Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

CO2 Emission from Geothermal Power Plants in Turkey

Niyazi Aksoy[1], Ozge Solak Gok[2], Halim Mutlu[3] and Gizem Kılınc[4]

[1]Dokuz Eylul University, Geothermal Energy Research and Application Center 35120 Torbali - Izmir

[2]Dokuz Eylul University, Engineering Faculty, Mining Eng. Dept. 35160 Buca – Izmir

[3]Ankara University, Engineering Faculty, Geology Eng. Dept. 06100 Tandogan - Ankara

[4]Dokuz Eylul University, The Graduate School of Natural and Applied Sciences, Geothermal Energy Dept. 35160 Buca – Izmir

niyazi.aksoy@deu.edu.tr, ozge.solak@deu.edu.tr, halimmutlu@ankara.edu.tr, gizemmkilinc@gmail.com

Keywords: Geothermal energy, environmental effect, CO2, greenhouse gas emission, Turkey.

ABSTRACT

Geothermal energy has been accepted as a clean and sustainable source of energy. However, the emission of dissolved CO_2 from geothermal water becomes more of an issue recently. Emissions from Turkish geothermal fields amounts to 1800 gr/kWh which is nearly two times more than the emission of coal burning plants. High CO_2 emissions can cost the geothermal energy sector carbon taxes of up to 4.5 ¢/kWh. The present study discusses CO_2 emissions from geothermal-based power plants in accordance with the data obtained from the plants and literature.

1. INTRODUCTION

The number of geothermal sources for energy generation increases with increasing environmental awareness, incentives, and technological development. The total capacity of 24 countries where the generation of energy is provided through the geothermal sources has reached up to 10,900 MW (Bertani, 2012). It has been expected that the geothermal sources will meet the energy need and provide great contributions upon emission reduction. It has been calculated that the extractable EGS (Enhanced Geothermal System) potential of the USA was 2,000 times higher than the 2005 primary energy consumption of the USA (MIT, 2006). It has been estimated that, in 2050, the generation of electricity from hydrothermal sources will reach up to 70 GW. With the help of EGS projects it will reach up to 140 GW, 8.3% of electricity will be provided from the geothermal sources, and CO_2 emission saving will be one billion tonnes/year (Bertani, 2012). Today, the direct using capacity of geothermal sources is 48,493 MWt (megawatt thermal), and CO_2 emission saving is 107 million tonnes/year (Lund et al., 2011).

Geothermal sources have serious environmental risks such as surface disturbance, noise, thermal effect, chemical pollution, subsidence, seismicity, and emission to atmosphere (Ellis, 1975; Arnmannsson and Kristmannsdottir, 1992; Eysteinsson, 2000; Arnmannsson, 2003). Gases such as CO_2, H_2S, NH_3, N_2, H_2, and CH_4 are generally found in the steam, and are invariably present in geothermal discharges from both natural features and wells. These gases are often referred collectively as ‘non-condensable gases’ (NCG), because they do not condense (become liquid) at the outlet pressure and temperature conditions of the turbines or heat exchangers. They are usually exhausted (Fig. 1) to the atmosphere if the H_2S levels do not exceed environmental standards (Lawless, 2010). The vast majority of the NCG (95–99%) is CO_2, while the rest are H_2S and CH_4. The emission reduction was encouraged by the carbon trade through the Kyoto Protocol that Turkey signed in 2009. The carbon trade has been actualized in voluntary markets. However, it has not subscribed for the greenhouse gas reduction yet.

