothermal energy resources at various locations in Pakistan. This work which is first of its kind in Pakistan, therefore, aims at the selection of optimum geothermal power plant configuration based on the available resources and the selection of optimum working fluid and working conditions based on the energy and exergy analysis.

4. MATHEMATICAL MODELING

Based on the overview of geothermal energy resources available in Pakistan and Literature Review small binary plants operating on geothermal resources in the range on 100°C to 150°C were selected for this study. The ambient conditions were selected to be 25°C and 100 KPa for mathematical modeling. Four configurations of ORC i.e.; simple Organic Rankine Cycle (ORC), Organic Rankine Cycle with an Internal Heat Exchanger (IHE), Regenerative Organic Rankine Cycle & Regenerative Organic Rankine Cycle with an Internal Heat Exchanger were analyzed analytically and numerically for finding the optimum power plant configuration.
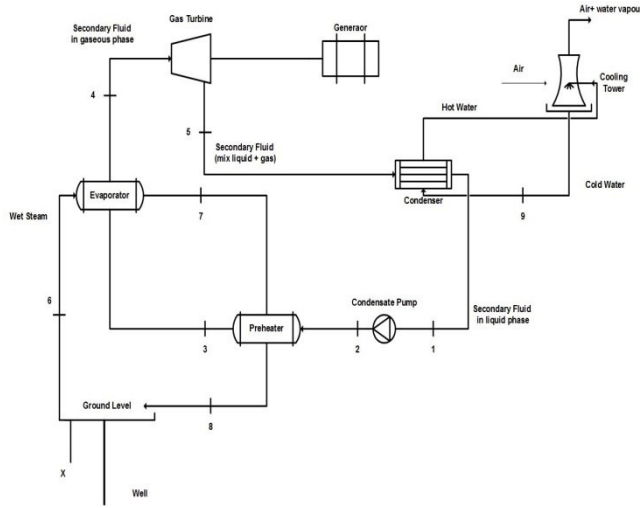
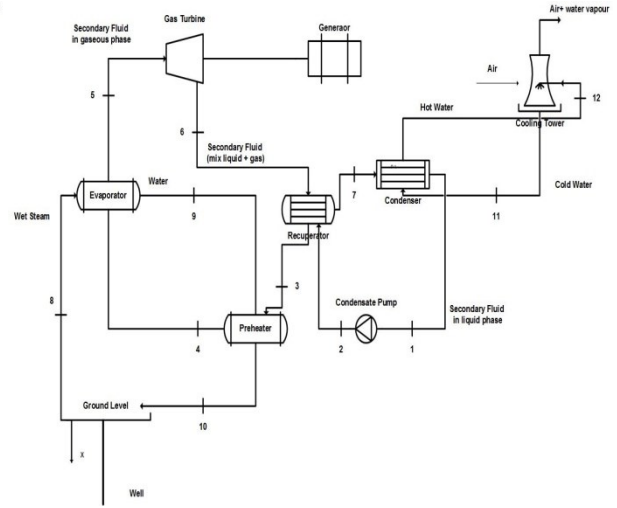Figure 4: Schematic Layout of Simple ORC [30]
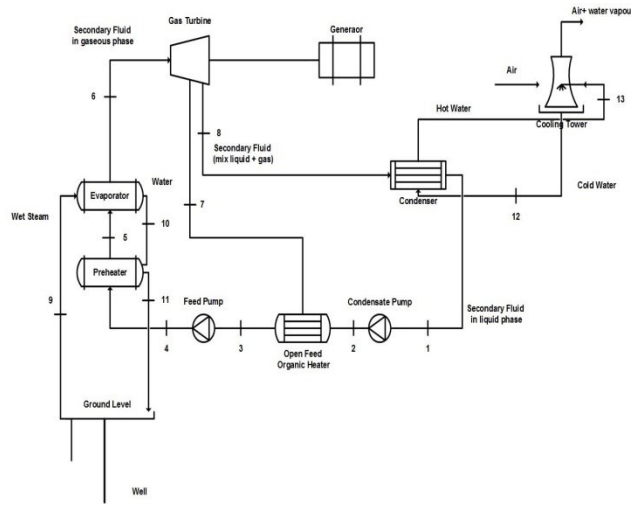

Figure 5: Schematic Layout of ORC with IHE[30]
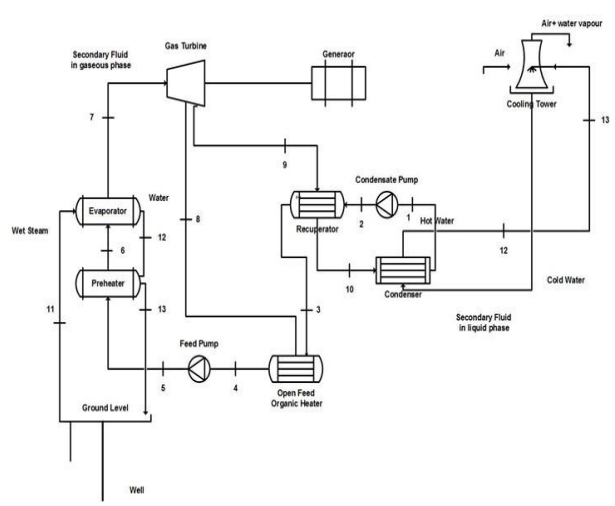

Figure 6: Schematic Layout of Regenerative ORC[30]

Figure 7: Schematic Layout of Regenerative ORC with IHE[30]

5. RESEARCH DESIGN

5.1 Energy and Exergy Analysis

Exergy, also termed as the available energy is the maximum theoretical useful work that can be extracted from the system which is at a specified thermodynamic state relative to its surroundings. If the system is at thermodynamic equilibrium with its surrounding, then it is said to be at a dead state and no useful work can be extracted from it without the expense of work.

