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Compare Water Consumption in Geothermal Power Plants and other Power Plants

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ABSTRACT

This paper first discusses the water consumption in geothermal power plants, second discussion is about water consumption in other thermal power plants, and then a comparison to each will follow.

Water consumption occurs in power plants at some main stages along construction and operation. In geothermal power plants, these stages vary between different power plants, water is required for the developing stage and especially in the drilling of production and injection wells. Water is also used in the operations of geothermal power plants for cooling systems and for other uses such as cleaning, domestic use, dust suppression, maintenance and water required for flow testing of wells (Harto et al., 2013).

In this paper we discuss water consumption in three models of cooling systems in geothermal power plants, these are as follow:

a. Wet cooling system
b. Hybrid cooling system
c. Dry cooling system

And finally, to conclude, it compares the water consumption in geothermal power plants and other thermal plants.

1. INTRODUCTION

Iran is situated in the Middle East and has an area of 1,648,195 km^2 with a population of about 75 million. It has big gas and oil reservoirs and also it is one of the world´s main oil producers. There are ample potentials of renewable energies in Iran, such as solar, biomass, wind and geothermal.

Due to the location of Iran, in dry and semi-arid areas, the rainfall and volume of fresh water are not enough, and the atmospheric fluctuations are not the same everywhere. Rainfall, evaporation and transpiration is different in the regions of world, shown in Table 1. Iran has 1.1% of total land in the world, with 0.34% of rainwater. The total annual precipitation is at billion 400 billion m^3, that 284 billion m^3 is evaporated directly, with only a small portion of it being surface water and groundwater supplying the country's water resources. At present, the total amount of available water to the country is 90 m^3.

Table 1 : Precipitation and evaporation in different parts of the world in mm

Continental	Annual precipitation (mm)	Annual Evaporation (mm)
Europe	734	415
Asia	726	433
Africa	686	547
America	1159	724
Australia	734	510
Average	800	485
Iran	255	180

Statistical surveys show that the average apparent consumption is 300 liters per person per day in advanced countries; virtual consumption is ~6000 liters for each person per day. This virtual consumption is shown in Table 2.

Table 2 : Virtual Water Consumption

Consumption	Volume (Liters)
Plants irrigation and supply, food production	2600
Electricity, fuel (Energy supply)	2400
Industries and mines	700
Commercial affairs and services	300

This indicates that virtual water consumption in the energy supply, is a lot, and if possible, overall water consumption can be significantly reduced (Abedi et al., 2016).

First, we use some information from the Sabalan project, and explain a little about this project. The geothermal activity in Iran started by the Ministry of Energy of Iran (MOEI) in 1975, a contract between MOEI and Ente Nazionale per L' Energia Electtrica of Italy (ENEL) was signed for geothermal exploration in the northern part of Iran (Azerbaijan and Damavand regions). In 1993 SUNA was established to justify priorities of the above-mentioned regions. As a result: Meshkinshar and Sarein areas in Sabalan region were proposed for electric and direct use respectively Figure 1. In 1998, SKM on behalf of SUNA completed a resistivity survey consisting of Direct Current (D.C.), Transient Electromagnetic (TEM) Magnetotellurics (MT) measurements in Meshkinshahr.

A variety of power generation development options have been formulated and assessed, with generation capacities ranging from 2 to 100 MWe, utilizing both condensing and non-condensing steam turbines by SKM (SKM, 2005).

