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Study on the Geochemistry of Potential High Temperature Geothermal Resources in Taxkorgan, Xinjiang, China

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ABSTRACT

The high temperature geothermal resources in China are concentrated on the Himalayan geothermal zone in Tibet. However, geothermal drilling has found high temperatures in the Taxkorgan County of the Xinjiang Uygur Autonomous Region in recent years. The downhole temperature is 158°C at a 350 m depth. In addition, the wellhead open flow of steam and hot water is at 146°C. Based on the tectonics, the Mediterranean-Himalayan geothermal zone turns at this joint. The Taxkorgan geothermal field is a fractured reservoir situated within granite and gneiss. The geothermal water in this reservoir is of a $ClSO_4$-Na type with a total dissolved solids concentration of 1,999 to 3,667 mg/L. Thus, these are considered to be mineral waters. The highest concentrations of silica and fluorine are 272.8 mg/L and 10.18 mg/L, respectively. Geothermometry shows high K-Mg temperature and silica temperature with temperature values of 126.4 to 166.5°C and 163.8 to 202.1°C, respectively. These geochemical features have characteristics that are similar to that of high temperature geothermal resources in the Yangbajain and Yangyi geothermal fields in Tibet. This discovery expands the distribution range of high temperature geothermal resources in China. These geothermal resources have the potential for geothermal power generation that can be used to provide district heating for the whole county.

1. INTRODUCTION

Chinese high temperature geothermal resources are mainly distributed in the Himalayan area in Tibet. The total number of identified areas of hydrothermal activity in China is more than 3000. Nearly 700 are in Tibet area, such as the Yangbajain geothermal power station built in Tibet in 1980's (Piovesana et al., 1987), the Yangyi geothermal plant under construction, and the Gulu high temperature geothermal field in the process of exploration (Zhang et al., 2014). Previous documents show that in the Xinjiang area, which is adjacent to the area of Tibet, the temperature of the geothermal water is below 60°C. Since 2001, the Second Hydrogeological and Engineering Geological Tam of the Xinjiang Bureau of Geology and Mineral Resources carried out a geothermal survey in the Taxkorgan Tajik Autonomous County in Xinjiang, and found some geothermal anomalies. Exploration drilling reached to the highest temperature of 101°C. In 2010, Pang et al. carried out a geothermal geology investigation in this area, where they analyzed the water chemical and isotope samples. This study estimated that the region had high temperature conditions with reservoir temperatures reaching as high as 173 to 191°C (Pang et al., 2011), which is suitable for geothermal development.

In this paper, the hydrochemical types of thermal waters of 15 drilling wells are analyzed and the geothermometers are calculated. The results will provide some basis for further exploration.

2. REGIONAL GEOLOGY BACKGROUND

The Mediterranean-Himalayan Geothermal Zone is classified as one of the high temperature geothermal belts in the world. It follows the boundaries of some plates. The Eurasian Plate is located in the north, while the African Plate, Arabian Plate, and Indian Plate are in the south from west to east. This boundary is not a straight line. One sketch map in the book "Generality of Geomechanics" written by Professor J.S. Lee, a Chinese geologist, shows the major tectonic zones exposed at the North Hemisphere, which trace a series of tectonic zones formed since the Mesozoic era between the latitudes of 30° to 40° N, (Lee, 1973) (Figure 1). The west side of the Mediterranean-Himalayan Geothermal Zone originates from the Mediterranean in Europe in the east, passing through the active volcanoes in Italy (Sicily and Pompei), the high temperature dry steam geothermal fields (Larderello), then Turkey, Iran and Afghanistan, before finally entering China. In China, the Himalayan geothermal zone is the main part of the Mediterranean-Himalayan geothermal zone. Its west section extends towards the northwest, along the Himalayan Mountains. Then, it goes through the Karakorum Mountains (NW direction) tectonics and joins the Hindu Kush Mountains (NE direction) tectonics to form an arc transition towards the north. The Himalayan tectonic zone and the Hindu Kush tectonic zone are relatively younger, being formed in the Mesozoic era.

