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Helium from Geothermal Sources

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ABSTRACT

Helium is a remarkable element possessing a broad bandwidth in the field of its application. It plays an indispensable role in many areas of fundamental research (cryogenics, nuclear science, material science), cutting edge technologies (nuclear reactors, space and rocket science, balloon and aerostat), medical diagnostic imaging (MRI), besides a host of other crucial uses. Presently there is a worldwide scarcity of helium supply. As of now globally the major source of commercial helium production is the petroleum natural gases. In Indian context, the natural gas reservoirs are lean in helium and India imports 100% of its total helium requirement. However many of the Indian hot springs are enriched in helium and may serve as the potential and indigenous source of helium. Indian geothermal provinces which are associated with high heat generating granites like those occurring in Bihar, Jharkhand, Chhattisgarh, West Bengal, Uttar Pradesh, Madhya Pradesh, Maharastra, Rajasthan and Karnataka are rich source of helium due to the high concentration of uranium in such granites. The helium content in the hot gases from Bakreswar and Tantloi (West Bengal-Jharkhand states) geothermal sites varies from 1-3% v/v. The volume of gas that escapes from the hot spring vents and the wells drilled in the above sites is 130 L/h and the flow rate of thermal water is 21000 L/h. Helium exploration field stations were also established in the above mentioned two sites. Hot spring gases are collected in cylinders and subsequently purified to the extent of 99.9% v/v. The temperatures of the thermal waters vary from 70-75 °C. The geothermal gradient and heat flow rate values of the Bakreswar-Tantloi geothermal area are 80 °C/km and 200 mW/m^2, respectively. It is proposed to drill an exploration cum production well in this geothermal to generate electricity using hydrothermal waters and to recover helium through installation of a large scale pilot plant.

1. INTRODUCTION

Helium is the lightest and only non-radioactive inert gas which is odourless, colourless, tasteless, non-toxic and mono-atomic. Helium stands out to be indispensable in fundamental research and modern technologies involving space, atomic energy, defense, medical sciences (MRI-magnetic resonance imaging technology), laser technology (He-Ne laser), superconductivity (as a refrigerant) and in many advanced researches, including fusion, magneto hydro-dynamics studies and behaviour of materials at very low temperatures. Its low cross-section for nuclear reactions leading to radio-nuclides under neutron bombardment and its high thermal conductivity make it useful in nuclear power plants and fusion reactors. Other uses are for leak detection, breathing mixtures for deep sea diving, chromatography and lifting gas for blimps and balloons. Helium, therefore, turns to be a commodity with wide potential applications in modern technology and has assumed considerable strategic significance. In recent years a serious helium shortage is anticipated. The crisis before the world is because USA, the global leader in helium production (supply about 95 % of the world's helium demand), has taken a decision that export of helium to other countries will be stopped soon (Mohr and Ward, 2014; Peterson, 2013; Bradshaw and Hamacher, 2013; Nuttall, 2012; Kaplan, 2007).

Helium consumption in India is approximately 0.15 billion cubic feet, about 2.3% of global helium consumption, most of which is imported from USA. Poland and Qatar are among the countries that produce helium, but have till the date limited export capability. India is entirely dependent on USA for tapping helium. USA is already turning off helium supplies to the outside world. The immediate implication is the serious consequences on India's space, defense and atomic energy programme along with a whole host of other areas such as MRI's medical equipment that will plunge into despair and come to a grinding halt. The switch off also implies serious problems to R&D programme in the Indian laboratories. However, no comprehensive effort has been undertaken so far in India to map the reserves and extract helium in a large scale. It is essential therefore for India to seriously initiate its own programme at a faster rate to produce helium in a large scale, in order to be reasonably self-reliant during crisis period.

Helium has so far been conventionally recovered from non-renewable natural resource (petroleum gas). However, geothermal areas with granitic basement heat and helium are found to be uniquely coupled. Crustal heat and helium are both produced by natural decay processes of uranium and thorium radioactive minerals that content in rocks. Geothermal areas having hot springs with high helium concentration are generally associated with high heat flow due to ascending high temperature hydrothermal fluids. Therefore, heat-helium coherence as found in some Indian geothermal areas may provide a unique possibility of obtaining bulk helium along with geothermal power if deep bore-holes are made in these areas. In the following section the article focused on the different aspects on discovery of helium, global resources of helium, and our attempt already made and future plan to extract helium in large scale from indigenous natural sources. The deep bore-holes (300-800 m) which are planned to be made in some specific Indian geothermal province (Bakreswar-Tantloi hot spring area) may provide simultaneously the supply of geothermal power and helium through installation of pilot scale helium and geothermal power plant.

2. THE HELIUM SAGA

2.1 The Discovery of Helium

Helium was first identified as a chemical element by the noted French astronomer PJC Janssen, on August 18, 1868 (Janssen, 1868). The observation was made through a spectroscopic measurements of the solar prominences monitored during a total solar eclipse that was viewed from Guntur in South India (Keesom, 1942a). The solar emission spectra revealed a dazzling yellow stripe close to the position of the well-known D1 and D2 lines of sodium. The observed new yellow line was designated as the D3 line. At the same time, the distinguished British astronomers, Edward Frankland and Norman Lockyer (Frankland and Lockyer, 1868; Cook, 1961; Amer. Chem. Soc. website) identified, independently, the same D3 line, using a much improvised spectroscopic observation of the normal sun. Both the astronomers Janssen and Lockyer were felicitated and credited by the French Academy of Sciences for the new discovery (Keesom, 1942b). The discovered new element was named as 'helium', derived from the Greek word '*helios*', meaning, the sun. Although helium was first observed in the solar spectra, the terrestrial helium was detected on the earth much later in March 26, 1895. Scottish chemist Sir William Ramsay isolated the component of the gas evolved upon heating a sample of a Norwegian mineral called '*cleveite*' (a mineral containing uranium) with sulphuric acid (Ramsay, 1895a and 1895b). British astronomer Sir Norman Lockyer and British chemist Sir William Crookes identified the component as helium. It was independently isolated in the same year by Swedish chemist Per Teodor Cleve and Abraham Langlet. Eventually, Sir Ernest Rutherford in 1908 proved that the source of helium in uranium minerals was α-particles given off during radioactive disintegration of uranium nuclei (Rutherford and Royd, 1909). A breakthrough was made on August 28, 1895 when German scientist Hermann Keyser found the other sources of terrestrial helium in the hot spring gas of Wildbad in the Black Forest of Germany (Keyser, 1895; Nath, 2012). The first commercial supplies of helium were generated from monazite sand (a thorium bearing mineral) of Ceylon and from Travancore, Kerala, of British India towards the beginning of the twentieth century. Thomas Tyrer, under the leadership of Ramsay, produced small quantities of helium from monazite. This was entrapped in specially prepared lead-glass containers. The entire work was performed in the Indian Institute of Science, Bangalore, India, through the enterprise of Prof. Morris Travers, the first director of the Institute (Keesom, 1942c). In 1908, helium was first liquefied by Dutch physicist Heike Kamerlingh Onnes and that helium was obtained by heating monazite sands supplied from the sea beach at Kerala, India (Onnes, 1908). Thus the helium saga happens to be closely interlinked with India (Chaudhuri et al., 2010).