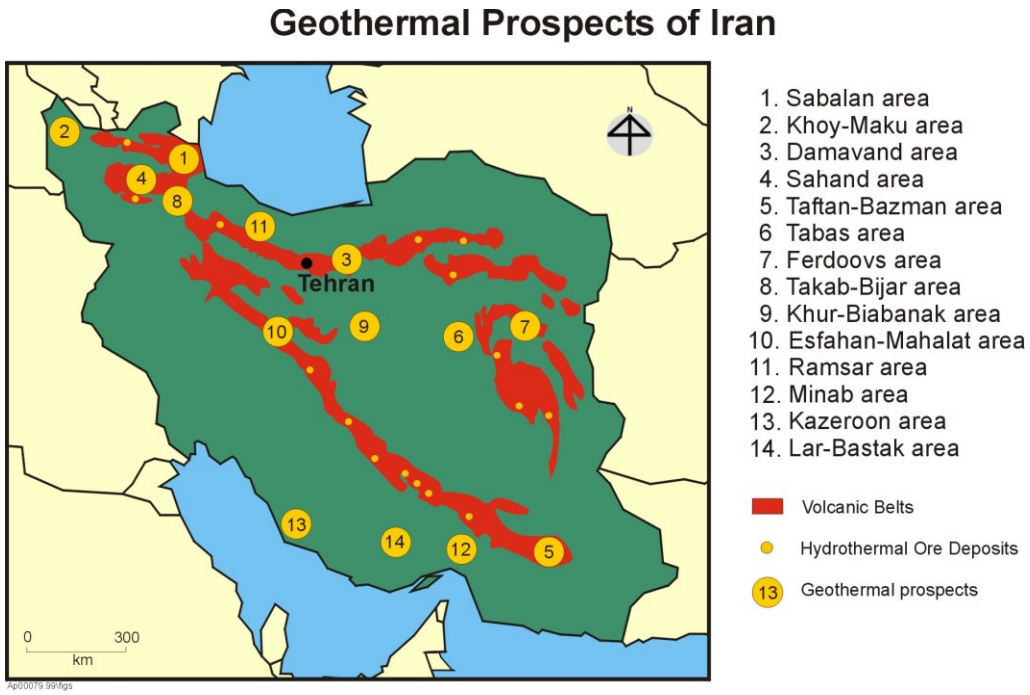

Figure 1: Map of IRAN (SKM, 2005)

The first phase (1998-2006) aimed to build drilling pads at sites A, B, C (see Figure 2) including excavation and construction concrete pad, accesses roads from Moil village to sites, a pump station, water reservoir, water intake and water pipelines from pump station to reservoir and all sites. This phase includes also to repair the existing road between Meshkinshahr and Moil village and to drill five exploratory wells. In the second phase, SUNA wants to drill 14 production or reinjection wells, including preparations of well pads A and B, for additional drilling, and well pads D and E, for new drilling. This phase includes also the accesses road to site E, water pipeline and new pump station in order to provide water for drilling in site E. After deeping 5th well and drilling 6 new wells in this phase, drilling operations were shut down because of lack of budget, now SUNA is starting to build a 5 MWe power plant in order to generate electricity.

