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UNDERGROUND COAL GASIFICATION AND UTILIZATION OF SYNGAS IN VARIOUS FIELDS: A REVIEW

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Abstract:

Coal is the most widely deposited fossil fuel on our planet. That is the reason why it plays a key role in the energy sector. Underground coal gasification (UCG) is a technique that is used in those areas where we cannot get coal by mining. Those coal reserves having a water layer cannot be extracted by mining easily. So this technique is used where we convert coal in to gas called syngas. This is an atmosphere clean process to reduce 90% Sulphur and CO_2in the air called green technology. Thar Desert (Pakistan) has world's 2nd largest coal reserve of 175 billion ton. In this paper energy scarcity issue in Pakistan has been addressed with focus on thermal psychiatry of Thar coal reserves. The syngas can be utilized for power generation or as feedstock in the production of liquid fuels, fertilizers, or other chemical products. Main benefit for coal gasification in underground is the fact that it is a clean form of energy, because most pollutants remain underground.

Key words: Syngas, Gasification, Gasifier, Lignite coal

1. INTRODUCTION

Among the developing countries, the Pakistan is one of the countries, which tried to achieve its goals for energy sector through hydal. According to latitude and longitude, Pakistan lies in that region of the world, which is blessed with abundant natural resources and hilly areas, which is more suitable for hydro electricity generation. From last few decades Pakistan intended to utilize its natural resources for the generation of energy, especially in power generation sector. Many of hydro electricity generation projects such as Mangla, Terbela, Ghazi-brotha etc. and many others on small and large scale has been installed and produced about 14000MW up to year of 2002 [6]. Most of the hydro power generation projects are under construction and some projects which were intended to start had run out in to political snag. As the installation cost of hydal projects is very high and huge patch of land is required for construction of dam. These are very severe problems which are being faced by Pakistan for installation of additional hydro power generation projects to meet the load demand of the country [1]. A couple of years ago, it is decided to install additional power generation projects to meet the growing demand of power sector through thermal, nuclear, fossil fuel etc.

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A nuclear power plant was installed in Chashma of about 300MW. Again the installation cost of nuclear power generation projects is also very high and enough crew members are required to run the nuclear power plants which are very infeasible for the country like Pakistan. Energy produced by fossil fuel was in very small scale and also causing environmental hazards [2]. Most of the thermal power generation was installed with natural gas and furnace oil as primary fossil fuels but Pakistan was unable to produce furnace oil indigenously as well as imports of oil on large scale, that's why the electricity produced through furnace oil was very costly [3]. Thermal power plants using natural gas being run from a decade to meet the load demand of the country. All thermal units are being run on the principle of single steam turbine, which gives the efficiency of about 27%.with such low efficiency and ever growing shortage of supplies, attention has been diverted towards exploration of new fossil fuels for these plants [4].Coal is a type of fossil fuel, it plays a vital role in the energy sector. Hence, there are various amount of technologies that are needed for coal's utilization in a more efficient way. Depleted oils and gas wells imposing bad factor on the fuel utilization and for this abundant coal in Thar can be used as a substitute for the future generations [5]. As the crude oil and natural gas are present at lower prices, the coal utilization and enhancement was slow in the last few runs. But as the oil and natural gas reserves are being consumed so coal will be again considered as perthe best option for the production of energy [6].Gasification of coal in underground is a multivariate application of explorative digging.

Amazing benefit that leads to adopt UCG technology is its eco-friendly behavior and less maintenance infrastructure. The most important benefit is that it increases the worker safety, no surface disposal of ash and coal tailings, low dust and noise pollution, low consumption of water, larger coal resource exploitation and lower amount of methane will be emitted to the atmosphere in this way [5–9]. This technique is most favorably adopted on those regions where coal deposits are more steeple inside the crust and where the cap lock layers or rock is present in the crust for benefiting of no leakage of Synthetic gas. [7]. for the feasibility of UCG, sites should be analyzed and assessed. UCG is relatively there in well developed countries like the USA, Russia, France, Spain and China [10]. Due to its capability of deterioration of underground water, this technology is adopted using hit and trial method. Pakistan has extremely potential for this technique to benefit the urbanization of country [8].