The abundance of helium in the atmosphere is very low. It comprises only 5.2 parts per million (ppm) by volume in atmospheric air. However, in 1905 American Scientist Prof. Erasmus Haworth, Prof. Hamilton Cady and David McFarland found the abundance of helium (1.84 vol.%) in the natural petroleum gas sample collected from gas well at Dexter, Kansas, USA. It was, so far, firmly believed that helium existed only in the sun. The gas was believed to be on the earth only in feeble traces in the atmosphere and in some isolated thermal spring gases and in minerals containing uranium like cleveite. The discovery of helium present in natural gas was revolutionary (Amer. Chem. Soc. website). It indicated the possibility that the element may exist in large abundance trapped within the earth. The breakthrough had immediate repercussions. It helped float a completely new chain of industries. The gas, subsequently, proved to be a major strategic boon for the USA, especially during the two World Wars. It has since then played a key role in the swift scientific and economic advancement of USA. As of now USA is the world's largest producer of helium with a total capacity of approximately 95 % of the global output.

2.2 Production Mechanism of Primordial Helium (^{3}He) and Radiogenic Helium (^{4}He)

Uranium and thorium concentration in some common crustal rocks

rock type	uranium, ppm averg. (range)	thorium, ppm averg. (range)
Igneous		
Alkaline Intrusives	8.2 (0.1 - 19.7)	17.2 (0.6 - 35.0)
Silicic Extrusives	5.0	
Granitic	4.8 (2.2 - 7.6)	21.5 (8.0 - 56.0)
Gabbroic	0.8 (0.2 - 3.4)	3.8
Basaltic	0.4 (0.1 - 1.0)	1.6 (0.2 - 5.4)
Sedimentary		
Shales	4.2 (3.2 - 8.0)	11.7 (10.2 13.1)
Limestones	2.1 (0.3 - 9.0)	2.2 (0.1 - 7.5)
Sandstones	1.3 (0.5 - 3.2)	3.4 (1.0 - 9.0)
Metamorphic	2.9 (0.2 - 11)	8.6 (0.1 - 27)
Soils	1.13 (0.27 - 2.08)	6.94 (4.03 14.1)

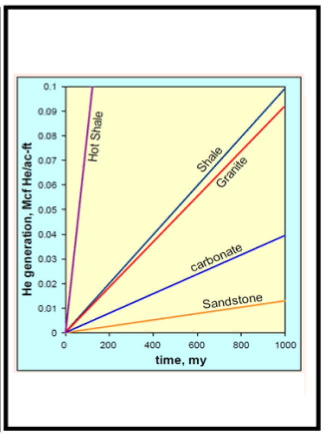

Figure 1: Variation in total volume of helium generation in various rocks with different geological time (modified after Bueno, 1980 and Brown, 2010).

Although there are nine known isotopes of helium (He) (standard atomic mass: 4.002602(2) u), only helium-3 (^{3}He) and helium-4 (^{4}He) are stable. All radioisotopes are short-lived, the longest-lived being ^{6}He with a half-life of 806.7 milliseconds. The least stable is ^{5}He, with a half-life of 7.6×10^{-22} seconds, although it is possible that ^{2}He has an even shorter half-life. In the Earth's atmosphere the isotopic abundance of helium is as follows - ^{4}He (99.99%) and ^{3}He (0.01%). However, isotopic abundance of helium varies greatly depending on its origin.

$$^{232}\text{Th} \rightarrow {}^{208}\text{Pb} + 6\ {}^4\text{He}$$
$$^{235}\text{U} \rightarrow {}^{207}\text{Pb} + 7\ {}^4\text{He}$$
$$^{238}\text{U} \rightarrow {}^{206}\text{Pb} + 8\ {}^4\text{He}$$

He production rate (P) in the earth's interior

$$P_U \rightarrow 1.02 \times 10^5 \text{ atoms/cm}^3\text{/sec}$$
$$P_{Th} \rightarrow 2.46 \times 10^4 \text{ atoms/cm}^3\text{/sec}$$

The radiogenic helium (or sometime called as crustal helium) is generated by the natural radioactive decay of heavy radioactive elements thorium (^{232}Th isotope) and uranium (^{238}U and ^{235}U isotopes) present in the rock matrix, although there are other mechanism. The mechanism of radiogenic helium production in the deep earth is shown schematically above. The helium is released through fractures, faults and hot spring vents via diffusion, fluid advection and fracturing process. The radiogenic helium is trapped with natural gas (petroleum gas form oil & gas fields and hydrothermal gas from hot springs, fumaroles, geyser etc.) in concentrations of 0.03-7.00 vol.% from which it is extracted commercially. Helium is a finite resource and is one of the only elements with very high escape velocity, meaning that once released into the atmosphere, it escapes into space. Most helium in the universe is believed to be formed during the Big Bang through nuclear fusion. Some contribution in the terrestrial helium also comes from helium-3 nuclei (primordial helium or sometime called as mantle helium) that formed during the accretion process of the earth and is trapped in the earth's mantle.

Availability of large volume of helium in natural petroleum gas / hydrothermal gas in geothermal areas depends on a number of factors such as,

- He is generated through the radioactive decay of U and Th in the crust. Then it diffuses to pore water. He concentration in pore water increases with increasing U and Th concentration, increasing age (geological time scale), and decreasing porosity. Helium generating power within a rock depend primarily on the uranium and thorium content of the rock (i.e. category of the rock) and also on the geological age (in geological time scale ~ mega annum; Ma i.e. million years) of the host rock. Figure 1 illustrates the variation in total volume of He generation in various rocks with different geological ages.
- The pore water must be old prior to gas interaction, preferably 100 Ma or more. Gas and water should interact at shallow depths to maximize He extraction from the water. He is concentrated into economic gas accumulations where pore water, rich in dissolved He interacts with a gas phase. More helium is partitioned from water into gas at low pressure, high salinity and cool temperature. These conditions are more likely to occur in shallow reservoirs than deep reservoirs.
- The total volume of gas that interacts with the pore water should be relatively small to avoid He dilution by later gas charge. High helium concentrations result from low gas to water ratio.
- Helium is generated by the interaction of helium-rich water and gas. Co-generation of helium and methane even in the leanest source rock would dilute helium concentration to uneconomic levels.
- Reservoir pressure and fluid pressure should not be high enough so that fluid rock interaction is unfavorable for generation of helium.
- Once He is entrained in the gas, it migrates with the gas to traps just like other gas accumulations.
- Old (Paleozoic) siliciclastic sediment, not deep basement, is the most probable source rock for economic He accumulations. Old fractured shale, arkoses, granite wash, and shallow fractured basement are potential source rocks for He. Sedimentary shales and granites have equal helium source potential. Either could be a good source. Sediment is closer to traps, but basement has a larger source volume.
- He generated in the deep crust is not likely to form economic accumulations. Deeply generated He cannot migrate to traps in overlying strata unless some fluid carries it out of the basement. Variation of He generation process with depth in pore water is shown in Fig. 2.

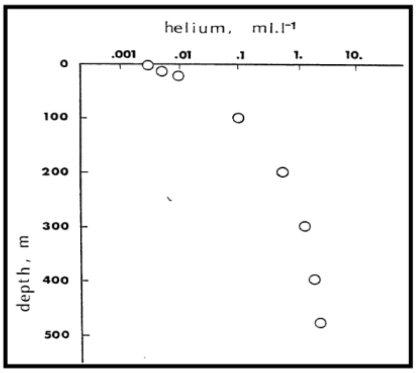

Figure 2: Variation of He generation process with depth in pore water (modified after Bueno, 1980).

