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PROTECTION OF CONDENSATE REINJECTION WELLS BY PH MANAGEMENT. A CASE STUDY OF OW-710C AND LAKE NGARE CONTAINMENT POND

Calyst Kitimo and Martin Opiyo

ckitimo@kengen.co.ke, MOdhiambo2@kengen.co.ke

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ABSTRACT

Currently Kengen Olkaria hosts five major power plants with several wellhead units that utilize the geothermal steam to generate power. These plants have single flash condensing turbines type with enormous condensate volumes per hour being reinjected into the cold reinjection wells. Separation of two phase fluids from the production wells also result in several tones of brine being re-injected into the hot reinjection wells which in turn recharges the reservoir. Once the steam has driven the turbines it is condensed in the condenser by spraying cold water and further cooled at the cooling towers with part of it being re-injected and some maintained as circulating cooling water component. The pH of the condensed steam (condensate) is usually very low, (pH~2.5-3.0) due to the dissolution of gases such as carbon dioxide (CO_2,), Hydrogen Sulphide (H_2S) and Sulphur Dioxide (SO_2), this brings about acidic environment that results in corrosion of carbon steel pipe works, cold re-injection wells master valves and the casing in the wells. The brine pH is alkaline in the pH range of (8 -10). Currently, Soda Ash is used to adjust the condensate pH from (2.5 – 3.0) to a desirable 6.0-8.0 for condensate re-injection purposes and also to accommodate the pH range for Biocides efficacy. There are also considerations to adopt the use of Caustic Soda (NaOH) as an alternative to condensate pH adjustments. The current dosing plan for the Olkaria Power Plants seems to have several challenges ranging from pump breakdowns and lack of spares, soda ash stock outs and manual solution preparations which faces manpower issues and long stoppage of dosing. As a result, six cold reinjection wells have been lost and new wells drilled for the condensate reinjection in the Olkaria field. This proposal seeks to find a local solution based on the resources available and minimize on operational cost by mixing brine from wells and condensate from power plants at proportions capable of adjusting the pH to a neutral range before reinjection. Two potential mixing sites have been identified as a case study. Olkaria well OW-710C which is a condensate reinjection well for Olkaria II power station and Brine from well OW-710. Lake Ngare Brine (OW-39, 37) and OIAU overflow condensate containment pond will be used to simulate the behaviour of the mixing tendencies before reinjection at well OW-R12. Expected benefits include saving cold re-injection wells from the frequent corrosion and leaks, improve on the re-injection efficiency and prevent condensate drain into the ponds due to low pH hence sustaining the reservoir. Reduce operational cost on drilling new reinjection wells, soda ash consumptions, repairs and maintenance as a result of corroded pipe works, pumps and other auxiliaries.

1.0. INTRODUCTION

Geothermal energy refers to the heat energy that emanates from beneath the earth's crust. For Olkaria, geothermal projects follow a carefully crafted exploration and development program. The scientific exploration methods quickly and at moderate cost assess vast potential areas that are then studied in detail followed by drilling to confirm the resource. During drilling of geothermal wells, they are classified into categories of production, make-up or cold/hot re-injection wells. These vary in depths as per their uses. Production wells give out the steam to be utilized by the power plants both conventional and binary. They range from 2000m to 3000m deep. Make-up wells are drilled and put on standby just in case online wells collapse. Hot re-injection wells are used to get the brine after separation from steam back to the reservoir. Cold re-injection wells get back the fluids from power plant cooling towers and condensate Drain Pots (CDP's) to the reservoir. They are fairly shallow and range from 1000m to 2000m deep and mostly drilled away from the production zone to avoid cold front breakthrough. Conventional geothermal power plants convert high temperature and pressure steam to electricity. When heat and pressure are utilized from the steam the power plant blowdown (condensate) which is acidic in nature is taken back to the reservoir through cold re-injection wells. Brine which is alkaline in nature, after separation from steam is also taken back to the reservoir through hot re-injection wells. The mixing of condensate and brine at specific quantities to adjust the fluids pH, dissolved solutes through dilutions and temperatures before reinjection will protect the infrastructure and well casing. The brine has a high solute saturation state after steam phase extraction thereby leading to increased scaling potential from silica and calcite, *Bonyo E. Brine and Condensate mixing for scaling control, United Nations University-Geothermal Training Programme (UNU-GTP), Report No. (2018*). Steam condensate has very low solute content but with low pH as a result of dissolved gases. When these two fluids are mixed, there will be brine solutes content dilution which will reduce the silica scaling potential in the brine. The condensate pH will be adjusted to neutral status thereby reducing the condensate corrosion potential as well. A schematic diagram for a single flash condensing turbine power plant is shown in Figure 1 below.