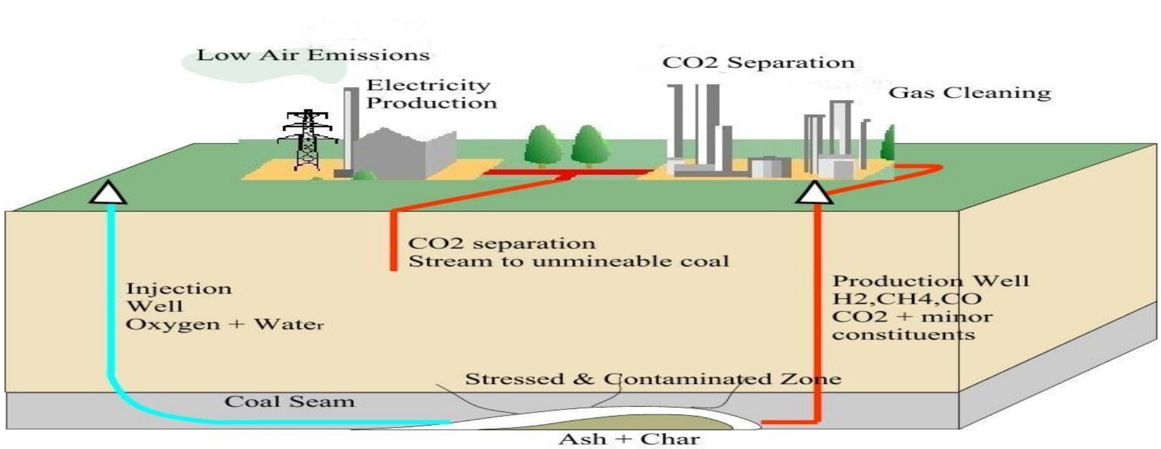

Figure 1. Components of the UCG process collocated with electricity generation

2. Materials and Methods

2.1. Designing UCG system at Thar coal field

Pakistan is blessed with immense resources of coal in the desert of THAR, 410 km from the Karachi, Sindh. Coalfields are located between latitude 24`15 North to 25`45 North and longitude 69`45 East to 70`45 East in southern region of the Province of Sindh, Pakistan. The Thar coal field is a part of Thar Desert of Pakistan and it is almost 9th largest desert of the world. According to geological survey and drill well shows the presence of three likely Aquifer zones at various depths: (i) above the coal zone Ranges between 50 m to 90 m depth.(ii) lies in 120 m depth of coal region: and there thickness up to 70 m and (iii) below the coal zone [10]. At 200 m depth: thickness up to 47 meters. 86 wells are drilled at a distance of 25 meters from each other for conversion of coal into syngas by underground coal gasification. According to the geological survey report of Pakistan 2008 on Thar coal reservoir it has been discover with estimated of 175 billion tons of pure lignite coal, which is spread over an area of more than 9100 km^2 with dimensions of 140 km (north-south) 65 km (east west). This coal can easily converted into syngas through some chemical process, the process is called underground coal gasification (UCG). In this process the bothering of mining is being avoided that syngas can be converted into furnace oil through a chemical process. It is more feasible to run the units on the principle of Integrated Gasification Combined Cycle (IGCC) [11].

In this process the gases and steam which comes out from single steam turbine at highly temperature will be given to another boiler to run a small turbine (which is directly coupled to electrical generator) for the generation of extra power. The both units combine will give the efficiency of about 57%. The cost of generation through thermal using IGCC will become half as compared with the conventional power plants employing single turbine principle [12].