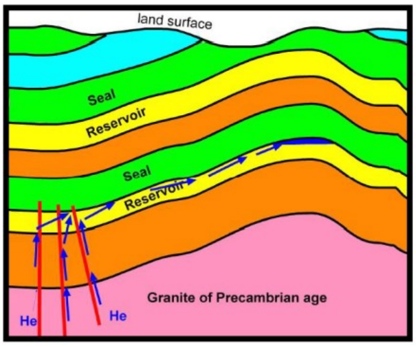

Figure 3: Schematic diagram of an underground natural helium reservoir (modified after Broadhead and Gillard, 2004).

Total quantity of helium that is present within a reservoir depends on its average concentration (Composition of the gas and fluids in the reservoir rock and the total volume of the natural petroleum gas. This in turn depends upon the porosity (the percent of void space in the reservoir rock) and the physical dimensions of the reservoir (thickness, length, and width). All these features, combined, determine the maximum amount of space available in the reservoir that can be occupied by gases. However, a part of this volume is usually reduced by water saturation - the percentage of the void filled by water.

Besides the above factors, the number of wells and spacing of the wells within the field, the diameter of the pipe, and the drilling path (or production path) - the physical path along which the well is drilled will also impact the primary production capability of the well. Enhancements to production, such as compression to change the pressure impact in a field will also play a vital role in production. Extraction of helium from natural gas largely depends on the makeup of the well-head production stream. Non-combustible gases such as helium, nitrogen, hydrogen sulphide, carbon dioxide, water vapor are cast as contaminates and are therefore required to be removed to improve the calorific value of the natural gas. In the process of removal of non-combustible gases helium is extracted from the gas stream.

Throughout the mid-continent, known high-helium concentrations exist where there is ample uranium and thorium in the basement “granitic” rock. With the help of tectonic activity (i.e. deep-seated faulting) and the brittle nature of the granites, helium will be expelled up into the sedimentary column. In all cases, helium requires a carrier gas (methane / nitrogen) so it will flow and ultimately collect in a gas reservoir. Helium is always found with methane and nitrogen. Carbon Dioxide is also found in some helium-bearing formations but the presence of this gas is primarily due to its proximity to ancient volcanic activity. The most important factor in a helium-bearing field is the presence of a cap rock (or seal) that is impermeable enough to withstand helium leakage. This is the primary reason why we do not see more helium fields throughout the world. Figure 3 shows the schematic diagram of an underground natural helium reservoir.

2.3 The Global Resources of Helium and Its Market

Helium is conventionally recovered from natural petroleum gas & oil fields. The commercially exploited helium bearing natural gas contains 0.4-8% helium and 12-80% nitrogen. The helium bearing natural gas deposits are distributed unevenly geographically and are available with fluctuating compositions as shown in Fig. 4. The recognized locations of helium- enriched (>0.3 vol.% He) natural petroleum gas are found in the middle-eastern part of the USA. Nearly 95% of the world’s helium production comes from the USA natural petroleum gas field. The average helium concentration in the natural petroleum gas there is around 0.8 vol.%. It is commonly known that Texas gas wells produce natural gas containing as high as 7-8 vol.% of helium. Helium is also available in the natural petroleum gas of Canada., Algeria, Poland, Russia and China. The average concentration of helium in the gas fields of these countries range between 0.18 vol.% to 0.9 vol.%. Helium content of some typical samples of helium bearing petroleum natural gases from India, USA, Canada, Poland and Netherlands etc. are shown in Table 1.

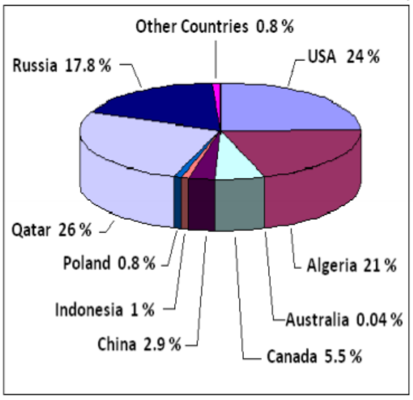

Figure 4: Distribution of helium resources throughout the globe (modified after Pacheco, 2006).

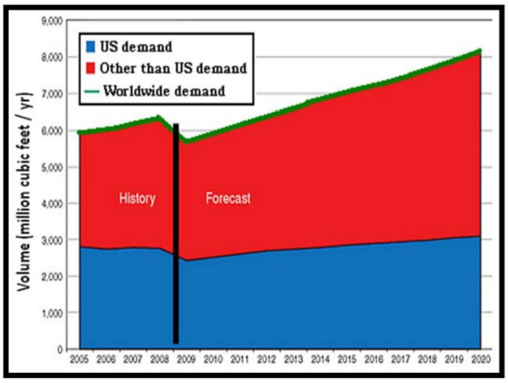

Figure 5: Actual (2005 and 2008) and projected (2009-2020) market demand for refined helium.

Figure 5 shows the actual (2005 and 2008) and projected (2009-2020) market demand for refined helium.

Table 1: Composition of helium bearing natural petroleum gas.

Constituent	India (Kuthalam Tamilnadu)	USA (Otis, Kansas)	USA (Petrolia, Texas)	Canada	Poland	North Sea	Netherlands
CH_4	88.5	78.2	51.8	80.0	56.0	90.4	81.3
CO_2 and C_2^+ etc.	10.2	7.7	---	12.0	0.48	5.1	3.5
N_2	1.18	12.7	46.4	8.0	42.8	3.8	14.3
He	**0.06**	**1.4**	**1.5**	**0.34**	**0.4**	**0.05**	**0.05**

Besides USA, several other countries such as Poland, Algeria, Russia, Qatar and Canada also produce helium. Table 2 shows the known helium reserves of some of these countries.

Table 2: Helium reserves of some principal countries producing helium.

Country	2011 production (million cubic metre)	Reserves (million cubic metre)	Resources (billion cubic metre)
United States (from natural gas)	8.3	4000.0	16.4
United States (from Cliffside Field Reserve)	57.0	--	4.3
Algeria	20.0	1800.0	2.0
Canada	N/A	N/A	2.0
China	N/A	N/A	1.1
India	***N/A***	***Not known as of today***	***Not known as of today***
Poland	3.0	33.0	--
Qatar	15.0	N/A	10.1
Russia	6.0	1500.0	6.8
Other countries	N/A	N/A	N/A
World Total	180 (Estimated)	N/A	N/A

3. THE INDIAN SCENERIO ON HELIUM EXPLORATION

3.1 Availability of Helium from Indigenous Sources

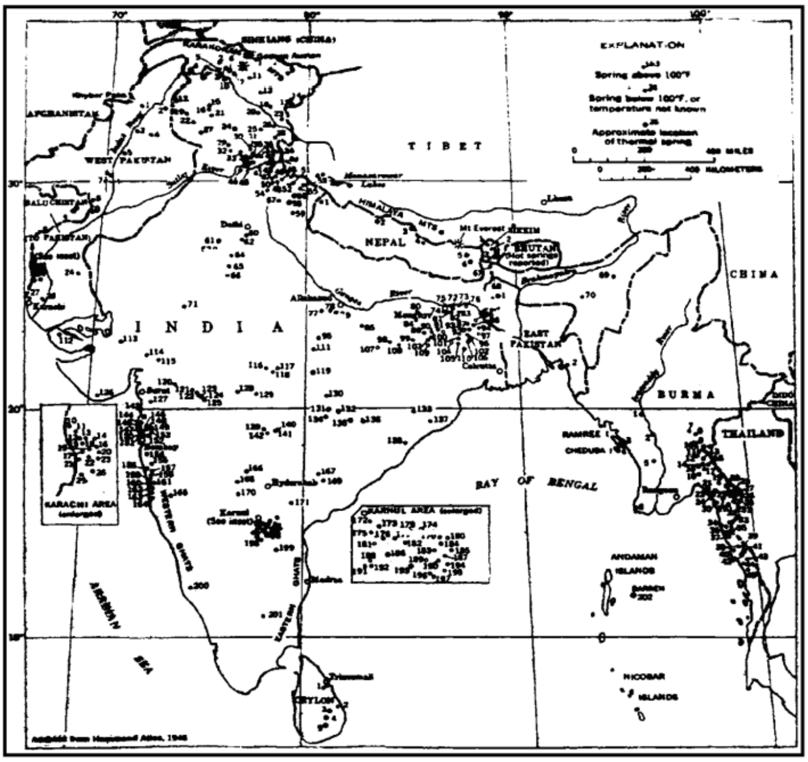

Figure 6: Location of hot springs in the map of India as identified by the British geologist (modified after, Oldham R.D., 1883) - Black dots indicate the hot springs.