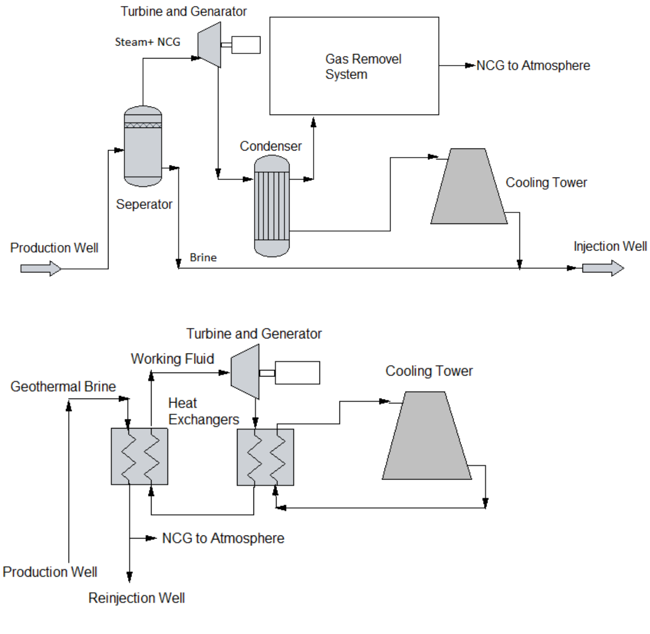

Figure 1. Single flash steam (top) and binary power plants (bottom).

Turkey's geological features offer opportunities for geothermal energy. Turkey is located in the central part of the Alpine-Himalayan Mountain Belt, which began to form due to the closing/shrinking of the Tethys Ocean in the Late Mesozoic. High mountain ridges were formed along the northern and southern sides of Anatolia, while some pre-Cambrian–Palaeozoic metamorphic shields (i.e., the Menderes and Central Anatolian Massifs) remained at its centre. Recent tectonics associated with the westward movement of the Anatolian sub-plate and related N–S extension, particularly in southeastern Anatolia, caused by the northward push of the Afro-Arabian Plate, created several major E–W oriented grabens (Fig. 2). The tectonic forces and resulting structures are thought to be responsible for the present high heat flow and high enthalpy geothermal systems in Western Anatolia. The largest (in size and output) regional heat flow anomaly in Turkey is found in the Menderes Metamorphic Massif (MMM). Several grabens have developed recently within the MMM, where all the geothermal fields are of medium-to-high enthalpy, with temperatures of 120–270^{0}C. Büyük Menderes Graben (BMG), Gediz Graben (GG), and Simav Graben (SG) contain many medium- and high-enthalpy geothermal resources. The geothermal system at Tuzla occurs on the SW border of the young (Lower Tertiary) Kazdağ Metamorphic Massif (KMM) (Fig. 2), where Miocene volcanism shaped the Biga Peninsula. Thermal recharge of the Tuzla system occurs by the ascent of deep waters through this N–S structural discontinuity, which also explains the presence of Pliocene lava domes in the area (Serpen et al., 2009).

Figure 2. Distribution of geothermal resources suitable for electricity generation in Turkey.

2. MATERIALS AND METHODS

2.1 Determining the Amount of NCG

The geothermal fluid rises from the well to the surface while generating from water dominated reservoirs (in liquid flow phase under reservoir temperature and pressure conditions), and the hydrostatic pressure decreases as coming up to the surface. The fluid in liquid phase in the reservoir starts to flow as two-phased from a certain point. At a generating well, depth-temperature measurement is performed with a wire-line unit. Accuracy and resolution of the used measurement tools for the pressure and temperature are 0.05–0.003% and 0.015–0.002% FS (full scale), respectively. The certain point where the gas phase releases is defined as the "flashing point" (Fig. 3). The pressure at flash point equals to the sum of partial pressure of NCGs and partial steam pressure of water (Eq. 1). According to Henry's Law, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid at a constant temperature. Since the 95% and over of the dissolved gas in geothermal systems is CO_2, accepting NCG as being formed of CO_2 facilitates calculations. The dissolved CO_2 amount in the CO_2-H_2O system, whose partial pressure and temperature is known, can be calculated by Henry's Law as follows:

$$P_{fp} = Z_c h_k + (1 - Z_c) P_s \quad (1)$$

P_{fp}	flash point pressure, (Pa)
P_s	steam pressure of pure water, (Pa)
Z_c	CO_2 mole fraction in brine, (dimensionless)
h_k	Henry's constant, (Pa)