Since Exergy Analysis depends upon the second law of thermodynamics and it is also based upon the first law, both laws are combined to get a series of equations for mass, energy and exergy balance of a system at steady state with negligible Kinetic and Potential energy changes. [29, 34 and 35]

Mass Balance is given by:

$$\sum \dot{m}_{in} - \sum \dot{m}_{out} = 0$$

Energy Balance is given by:

$$\sum \dot{m}\, h_{out} - \sum \dot{m}\, h_{in} = \dot{Q} - \dot{W}$$

Exergy balance is given by:

$$\dot{E}x_{heat} - W + \sum \dot{m}_{in}\Psi_{in} - \sum \dot{m}_{out}\Psi_{out} = i$$

Net work in a cycle is given by: [35]

$$\dot{W}_{net} = \dot{W}_t + \dot{W}_p$$

Table 1: Properties of selected Refrigerants [31, 32 and 33]

Working fluid	R123	R152a	R600a	R601	R-245fa	R-113
Name	2,2-Dichloro-1,1,1-trifluoro-ethane	1,1-Difluoro-ethane	Isobutane	n-Pentane	1,1,1,3,3-penta-fluoro-propane	1,1,2-trichloro-1,2,2-trifluoro-ethane
Chemical formula	$CHCl_2C\text{-}F_3$	$CH_3CH\text{-}F_2$	C_4H_{10}	C_5H_{12}	$CF_3CH_2CHF_2$	$C_2Cl_3F_3$
Type	HCFC	HFC	HC	HC	CFC	CFC
Molecular weight	152.93	66.05	58.12	72.15	134	187.38
T_{bp}@ 1atm [C]	27.82	-24.02	-11.67	36	15.3	47.59
T_{cr}[C]	183.68	113.26	134.67	196.55	154.05	214.06
Cpv [J/Kg.K]	738.51	1456.02	181.42	1824.12	980.9	1524.06
P_{cr}[MPa]	3.662	4.517	3.62	3.37	3.64	3.392
ALT [year]	1.3	1.4	0.02	1	7.2	85
ODP	0.02	0	0	0	0	0.9
GWP [100 years]	77	120	~20	11	1050	6130

Exergy input to the system in given by: [27, 28, 34 and 36]

$$\dot{E}x_{in} = \dot{m}_{geo}[(h_{geo} - h_o) - T_o(S_{geo} - S_o)]$$

Exergy destroyed in the cycle and the plant are given by [34, 35]

$$I_{cycle} = \sum allcomponents I_i = I_p + I_{HEs} + I_t + I_c$$

$$I_{plant} = I_{cycle} + I_{rej} + I_{CS} = \dot{E}x_{in} - W_{net}$$

5.2 Performance Analysis

The performance of the system can be analyzed in a number of ways. First and second law efficiency in the based on ambient temperature and inlet state of the geothermal fluid is given by: [27, 28, 35, and 36]

$$\eta_I = \frac{networkoutput}{totalenergyinputs} = \frac{W_{net}}{\dot{m}_{geo}(h_{geo} - h_o)}$$

$$\eta_{II} = \frac{networkoutput}{totalenergyinputs} = \frac{W_{net}}{\dot{m}_{geo}(h_{geo} - h_o) - To(Sgeo - So)}$$

Another approach is to calculate the first and second law efficiency on the basis of heat transfer: [27, 28, and 37]

$$\eta_{I,2} = \frac{W_{net}}{\dot{m}_{geo}(h_{geo} - h_{rej})} = \frac{W_{net}}{\dot{m}_{wf}(h_{wf,out} - h_{wf,in})}$$

Syed et al.

$$\eta_{II,2} = \frac{W_{net}}{\dot{m}_{geo}[(h_{geo} - h_{rej}) - To(S_{geo} - S_{rej})]}$$

Cycle effectiveness can also be used to analyze the efficiency qualitatively as well as quantitatively, based on the effectiveness of heat transfer to the cycle from the hot geo fluid. [27, 28, 33, 36]

$$\varepsilon = \frac{\dot{W}_{net}}{\dot{m}_{geo}[(h_{wf,out} - h_{wf,in}) - To(S_{wf,out} - S_{wf,in})]}$$

Several dimensionless parameters have been used in the literature to assess the performance of individual cycle components, three of these parameters are: [26, 29]

Relative Irreversibility:

$$\varkappa_i = \frac{\dot{I}_i}{\dot{W}_{net}}$$

Productivity Lack:

$$\xi_i = \frac{\dot{I}_i}{\dot{I}_{plant}}$$

Fuel Depletion Ratio:

$$\delta = \frac{\dot{I}_i}{\dot{E}_{xin}}$$

5.3 Mathematical Model Validation

The mathematical model developed in section is validated by comparing the results with published result [29]. Reference conditions used in our calculations are similar to the one used by Mortaza Yari [29] i.e.; ambient pressure 100 KPa, ambient temperature 25°C, Condenser Temperature 40°C, Evaporator Inlet temperature 120°C, geothermal fluid temperature 180°C, pump efficiency 90%, turbine efficiency 80% and pinch point temperature 10°C.