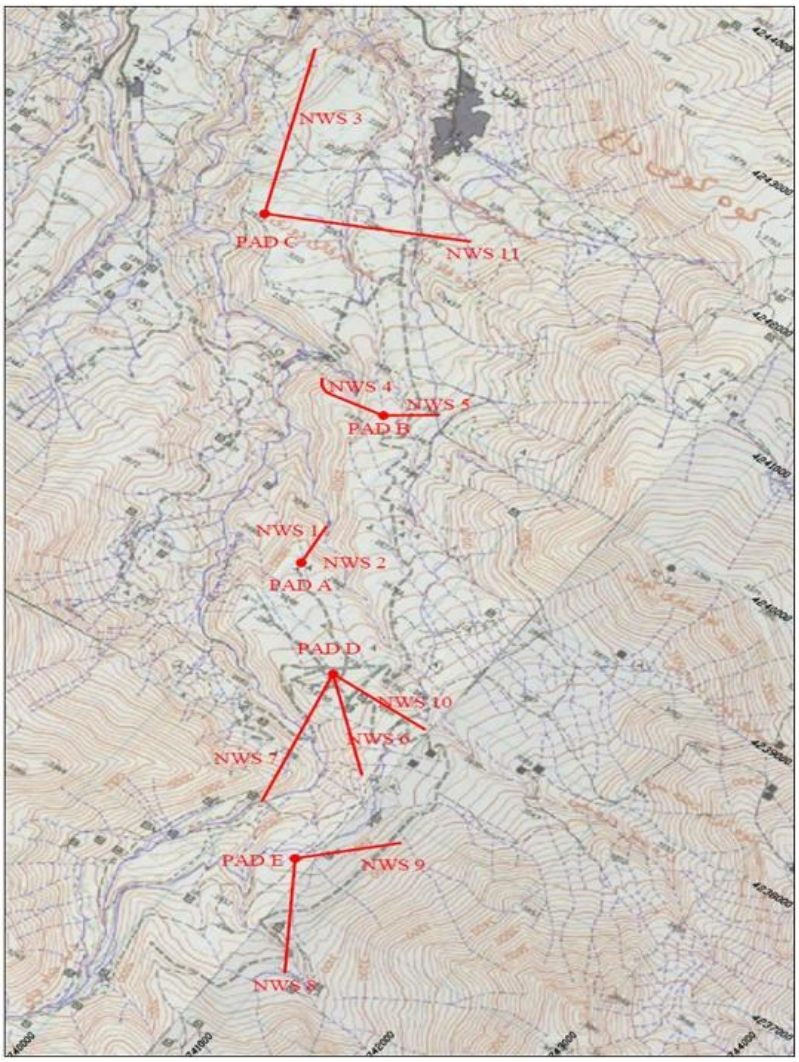

Figure 2: Plan of Sabalan area

In the first phase of the three deep exploration wells which were drilled are coded to as NWS-1, NWS-3 and NWS-4 on well pads A, C, and B, respectively. The wells vary in depth from 2265 to 3197 m MD. Well NWS-1 was drilled vertically while NWS-3 and NWS-4 are deviated wells with throws of 1503 and 818 m, respectively. Additionally, two shallow reinjection wells have been drilled to 600 m depth, NWS2R, located on pad A alongside well NWS-1, and NWS-5R on pad B alongside well NWS-4. The basic well completion data are summarized in Table 3.

Table 3: Basic completion information of NWS wells (SKM, 2005)

Well	Spud date	Completion date	Depth (mMD / mVD)	Product casing		Product liner	
				Size (in)	Depth (mMD)	Size (in)	Depth (mMD)
NWS-1	22 Nov 02	1 Jun 03	3197	9⅝	1586	7	3197
NWS-3	2 Jul 03	27 Nov 03	3166 / 2603	13⅜	1589	9⅝	3160
NWS-4	17 Dec 03	27 Mar 04	2255 / 1980	9⅝	1166	7	2255
NWS-2R	7 Jun 03	25 Jun 03	638	13⅜	360	9⅝, 5	638
NWS-5R	7 Apr 04	2 May 04	538	20	139	9⅝	482

In second phase the drilling and testing program was carried out between May 2008 and October 2012. The well NWS-5R was deepened to 1901 m and The five deep Delineation wells and one reinjection well which were drilled are coded as NWS-5D, NWS-6D, NWS-7D, NWS-8D, NWS-9D, NWS-10D and NWS-11R on well pads D, E, B, and C, respectively. The wells vary in depth from 1901 to 2813 m MD. All of the wells were drilled directionally. The basic well completion data is summarized in Table 4.

Table 4: Basic completion information of NWS wells (EDC-2013)

Well	Spud date	Completion date	Depth (mMD / mVD)	Product casing		Product liner	
				Size (in)	Depth (mMD)	Size (in)	Depth (mMD)
NWS-5D	May-30-2008	Aug-31-2008	1901	9⅝	745	7	1901
NWS-6D	Oct-16-2008	Feb-19-2009	2377	9⅝	1250	7	2371
NWS-7D	Mar-26-2009	Aug-17-2009	2705	9⅝	1313	7	2705
NWS-8D	Aug-21-2009	Jan-21-2010	2640	9⅝	1438	7	2640
NWS-9D	Feb-08-2010	Mar-19-2010	500	9⅝	-	7	-
NWS-10D	Apr-10-2010	Sep-o5-2010	2300	9⅝	977	7	-
Re-NWS-9D	Sep-16-2010	Dec-16-2010	2703	9⅝	1101	7	2703
NWS-11R	Dec-25-2010	May-10-2010	2813	9⅝	1286	7	2813