In this study, the amount of NCG within the geothermal fluid was calculated using Eq. 1. The P_{fp} value in Eq. 1 was obtained from the dynamic temperature and pressure profile measured from the wells. Pressure-depth relationship in the aforementioned pressure profiles was linear up to P_{fp} point (Fig. 3) due to constant fluid density. The density decreased through the release of the gas and the linear relationship broke down. The pressure at this point was P_{fp}. The temperature at P_{fp} depth was re-obtained from the same graph and Ps value corresponding to this temperature was found from steam tables. Ellis and Golding's (1963) relations were used for estimating Henry's Law constant h_k. CO_2/geothermal brine rate calculated from the geothermal fields used for the generation of electricity in Turkey was presented in Table 1. Considering the installed capacity and used geothermal fluid amount of the geothermal plants, CO_2 emissions per unit were calculated in gr/kWh (Table 1).

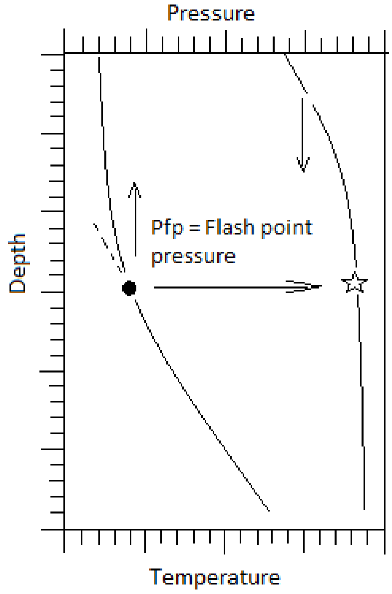

Figure 3. Determining flash point pressure.

Table 1. NCG contents of the geothermal power plants in Turkey.

Place	Licence Holder	Unit Name	Capacity, MW	Mean Source Temp.,°C	NCG Content, kg NGC/kg brine	CO_2 emission g/kWh	Start Date
Kizildere Denizli	Zorlu Energy	Kizildere – I Kızıldere - II	15 60 10 +10	230	0.02-0.044 [22,23,24]	900 (xx) 1300	1984 2013
	Bereket E.		7.06	150	n/a	n/a	2008
Salavatlı Aydın	Mege	Dora-I Dora-II Dora-IIIa Dora-IIIb	7.95 9.5 17 17	170 172 165 170	0.015	1120(xx) 900(xx)	2006 2010 2013 2014(x)
Germencik Hıdırbeyli Gümüşköy Aydın	Gürmat		47.4 22.5 47.4	220 220 230	0.02 [24]	1100	2009 2014(x) 2015(x)
	BM		6.6 6.6	160	n/a n/a	n/a n/a	2013 2014(x)
	Maren Energy	Irem Sinem Deniz Kerem	22 22 24 24	170 180 180 175	0.015-0.02	900 900 900	2011 2012 2012 2014(x)
Yılmazköy	KenKipaş Energy		24	175	0.02		2014(x)
Tuzla Çanakkale	Enda Energy	Enda	7.5	165	0.005	400	2010
Sarayköy Denizli	Jeoden Energy	Jeoden	0.84	101	n/a	?	2012
Pamukören Aydın	Çelikler Energy	Çelikler	45.02	170	0.02		2013
Alaşehir Manisa	Türkerler Energy	Türkerler	24	190	0.034[24]		2014(x)

NCG : Non condansable gases
B : Binary type- working fluid.
(x) Under construction
(xx) CO_2 is used in commercial gas production.

2.2. Gas Sampling and Determination of Gas Composition

For NCG sampling, the fluid generated from the well was primarily decomposed as hot water and steam in a Webre Separator was adjusted to the atmospheric pressure. Almost all of the NCG dissolved in the geothermal fluid followed steam. Steam and NCG were passed through an ice bath. Condense of steam was produced and the gas separated. At this point, gas was filled into 500 cc steel tubes with double headed valves and the samples were collected (Fig. 4). The samples were analyzed in the TPAO (Turkish Petroleum Corporation) Research Laboratory. Carbon isotope analysis were performed using GV Instruments Isoprime (GC-IRMS), and the gas composition was analyzed according to ASTM D1945 and D5504 using gas chromatography (Table 2).