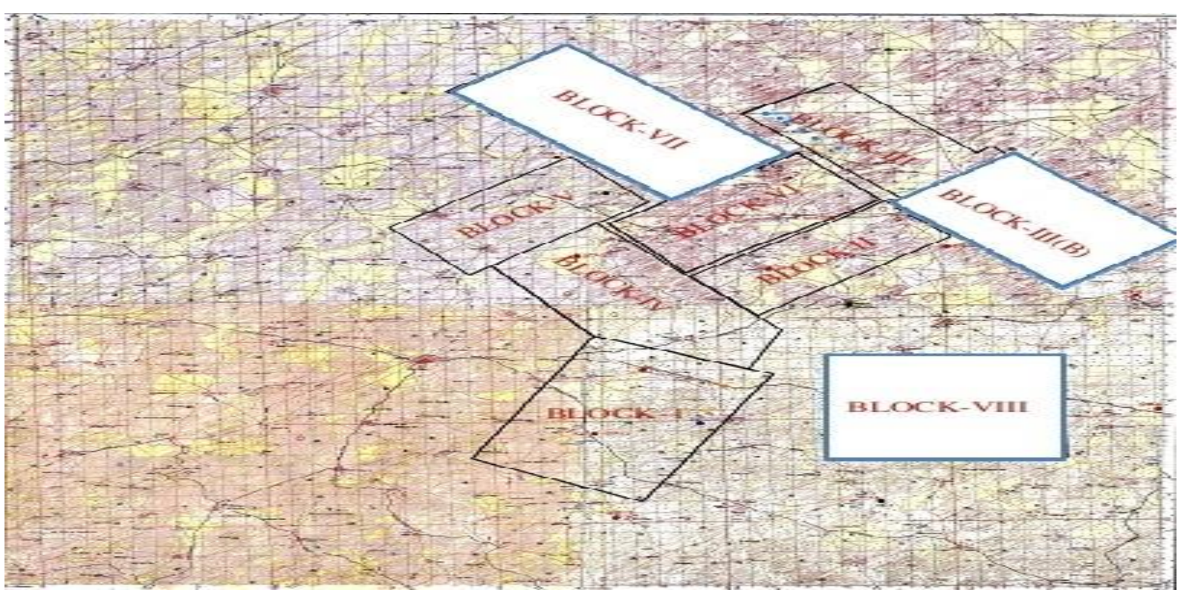

Figure 2. Block wise diagram of Thar Coal Field

2..2 Geography of Block III

Block III consists of 99.5 km^2 which is about 1% of the total Thar coal field.

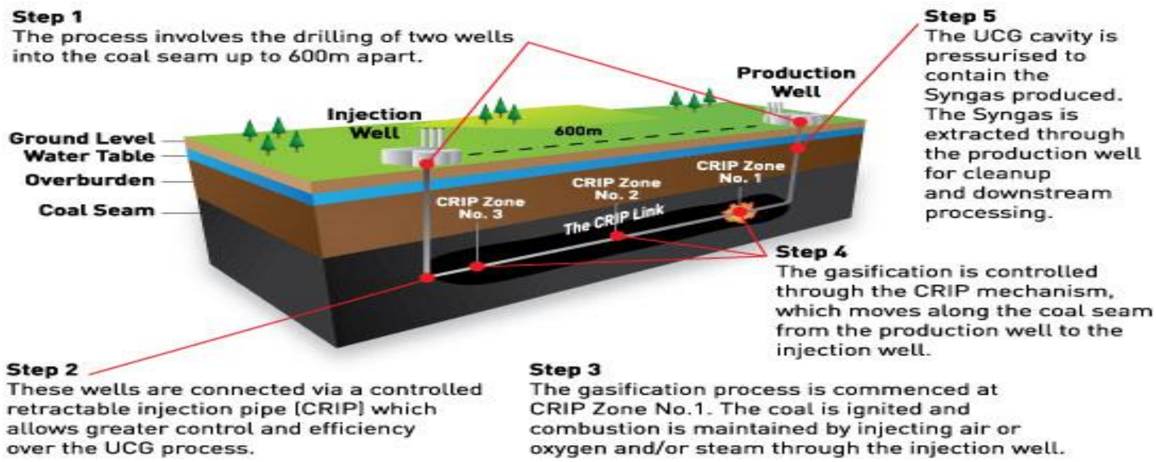

Figure 3. Design parameters of CRIP well of on Block III (A) at Thar Coal

The number of holes drilled in this block is 41. And approximation of coal present in this particular section is about 2008 Million T, which is about 1.143% of total coal present in the field. The III block is named as Saleh Jo Tar, and located at coordinates of latitude 49^{0}49’ N to 24^{0}58’ N and longitude 70^{0}12’ E to 70^{0}18’ E. Accumulative coal seam thickness ranges about 7.2 m to 24.5 m, it has depth about 114 m to 203 m [13].

2.3 Chemical Composition

Analysis of four blocks of Thar coal can be seen in Table 1. The weighted average chemical analysis of the coal samples of the four blocks show variation and are as given in Table 1.

Table 1. Chemical composition of Thar Coal field

Moisture (%)	44.24 to 49.01
Ash (%)	5.18 to 6.56
Volatile Matter (%)	26.50 to 34.04
Fixed Carbon (%) 1	9.35 to 24.00
Sulphur (%)	0.92 to 1.34
Heating value (Btu/lb)	
As Received	5780 to 6398
Dry	10723 to 11353
DAF	11605 to 12613
MMM Free	6101 to 6841

2.4. Design parameters of CRIP well of on Block III (A) at Thar Coal

For the data available from United States Geological Survey Report, the coal seam is available at the depth of about 114 m to 203 m, and accumulative coal seam thickness is about 7.2 to 25 m. By keeping these parameters in mind we can design the depth of the well to maximum that is 203 m. The width of the two wells is not restricted in CRIP Technique of the well designing [14].