The possibilities of extraction of bulk amount of helium from indigenous sources in India are as follows:

- *Natural petroleum gas deposits*: India has natural gas reserve typically of Cretaceous age (145-66 Ma). The helium content in natural gas in India is comparatively low – mostly of the order of 0.03-0.05 vol.% with high flow rate 10^3–10^5

Nm^3/hr. The natural gas fields are located in many parts of India. They are the western off-shore region and the Mumbai High complex. There are also on-shore natural gas fields in Assam, Tamilnadu – Cauvery Basin, Andhra Pradesh - Krishna-Godavari Basin spread and the Gujarat state and the oil-rich Barmer Block in Rajasthan.

- *Monazite sand*: Monazite is a phosphate of thorium. It contains on the average about 1 ml. He per gram of monazite, or about 1 cubic meter He per ton of the treated mineral. India has one of the world's largest reserves of Monazite. It exists in the beach sands along the Travancore – Cochin sector of the Malabar Coast; the beaches of Kerala and in Tamilnadu between Kollam (Quilon) and Kanya Kumari. It is also present in the estuary of the Narbada River on the Gujarat Coast; in Ratnagiri in the Gulf of Cambay south of the Narbada. Rich deposits of monazite are also found in Orissa in the East Coast, in Andhra Pradesh Vishakapatnam and the mouths of Godavari and Brahmani rivers and the Coromondal Coast near Chilka and Jharkhand.
- *Hydrothermal gas (Hot spring gas)*: Several hot springs are scattered throughout the country in different geothermal areas in the state of West Bengal, Jharkhand, Bihar, Chhattisgarh, Maharastra, Gujarat, Rajasthan, Karnataka, Orrisa, Uttarakhand, Himachal Pradesh and Jammu & Kashmir etc. British geologist identified more than three hundred hot springs in India as shown in the map of India (Fig. 6). Many of these hot springs contain helium in excess of 1.0 vol.% and even up to 6.8 vol.%. Table 3 shows the He content of some of these hot springs. On the other hand all the known natural petroleum gas fields in India are lean in helium (0.05 vol.% in average). And to recover helium from natural petroleum gas, a host of allied factors need to be taken into account including the natural petroleum gas well life-time, before a helium extraction unit can be set-up. As an alternate measure, exploring helium extraction from geothermal areas appears promising because of higher helium concentrations (1.0 vol% in average in hot spring gases, 20 times higher than helium concentration in natural petroleum gases) available for virtually inexhaustible time-scale durations (geological time scale). It is always economical to recover helium from a gas source having high helium content with high flow rate. These hot springs may also be utilized as a source of geothermal power - a vital source of energy (green energy) still completely ignored in India.

Table 3: Helium concentration in hot spring gases of various geothermal areas in India.

Sr. No.	Test Site	State	Sample type	Temp. (in ^oC)	He (in ppm)
01	Bakreswar Agni Kunda	West Bengal	Hot spring gas	69.10	**18800.00**
02	Bakreswar Khar Kunda	West Bengal	Hot spring gas	66.00	**13600.00**
03	Tantloi (main spring)	Jharkhand	Hot spring gas	66.00	**13000.00**
04	Suraj Kunda	Jharkhand	Hot spring gas	52.00	**9400.00**
05	Attri	Orissa	Hot spring gas	54.80	**11600.00**
06	Taptapani	Orissa	Hot spring gas	40.90	**7200.00**
07	Tarabalo	Orissa	Hot spring gas	41.80	**5100.00**
08	Jakrem	Meghalaya	Hot spring gas	46.40	**9200.00**
09	Garampani	Assam	Hot spring gas	37.10	**8000.00**
10	Borpung Nambour	Assam	Hot spring gas	36.70	**3000.00**
11	Manikaran	Himachal Pradesh	Hot spring gas	94.20	**<100.00**
12	Kasol	Himachal Pradesh	Hot spring gas	69.40	**<100.00**
13	Tattapani	Himachal Pradesh	Hot spring gas	54.60	**3000.00**
14	Tatta Pani Bathing ghat	Jammu and Kashmir	Hot spring gas	55.00	**1600.00**
15	Tatta Pani Meherot	Jammu and Kashmir	Hot spring gas	45.10	**11500.00**
16	Tuwa	Gujrat	Hot spring gas	63.00	**7600.00**
18	Unai	Gujrat	Hot spring gas	-	**68900.00**
19	Tural	Maharastra	Hot spring gas	62.00	**17400.00 to 30500.00**
20	Koknere	Maharastra	Hot spring gas	58.00	**10000.00 to 21200.00**
21	Unhavre	Maharastra	Hot spring gas	70.00	**15000.00 to 24300.00**
22	Akoli	Maharastra	Hot spring gas	54.00	**23600.00**
23	Ganeshpuri	Maharastra	Hot spring gas	52.00	**21300.00**
24	Pali	Maharastra	Hot spring gas	43.00	**29200.00**
25	Sov	Maharastra	Hot spring gas	42.00	**28300.00**
26	Salbardi	Maharastra	Hot spring gas	42.00	**33000.00**
27	Sativli	Maharastra	Hot spring gas	52.0	**15900.00**
28	Arnala	Madhya Pradesh	Hot spring gas	-----	**7900.00**
29	Tatta Pani	Chhattisgarh	Hot spring gas	95.0	**2000.00**
30	Baratang	Andaman and Nicobar Islands	Mud Volcano	Ambient	**2000.00**

3.2 A Brief History of Helium Recovery in India

3.2.1 Hydrothermal Gas (Hot Spring Gas)

Serious search for large-scale helium in India began during the first years of the 1970's by the legendary scientist S. N. Bose, FRS, National Professor of Physics. Prof. Bose is famous for his remarkable discovery (in 1924 with Albert Einstein) on statistics of fundamental particles. These particles are called as Boson after the name of Prof. Bose. Professor Bose had the foresight to recognize that India would need substantial quantities of helium gas in future to feed its emergent requirements in crucial scientific areas. And this supply must essentially come out of its own natural resources. Accordingly, he started off a 'Helium Recovery' project at the India Association for the Cultivation of Science (IACS) at Jadavpur, Kolkata, during 1971. The entire task of planning and execution of this project was entrusted to the well-known experimental physicist, Professor S. D. Chatterjee, one of the distinguished students of Professor Bose. Prof. Chatterjee noted the presence of helium in the hot spring (72^oC) gas emissions at Bakreswar, near Santiniketan, West Bengal. The helium content of the Bakreswar gas was about 1.8 volume percent. The helium recovery pilot plant (helium recovery from hot spring gas) built by Prof. Chatterjee and his colleagues at Bakreswar was a remarkable breakthrough. It immediately attracted the attention of Department of Science and Technology (DST) and Department of Atomic Energy (DAE). And so, in 1977 at the insistence of Dr. H. N. Sethna, the then Chairman, Atomic Energy Commission (AEC) along with Dr. A. S. Divatia, Project Manager, Variable Energy Cyclotron Centre (VECC), Kolkata the work concerning helium recovery done at IACS was transferred to VECC from March 1978. The related field work was taken charge of by the Atomic Mineral Directorate (AMD) of DAE. This part was also subsequently transferred to VECC in 1982. Around 1984, Prof. Bikash Sinha joined VECC and he got interested in the project, especially after meeting Professor S.D. Chatterjee who had extraordinarily original and innovative ideas. These novel ideas were greatly admired by Dr. Raja Ramanna (former Chairman, Atomic Energy Commission) and Prof. Sinha. Meanwhile, helium extraction from the nearby geothermal field at Tantloi (Jharkhand) also started through a joint venture of DST, VECC and Saha Institute of Nuclear Physics (SINP), Kolkata. A purification plant (cryo-adsorption followed by and cryo-condensation) was installed to improve recovered helium purity upto 99.99%.