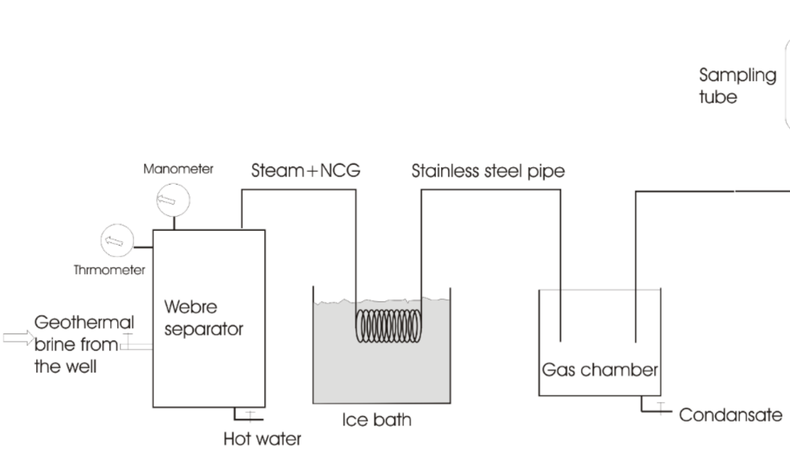

Figure 4. NCG separation and sampling.

Table 2. Gas content and $\delta^{13}C$ values of the CO_2 derived from the Turkish geothermal plants.

Fields	CO_2 ppm	H_2S Ppm	CH_4 ppm	N_2 ppm	$\delta^{13}C$ %o
Alaşehir - Akkeçili	98.6	1.1	0.23	0.1	
Kemaliye	99.0	0.4	0.5	0.1	
Germencik	98.3	1.1	0.5	0.1	0.68
Salavatlı	98	1.8	0.1	0.1	
Yılmazköy	95.7	3.8	0.3	0.2	0.06
Kızıldere	99.2	0.005	0.4	0.3	0.07-0.17*

*Haizlip et al, 2013;2013. Durak et al., 1995

3. RESULTS AND DISCUSSION

3.1. Origin of CO_2

The $\delta^{13}C$ values are 0.07–0.17‰ for Kızıldere (Haizlip et al., 2012), 0.06‰ for Yılmazköy and 0.86‰ for Germencik geothermal fields, indicating that CO_2 is released due to the thermal degradation of marine carbonate rocks (Fig. 5) (Hoefs, 1997).

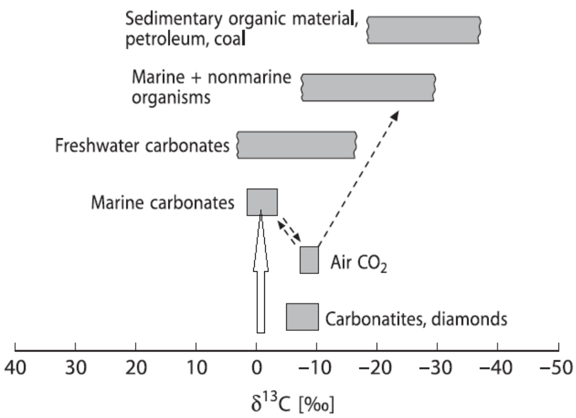

Figure 5. Origin of the CO_2, (adopted from Hoefs, 1997).

The geothermal resources within the Büyük Menderes and Gediz Grabens are composed of carbonate rocks such as marble and limestone. This causes large amount of CO_2 emission from the geothermal system hosted in carbonate systems. If calcite is formed in cores or as cuttings of the reservoir lithology, then the geothermal brine is assumed to be in equilibrium with calcite, and the solubility of calcite can be expressed by Eq. 2.

$$CaCO_{3(S)} + 2H^{+}_{(aq)} \leftrightarrow Ca^{++}_{(aq)} + H_2O_{(l)} + CO_{2(aq)} \quad (2)$$

$CaCO_3$ precipitates at the flash point depth during the generation, and CO_2 gas is released (Eq. 3). Scaling inhibitors are used to prevent $CaCO_3$ precipitation.

$$Ca^{++}_{(aq)} + 2HCO^{-}_{3(aq)} \leftrightarrow CaCO_{3(s)} + H_2O_{(l)} + CO_{2(g)} \quad (3)$$

3.2. CO_2 Emission

The geothermal plants established in Turkey are presented in Table 1. The fields where the plants are in process (except from Çanakkale-Tuzla) are located in the Menderes Metamorphic Massif. Geothermal reservoirs in these sites are within the metamorphic basement, which consists of carbonate rocks such as marble and limestone, and schist and quartzite.