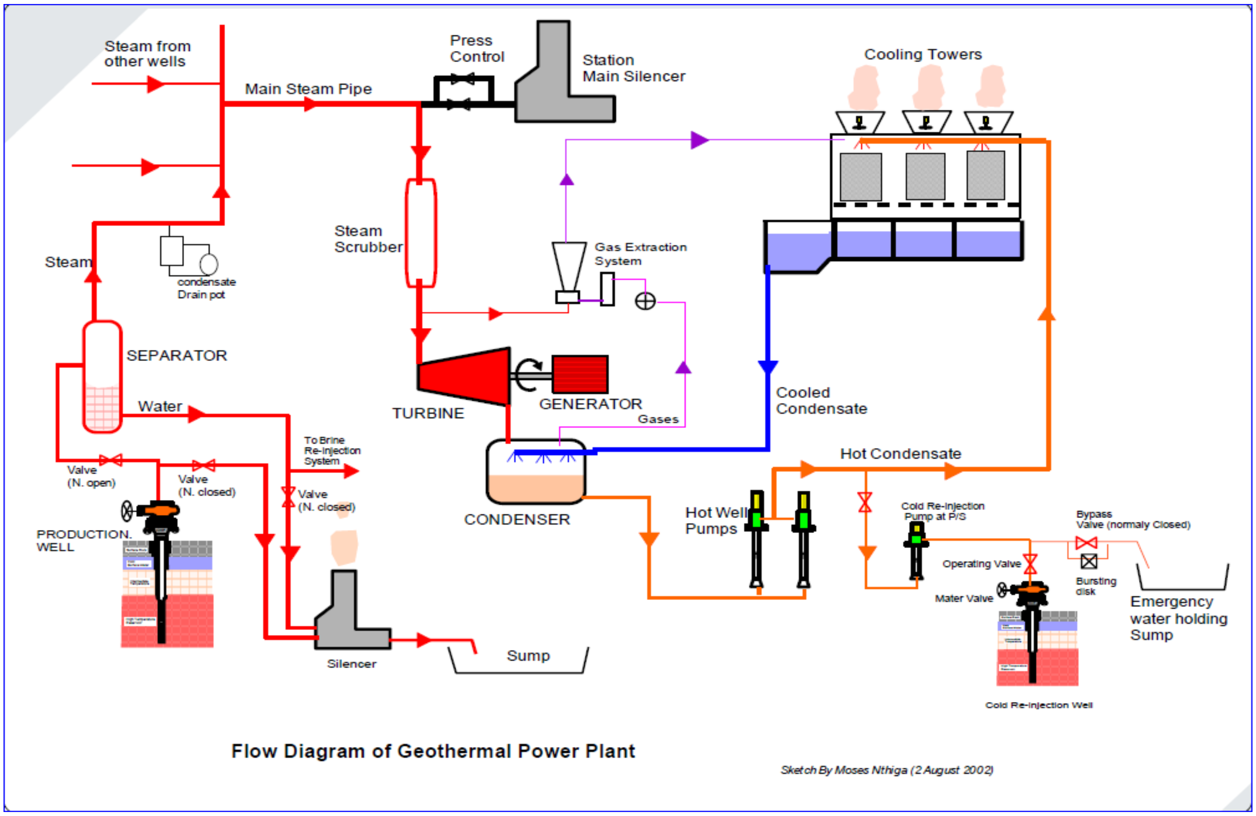


Figure 1. Schematic diagram for single flash condensing turbine power plant

2.0. DEVELOPMENT PLANNING AND DECISION MAKING

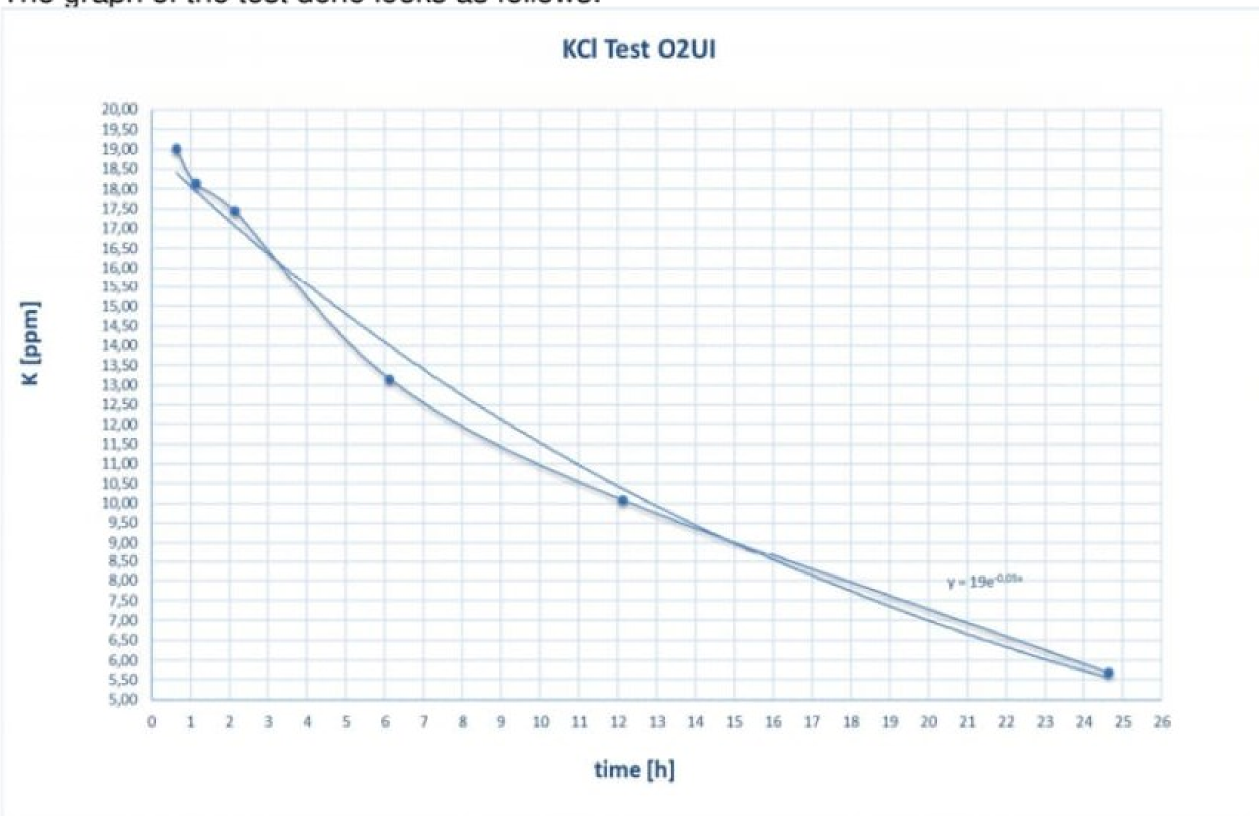
After confirmation of the potential of mass flow output of the wells through discharge tests and condensate from power plants, the field developer will have to decide and plan for its utilization. The utilization of these fluids is mainly dependent on the temperatures, pressures, pH, amount of fluids discharge (condensate and brine in t/hr) from the wells and the plants. In this case study the best cold re-injection wells are the ones that are permeable with ambient or moderate pressures and temperatures with depths not exceeding 1500m. This is because beyond this depth we are likely to encounter the production aquifers which can result to cold front breakthrough of the reservoir. To estimate the condensate produced from the power plants, a water balance test was conducted for the Olkaria II and IAU power plants. The results of this test are shown in Figure 2 below. These tests were conducted to estimate the losses of water from the cooling water circuit through the cooling towers and the condensate blowdown.

2.1. OLKARIA II WATER BALANCE TEST (KCL) FOR SYSTEM VOLUME ESTIMATES.

The results of the test done at Olkaria 2, unit 1 are as follows:

date		time [h]	K [ppm] corrected	K [ppm] results			Graphical		Calculated
12-4-2022	09:55	0,00		0,16					
	10:33	0,63	19,02	19,17					
	11:03	1,13	18,13	18,29	Average Max				
	12:03	2,13	17,44	17,60	19,017	Dosage:	50	kg KCl	
	16:03	6,13	13,16	13,31		Holding volume:	1324	m^3	
	22:03	12,13	10,09	10,24		Total Blowdown:	66,18	m^3/h	65,18 m^3/h
13-4-2022	10:33	24,63	5,70	5,85		$t_{1/2}$:	13,86	h	14,21 m^3/h
						t_R	–	-	20,31 m^3/h

The graph of the test done looks as follows:



From the water balance test, we can conclude as follows:

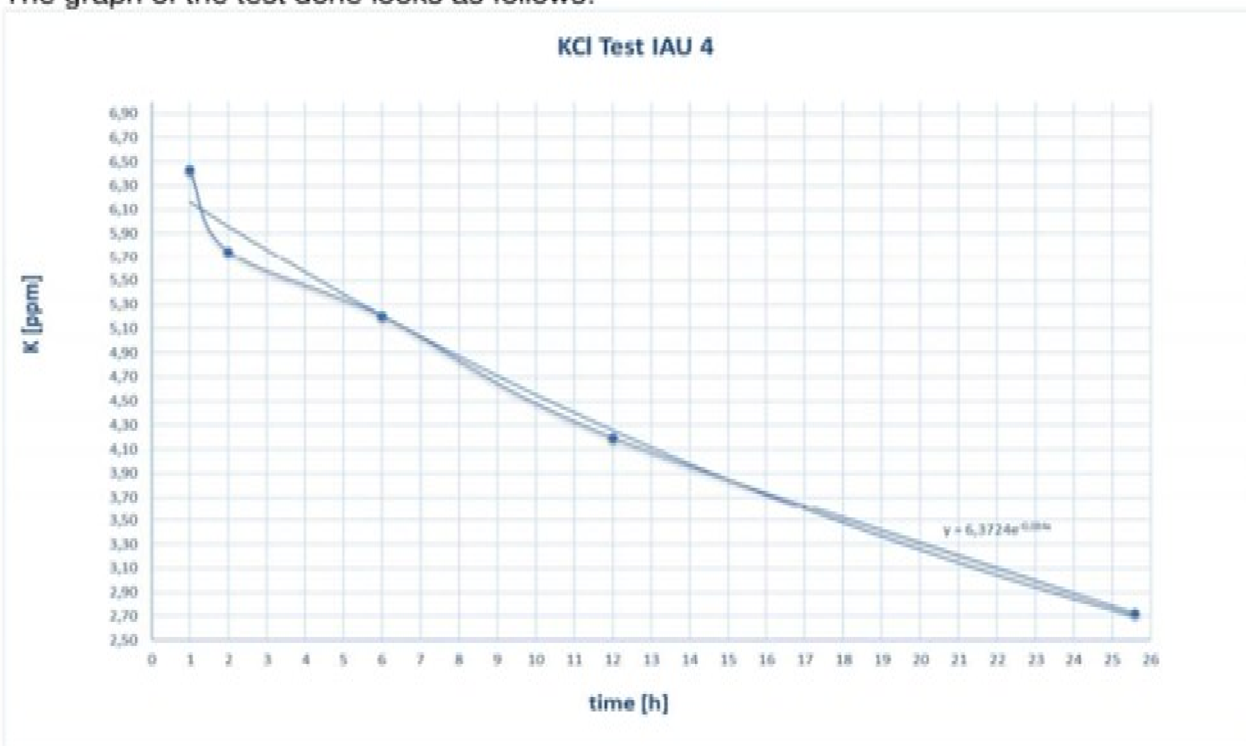
- Holding volume = 1324 m^3
- Water losses = 65 m^3/h

2.2. OLKARIA I ADDITIONAL UNIT IV WATER BALANCE TEST (KCL) FOR SYSTEM VOLUME ESTIMATES.

The results of the test done at Olkaria 1au, unit 4 are as follows:

date		time [h]	K [ppm] corrected	K [ppm] results				
11-4-2022	10:45	0,00		0,14				
	11:15	0,50	6,10	6,24				
	11:45	1,00	6,43	6,58	**Average Max**		**Graphical**	***Calculated***
	12:45	2,00	5,75	5,89	6,433	**Dosage:**	50 kg KCl	
	16:45	6,00	5,20	5,34		**Holding volume:**	3913 m³	
	22:45	12,00	4,20	4,34		**Total Blowdown:**	133,03 m³/h	*137,06 m³/h*
12-4-2022	12:20	25,58	2,72	2,86		**$t_{1/2}$:**	20,39 h	*19,98 m³/h*
						t_R	– -	*28,55 m³/h*

The graph of the test done looks as follows:



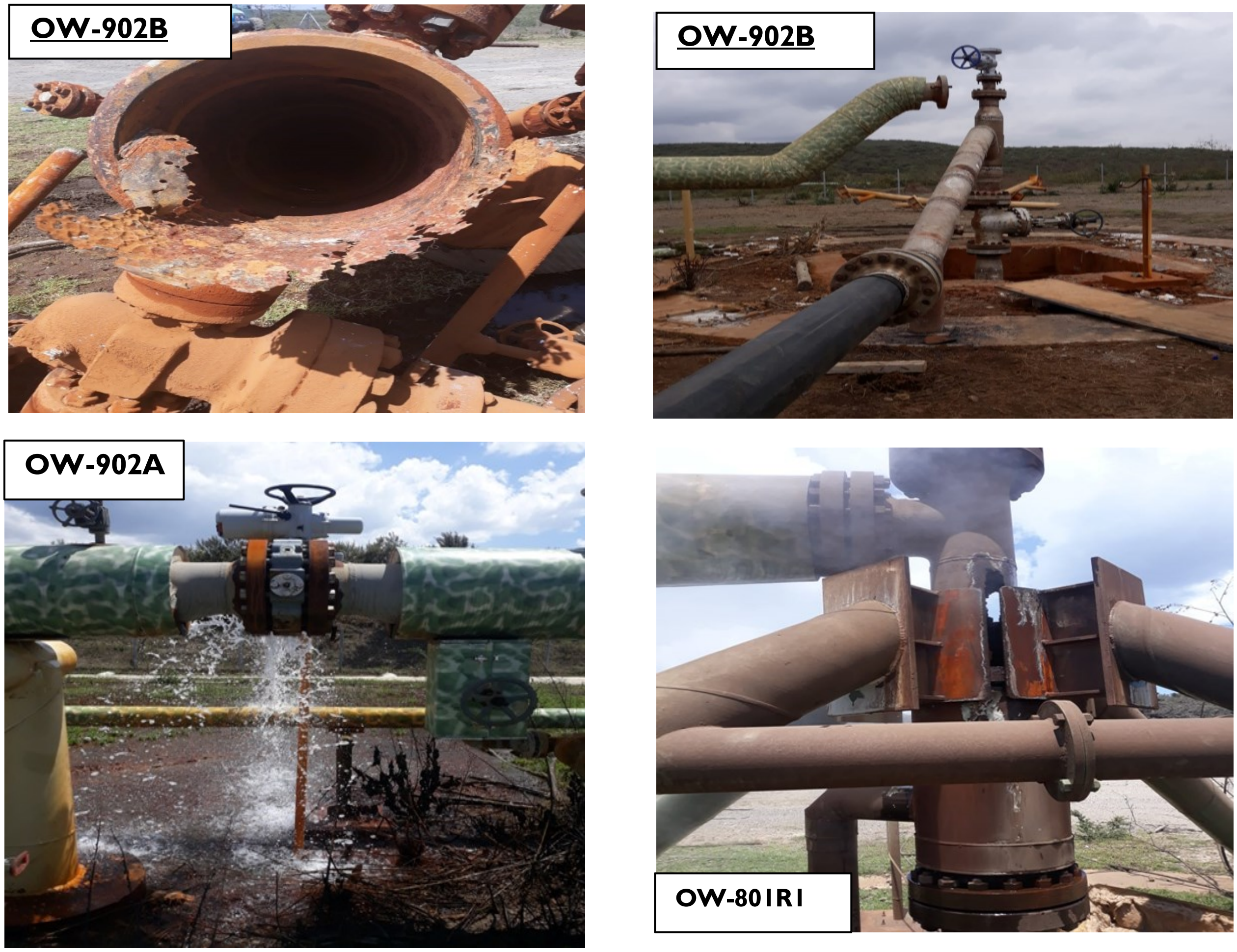
From the water balance test, we can conclude as follows:

- Holding volume = 3913 m³
- Water losses = 135 m³/h

From both the system design values and the water balance tests, Olkaria II condensate amount to an average of 65 t/h from each unit. This translates to 195 t/h of blowdown for the three units. Olkaria IAU average condensate blow down discharge rate amounts to 135 t/h per unit, this translates to 270 t/h for units IV and V. Unit VI blowdown discharge rate stands at 119 t/h. This translates to a total condensate output of 390 t/h from all the three units at Olkaria IAU power plant.

3.0. CURRENT SITUATION AND CHALLENGES

The current dosing plan seems to have several challenges ranging from pump breakdowns, lack of spares, soda ash stock outs, manual solution preparations which suffers manpower issues and long stoppage of the dosing. As a result, acidic condensate is re-injected into the condensate reinjection wells. Consequently, six condensate reinjection wells have been lost due to corrosion. Alternative reinjection wells have been drilled and wells that are no longer productive have been converted to reinjection wells. There is an eminent possibility of losing these new wells if no mitigation measures are taken to correct the low pH situation of the condensate.



Pictures showing the effects of low condensate pH on the condensate re-injection wells.

4.0. BRINE AND CONDENSATE MIXING PROCESS AND REQUIREMENTS

The mixing process require continuous brine flow from a separator station facility which discharges into a weir box. From the weir box, the brine flows by gravity into a pipe line which joins the condensate pipe line from the power plant. This junction can be positioned slightly some few meters from the reinjection well wellhead to enable proper mixing of the two fluids before getting into the well. This is the mixing process at OW-710 C with brine weir flow from well OW-710 and condensate from Olkaria II power plant. (A figure or sketch showing brine and condensate stream at some mixing front can illustrate this better). As for the Lake Ngare brine and condensate containment pond, the two fluids are mixed by a pumping process. The pond is divided into two i.e. Brine pond and Condensate pond, a pump is positioned at the middle with two suction pipes positioned in the two ponds to feed the reinjection line with the mixture into OW-R12. Since these reinjections well are located at lower elevations from the brine feed points, there is an advantage of a guaranteed continuous brine flow into the well. Condensate feed might be interrupted due to low basin levels and pumps breakdown or during scheduled annual and emergency shut downs.