The comparison table exhibits that the results of mathematical model are in concurrence with the reference paper.

Table 2: Model Validation for Simple ORC and ORC with IHE

Performance parameters	Simple ORC using n-Pentane			ORC with IHE using R113		
	Mortaza Yari [29]	Present Work	Relative Error	Mortaza Yari [29]	Present Work	Relative Error
$\dot{W}$net [kJ/kg]	48.57	49.23	1.36%	47.87	48.12	0.52%
$\dot{I}_{plant}$ [kJ/kg]	81.11	80.74	0.46%	82.48	81.85	0.76%
ηI,1 [%]	7.376	7.213	2.21%	7.27	7.051	3.01%
ηI,2 [%]	12.6	12.64	0.32%	14.45	14.29	1.11%
ηII,1 [%]	37.37	37.04	0.88%	36.83	36.2	1.71%
ηII,2 [%]	46.8	47.15	0.75%	51.33	51.14	0.37%
ξ [%]	61.3	61.73	0.70%	65.84	64.6	1.88%

6. ANALYSIS AND RESULTS

6.1 Performance Analysis of Organic Working Fluids

The effects of variation in turbine inlet temperature on several parameters were analyzed at ambient pressure 100 KPa, ambient temperature 25°C, Condenser Temperature 40°C, geothermal fluid temperature 150°C, pump efficiency 90%, turbine efficiency 80% and pinch point temperature 5°C.

All the binary fluids demonstrated nearly similar net power output per unit mass flow rate of geo fluid for the Simple ORC and ORC with IHE, whereas for the regenerative cycles the behavior is quite different. The optimum Turbine Inlet Temperature corresponding to maximum net work output is also elicited from this plot. The comparison of cycles shows that the isobutene exhibits similar net power output for both simple and regenerative cycles, while other refrigerants exhibit significant reduction in power when used with Regenerative Cycles i.e., an average reduction of 27% for R123, 19% for R152a, 45% for n-pentane, 10% for R245fa and 63% for R113.

Table 3: Model Validation for Regenerative ORC and Regenerative ORC with IHE

Performance parameters	Regenerative ORC using R123			Regenerative ORC with IHE usingR123		
	Mortaza Yari [25]	Present Work	Relative Error	Mortaza Yari [25]	Present Work	Relative Error
$\dot{W}_{net}$ [kJ/kg]	43.361	44.13	1.77	44.02	43.88	0.32
$\dot{I}_{plant}$ [kJ/kg]	85.98	85.84	0.16	86.59	86.09	0.58
$\eta_{I,1}$ [%]	6.623	6.466	2.37	6.685	6.429	3.83
$\eta_{I,2}$ [%]	14.52	14.48	0.28	15.35	15.08	1.76
$\eta_{II,1}$ [%]	33.56	33.2	1.07	33.87	33.01	2.54
$\eta_{II,2}$ [%]	50.39	50.64	0.5	52.73	52.2	1.01
ξ [%]	62.67	62.49	0.29	65.41	64.24	1.79

It is also observed that the Net Work Output increases exponentially with increase in geo fluid temperature under sub critical pressure operating conditions and turbine inlet temperature increases linearly with increase in geo fluid temperature.
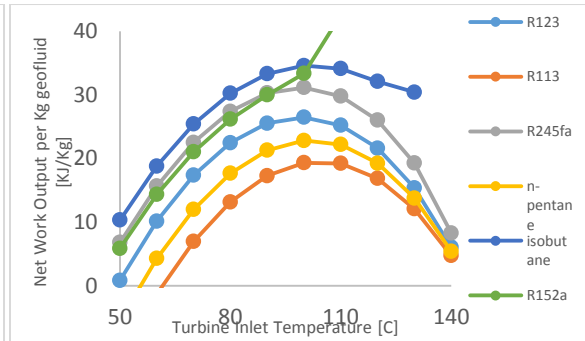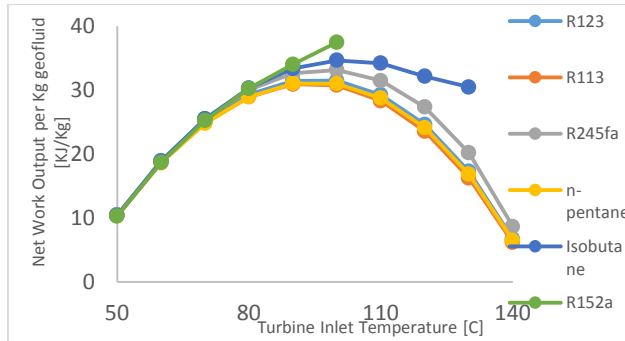