2. WATER CONSUMPTION IN THE GEOTHERMAL POWER PLANTS

Water consumption in the geothermal power plants occurs in main stages along construction and operation of power plants and is as follows:

a. Construction requirement for drilling
b. Drilling production and injection wells
c. Flow testing and injection testing of wells
d. Construction for power plants and pipelines for two phase, steam and brine water transmission
e. Cooling systems during operation

Also, water is required in the operations of geothermal power plants for other uses such as cleaning, domestic, dust suppression, and maintenance that cannot be accurately calculated.

In order to calculate water composition, we assume life span for 30 MWe geothermal power plant electricity in Sabalan is 30 years, according to information found during our experience and from other sources, in Sabalan, each production well (with 2700 m deeps) could approximately generate 5 MWe electricity and each 2 production wells need one injection well, thus we need 6 production wells and 3 injection wells to generate 30 MWe of electricity.

First, we calculated water consumption for construction, drilling and testing before starting operation of power plants then calculate water consumption for generation every kWh of electricity generated, based on capacity and life cycle of the power plant, then calculate water consumption for operation of cooling system.

2.1 Construction for Requirement for Drilling

In order to preparation for requirement of drilling 9 wells, two sites need to be constructed, and also need to construct some sites roads, water intake, pipeline and electricity transmission line, that the amount of these are shown in Table 5.

Table 5 : General amount

Item	Amount	Unit
Drilling sites	2	Set
Roads	10	Km
Water intake	1	Set
Pipeline	8	km
Electricity transmission line	8	km

Each drilling site include 1100 m^3 reinforcement concrete, 100000 m^3 cutting, 2000 m^3 filling and 3000 m^3 stone masonry. Each m^3 reinforcement concrete (with 80 kg/m^3 re-bar) required 7.98 m^3 water for re-bar, cement and aggregates, (Bahadorinejhad et al., 2016), cutting does not need water, each m^3 filling required 0.12 m^3 water for compaction and Each m^3 stone masonry required 0.10 m^3 water MPO (2019). Water consumption for construction one site is shown in Table 6.

Table 6 : Water consumption for one site

Item	Amount	Consumption (m^3)	Total Consumption (m^3)
Reinforcement concrete	1100	7.98	8778
Cuting	100000	0.00	0
Filling	2000	0.12	240
Stone masonry	3000	0.10	300
SUM			9318

Each kilometer of road needs 10 m3 reinforcement concrete, 1750 m^3 filling and approximately 200 m^3 stone masonry.

Water consumption for construction of one kilometer of road is shown in Table 7

Table 7 : Water consumption for one site kilometer of road

Item	Amount	Consumption (m^3)	Total Consumption (m^3)
Reinforcement concrete	10	7.98	80
Filling	1798	0.12	216
Stone masonry	200	0.10	20
SUM			316

For water intake needs 250 m^2 building and each m^2 of construction of building for concrete structure needs 7.00 m^3 and for steel structure needs 11.00 $m^{3,}$ (Bahadorinejhad et al., 2016). We assume an average of 9.00 m^3 for each m^2 of building.

Water consumption for construction of water intake is shown in Table 8.

Table 8 : Water consumption for water intake

Item	Amount	Consumption (m^3)	Total Consumption (m^3)
Building	250	9.00	2250
SUM			2250

For pipeline construction the water that is needed for steel pipe (31 kg/ml equal 31 ton/km) and each ton steel production required 84 m^3 water, (Bahadorinejhad et al., 2016), is calculated and shown in Table 9.