Figure 7: Photographs of helium plants installed at Bakreswar and Tantloi.

With a mission to extract helium from hot spring gas Helium Recovery Plants (Pilot Plant) were established at Bakreswar (West Bengal) during 1990 and Tantloi (Jharkhand, 25 km apart from Bakreswar) during 2003 (Das et al., 2003). The rate of gas outflow in these springs varies between 200-500 lit/hr with helium concentration 1.2–1.4 vol.%. It was the country's first attempt to extract helium from unconventional terrestrial sources such as hot spring emanations. Figure 7 shows the photographs of helium plants at Bakreswar and Tantloi.

Figure 8: Helium Purification Plant installed at SINP/VECC Campus, Kolkata.

A helium purification plant, working on the principle of cryo-adsorption (using LN_2), was installed and commissioned at VECC/SINP campus during 2004 with a view to purify the impure helium to Grade-A (99.995 vol. %) helium. The overall recovery of the plant is virtually 100 % (Das et al., 2005). Figure 8 shows the photograph of the cryo-adsorption (using LN_2) based Helium Purification Plant installed at SINP/VECC campus, Kolkata.

Later on Prof. Bikash Sinha and his group also performed detailed geochemical and geophysical research activities at Bakreswar-Tantloi geothermal region, West Bengal and in Jharkhand through a research grant from Ministry of Earth Sciences (MoES). The work brought to light two vital conclusions:

- A huge reservoir of helium exists within the crust not far beneath from the top soil at the Bakreswar-Tantloi geothermal area. The surface expression of helium, as seen at hot spring bubble gas, figures only but a tiny fraction of this reservoir. This region hosts almost 60 hot springs within 2500 square km area. These hot springs are enriched with high concentration of helium (1.88-2.77 vol.%.). Indeed, this fact was surmised and mentioned long time ago by Professor S. D. Chatterjee to Prof. Bikash Sinha.
- The high geothermal heat outflow (230 mW/m^2) and geothermal gradient (90 ^{o}C/km) are seen in this area. Also high concentration of helium and radon (radioactive gas) are emanating from the hot springs of this zone. These data indicates

the presence of a potential geothermal resource in the area. This area will be ideal for setting up a "geothermal" energy reactor - a vital source of energy (green energy) still completely ignored in India.

Presently research scientists from National Institute of Technology, Durgapur (a premier institute under the Ministry of Human Resource and Development [MHRD]), has taken the initiative to explore the helium and geothermal reservoir at Bakreswar-Tantloi area.

3.2.2 Natural Petroleum Gas

Figure 9: Four-stage PSA Helium Plant (proto type) installed at ONGC's gas field (Karaikal Asset) at Kuthalam, Tamilnadu.

In the leadership of Prof. Sinha, in 2008, a prototype helium extraction plant was also installed at natural gas field at Kuthalam, Tamilnadu by VECC, SINP in collaboration with DST and Oil and Natural Gas Corporation (ONGC) to extract helium from natural gas. It was demonstrated for the first time in the country that it is very much possible to recover helium from natural petroleum gases. Moreover that extremely low concentration helium bearing natural petroleum gas was purified using Pressure Swing Adsorption (PSA) technique to produce a high grade helium (99.0 vol.% pure helium). Photograph of the four stages PSA Helium Plant is shown in Fig. 9. The said PSA helium plant produced a constant stream of pure helium (99.0 vol. %) from a natural gas feed stream having helium content to the tune of 0.06 vol.% at an overall recovery rate of approximately 61% (Das et al., 2008). The above proto type pilot plant was operated by taking the feed gas supply through an auxiliary line where the flow was restricted to 50 Nm^3/hr, whereas the actual flow of the Kuthalam Gas Collection System from oil and gas wells are of the order of 10^4 Nm^3 /hr. It was demonstrated that helium separation from natural gas was feasible out of a feed gas containing 0.06% He. Total helium yield from this prototype plant was 7 nos. cylinders per month. This was a remarkable breakthrough. However there is a substantial possibility to extract helium of the order of 300 nos. cylinders per month, by installing a large scale plant at the same site using the full potential of the flow rate of the order of 10^4 Nm^3 /hr. [1 pressurised helium cylinder contains about 6.5 Nm^3 gas]. Helium extraction in large volume by this source gas is inextricably tied up with the economics of the natural gas production.

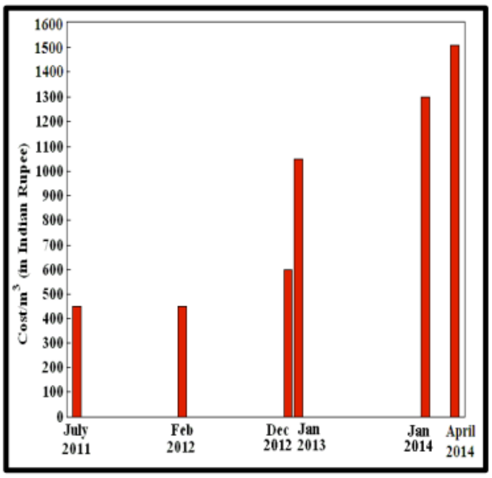

Figure 10: Fluctuation in helium price in the last three years (2011-2014) as per Indian Helium market.

3.2.3 Monazite Sand

In 1952, the Rare Earths Division (RED) in Udyogamandal, Kerala was established. The RED is engaged in activities related to mineral separation and value addition to radioactive minerals including monazite. It is well-known that helium can be recovered as a valuable byproduct from the gas emanated when monazite is processed for production of thorium oxides, uranium oxides and oxides of other rare earths. Accordingly a pilot plant was installed by Bhabha Atomic Research Centre (BARC) to extract helium from monazite sand.

3.3 The Crisis of Helium in India

Helium consumption in India is approximately 0.15 billion cubic feet, about 2.3% of global helium consumption, most of which is imported from USA. However, in recent years a serious helium shortage is anticipated. The crisis before India is because USA (the global leader in helium production) is already restricted the export of helium. The US decision indeed seriously affected the helium market in India. In the last three years (2011-2014) the price of helium increased drastically. Present day (2014) price of helium (per m^3) is 3 times higher than that of 2011 as per the record of Central purchase department (Department of Atomic Energy) of Government of India (Fig. 10).