Figure 8: Comparison of net work output for Simple ORC   Figure 9: Comparison of net work output forregenerative ORC

6.1 Performance Analysis of Organic Rankine Cycle Configurations

R245fa has been selected as the reference fluid for the selection of optimum cycle configuration. It is found that the net work output of the ORC does not change by the addition of IHE to simple configuration, however it decreases by 10% on average on addition of Open Feed Organic Heater (OFOH) and by 13% on addition of a combination of OFOH and IHE. It is also observed that the thermal efficiency increases with increase in turbine inlet temperature for all configurations but Simple ORC are more efficient at lower turbine inlet temperatures as the turbine inlet temperature increases the regenerative cycles become more efficient. The lower thermal efficiency is attributed to the large difference in the temperatures of working of fluid and geo fluid in the primary heat exchanger.
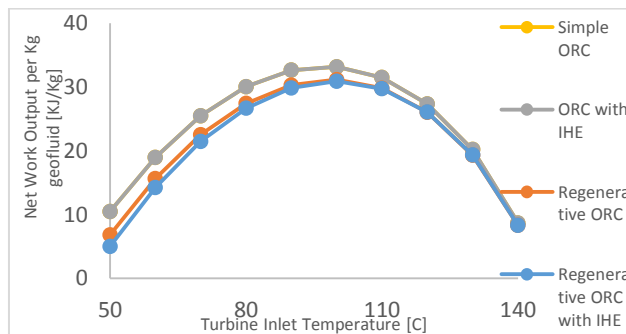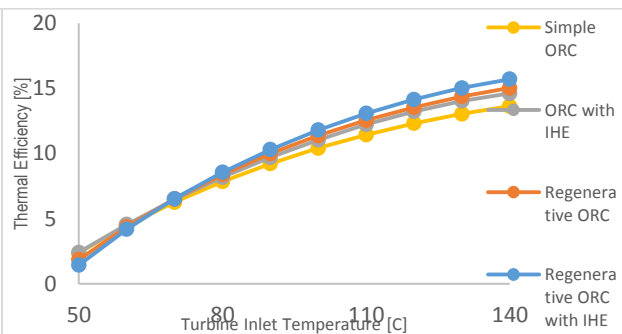

**Figure 10: Comparison of net work output**   **Figure 11: Comparison of thermal efficiency**

On analyzing the effect of change in Turbine Inlet Temperature on First and Second Law Efficiencies based on energy input to the system, it is found that beyond an optimum turbine inlet temperature there is not any substantial increase in the efficiencies. At low turbine inlet temperatures basic ORC exhibits better performance however as the temperatures increase regenerative ORC with IHE becomes most efficient owing to reduction in the irreversibility during the heat transfer processes.
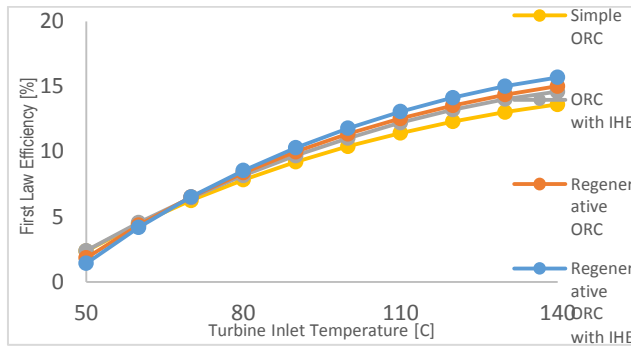
Figure12 : Comparison of 1ˢᵗ law efficiency (I)
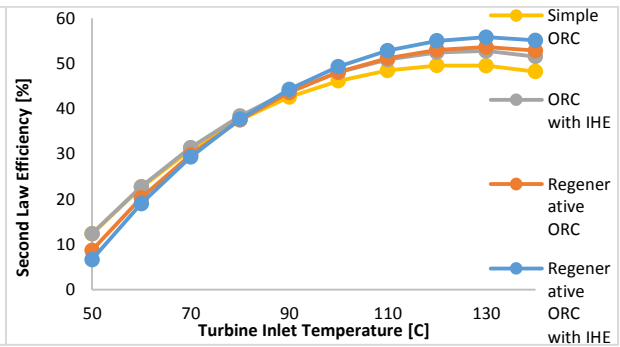
Figure 13: Comparison of 2ⁿᵈ law efficiency (I)