The Taxkorgan high temperature geothermal field is located 8 km north of the Taxkorgan Tajik Autonomous County, 200 km south of Kashi City, at the west rim of Xinjiang Uygur Autonomous Region. The field is located on the Pamirs Plateau, on latitude 37°50'-37°52' N, longitude 75°11'-75°13' E. Its elevation is 3,300 m above sea level. Tectonically, it is located at the turning point of two tectonic zones, the Hindu Kush Mountain tectonic zone and the Himalayan Mountains tectonic zone. It is likewise the connecting point of the Mediterranean-Himalayan Geothermal Zone.

3. GEOCHEMISTRY OF THE GEOTHERMAL FLUIDS IN TAXKORGAN

The Taxkorgan high temperature geothermal field is located on the Quman area, 8 km north to the county, where the zone collects seasonal waters from the Quman gully to the south-north Taxkorgan Basin from west to east (Figure 2). The surface layer of the central area of the basin is covered by Quaternary deposits that are less than 100 m thick. The underlying stratum is composed of quartzite and gneiss from the Proterozoic Eon, which occurs on the edge of the basin. The Taheman spring, which is at 61°C, is exposed in the contacts of granite and gneiss that are controlled by fractures. Geothermal fluids are reserved in the bedrock cracks, part of which rise up and are stored in Quaternary loose deposits. The field is a fractured reservoir.

At the depth of 100 m, the well ZK7 with high temperatures was drilled into the gneiss. Furthermore, at a depth of 220 m, the fault transferring heat and fluids was intersected. The downhole temperature was 158°C at 350 m depth. Moreover, the temperature for the wellhead open flow of steam and hot water was 146°C (Pang et al, 2013). The Second Hydrogeological and Engineering Geological Team of the Xinjiang Bureau of Geology and Mineral Resources drilled more than ten wells. Water chemistry from each well was analyzed. Based on the water chemical data, the geochemical features of the geothermal fluids were evaluated.

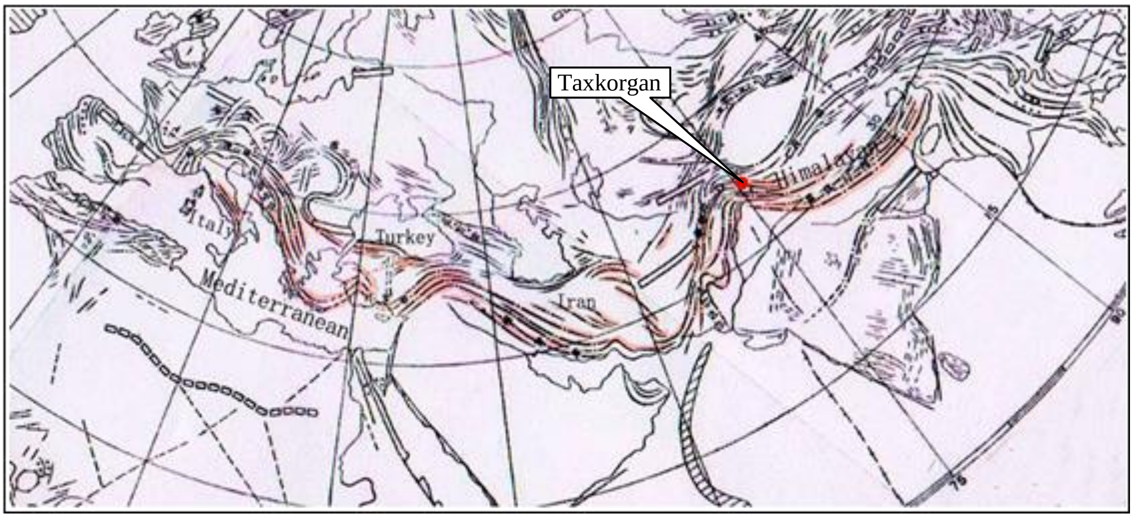

Figure 1: Spreading of the Mediterranean-Himalayan Geothermal Zone (taken from Lee, 1973)