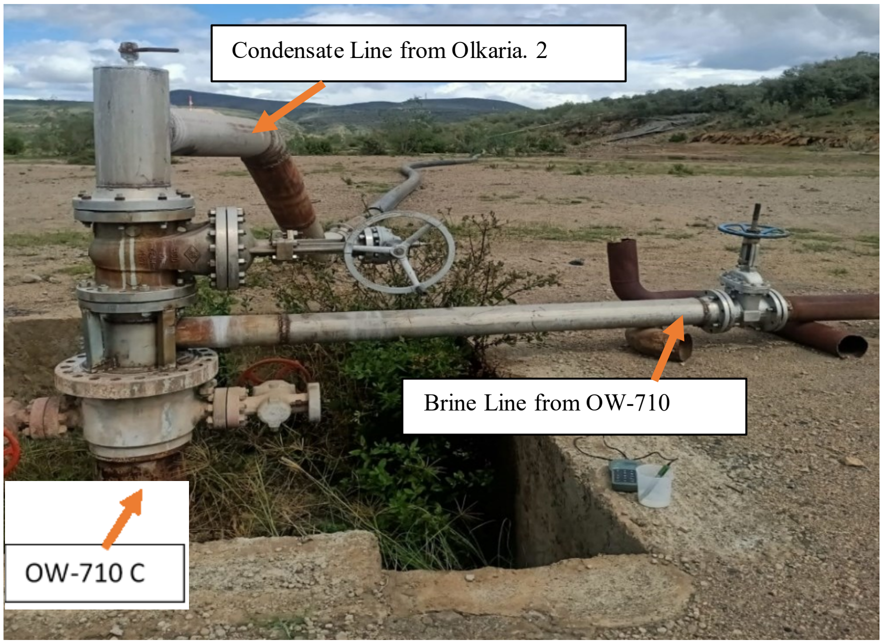


Figure 4. Configuration of brine – condensate mixing at OW-710C Cold reinjection well.

4.1. FACTORS TO BE CONSIDERED IN THE MODELLING AND MIXING DESIGNS.

The system design parameters such as the condensate blowdown discharge quantities at full load and at minimum will be considered in the mixing design. The desired pH range (6 -7) will be the guiding factor and in case there will an intermittent or no condensate flow then its pure brine that will be re-injected.

A SUMMARY OF WELLS PROFILE, BRINE AND PLANTS CONDENSATE QUANTITIES.

	OW-710C	**OW-R12**	**OW-710**	**OW-37, 37A 37B**	**OW-39, 39D**	**Olkaria II Condensate Reinjection Discharge rate per Unit. (Units I, II&III)**	Olkaria IAU **Condensate Reinjection Discharge rate (Units IV, V&VI)**
Depth	3100 m	-				Condensate	Condensate
Brine quantity(t/h)	Cold reinjection wells	Cold reinjection wells	6.3 t/h	23.4 t/h	43.67 t/h	Condensate	Condensate
Condensate quantity(t/h)	Cold reinjection wells	Cold reinjection wells	Brine	Brine	Brine	40 t/h -70 t/h Per Unit Total: 195 t/h	Unit IV & V 270 t/h Unit VI 119 t/h Total: 390 t/h
Temperature			90^{O} C	25^{O} C	25^{O} C	45 – 50 ^{O} C	45 – 50 ^{O} C

pH Data and Mixing ratios

Date	Sampling Point	pH	Temperature
18-July-23	Lake Ngare Brine side (OW-37/39)	10.10	21 ^{O} C
	IAU Condensate (Lake Ngare Condensate pond)	4.465	23 ^{O} C
	OW-710 Brine	9.66	40.2 ^{O} C
	Olkaria II Condensate unit III	2.98	31 ^{O} C
20-July-23	Lake Ngare Brine side (OW-37/39)	9.952	23.5 ^{O} C
	IAU Condensate (Lake Ngare Condensate pond)	4.449	26.7 ^{O} C
	OW-710 Brine	9.632	40.6 ^{O} C
	Olkaria II Condensate unit III	3.01	30.6 ^{O} C
13-Oct-23	Lake Ngare Brine side (OW-37/39)	9.922	29.2 ^{O} C
	IAU Condensate (Lake Ngare Condensate pond)	2.923	43.4 ^{O} C
	OW-710 Brine	9.529	39.4 ^{O} C
	Olkaria II Condensate unit III	2.639	30.8 ^{O} C