First and second law efficiencies based on geofluid inlet state conditions provides a basis of selection of optimum Turbine Inlet Temperature. Efficiencies based on geofluid inlet state are found to have similar first law efficiency, however the first law efficiency is slightly lower for regenerative cycles at lower temperatures but the difference minimizes with increase in turbine inlet temperature.
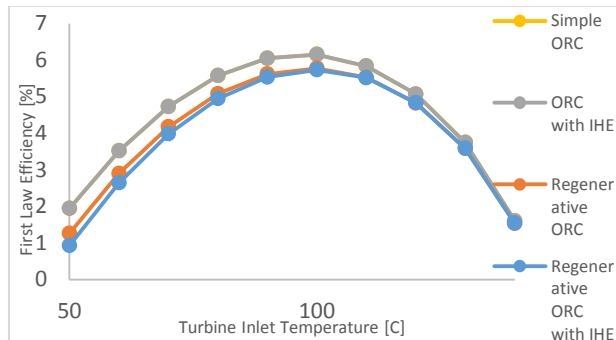
Figure 14: Comparison of 1ˢᵗ law efficiency (II)
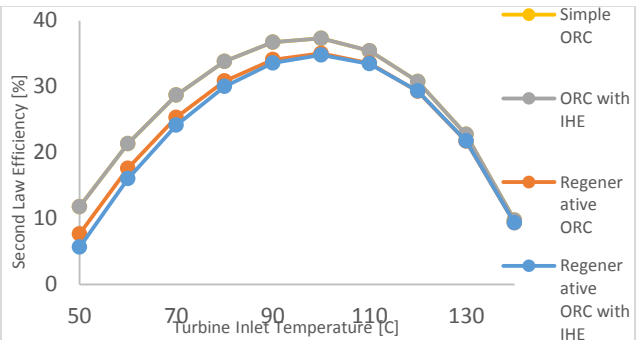
Figure 15: Comparison of 2ⁿᵈ law efficiency (II)

Cycle effectiveness measures qualitatively as well as quantitatively the amount of available energy transferred from the geo fluid to the working fluid. It is observed that beyond a certain optimum temperature, there is no significant increase in cycle effectiveness; furthermore, basic ORC configurations are found to be more efficient at lower temperatures whereas the regenerative ORC with IHE were found most effective at higher temperatures due to reduction in irreversibility in the heat transfer processes.Overall Plant Irreversibility is the sum of exergy loss in all the components of ORC. An optimum turbine inlet temperature can be obtained where the overall plant irreversibility is minimum, maximum First- and Second-law efficiencies also occur at the same point.
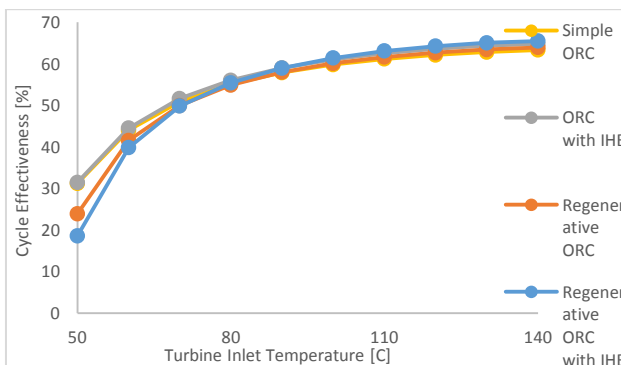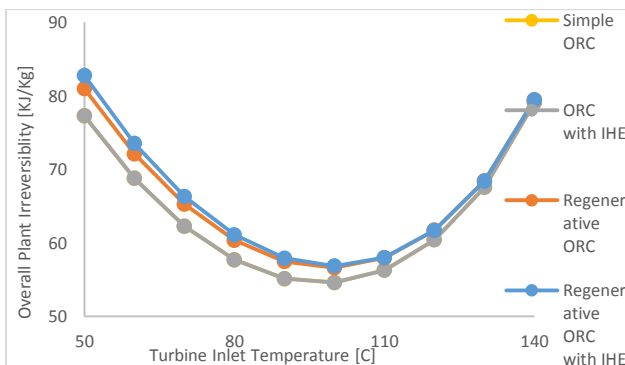

Figure 16: Comparison of Cycle Effectiveness

Figure 17: Comparison of Overall Plant Irreversibility

Fuel depletion ratio is the thermodynamic parameter that measures the ratio of exergy destruction in the individual components to total exergy input to the ORC. The processes involving major exergy destruction were found to be rejection, evaporation, condensation and expansion in turbine. It is also observed that with increase of 10 ºC in turbine inlet temperature, the rejection exergy loss increases by 22% on average for regenerative cycle with IHE, 24% for regenerative cycle, 37% for ORC with IHE and 38% for basic ORC Configuration. However, the exergy destruction in the evaporator is reduced by 20% on average; the exergy loss in the condenser is reduced by 15%-18% on average.
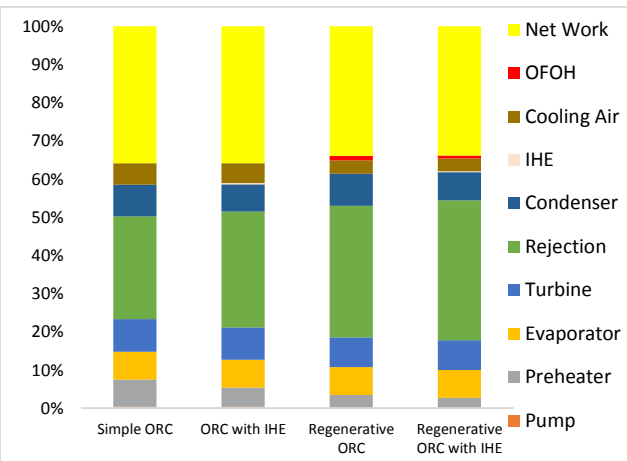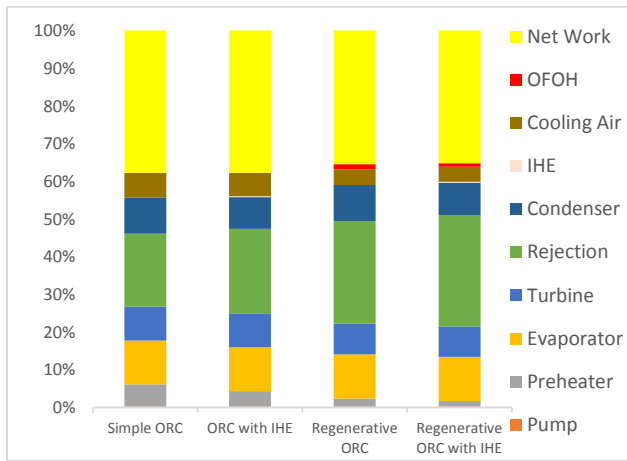
Figure 18: Comparison of Fuel depletion ratio at T_{turbine in}=100ºC **Figure 19: Comparison of Fuel depletion ratio at T$_{turbine}$$_{in}$=110ºC**