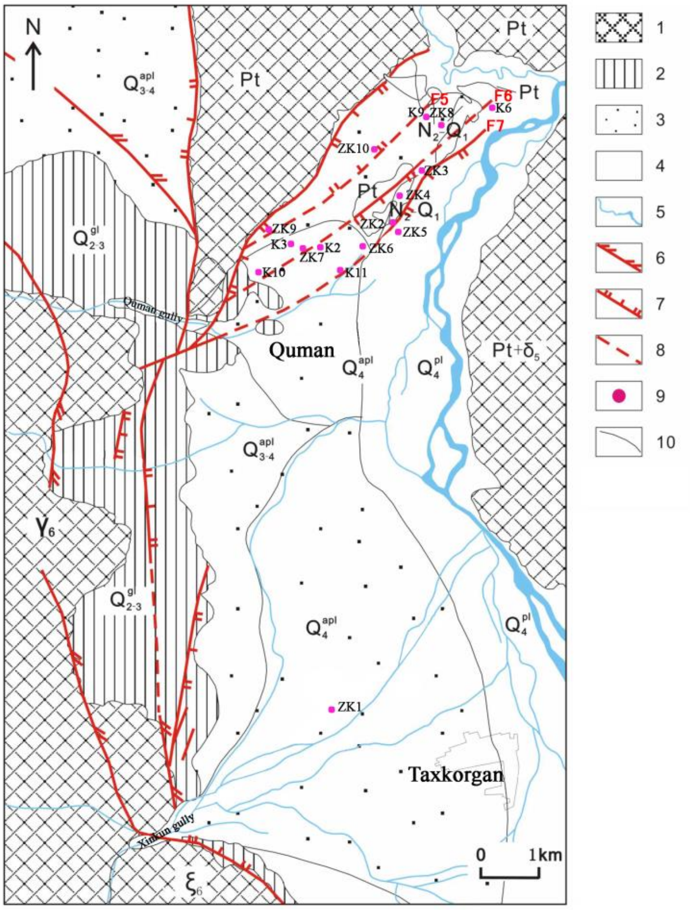

Figure 2: Location of the Study Area and the Drilling Holes. 1-denudation area, 2-till mound, 3-alluvial-porluvial plain, 4-alluvial plain, 5-water system, 6-tension-shear fault, 7-normal fault, 8-inferred fault, 9-drilling hole, 10-geological and geomorphological boundary

3.1 Water Type

According to the results of the water chemical analysis, 16 water samples from 15 wells can be classified as one of four types: high temperature geothermal water, salty thermal mineral water, medium-low temperature geothermal water, and fresh water (Table 1). For high temperature geothermal water, taking well ZK7 as a representative, the water is of the $ClSO_4$-Na type. The water sample from well K10 is also of this type. The total weight of HCO_3 is slightly higher than that of SO_4 in the water samples from well ZK8. Thus, these water samples can be found on the top left corner of the Langelier-Ludwig diagram (Figure 3) (Langelier and Ludwig, 1942). To simplify the analysis, these three wells can be approximated to have the same type. The temperature of well ZK7 is the highest, with a 158°C downhole temperature at a 350 m depth and a 146°C temperature at the wellhead open flow of steam and hot water. Thus, it belongs to the high temperature geothermal resources. Its total dissolved solids (TDS) ranges from 1,999mg/L to 3,667mg/L, belonging to the brackish water.

Table 1: Geothermal Water Chemical Types in Taxkorgan County, Xinjiang

Well No.	Well type	Water type	TDS(mg/L)	
ZK7	high temperature geothermal well	$Cl·SO_4$-Na	3,667	2,785(Brackish water)
ZK10		$Cl·SO_4$-Na	1,999	
ZK8		$Cl·HCO_3·(SO_4)$-Na	2,690	
K3	salty thermal mineral water well	SO_4-Na	8,977	5,401 (Salty water)
ZK9		$SO_4.HCO_3$-Na*	1,824	
K9	medium-low temperature geothermal well	$HCO_3·Cl·SO_4$-Na	2,382	2,210 (Brackish water)
ZK2		$HCO_3·SO_4·(Cl)$ -Na	2,677	
ZK6		$HCO_3·SO_4·(Cl)$ -Na	2,791	
K10		$HCO_3·SO_4·(Cl)$ -Na	1,999	
ZK4		$HCO_3·(SO_4·Cl)$ -Na	2,716	
ZK3		$HCO_3·(Cl·SO_4)$-Na	2,111	
ZK5		$HCO_3·(SO_4)$-Na	2,366	
K6		$HCO_3·(Cl)$-Na	2,344	
K11		HCO_3-Na	502	
ZK1-	low temperature well	$HCO_3·(SO_4)$-Ca·Na	277	278 (Fresh water)
ZK1		HCO_3-Ca	279	