4. EXPLORATION STRATEGY ON LARGE SCALE HELIUM EXTRACTION AND GEOTHERMAL POWER AT BAKRESWAR-TANTLOI GEOTHERMAL AREA

Bakreswar-Tantloi geothermal province is located at the eastern end of the Son-Narmada-Tapi (SONATA) mid-continental rift SONATA and lies within the Singhbhum shear zone dominated by the Chota Nagpur granites and Gondwana sedimentary formations. Geological backdrop of the eastern part of the SONATA geothermal region along with the extension of deep rooted faults, folds, lineament and associated rock structure and the location of Bakreswar-Tantloi hot spring sites are shown in Fig. 11. The Bakreswar-Tantloi geothermal region lies in the vicinity of the extinct (~ 117 Ma) Rajmahal volcanic (Rajmahal Trap) which is located towards the north-western part of the said area. This region reflects a very high geothermal gradient (~90^0 C/km) and high heat flow rate (~*200mW/m*^{2}). The hot springs at Bakreshwar (Agnikund) and Tantloi are controlled by E-W and N-S faults. There are a number of deep fault systems aligned E-W superimposed by NE-SW structural features and folds that are aligned North-South. These hot springs were issued through the Gondwana-granite contact, characterized by siliceous and ferruginous breccias, with issuing temperature of 40-72° C. The Archean metamorphic and igneous rocks near the springs are sheared and brecciated and can be seen along the Sidheswari river section (north of Tantloi) and Bakreswar river sections (north of Bakreswar). The entire region hosts about 60 (sixty) hot springs. Surface manifestation of emerging hot waters from depth and flowing into adjacent streams and ponds are seen in several places in this region including those at Mallarpur, Bhuri, Kendughata, Boleghata, Tantni, Bakreswar, Tantloi etc. which provides first sight information on the vast extent of geothermal activity in the region (Chaudhuri et al., 2010; Majumdar et al., 2000; Sarkar, 1982; Ravi Shanker, 1991, Nagar et al., 1996).

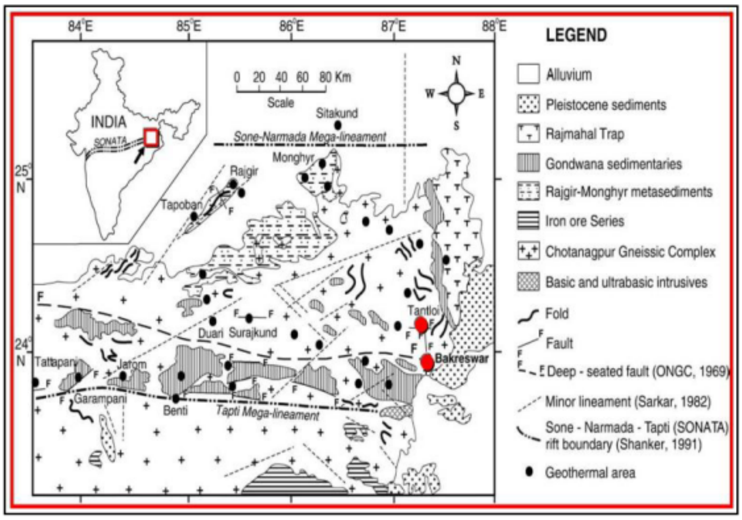

Figure 11: Geological backdrop of the eastern part of the SONATA geothermal region along with the location of Bakreswar and Tantloi hot spring sites (modified after Majumdar et al., 2009).

In the Bakreswar-Tantloi geothermal region, it is reported, that magma is present at relatively shallower depths (Singh et al., 2004) as shown in Fig. 12. The modeling shows a 10–15 km thick high-density (ρ = 3.02 g/cm^3) homogeneous but anomalous crustal layer above a depth of 38 km below the Rajmahal Traps. In areas where the mantle is significantly uplifted as in the Bakreswar-Tantloi areas lying within the Rajmahal Volcanic Traps, access to significant quantity of helium source is expected to be reasonably high. The hydro-geologic setting and extension of the Bakreswar-Tantloi geothermal region would suggest that this geothermal area is of the liquid dominated type, with a pressure gradient that is dominated by hydrostatics rather than a vapour-static pressure gradient. However, the possibility that this liquid-dominated system may be the 'surface expression' of a vapor-dominated system located at considerable depth cannot be ruled out. Silica thermometry studies point out that reservoir temperature of the Bakreswar-Tantloi geothermal region is in the range of 160-180^0 C. Majumdar et al. (2009) estimated the reservoir temperature of the Bakreswar geothermal resource. In his estimation both the quartz and SiO_2 geothermometers give an estimate of 100±5 °C for the probable temperature of reservoir. On the other hand, Mukhopadhyay and Sarolkar (2012), suggested that the reservoir temperatures of Bakreswar hot springs (TSiO2) may vary from 110-124 °C (by TSiO2 method) and 130-175 °C (by Na /K ratio method) The data suggest that higher temperatures may be available in deep reservoir. In the Bakreswar-Tantloi geothermal area this heat source comes from the thermal activity of the extinct Rajmahal volcanism as well as the high heat generating Chota Nagpur granites that host uranium mineralization (Jaduguda, Jharkhand) within the Singhbhum craton (Sarangi, 2003).

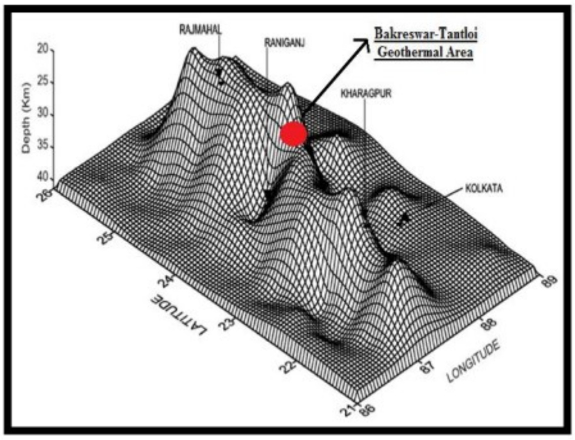

Figure 12: A three dimensional configuration of the accreted igneous layer beneath the Rajmahal Traps lying over a Moho of about 38 km depth (modified after Singh et al., 2004).

Electromagnetic imaging of the sub-surface beneath Bakreswar geothermal area was conducted by Sinharay et al. (2010) by measuring the electrical and magnetic field variations using the Audio magneto telluric (AMT) technique. AMT studies revealed the existence of a deep heat source/reservoir in the N-W part of Bakreswar. Figure 13 shows the resistivity profile at shallow depth at Bakreswar-Tantloi geothermal region. It is conjectured that the springs were originate from the contact between groundwater and high temperature intrusive magmas or by hydrothermal alteration of silica. The hot spring gas and water are enriched with helium (> 1.0 vol.%) as well.

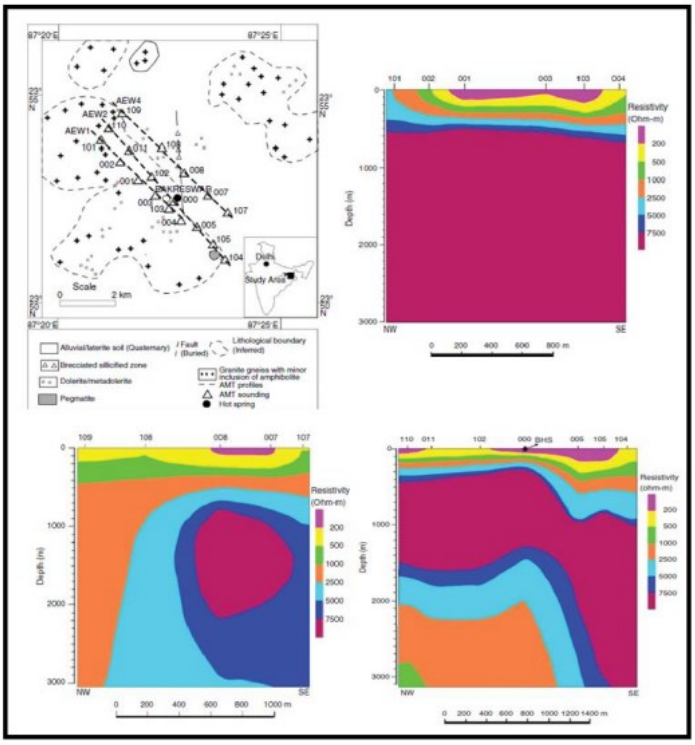

Figure 13: Resistivity profile at shallow depth at Bakreswar-Tantloi geothermal region (modified after Sinharay et al., 2010).