Relative irreversibility is the ratio of individual plant component irreversibility to the overall plant irreversibility. The addition of IHE to basic configuration resulted in a substantial decrease in relative irreversibility of the preheater and evaporator. The relative irreversibility of the preheater evaporator unit and condenser are reduced by 28% and 11% on average respectively. The addition of OFOH to a basic ORC results in substantial reduction in relative irreversibility of all the components of ORC particularly 65% on average for Preheater Evaporator Unit, 25% on average for pumping system, 14% on average for Turbine and 37% on average for Condenser and cooling air. The addition of a combination of OFOH and IHE to a basic ORC results in substantial reduction in relative irreversibility of all the components of ORC particularly 78% on average for Preheater Evaporator Unit, 61% on average for pumping system, 17% on average for Turbine and 41% on average for Condenser and cooling air. However, these reductions in relative irreversibility is quelled by the increase in rejection exergy loss, which increase by 9% , 25% and 33% on average on addition of IHE, OFOH and a combination of OFOH and IHE respectively.
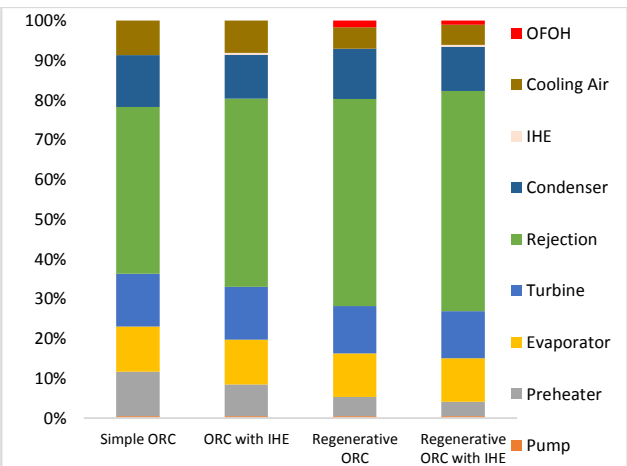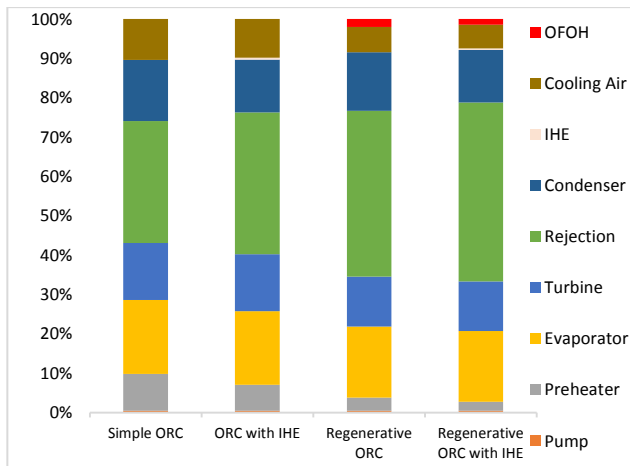

Figure 20: Comparison Relative irreversibility at T_{turbine in}=100ºC Figure 21: Comparison of Relative irreversibility at T_{turbine in}=110ºC