*mixed with HCO_3 water

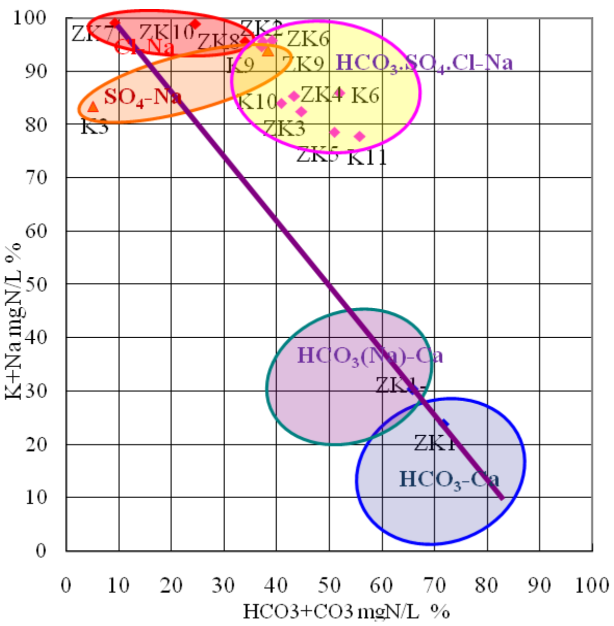

Figure 3: Langelier Ludwig Diagram of Taxkorgan Geothermal Waters

On the other hand, the salt thermal mineral water, such as the water sample from well K3, is of the SO_4-Na type. Similar to the high temperature geothermal water, this can likewise be found on the top left corner of the Langelier-Ludwig diagram. However, there is a difference between the high temperature geothermal waters and the salt thermal mineral waters. Firstly, the temperature of the salt thermal mineral water is relatively lower, with a 77°C downhole temperature at 53 m depth. Secondly, the concentration of SO_4 in this type is up to 5,668.76mg/L. These SO_4-Na type water samples have never been discovered in other high temperature geothermal fields in the world. The TDS of this water type can reach up to 8,977mg/L, which belongs to salty water. This is why it has been labelled as salt thermal mineral water. The mechanism for salt thermal mineral water creation may be that the water mixed with sulfide minerals near the well, which then oxidized to become SO_4. Thus, it cannot be confused with high temperature geothermal waters. Water samples in well ZK9 are of the $SO_4·HCO_3$-Na type. The concentration of HCO_3 in well ZK9 is slightly higher than in well K3. The distance between wells ZK9 and K3 is about 500 m, so well K3 may have some impact on well ZK9, resulting in the concentration decline of TDS. This type of thermal water is considered to be from local influences in a geothermal field.

The medium-low temperature geothermal water, which includes the rest of the wells (except for ZK1) in the Taxkorgan geothermal field, are all of the HCO_3·SO_4·(Cl)-Na type. In this water type, the concentration of Cl is slightly higher than that of SO_4 in well K9 and is slightly less than that of SO_4 in well ZK5. Moreover, the concentration of Cl is much less in wells K6 and K11. Except well K11 at south-east corner with a TDS value of 502 mg/L, the concentration of TDS in the other wells range from 1,999 mg/L to 2,791 mg/L with an average of 2,210 mg/L, which are all of the brackish water type. The temperature values of these wells range from 38 to 94°C, belonging to medium-low geothermal resources. All the samples are on the upper middle part of the Langelier-Ludwig diagram. Compared to the top left corner, it has less Cl and SO_4, which means that the percentage of HCO_3 increases relative to the other two. This may be the result of a mixture in the geothermal water and precipitation recharge in the shallow underground.