The average temperature of the sites used for electricity generation varies between 101 and 230°C. The first geothermal plant of Turkey, the Kızıldere-I plant, was established in 1983 by the state. Dora-I plant (7.95 MW) started operation in 2006 as the first private enterprise. Power plant investments have increased substantially since 2006 and the power generation reached up to 310.8 MW as of 2013. The installed power plants attain a capacity of 700 MW with the licensed plants under construction, which are in the range of 2.52 to 60 MW (EMRA, 2013). Three of the 20 working power plants are steam power plants, and 17 are binary-type power plants (Fig. 1).

The mass amount of NCG within the geothermal brine varies between 0.015–0.044 in geothermal power plants in process (Table 1). The lowest NCG emission value of the power plant in Çanakkale Tuzla site is 400 gr/kWh. In-situ NCG emission of the Büyük Menderes Graben varies between 900 and 1200 gr/kWh. The highest emission value in the Gediz Graben is 1800 gr/kWh. In the Gediz Graben, research and development borings continue in a great number of sites, and according to the EMRA data, it will be possible to reach an installed power higher than 100 MW within the following few years.

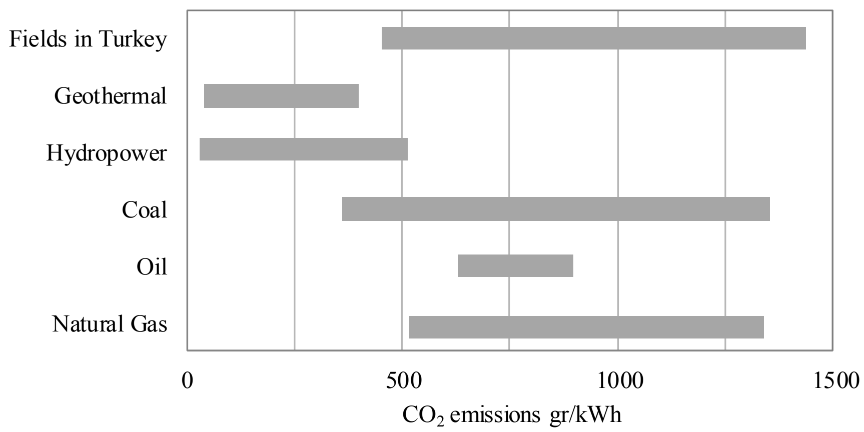

Figure 6. Contribution of geothermal resources to CO_2 emissions in Turkey (modified from Kristmannsdottir and Armansson, 2003).

When the temperature of the source increases, less geothermal brine is used for per kWh electricity production. For that reason, CO_2 emission per kWh is relatively higher in sites with lower enthalpy. In Fig. 6, emission amounts of power plants with different types of fuels are presented. It is remarkable that the CO_2 emission of the geothermal power plants in Turkey is higher than the emission from fossil fuels. CO_2 emissions are reported to be fairly low in the literature (Bloomfield et al., 2003; Bertani and Thain, 2002) related with the CO_2 emission from the geothermal power plants. Bloomfield et al. (2003) compared resources used for electricity generation in the USA and reported that the lowest CO_2 emission was achieved using geothermal resources. Bertani and Thain (2002) stated that 2% of the geothermal-based power plants had CO_2 emissions of at least 0.5 kg/kWh, whereas 50% had emissions of 0.1 kg/kWh or less.

3.3. CO2 Trading

Dora-I and Dora-II power plants in Turkey make use of carbon trading in the voluntary carbon market. Zero-emission production is applicable for projects in which released NCG is sold to CO_2 facilities installed near the power plants. However, because of the commercial CO_2 market is close to the saturation point, new projects may not be able to make use of this benefit. Currently, there is a large risk facing the geothermal sector in Turkey, who signed the Kyoto Protocol of United Nations Climate Change Agreement in 2009. Also Turkey has not yet made any commitment for decreasing greenhouse gas emissions, because in the case of commitment, Turkey would be paying two times more carbon tax than the coal burning power plants for the electricity it produced from the geothermal sources.