Table 9 : Water consumption for one kilometer pipeline

Item	Amount	Consumption (m^3)	Total Consumption (m^3)
Pipe	31	84.00	2604
SUM			2604

For electricity transmission line construction, the water that is needed to construct poles and used in cable production, each kilometer needs 50 poles and each one has 1.5 m^3 reinforcement concrete and each kilometer needs 5 tones cable water for cable production and is near to steel production, we assume 80 m^3/ton. Water consumption for construction of one-kilometer electricity transmission shown in Table 10.

Table 10 : Water consumption for one kilometer electricity transmission

Item	Amount	Consumption (m^3)	Total Consumption (m^3)
poles	75	7.98	599
Cable	5	84.00	420
SUM			1019

The total consumption for Construction Stage is shown in Table 11.

Table 11 : Water consumption for Construction Stage for requirement for drilling

Item	Amount	Unit	Consumption (m^3)	Total Consumption (m^3)
Drilling sites	2	Set	9318.00	18,636
Roads	10	Km	316.00	3,160
Water intake	1	m^2	2250.00	2,250
Pipeline	8	km	2604.00	20,832
Electricity transmission line	8	km	1019.00	8,152
SUM				53,030

2.2 Drilling Production and Injection Wells

In the duration of drilling wells, the amount of water is used to make mud and cement, also in the process of casing pipe production, some of water is consumed for steel production. The average water used to make mud and cement is approximately

180,000 gallons per 100 feet of drilling averaged (Harto et al., 2013). Approximately 2.23 m^3 per meter of drilling for 9 wells with 2700 deeps water consumption is equal (9×2700×2.23) 54189 m^3.

The total weight of casing that used for one of wells (with 2700 deeps) in Sabalan project assume as a base for calculating water consumption. The total weight of casing for one well is shown in Table 12.

Table 12 : Total weight of casing for one well

Size (in)	L (m)	Unit weight (kg)	Total weight (kg)
20	100	146	14600.00
13 3/8	400	101	40400.00
9 5/8	1500	64	96000.00
7	1200	38	45600.00
SUM			196600.00

Each ton steel production required 84 m3 water, (Bahadorinejhad et al., 2016), therefore, the water consumption to produce casings for 9 wells is equal (9×196.6×84) 148629 m^3. For drilling production and injection wells the water consumption is shown in Table 13.

Table 13 : Water consumption for drilling 9 wells

Item	Total Consumption (m^3)
Mud and Cement	54,189
Casing	148,629
Sum	202,818

2.3 Flow Testing and Injection Testing of Wells

In order to obtain the information of production and injection wells, after the completion of the drilling, the wells should be tested. In production wells, in order to estimate the power capacity of the well, the parameters such as enthalpy, the amount of steam generated by the well, the chemical characteristics of the fluid, etc. should be measured.

The water consumed for circulation testing is similar to the volumes required for drilling and cementing and stimulating per lifetime energy output (Harto et al., 2013). Approximately 2.23 m^3 per meter of well, for each production well with 2700m deep water consumption is equal (2700×2.23) 6021 m^3

The water required for testing the injection wells depends on the environmental conditions of the reservoir, which is estimated between 1500000 to 7700000 gallons per well. The average of 5100000 gallons was consistent with the 5300000 gal used (Clark et al., (2011). We assume 5200000 gallons, equal 19500 m^3 for each well (Clark et al., 2011)

For flow testing production and injection wells the water consumption is shown in Table 14.

Table 14 : Water consumption for drilling 9 wells

Item	No. of Wells	Consumption for each well (m^3)	Total Consumption (m^3)
Production Wells	6	6021	36,126
Injection Wells	3	19500	58,500
Sum			94,626

2.4 Construction Stage Power Plant and Pipelines for Two Phase, Steam and Brine Water Transmission

A study was performed using Google Earth for another existing geothermal power plants such as Svartsengi-46 MWe in Iceland, Berlin-95 MWe, Ahuachapán-95 MWe in El Salvador, and Okaria-45 MWe in Kenya for 50 MWe by me that shows the requirement construction for a power plant with capacity 50 MWe (Ghaderi, 2007), constructions reduced, based on my experience, for a power plant with capacity 30 MWe. The required area for construction are shown in Table 15 and Table 16.