The last water sample type, which is fresh water, includes well ZK1, which is located at the entrance of the Xinkun valley on the edge of the Taxkorgan geothermal field. Fresh water samples are of the HCO_3-Ca type, which is the typical cold groundwater. All the samples are on the lower right side of the Langelier-Ludwig diagram. However, the water samples from well ZK1- (sampled later) is of the HCO_3·(SO_4)-Ca·Na type. The increase in concentration for Na and SO_4 are the results of the impact from thermal waters. The depth of this well is 300 m with a temperature of 27℃. It is considered to be a geothermal resource (≥25°C), but with low temperature water. Furthermore, the concentration of TDS is 279 mg/L, which is classified as fresh water. A straight line is drawn between wells ZK7 and ZK1 on the Langelier-Ludwig diagram, which is called mixture line of cold and hot water, shown as the purple line on the diagram. The mixing of hot water and cold water will change in a manner that follows the mixture line. For example, the water sample from well ZK1- is located on this line, which means that the cold fresh water in this area has been affected by the geothermal waters of the Taxkorgan geothermal field.

3.2 Standard Components

The concentrations of silica and fluorine in the thermal waters are higher than that in cold water sources. Thus, these can be used as the standard components of geothermal water. Table 2 shows the concentrations of silica and fluorine in the Taxkorgan geothermal fluids. The salt thermal mineral water type, represented by well K3 as discussed above, is a special case, so it is not discussed in this paper. The characteristics of the standard components for the other three groups are in accordance with geothermal regularities. Concentrations of silica and fluorine are the highest in high temperature geothermal wells. Moreover, silica and fluorine concentrations are also high in medium-low geothermal wells, a vast majority of which meet the mineral water standard and the standards for silica water (SiO_2≥38.5mg/L) and fluorine water (F≥2mg/L). On the other hand, the concentration of the standard components are the lowest in low temperature wells.

Table 2: Standard Components in Taxkorgan Geothermal Waters

Well No.	Well type	silica SiO_2 (mg/L)		fluorine F (mg/L)	
ZK7	high temperature geothermal well	272.82	201.19	11.41	9.69
ZK10		156.29		10.18	
ZK8		174.45		7.48	
K3	salty thermal mineral water well	11.86	62.26	1.01	3.91
ZK9		112.66		6.80	
K9	medium-low temperature geothermal well	71.64	119.79	5.95	5.80
ZK2		92.60		7.55	
ZK6		156.69		7.97	
K10		68.21		4.13	
ZK4		145.58		6.76	
ZK3		257.38		4.74	
ZK5		106.12		5.54	
K6		101.80		6.72	
K11		15.84		2.86	
ZK1-	low temperature well	156.9*	153.21 *	6.7*	4.51*
ZK1		29.73		2.32	

* affected by geothermal waters

3.3 Geothermometers

Thermal waters sampled at the wellhead hold geochemical information from deep in the earth. Geochemical geothermometry is a method to recover data from circulating groundwater, which can be used to deduce and calculate underground temperature values. According to the ratio of K/Mg from the water and rock equilibrium, the K/Mg temperature can be obtained from K/Mg geothermometer equations deduced from the thermodynamic equilibrium equations. This is also called the drilled temperature, which represents shallow underground temperature (Giggenbach, 1986). In addition, the silica temperature can be deduced from the concentration of silica in the water. It is the dissolved curve of silica under different temperatures. When the thermal water flows out of the geothermal reservoir with decreased temperatures, the silica in the thermal water does not deposit immediately. Thus, it can be used to determine the circulating temperature in the deep underground (Ellis and Mahon, 1977).

The K/Mg temperature and silica temperature of the Taxkorgan geothermal field calculated by two geothermometers are shown in Table 3. Salt thermal mineral water cannot be represented in a real geothermal system, so it is not included in this study. The K/Mg temperature and silica temperature are the highest in high temperature wells, followed by medium-low geothermal wells, and the lowest in low temperature wells. The results meet the objective of geothermometry. In addition, the silica temperature of well ZK7 reaches 202.1°C. This was the highest temperature reached in the deep reservoir for the Taxkorgan geothermal field, but it has not been obtained in drilled wells. It may be the highest temperature potential in the field.