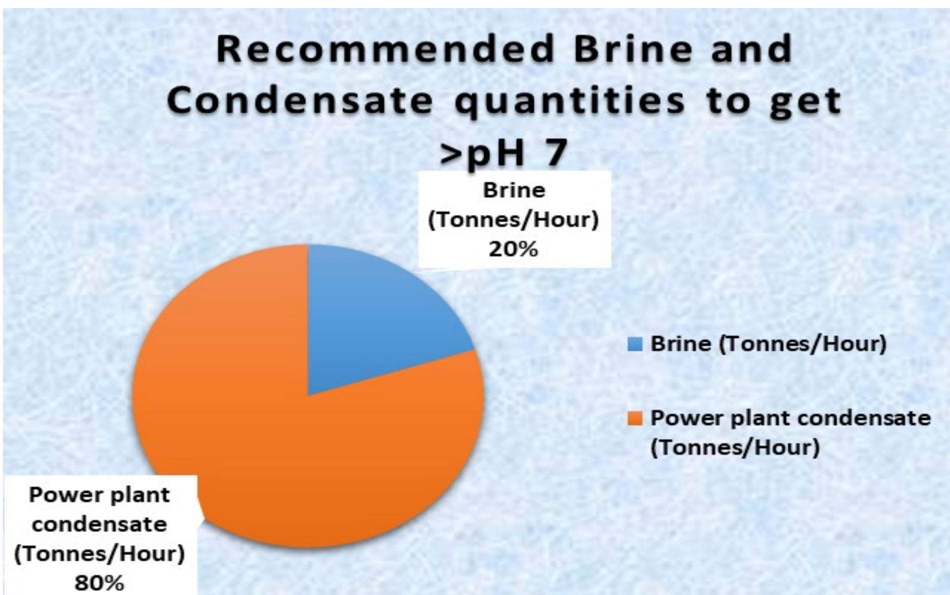
THE MIXING RATES AND QUANTITIES AT OW-710 C AND R12 REINJECTION WELLS

OW-710 Brine	Olkaria II Condensate	pH	Temperature
1000 mL	0 mL	9.98	25 ^{O} C
900 mL	100 mL	9.91	25 ^{O} C
800 mL	200 mL	9.9	25 ^{O} C
700 mL	300 mL	9.88	25 ^{O} C
600 mL	400 mL	9.81	25 ^{O} C
500 mL	500 mL	9.67	25 ^{O} C
400 mL	600 mL	9.52	25 ^{O} C
300 mL	700 mL	9.34	25 ^{O} C
200 mL	800 mL	7.89	25 ^{O} C
100 mL	900 mL	3.59	25 ^{O} C
0 mL	1000 mL	3.11	

Table 1. Showing the brine and condensate mixing ratios at OW-710C.

OW-37/39 Brine	Olkaria IAU Condensate	pH
100 mL	0 mL	10.29
90 mL	10 mL	10.23
80 mL	20 mL	10.19
70 mL	30 mL	10.12
60 mL	40 mL	10.04
50 mL	50 mL	9.92
40 mL	60 mL	9.75
30 mL	70 mL	9.48
20 mL	80 mL	8.78
10 mL	90 mL	4.13
0 mL	100 mL	2.92

Table 2. Showing the brine and condensate mixing ratios at Lake Ngare Containment pond.



A graph showing the recommended percentage brine and condensate mixing ratios.

5.0. PROPOSED REINJECTION PLAN AND CONFIGURATION

The reinjection plan is to have a containment pond or tank with compartments to provide enough time for mixing. There will be an online pH and temperature sensors that will log in the readings. The reinjection is preferred to happen by gravity hence no need for pumping system, however, where necessary and depending on the elevations, there will be a need to boost the reinjection pressures by a pump.