Productivity lack is another parameter used in research to measure the Exergy Destruction in the individual component in relation to net work output per Kg of geo fluidIt is observed that with increase of 10 ºC in turbine inlet temperature, the productivity lack in the pump reduces by 16% on average, productivity lack in the pre heater reduces by 30-33% on average for Basic ORC and 48%-57% for regenerative cycles. However, the productivity lack of the evaporator is increased by 37% on average; the productivity lack of the condenser is increased by 7%-9% on average.The addition of IHE to basic configuration resulted in a substantial decrease in productivity lack of the pre heater and condenser. The productivity lack is reduced by 29% on average and 15% on average for the pre heater and condenser respectively which is very low as compared to the increase in overall productivity lack due to addition of IHE. The addition of OFOH to a basic ORC results in substantial reduction in productivity lack of the pre heater. The productivity lack of the pre heater is reduced by 53% on average which is very low as compared to the increase in overall productivity lack due to addition of IHE and 4% on average increase in productivity lack of condenser. The addition of a combination of OFOH and IHE to a basic ORC results in substantial reduction in productivity lack of the pre heater. The productivity lack of the pre heater is reduced by 64% on average which is very low as compared to the increase in overall productivity lack due to addition of OFOH and IHE. The addition of a combination of OFOH and IHE to a basic ORC also results in marginal reduction by 6% in productivity lack of the condenser.
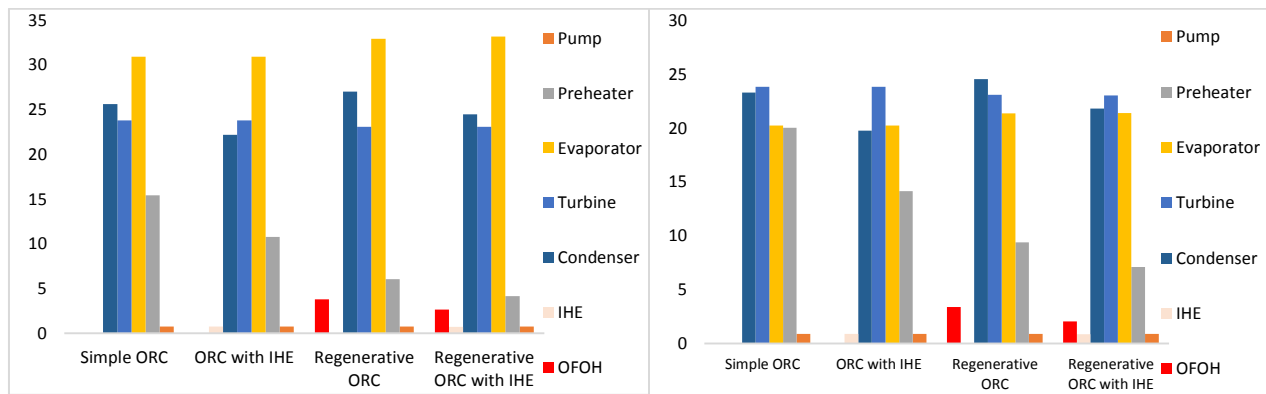
Figure 22: Comparison of Productivity lack at $T_{turbine\ in}$=100ºC Figure 23: Comparison of Productivity lack at $T_{turbine\ in}$=110ºC

7. CONCLUSION

This work presents an analysis of possibilities of exploiting geothermal energy resources in Pakistan and addresses the idea of power generation from geothermal energy sources in Pakistan. It encompasses energy and exergy analysis and performance optimization of different configurations ofOrganic Rankine Cycle Power Plants using different binary working fluids with geo fluid temperature of 150ºC for the available geothermal resources in the Pakistan are moderate to low temperature, water dominated resources. It is concluded that the binary fluids with higher boiling point temperature or lower specific heat capacity have relatively lower optimum turbine inlet temperature corresponding to maximum work output. Therefore, higher boiling point organic working fluids are recommended for Simple ORC configurations, whereas organic working fluids with lower vapor specific heat capacity are recommended for Regenerative ORC.

Optimal operating conditions corresponding maximum cycle output and efficiencies and minimum overall plant irreversibility were elicited by analyzing the variations of these parameters with Turbine Inlet Temperature. The increase in geothermal fluid temperature results in an exponential increase in maximum cycle output and a linear increase in turbine inlet temperature. The addition of an IHE and/or an OFOH improved significantly the effectiveness of the ORC by reduction in irreversibility in the heat transfer processes, therefore it is recommended to use Regenerative ORC with IHE. The processes involving major Exergy destruction were found to be rejection, evaporation, condensation and expansion in turbine. The addition of OFOH and IHE to a simple ORC results in substantial reduction in fuel depletion ratio, relative irreversibility and Productivity lack of the processes involving major Exergy destruction.

REFERENCES

[1] IEA 2013, Key World Energy Statistics 2013.

[2] IEA 2013, CO2 Emissions from Fuel Combustion Highlights 2013.

[3] IEA 2013, World Energy Outlook 2013, Renewable Energy Outlook 2013, Chapter 6, p192-232

[4] Ministry of Petroleum and Natural Resources, Hydrocarbon Development Institute of Pakistan 2013, Pakistan Energy Year Book 2012 p81-91

[5] Muslim M, Das B. A preliminary report on suitable springs for bottling mineral water in Sindh and part of Baluchistan.Geological Survey of Pakistan 1988; p304-12.

[6] Shuja TA. Geothermal areas in Pakistan.Geothermics 1986; 15: 719–23.

[7] Arthurton RS, Farah A, Ahem W. The late Cretaceous-Cenozoic history of western Baluchistan, Pakistan, the northern margin of the Makran subduction complex. In: Leggett JK, editor. Trench-fore arc geology (Special Publication 10).London, 1982. p. 373–85.

[8] Arthurton RS, Alam GS, Ahmed A, Seed I. Geological history of the Alamreg-MashkiChah area, Chagai District, Baluchistan. In: Farah A, DeJong KE, editors. Dynamics of Pakistan. Quetta: Geological Survey of Pakistan; 1979. p. 325–31.