3.3.1. How much financial burden will carbon tax place upon the geothermal energy sector?

The cost of CO_2 is about 2.3–2.5 ¢/kg in the free market. Under these circumstances, the current power plants will be able to face with 1.2–4.5 ¢/kWh carbon tax. In Turkey, according to the Law No. 6094 accepted in 2011, the electricity generated from the renewable resources has been provided to have a purchase and price guarantee by the state for seven years. The price has been determined as 10.5 ¢/kWh for the electricity generated from the geothermal sources. Under these circumstances, it will provide a great cost to the geothermal energy sector expecting to get a share from the carbon trade.

3.3.2. Are Geothermal Power Plants Environmentally Friendly? How can geothermal energy sector overcome the problem of CO_2 emission it will face with?

It is suggested that CO_2 emission from the geothermal sources is anthropogenic based and CO_2 is not re-generated as in fossil fuels. CO_2 naturally diffuses to the atmosphere from the geothermal sites, and geothermal power plants have no additional contribution. There are two samples at this point. According to Bertani (2012), all of the natural CO_2 is embedded in the geothermal fluid and conveyed to the atmosphere through the geothermal power plants. In places where geothermal power plants are established, natural emissions decrease drastically. On the other hand, Fridriksson et al. (2006) showed that the planned power plant at Reykjanes would increase the CO_2 emissions from the geothermal system about six-fold, if the natural CO_2 flow would not decrease with time.

A study was conducted in the Gediz Graben for the natural emission of geothermal sites. According to the CO_2 flow measurement results performed in 3000 points in a 25-km^2 area, the natural CO_2 emission of the site was found as 11.6 kg.m^{-2}.day^{-1} (Ongur, 2013). The anticipated geothermal power plant capacity for the determined site is 30 MW. When the natural CO_2 emission of the site is 12 t/h, the CO_2 emission will be 9 t/h depending on the establishment of the planning power plant. After the commissioning of the power plant, whether the natural CO_2 emission will decrease or not has been an issue that is worth research.

Another way of decreasing the CO_2 emission is the use of CO_2 with 95% and higher purity obtained from geothermal sources to meet the industrial and agricultural CO_2 need. CO_2 emission of Kızıldere-I, Dora-I and Dora-II power plants in Turkey is processed by commercial CO_2 plants established next to the power plant. By this means, the facilities generate through zero emission, and they benefit from commercial carbon sale incomes and carbon emission trade, as well.

Baldacci et al. (2005) reported that they developed a successful method related to injection of mercury, sulfur dioxide and hydrogen sulfide gases into the reservoir. Injection of CO_2 into the reservoir as dissolved in re-injected water can provide contributions upon reduction of gases released to atmosphere and geothermal energy's being more environmentally benign.

4. CONCLUSION

Processing of geothermal sources has both positive and negative effects on the environment. The key point is to minimize the drawbacks to attain acceptable limits and sustainably manage the geothermal sources and the environment. Geothermal-based electricity generation in Turkey can cause two-fold more emission than the coal burning power plants. This is a serious risk for the developing geothermal energy sector. The investors can face with the risk of carbon tax reaching up to 4.5 cent/kWh. Since CO_2 has anthropogenic origin, the amount of CO_2 released naturally to the atmosphere from the in-service geothermal power plants should be monitored. Also it should be discussed if CO_2 released from the plants causes a decrease at natural output or not. An easily applicable and reliable method was suggested by Chiodini et al. (1998) for monitoring the natural CO_2 emission. Use of CO_2 for industrial needs and its re-injection to the geothermal reservoir can be a solution for the zero-emission generation.

ACKNOWLEDGMENTS

This study is supported by TUBITAK (The Scientific and Technological Research Council of Turkey) under Project No. 112M942.

REFERENCES

Armannsson, H. and Kristmannsdottir, H.: Geothermal environmental impact. *Geothermics* **21**, (1992), 869-880.