Table 4 shows the composition of the gas released from some of the hot springs (temperature 40-72 ^{o}C) in the Bakrewar-Tantloi geothermal region. Hot spring gases in this area are enriched with nitrogen. However the concentration of helium emanating from the hot springs in this area are quite high (1.8-2.7 vol.%). Table 5 also clearly indicates the presence of high He content in some of the hot springs, ambient air, soil gases and bore-hole gases in the Bakreswar-Tantloi geothermal area. Long-period observations by Indian Associate of Cultivation of Science (IACS), Kolkata [during 1960-1970]; Atomic Mineral Directorate (AMD) [during 1970-1982]; and Variable Energy Cyclotron Center (VECC) [since 1982 to till the date] & Saha Institute of Nuclear Physics (SINP) [during 2002-2009], have shown that the temperatures of the hot spring waters, helium content in hot spring gases, out flow rate of the thermal water discharge and thermal gas discharge have not been altered for several years (last 50-60 years). The out flow rate of the hydrothermal gas discharge (130 L/h), hydrothermal water discharge (21000 L/h), temperature of the hot spring water (72^{o}C) and helium content in hot spring gases (1.8 vol.%, surface manifestation) are not affected by seasonal changes and those were maintained at the mentioned values in the last 50-60 years. Moreover concentration of helium in hot spring gases of Bakreswar and Tantloi vary from 0.91-1.88 vol.% and 0.33-1.30 vol.% respectively. In the hot springs at Bara Palasi, Dalahi, Tantni, Suraj Kunda, Jarom, Tatta concentration of helium vary from 0.42-2.10 vol.%. In Dalahi helium concentration in very high 2.10 vol.%. Helium concentration at atmospheric air at Bakreswar-Tantloi geothermal area is also very high – 0.03420-0.07800 vol.% (3420-7800 ppm) in comparision to that at non-geothermal area – 0.00005 vol.% (5 ppm). AMD made some bore-hole at Tantloi geothermal area and it was observed that concentration of helium increased with depth in the following manner – 0.03420 vol.% at atmospheric air at a height of 1 m, 1.30 vol.% at surface manifestation of hot springs, 1.47 vol.% at the depth of 175 m and 1.85 vol.% at the depth of 175.6 m. However in Tantloi the other bore-hole (65 m depth) showed significantly high helium concentration – 2.77 vol.%.

Table 4: Composition of the gas released from some of the hot springs in the Bakreswar-Tantloi geothermal region.

Location	Temp. (ºC)	H_2 (vol.%)	**He (vol.%)**	N_2 (vol.%)	O_2 (vol.%)	Ar (vol.%)	CO_2 (vol.%)	CH_4 (vol.%)
Agnikunda (Bakreswar, West Bengal)	72	52 ppm	***1.88***	91.45	0.85	1.80	1.20	2.82
Surajkund (Hazaribagh, Jharkhand)	52	0.21	***0.94***	94.34	1.40	2.30	0.67	0.14
Tantloi (Dumka, Jharkhand)	66	0.70	***1.25***	91.38	2.65	1.92	Trace	2.80
Kendhughata (Jharkhand)	65	0.50	***1.10***	92.70	1.70	1.30	0.60	2.10
Bholeghata (Jharkhand)	42	Nil	***0.80***	62.10	12.40	0.80	17.90	Nil
Tantni (Jharkhand)	62	0.40	***1.00***	94.80	0.30	2.60	0.30	0.60

Table 6 shows a comparison between the characteristics of the Bakreswar Springs of Birbhum district, West Bengal, India and Navajo Springs of Arizona, USA where helium is found in very high concentration (8.0 vol.%) with high reservoir pressure (8.4 kg/cm^2). Total bore depth at Navajo is 1140 ft (347 m).

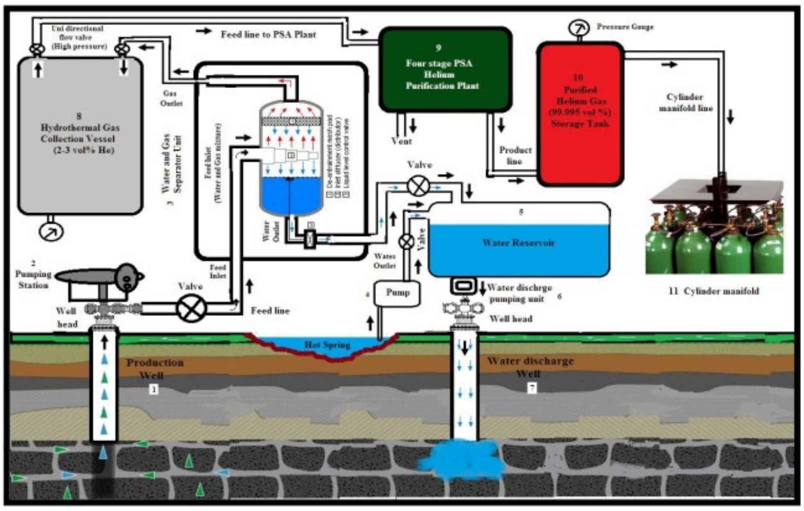

Figure 14: Schematic diagram of a large scale helium extraction and purification plant.

To develop a large scale helium recovery plant based on hydrothermal system deep drilling (approximate 500-1000 m) is planned for developing injection well where cold water (ambient temperature) will be pumped down the well. This cold water will filter through the under earth helium reservoir and then high pressure will used to bring the hydrothermal water back up through production well. Once the high pressure and high temperature hydrothermal water-gas mixture containing high helium concentration will reach the surface (well-head), a vapor-water separator will be used to separate the gas phase from liquid phase. Helium reach hydrothermal gas will be then transferred to Helium Purification Plant to enrich the helium level. Residue water will be pumped down again through the injection well as a recycle process. Fig. 14 shows the schematic diagram of the proposed large scale helium extraction plant to recover helium from geothermal resources. Subsequently helium will be purified in combination of cryogenic technique (using liquid nitrogen) or non-cryogenic pressure swing adsorption (PSA) technique to enhance the recovery. Hydrothermal gas which will be collected from bore-hole (Feed gas) will be passed through a series of vessel containing different chemical absorber such as silica gel, activated carbon, zeolite etc. Different physical processes such as feeding, pressurization, purging, rinsing, blow down and evacuation will be performed at varying pressure (pressure swing at both positive and negative pressure) for different time duration. After removal of the hydro carbon components and other components such as nitrogen, hydrogen etc. ultra-pure helium will be collected at a high pressure in large amount (purity > 99.0 vol.%).

Table 5: Helium concentration in hot spring gases, soil gases, borehole gases and geothermal water of Bakreswar-Tantloi geothermal area.