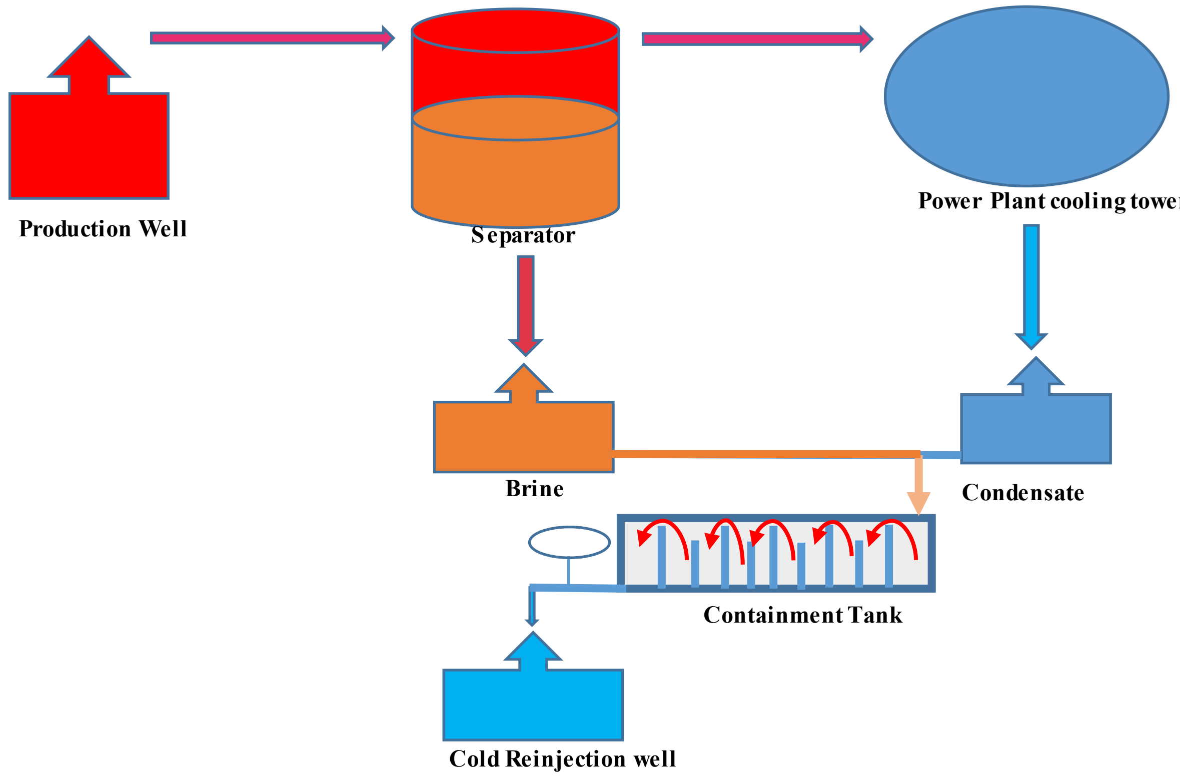


Figure 5: The proposed mixing of brine and Condensate configuration

6.0. COST BENEFIT ANALYSIS

Item	**Quantity/Number of Staff**	**Overtime incurred**	**Number of times OFF Duties.**	**Duration (Months)**	**Total Approx. Cost incurred in USD**
Cost of Drilling a well					USD 5,000,000
Soda ash (Olkaria II & IAU)	6 tones/day*23,5788-*30*12			12	USD 390,000
Pumps repairs, Welding, Wells repairs. (Welders, welding rods, fuel, pipes and valves)	4 welders and fitters. Material cost.	30,000@ 500,000	4	6	USD 5,500 USD 3,850
Other Resources; (Transportation, Auxiliary plant maintenance cost etc.)				12	USD 1550
TOTAL COST					**USD 5,400,900**

6.1. PROJECT REQUIREMENTS

ITEM	QTY	AMOUNT
Holding Tank/Pond (Capacity $30M^3$)	1 PC	USD 3,850
Online pH Sensors	2 PCS	USD 385
Pipes & Connections		USD 1,925
Cost of installation		USD 1,550
TOTAL COST	**USD 7,710**	

Project implementation period will be 6 months.

7.0. CONCLUSION

There is a need to take counter measures to mitigate the effects of corrosion in our cold reinjection wells infrastructure and power plants circulation and auxiliary facilities. Brine and condensate mixing is a viable process that can greatly impact positively to manage condensate pH. This process will utilize the already available resources and skills to be fully implemented and operational.

The benefits that will come with the implementation of this project would include:

Minimal shutdowns hence improved revenue

Reduction on operation cost.

Saving on the cost of drilling new cold reinjection wells.

Reduced environmental and social conflicts.

Continuous reinjection hence sustainable geothermal resource.

8.0. RECOMMENDATION

The project strongly emphasizes on pH management of cold reinjection wells through mixing of brine and condensate. It also reinforces the principles of reinjection as a sustainable means for our geothermal resource utilization. This will ensure that our cold re-injection wells will be safe and functional with a well replenished reservoir.

REFERENCES

1. *Bonyo E. Brine and Condensate mixing for scaling control, United Nations University-Geothermal Training Programme (UNU-GTP), Report No. (2018*)
2. *Steam field well connection and operation data.*
3. *Kengen -Reservoir Section Mass flow data.*
4. *Olkaria Power Plant Chemistry pH Data (2016 – 2024).*
5. *Olkaria IAU Geothermal Power Project Maintenance Manual System – Circulating water*
6. *Olkaria II Geothermal Power Project Maintenance Manual System 5 – Circulating water*
7. *Olkaria II Geothermal Power Project Maintenance Manual System 10 – Chemical Injection*