Table 3: Results of Geothermometers in Taxkorgan Geothermal Field

Well No.	Well type	K/Mg temperature(°C)		Silica temperature (°C)	
ZK7	high temperature geothermal well	166.5	199.2	202.1	178.9
ZK10		151.5		163.8	
ZK8		126.4		170.8	
K3	salty thermal mineral water well	90.24	100.6	44.88	94.44
ZK9		110.9		144.0	
K9	medium-low temperature geothermal well	150.7	127.2	119.4	136.0
ZK2		128.6		132.9	
ZK6		127.5		163.9	
K10		97.62		116.9	
ZK4		120.0		159.3	
ZK3		111.3		197.8	
ZK5		116.0		140.5	
K6		118.9		138.2	
K11		73.98		54.90	
ZK1-	low temperature well	125.5*	87.21*	164.0*	121.5*
ZK1		48.91		79.03	

* affected by geothermal waters

4. COMPARISON WITH TIBETAN HIGH TEMPERATURE GEOTHERMAL RESOURCES

The Yangbajain geothermal power plant started geothermal power generation 38 years ago (26 MW production at present). There is another 32 MW plant under construction for the Yangyi geothermal field. A comparison of the geochemistry between the two high temperature geothermal fields and the Taxkorgan geothermal field was conducted.

Water types of the high temperature geothermal fluids of the Yangbajain and the Yangyi geothermal fields are shown in Figure 4 (Zheng and Chen, 2013). These are quite similar to the water types of the Taxkorgan geothermal field. In particular, the water type of the Yangbajain geothermal field is Na-Cl, and the mixed line is similar with that of the Taxkorgan geothermal field. Moreover, the water type of the Yangyi geothermal field is Na-Cl·HCO_3, and the mixed line deviates to right. Comparisons of the standard components and geochemical temperatures between these three geothermal fields are presented in Table 4, which show that the geothermal characteristics of the three fields are similar.

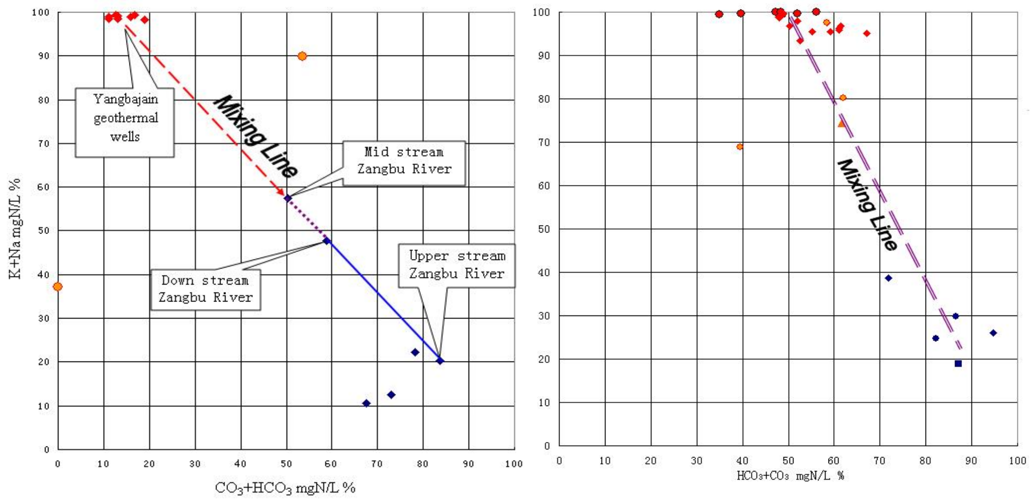

Figure 4: Water Types of the Yangbajain (left) and the Yangyi Geothermal Field (right) (Zheng & Chen, 2013)

Table 4: Comparisons of the Standard Components and Geochemical Temperature between the Taxkorgan and Tibetan High Temperature Geothermal Fields