2.5. UCG Process

Underground coal gasification (UCG) technique is only solution for those coal reserves which are sandwiched between water beds. Before the invention of the underground coal gasification technique the coal reserves which were present below the water ground level, was useless [3]. Because preceding mining techniques were failed due to presence of water bed above the coal seams. Now due to this technique (UCG) it becomes possible to use the coal which is below the water bed.

In underground coal gasification process vertically holes are being drilled up to the coal seams with regular distances [4]. Then hot compressed air with steam is being injected in to the well (in case of lignite coal steam can be avoided) in the presence of hot compressed air the coal start burning in the bottom of well. Due to injected pneumatic pressure a channel is formed between two wells and gas starts coming out from next hole. The gas collected from collection well will be mixture CO, CO_2, CH_4, N_2 and steam. After collection this mixture of gasses being passed through a gas cleaning plant to capture CO_2. After capturing CO_2, it is again being injected into gasifier to use in chemical process, so that it can be avoided to release carbon dioxide in to the air for clean environment [5]. After cleaning the gas it is given to the syngas engine for the generation of electricity through (IGCC) process.

Table 2. Predicted production through UCG of Block III-A

C (Million Tones)	**H_2 (Million Tones)**	**CO ((MillionTones)**	**CH_4 (Million Tones)**	**Volume of CH_4 (Million Cubic Feet)**
2008	44.294	620.116	59.06	46.718

3. Chemical Reaction Zones in UGC:

The chemical reaction involved in Underground Coal Gasification (UCG) is divided in to three different zones are (a) Oxidation zone (b) Reduction zone (c) Drying zone [17].

3.1. Oxidation Zone

Oxidation means addition of oxygen or removal of hydrogen. In this zone we injected hot compressed air at high pressure through injecting well. The temperature of this zone is about 900°C. When oxygen react with coal CO_2, CO and H_2O is formed. CO_2 is harmful for environment so it is captured by purification plant [16].

Figure 4. UCG Production Process

3.2. Reduction Zone

Reduction means addition of hydrogenor removal of oxygen. The temperature of this zone ranges between 500°C to 900°C. In this zoneCO_2 and H_2O react to formed CO_2 and H_2O. This reaction is reversible (means carbon monoxide and water can also be formed by the reaction of $CO_2$and H_2O) CO_2 is again captured. Finally CO and H_2 react to form CH_4 gas [18].

3.3 Drying Zone

The temperature of this zone ranges between 200°C to 500°C. Methane gas formed in reduction zone includes moisture. This moisture is removed from gas at drying zone and finally we obtained CH_4, H_2O, CO_2, CO, H_2, C and hydrocarbons from burning of coal [12].

4. Results and Discussion

UCG has been one of the most environmental friendly technique that is used through out of world to avoid environmental hazards such as global warming, acid rain and also damages of ozone layer. This technique is widely used instead of on ground burning of coal. Through UCG we can produce Syn Gas that will efficiently produce fuel, fertilizer, diesel and other chemicals that are largely used in industries. The mined coal (solid coal) is hard to handle or transport and also it requires some complexes pre combustion treatment. For example fluidized bed and pressurized bed, while on other hand output of UCG (syngas) can directly be used for many processes and it is east to transport. Open mining requires some heavy and costly instruments which would bear a certain load on national economy, while UCGS requires two drill holes which is cheaper and handy process [10].It is impossible for an area of 9100 m^2 to dig such a large mine and maintain it for years until an complete coal can be extracted. Thar region where dune sand is friendly for mine, the situation's complexity rises to critical level. In that case it is suggestible that where the block seam is quite thin must be avoided for digging and an alternative process of utilization is to be practiced and only suitable method in such condition underground coal gasification is suitable [8-10].