Armannsson, H.: CO2 emission from geothermal plants. *Proccedings: Internatioanl Geothermal Conference*, Sept. 2003, pp 56-63, paper 103, Reykjavik, (2003).

Baldacci, A., Mannari, M. and Sansone, F.: Greening of geothermal power: an innovative technology for abatement of hydrogen sulphide and mercury emission. *Proceedings: World Geothermal Congress,* Turkey, (2005).

Bertani, R. and Thain, I.: Geothermal power generating plant CO2 emission survey. *IGA News* **49**, (2002), 1–3.

Bertani, R.: Geothermal power generation in the world 2005-2010 update report. *Geothermics* **41**, (2012), 1-29.

Bloomfield, K.K., Moore, J.N. and Neilson, R.N.: Geothermal energy reduces greenhouse gases. *Geothermal Resources Council Bulletin* **32**, (2003), 77-79.

Chiodini, G., Cioni, R., Guidi, M., Raco, B. and Marini, L.: Soil CO_2 flux measurements in volcanic and geothermal areas. *Applied Geochemistry* **13**, (1998), 543-552.

Durak, S., Erkan,B. and Aksoy,N.: Calcite removal from wellbores at Kızıldere geothermal field, Turkey. *Proceedings: 15th Geothermal Workshop*, Auckland, New Zealand, (1995).

Ellis, A.J. and Golding, R.M.: The solubility of carbon dioxide above 100^{o}C in water and in sodium chloride solutions. *American Journal of Science* **261**, (1963), 47-60.

Ellis, A.J.: Environmental impact of geothermal utilization. Report prepared for the United Nations Environment Programme. UNEP, (1975), 62 p.

EMRA Power Licence List. Available at: <http://www2.epdk.org.tr/lisans/elektrik/lisansdatabase/verilenuretim.asp> December 30, (2013).

Eysteinsson, H.: Elevation and gravity changes at geothermal fields on the Reykjanes peninsula, SW Iceland. *Proceedings: World Geothermal Congress 2000*, pp. 559-564, Kyushi, Japan, (2000).

Fridriksson,T., Kristjansson, B. B., Armannsson, H., Margretardottir, E., Olafsdottir, S. and Chiodini, G.: CO_2 emissions and heat flow through soil, fumaroles, and steam heated mud pools at the Reykjanes geothermal area, SW Iceland. *Applied Geochemistry* **21**, (2006), 1551-1569.

Haizlip, J.L., Gunay, A., Haklidir, F.T. and Garg, S.K.: The impact of high noncondensible gas concentrations on well performance Kızıldere geothermal reservoir, Turkey. *Proccedings: 37th Workshop on Geothermal Reservoir Engineering*, Stanford University, January 30-February 1, California, USA, (2012).

Haizlip, J.L., Haklidir, F.T. and Garg, S.K.: Comparison of reservoir in high noncondensible gas geothermal system. *Proceedings: 38th Workshop on Geothermal Reservoir Engineering*, Stanford University, 11-13 February, California, USA, (2013).

Hoefs, J.: Stable isotope geochemistry. Springer-Verlag, (1997).

Kristmannsdottir, H. and Armannsson, H.: Environmental aspects of geothermal energy utilization. *Geothermics* **32**, (2003), 451-461.

Lawless, J.: Geothermal lexicon for resources and reserves definition and reporting. Australian Geothermal Energy Group, (2010).

Lund, W.J., Frestone, H.D. and Boyd, L.T.: Direct utilization of geothermal energy 2010 worldwide review. *Geothermics* **40**, (2011), 159-180.

MIT – Led Report.: The Future of Geothermal Energy. Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century. Assessment by a MIT-led interdisciplinary panel (J.F.Tester, Cahirman), (2006), 372 pp.

Öngür, T.: Personal Communication. Unpublished report on "Natural CO_2 emission in Alaşehir-Gediz Graben", (2013).

Serpen, U., Aksoy, N., Ongur, T. and Korkmaz, E. D. Geothermal energy in Turkey: 2008 Update. *Geothermics* **38**, (2009) 227–237.