Table 15 : Requirement Building

Descriptions	Requirments	Unit
Building		
Offices and workshop	500.0	m^2
Powerhouse and electrical annex	800.0	m^2
Pump station	200	m^2
Water reserviore	200	m^2
Gate house	50	m^2
Change room	140	m^2
First aid station	50	m^2
N-C Gas extraction	250.0	m^2
Sum of Building	2190.0	m^2

Table 16 : Requirement another construction

Descriptions	Requirments	Unit
Switchyard and power take-off	800.0	m^2
Cooling towers	1500.0	m^2
Separator station	600	m^2
Pipeline	3	km
Access and parking	600.0	m^2

Based on calculation water consumption in section 2.1, the total consumption for construction power plant is shown in Table 17.

Table 17 : Water consumption for construction power plant

Item	Amount	Unit	Consumption (m^3)	Total Consumption (m^3)
Buildings	2190	m^2	9.00	19,710
Switchyard and power take-off	800	m^2	3.00	2,400
Cooling towers	1500	m^2	6.00	9,000
Separator station	600	m^2	6.00	3,600
Pipeline	3	km	2604.00	7,812
Access and parking	600	m^2	0.12	72
SUM				42,594

Total water consumption before starting power plant is shown in Table 18.

Table 18 : Water consumption before starting power plant

Stage	Consumption	Unit
Construction stage for requirement for drilling	53,030	m^3
Drilling production and injection wells	202,118	m^3
Flow testing and injection testing of wells	94,626	m^3
Construction stage power plant	42,594	m^3
SUM	392,368	m^3
time of generation electricity (365x.85x24x30000)	223380000	hr
Water consumption for generate each kWh electricity	1.76	liter

Water consumption to generate each kWh of electricity is 1.76 liter. That more than 1.15 liter is related to production of materials (virtual consumption section 1) that no one pays attention to.

2.5 Cooling Systems during operation

The most used water during the operation of a geothermal power plant and also another thermal power plant is water that use for the cooling system and other water consumption of the power plants is negligible. For this reason, we just estimate the water consumption of cooling systems.

There are three model of cooling system in geothermal power plants these are as follow:

a. Wet cooling system
b. Hybrid cooling system
c. Dry cooling system

Water consumption of cooling system ranged from 0.01 to 0.72 gal/kWh based on the cooling system for a wet cooling system is 0.72 gal/kWh (2.73 liter/kWh), for hybrid cooling systems is 0.29 gal/kWh (1.10 liter/kWh) and the water consumption for dry cooling systems is 0.01 gal/kWh (0.04 liter/kWh) (Clark et al., 2011). The water consumption for wet cooled flash plant maybe ranges from 0.7 to 3.8 gal/kWh with an average of 2.4 gal/kWh (9.10 liter/kWh) (Harto et al., 2013). The averages of consumption are shown in Table 19.

Table 19 : Average water consumption in geothermal power plants (steam plant)

Cooling system	Consumption	Unit
Wet	2.73	liter/kWe
Hybried	1.10	liter/kWe
dry	0.04	liter/kWe

3. WATER CONSUMPTION IN THE THERMAL POWER PLANTS

Water consumption in the thermal power plants similar to geothermal power plants and occurs in main stages along construction and operation of power plants and is as follow:

a. Construction for power plant
b. Fuel production during operation
c. Cooling systems during operation

Other uses such as cleaning, domestic, dust suppression, and maintenance similar to the geothermal power plants, has not been considered

In order to compare with a geothermal power plant, we assume life for 30 MWe thermal power plant electricity at 30 years.