Sr. No.	Test Site	State (Location)	Sample type	Temp. (in ^oC)	He (vol.%)
01	Bakreswar Agni Kunda	West Bengal	Hot spring gas	72.00	1.88000
02	Bakreswar Khar Kunda	West Bengal	Hot spring gas	66.00	1.30000
03	Bakreswar Bhairab Kunda	West Bengal	Hot spring gas	62.20	1.12000
04	Bakreswar Bramha Kunda	West Bengal	Hot spring gas	46.10	1.26000
05	Bakreswar Suraj Kunda	West Bengal	Hot spring gas	63.30	0.31000
06	Bakreswar Reserve Tank	West Bengal	Hot spring gas	52.00	0.91000
07	Bakreswar 1	West Bengal	Soil Gas	-	0.00530
08	Bakreswar 2	West Bengal	Soil Gas	-	0.00470
09	Bakreswar 3	West Bengal	Soil Gas	-	0.00383
10	Bakreswar 4	West Bengal	Soil Gas	-	0.00192
11	Bakreswar 5	West Bengal	Ambient Air	-	0.05620
12	Bhabanipur	West Bengal	Ambient Air	-	0.07800
13	Tantloi (main spring)	Jharkhand	Hot spring gas	66.00	1.30000
14	Tantloi (in stream, Tanteswari)	Jharkhand	Hot spring gas	45.00	0.33000
15	Tantloi 1	Jharkhand	Soil Gas	-	0.00380
16	Tantloi 2	Jharkhand	Soil Gas	-	0.00280
17	Tantloi 3	Jharkhand	Ambient Air	-	0.03420
18	Tantloi 4 (65m)	Jharkhand	Borehole Gas	-	2.77000
19	Tantloi 5 (175m)	Jharkhand	Borehole Gas	-	1.47000
20	Tantloi 6 (141-177.4m)	Jharkhand	Borehole Gas	-	1.70000
21	Tantloi 7 (175.6m)	Jharkhand	Borehole Gas	-	1.85000
22	Tantloi 8 (200m)	Jharkhand	Borehole Gas	-	1.29000
23	Bara Palasi	Jharkhand	Hot spring gas	-	1.68000
24	Dalahi	Jharkhand	Hot spring gas	-	2.10000
25	Tantni	Jharkhand	Hot spring gas		1.00000
26	Tarasol	Jharkhand	Ambient Air	-	0.03670
27	Raneswar	Jharkhand	Ambient Air	-	0.06340
28	Bholeghata	Jharkhand	Hot spring gas	42.00	0.80000
29	Kendughata	Jharkhand	Hot spring gas	65.00	1.10000
30	Suraj Kunda	Jharkhand	Hot spring gas	52.00	0.94000
31	Jarom	Jharkhand	Hot spring gas	52.00	1.18000
32	Tatta	Jharkhand	Hot spring gas	73.00	0.42000

Table 6: Relative characteristics of Bakreswar hot Springs (West Bengal, India) and Navajo hot Springs (Arizona, USA).

<table>
<tr><td rowspan="5">Gas characteristics</td><td>Gas concentration (in vol.%)</td><td>Bakreswar Hot Springs (69 ºC) West Bengal, India</td><td>Navajo Hot Springs (62.2 ºC) Arizona, USA</td></tr>
<tr><td>He</td><td>1.8 (Surface manifestation of the hot spring, depth – 0 m)</td><td>8.0 (At a depth of 347 m bore-hole at hot spring site)</td></tr>
<tr><td>N_2</td><td>91.4</td><td>89.9</td></tr>
<tr><td>CH_4</td><td>2.8</td><td>0.2</td></tr>
<tr><td>Others</td><td>4.0</td><td>1.9</td></tr>
<tr><td>Oil characteristics</td><td></td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="4">Spring Characteristics</td><td>Geological Age</td><td>Jurassic ~ 200 Ma</td><td>Permian ~ 275 Ma</td></tr>
<tr><td>Producing formation</td><td>Rajmahal traps -Faulted anticline</td><td>Faulted anticline trap</td></tr>
<tr><td>Total depth</td><td>Not determined as yet</td><td>1140 ft = 347m</td></tr>
<tr><td>Reservoir pressure</td><td>Not determined as yet</td><td>124 psi (8.4 kg/cm^2)</td></tr>
</table>

5. DISCUSSION AND CONCLUSION

The results presented here are preliminary; however these indicate the presence of large and extended source of helium and geothermal reservoir in the said location. It is strongly anticipated that the out flow of thermal water and gases along with the concentration of helium and temperature of the hydrothermal water will increase many folds when a deep bore-hole (300-800 m) will be made near the hot spring site at Bakreswar-Tantloi geothermal area. With the commissioning of the deep drilling the production rate of the helium at this site will be scaled up by drastically from the present production rate (restricted to surface manifestation only). In fact, both the idea of "extraction of helium in large scale" and "geothermal power" at Bakreswar-Tantloi geothermal area is complementary to each other. Helium and geothermal heat is coupled to each other. Both of them are produced from common source of uranium and thorium, present in the crustal rock and also in mantle. Hot spring with sizeable helium content in the emanating natural gas should in principal lead to large natural heat source not too far away from the surface of the earth. This is a fact especially so if one compares the depth to which one has to drill in areas where there is no hot spring with escaping natural gas. Therefore it is recommended to make a number of bore-holes (300-800 m) at this geothermal area followed by a detailed geophysical survey (resistivity survey and MT survey). A common deep drilling (~300-800 m deep) could be used to tap both the helium sources and geothermal resources.

Our immediate plan is to install bore-holes (300-800 m) at least at five locations near the hot spring. Subsequently experimental work will be carried out to evaluate the change in temperature, geothermal gradient, heat flow rate, helium concentration and outflow rate of geothermal gas and hydrothermal water discharge with depth. Data logging will be performed in each 10 m. A detailed geochemical and geophysical database (geothermal mapping and helium mapping) will be prepared through mathematical and statistical analysis to develop an initial model of the subsurface using all available data. Numerical simulations will also be done to optimize the location and quantify uncertainty. Once sustained outflow of the order of 300-500 Nm^3hr^{-1} (with pressure 2-5 kg/cm^2) of geothermal gas and hydrothermal water (with temperature 70-100 ^oC) is available with considerable concentration of helium (> 2.0-2.5 vol.%) at the mentioned 300-800 m deep bore-holes, a proposal could be made to install a large scale helium recovery plant (pilot scale) along with purification system with capacity to produce 99.0 vol.% pure helium. Simultaneously effort will be given to set up a small scale geothermal power plant (pilot plant) at Bakreswar-Tantloi geothermal area.

The deep drilling at Bakreswar-Tantloi geothermal area will be used to produce large volume of helium that can be utilized to reduce the volume of imported helium in the country and in course of time it will play an important role to make India self-reliant on helium. All our major scientific institutions including space, atomic energy and defence need helium on a large scale. Besides, helium is indispensable to various other sectors such as Magnetic Resonance Imaging (MRI), manufacturing of optical cables, fabrication of integrated circuits etc. Helium is also used in super- conductivity technology which is the frontier technology of tomorrow. Despite significant progress in India in recent years, Bakreswar-Tantloi area, the border district of West Bengal-Jharkhand especially, still has a low electrification rate and an inadequate electricity supply, while the demand for electricity continues to rise. Moreover, the problems related to CO_2 emissions from the existing thermal power plant (1000 MW) at Muthabaria, (8 km from Bakreswar) and the coal ash that is being accumulated in the ash ponds (creating environmental hazard) can be mitigated to certain extent by harnessing the geothermal resources in this area.

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