Geothermal field	Standard Components（mg/L）		Geochemical Temperature（°C）	
	Silica	Fluorine	K/Mg temperature	Silica temperature
Taxkorgan	156.3-272.8	7.48-11.41	126.4-166.5	163.8-202.1
Yangbajain	150.8-441.2	4.46-34.22	143.2-202.6	145.7-219.1
Yangyi	200.2-393.3	9.50-22.04	125.4-168.4	170.7-210.0

5. CONCLUSIONS AND FUTURE PROSPECTS

The geochemical characteristics of the water samples from the Taxkorgan geothermal field are consistent with the features of high temperature fluids. Comparisons between the Taxkorgan geothermal field and other Tibetan high temperature geothermal fields show that their geochemical characteristics are similar. Thus, the Taxkorgan geothermal field in Xinjiang, as the middle joint of the Mediterranean-Himalayan Geothermal Zone, has a potential in producing high temperature geothermal resources. Although the geothermal exploration is still going on, with the total area and reserves of the field still waiting to be identified, this is expected to be another high temperature geothermal field in Xinjiang.

Furthermore, the Taxkorgan Tajik Autonomous County is an impoverished county inhabited by minorities in the border area, which is lacking in conventional energy resources. Thus, this geothermal resource is a bright prospect. In the future, high temperature geothermal resources can be used to yield electricity first, then, thermal waters gathered after separation can be used for geothermal space heating. The mean annual temperature in Taxkorgan County is 3.3°C, so this area needs space heating. A population of 60,000 needs housing with an equivalent area of 600,000 m^2, which, combined with public buildings, will not be more than 1,000,000 m^2 in total. The total heating demand will be about 70 MWt. After power generation from geothermal fluids flowing at a rate 20,000 m^3/d, the extracted heat from the tail water of 90°C dropping to 18°C can meet the heating demand. This goal can be realized if this project of space heating is applied to the Taxkorgan Tajik Autonomous County, where it may get national financial support. The total power generation with geothermal energy cannot satisfy the electricity demand of whole county, but it will still be a county-level model in using renewable geothermal energy.

REFERENCES

Ellis, A.J., and Mahon, W.A.J.: *Chemistry and Geothermal Systems,* Academic Press (1977), 392.

Giggenbach, W.F.: Graphical techniques for the evaluation of water/rock equilibration conditions by use of Na, K, Mg and Ca contents of discharge waters, *Proceedings,* 8th New Zealand Geothermal Workshop (1986), 45-47.

Langelier, W.F., Ludwig, H.F.: Graphical methods for indicating the mineral character of natural waters. *J. Am. Water Works Assoc.*, **34**, (1942), 335.

Lee, J.S.: *Generality of Geomechanics*. Science Press (1973), 166. (in Chinese)

Pang Z.H., and Liu B., et al.: A preliminary study of neotectonic control of Taxian high temperature geothermal field, Xinjiang Uygur Autonomous Region, *Proceedings,* Exploration and Development of High Temperature Geothermal Resources in China, Geological Publishing House, China (2013). (in Chinese with English abstract)

Pang Z.H., and Yang F.T., et al.: Geothermal display and geothermal reservoir temperature prediction of Taxkorgan, Xinjiang , *Gelogical Review*, **57**, (2011) 86-88. (in Chinese)

Piovesana, F., Scandiffio, G., Zheng, K., Zuppi, G.M.: Geochemistry of thermal fluids in the Yangbajain area (Tibet/China). *Proceedings*, International Symposium on the Use of Isotope Techniques in Water Resources Development, IAEA-SM-299/136, (1987), 47-70.

Zhang M., and Lin W. J., et al.: Hydrogeochemical characteristics and genetic model of Gulu high-temperature geothermal system in Tibet, China, *Journal of Chengdu University of Technology (Science & Technology Edition)*, **41** ,(2014), 382-392. (in Chinese with English abstract)

Zheng K.Y., and Chen Z.H.: A comparison of fluid geochemistry between Kangding and Tibet high temperature geothermal resources, *Proceedings,* Exploration and Development of High Temperature Geothermal Resources in China, Geological Publishing House, China (2013). (in Chinese with English abstract)