[9] Muslim M. Koh-e-Sultan sulphur evaluation. GSP Report—5, vol. 21, Baluchistan, Pakistan, 1972. 8pp.

[10] HSC. Reconnaissance geology of part of West Pakistan: Colombo Plan Cooperative project for Government of Pakistan. Government of Canada, 1960. 550pp.

[11] 'Joint Programme on Geothermal Energy' of the Europe's Energy Research Alliance (EERA), TNO ThermoGIS, http://www.thermogis.nl/worldaquifer.html

[12] Armstead HC. Geothermal energy. London: Spon Ltd.; 1979.

[13] Eickhoff G, Alam S. On the petroleum geology and prospectivity of Kirthar range, Kirthar depression and Sibi trough, southern Indus basin, Pakistan. Islamabad: Hydrocarbon Development Institute of Pakistan; 1991.

[14] Kazmi AH. Active fault systems in Pakistan. In: Farah A, Dejong KA, editors. Geodynamics of Pakistan. Quetta: Geological Survey of Pakistan; 1979. p. 286–94.

[15] Oldham T. Thermal springs of India. GeolSurv India Mem1882; 19(2):63.

[16] Bakr MA. Thermal springs of Pakistan.GeolSurv Pak Rec 1965; 16:3–4.

[17] Zaigham NA. Belaophiolites and associated mineralizations in southern part of axial-belt of Pakistan.PhD thesis, University of Karachi, 1991.

[18] Khan MA, Raza HA. Role of geothermal gradients in hydrocarbon exploration in Pakistan. J Petro Geol 1986; 9(3):245–58.

[19] Zaigham NA, Ahmed M, Hissam N. Thar-rift and its significance for hydrocarbon. Special Publication of SPE & PAPG, 2000. p. 117–30.

[20] Calkins JA, Jamiluddin S, Bhuyan K, Hussain A. Geology and mineral resources of Chitral-Partsan area, Hindu Kush Range, northern Pakistan. USGS Paper, vol. 716-G, 1981. 33pp.

[22] Shuja TA, Khan AL. Prospects of geothermal energy in Pakistan. GSP Info Rel 1984; 242. 22pp.

[23] Shuja TA, Sheikh MI. A study of geothermal resources of Gilgit and Hunza agencies, northern Pakistan.GeolSurv Pak Info Rel 1983; 179. 22pp.

[24] Todaka N, Shuja TA, Jamiluddin S, Khan NA, Pasha MA, Iqbal M. A preliminary study of geothermal energy resources of Pakistan.GSP Info Rel 1999; 407. 93pp.

[25] Quittmeyer RC, Farah A, Jacob KH. The seismicity of Pakistan and its relation to surface faults. In: Farah A, Dejong KA, editors. Geodynamics of Pakistan. Quetta: Geological Survey of Pakistan; 1979. p. 271–84.

[26] Hepbasli, A 2008, 'A key review on exergetic analysis and assessment of renewable energy resources for a sustainable future', Renewable and Sustainable Energy Reviews, vol. 12, pp. 593-661.

[27] Subbiah, S & Natarajan, R 1988, 'Thermodynamic analysis of binary-fluid rankine cycles for geothermal power plants', Energy Conversion and Management, vol. 28, no. 1, pp. 47-52.

[28] DiPippo, R 2004, 'Second Law assessment of binary plants generating power from low temperature geothermal fluids, Geothermics, vol. 33, no.1, pp. 565–86.

[29] Yari, M 2010, 'Exergetic analysis of various types of geothermal power plants', RenewableEnergy, vol. 35, no. 1, pp. 112-121.

[30]DiPippo, R 2008, Geothermal power plants principles, applications, case studies and environmental impact, Butterworth-Heinemann, London.

[31] Saleh, B, Koglbauer, G, Wendland M & Fischer, J 2007, 'Working fluids for low temperature organic Rankine cycles', Energy, vol. 32, no. 7, pp. 1210-1221.

[32] Calm, JM &Hourahan, GC, 2001, 'Refrigerant Data Summary', Engineered Systems, vol.18, no. 11, pp. 74-88.

[33] Calm JM, Hourahan GC, 2011. "Physical, Safety, and Environmental Data for Current and Alternative Refrigerants," Refrigeration for Sustainable Development (proceedings of the 23rd International Congress of Refrigeration (ICR 2011, Prague, Czech Republic, 2011.08.21-26), International Institute of Refrigeration (IIR/IIF), Paris, France

[34] Kanoglu, M &Bolatturk, A 2008, 'Performance and parametric investigation of a binary geothermal power plant by exergy', Renewable Energy, vol. 33, no. 1, pp. 2366–74.

[35] Aljundi, IH 2011, 'Effect of dry hydrocarbons and critical point temperature on the efficiencies of organic Rankine cycle', Renewable Energy, vol. 36, no.1, pp. 1196-1202.

[36] Bejan, A 1993, Heat transfer, Wiley, New York.

[37] Kanoglu, M 2002, 'Exergy analysis of a dual-level binary geothermal power plant', Geothermics, vol. 31, no. 1, pp. 709-724.