We first discuss water consumption for construction of power plant, then calculate water consumption for generation for each kWh electricity based on capacity and life time of the power plant, later calculate water consumption and fuel production and finally based on actual water consumption of some thermal power plants in Iran we calculate water used for cooling systems.

3.1 Construction Stage Power Plant

For thermal plant, the use of previous calculations of the geothermal power plant to calculate the water consumption during the construction stage and also we consider that we should construct a boiler instead of the separator at the thermal power plant. Assuming the water used to construct the separator is similar to the boiler, Table 18 can then be used by deleting some rows. Total water consumption before starting power plant is shown in Table 20.

Table 20 : Water consumption before starting power plant

Stage	Consumption	Unit
Construction stage power plant	42,594	m^3
time of generation electricity (365x.85x24x30000)	223380000	hr
Water consumption for generate each kWh electricity	0.19	liter

Water consumption for generation of each kWh electricity is equal 0.19 liter

3.2 Fuel production during operation

The heat for combustion of a fuel is the amount of heat released by the complete combustion of a unit of mass from that fuel at a specific temperature and pressure and the unit of energy per unit mass. One liter of gasoline can release 9332 Kcal energy, that is equal 0.0386 Gj. Water consumption estimated for generation of 1 Gj energy approximately is equal 0.114 m^3 (Spang, 2014).

Based on this data for production, one liter gasoline we need (0.114x0.0386) 0.0044 m^3 water, that is equal 4.4 liters. According to the actual statistics of fuel consumption of thermal power plants in Iran, in order to generate one kW of electricity, about 0.2 liters of gasoline is required (Tavanir Co., 2018). It is shown water consumption for generation of one kW electricity is equal (4.4x0.2) 0.88 liter.

3.3 Cooling systems during operation

The water consumption of some thermal power plants in Iran has been collected and is shown in Table 21 (Abedi et al., 2016).

Table 21 : Water consumption of some thermal power plants in Iran

Power plant	Capacity MWe	Cooling system	Consumption	Unit
Montazer Ghaem (steam)	140	Wet	2300	liter/MWe
Besat	75	Wet	3100	liter/MWe
Tarasht	100	Wet	1800	liter/MWe
Tabriz (Combined Cycle)	800	Wet	2250	liter/MWe
Average wet system			2.36	liter/kWe
Shahid Rajaiee (steam)	250	Hybrid (Heller)	320	liter/MWe
Shahid Rajaiee (Combined Cycle)	100	Hybrid (Heller)	420	liter/MWe
Montazer Ghaem (Combined Cycle)	100	Hybrid (Heller)	324	liter/MWe
Damavand (Combined Cycle)	160	Hybrid (Heller)	435	liter/MWe
Average wet system			0.37	liter/kWe
Qom (Combined Cycle)	100	dry (ACC)	76	liter/MWe
Average wet system			0.08	liter/kWe

4. CONCLUSION

This paper discusses water consumption in the geothermal power plants and calculates the amount of water used for construction and drilling testing that should be done before starting a power plant and then research about water used during operation, this calculation and research shows that water consumption is about 1.76 liter/kWh that more than 1.15 liter is related to production of materials (virtual consumption section 1).

Also in this paper research about water consumption during operation in geothermal power plants and thermal power plants the compare results based on cooling system are shown in Table 22.

Table 22 : Compare water consumption between geothermal power plants and thermal power plants

Cooling system	Geothermal Power Plant liter/kWe			Thermal Power Plant liter/kWe			
	Construction	Cooling System	SUM	Construction	Fuel Production	Cooling System	SUM
Wet	1.76	2.73	4.49	0.19	0.88	2.36	3.43
Hybrid	1.76	1.10	2.86	0.19	0.88	0.37	1.44
dry	1.76	0.04	1.80	0.19	0.88	0.08	1.15

The results show that the water consumption in geothermal power plants is more than thermal power plants and should be considered by designers in future to reduce this amount and also showed that virtual water consumption, considering the weight of casing for wells, is a very high. Finally, it is suggested that in most designs, it is better to use a dry cooling system.

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