Table 3. Analysis of Thar coal

Moisture	36.82 %
Ash	18.92 %
Volatile matter	38.24 %
Fixed carbon	28.22 %
Sulphur	1.2%
Heating Value	3921 K Cal / Kg
The type of coal	Lignite-B

4.1. Utilization of Thar Coal

In 2009-2010, the oil consumption in Pakistan is estimated round about 63.1 million t. Pakistan consumes different percentage of conventional fuels like LPG, Coal, oil for the total energy mix having 29.7% oil, 11%coal, 15.6%electricity, 1.5%LPG. There is an increment in the fuel consumption of 7.7% from 2004 to 2010. Usages of Oil in the country declining at the rate of 8.6% because of heavy impose taxes and importing cost. Due to escalating price of imported oil Pakistan government paying millions of dollars to imported country [11]. While, if we are using the Thar coal, we may be generating enormous amount of electricity and other petroleum products and many other chemical that are used in different industries. With the help of coal gasification technology we can convert coal into SYN gas that use as natural gas. Several products can be obtained from the syn gas of coal by gasification like ammonia, hydrogen diesel and DME. Thar coal estimated to be round about 175.5 billion tons of coal which has the ability of 5000Megawatt generation of electricity and 100 million gallon diesel production per year. With utilization of Thar coal accepting coal gasification technology we can export diesel and other chemical products to other country.

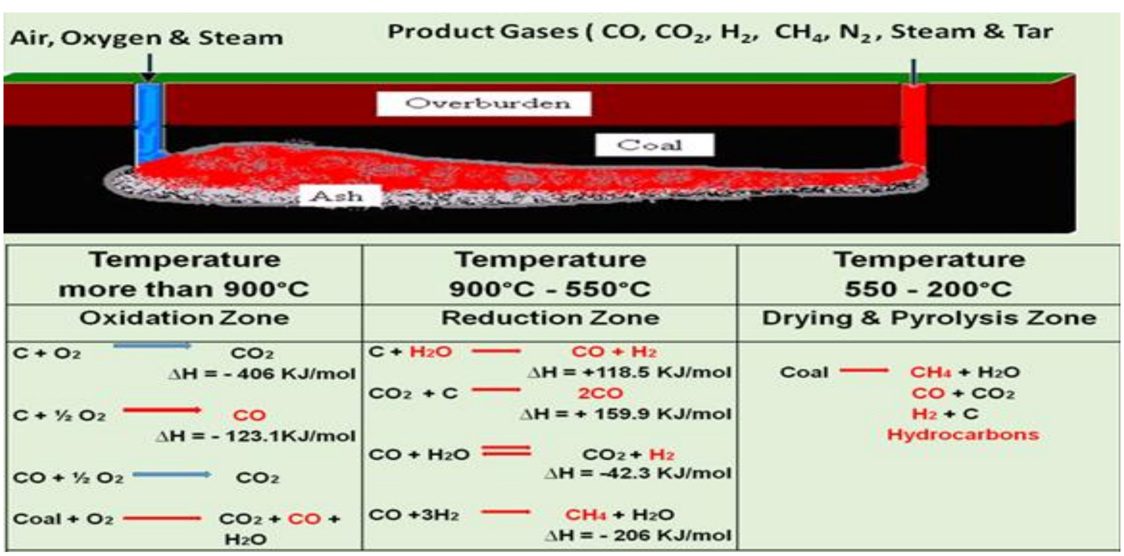

Figure 5. Analysis of block V coal

UCG Thar Pilot plant experiment was performed in Thar Coal Field block V. Total reserves of block V are 1385 million tons over 63 Km^2area.The minimum coal seam thickness was considered during target seam selection for pilot plant experiment, keeping in view site specificities for underground coal gasification. Pilot plant experiment was carried out at depth of 435-461 feet. Geological and hydrological studies were performed to know possible water influx during course of experiment. In block V coal seam cumulative thickness is 15.69 meter. Figure 3 shows litho log of target seam & block V exploration map. Analysis of block V coal is shown in (Table 2). Pilot plant experiment was carried out at depth of 435-461 feet. Geological and hydrological studies were performed to know possible water influx during course of experiment. In block V coal seam cumulative thickness is 15.69 m. Figure 3 shows litho log of target seam & block V exploration map. UCG Thar, Pilot study has been carried out on air stream rather than oxygen enriched air. The selection of oxidizing agent is however done by type of coal, coal characteristics, physical and chemical properties and; to larger extent on process economics [7]. At UCG Thar coal project different air flow rates were injected into gasification reactor ranging from 500 Nm^3/h to 3300 Nm^3/h to optimize the heating value of Syngas. In Thar coal field the area which is feasible for underground coal gasification is block III & block V. the block V is already under process by a veteran scientist so, we have selected block III-A for our studies. The advantages and restrictions which lead us in the favor of having UCG at that block is given above. The coal beds are of variable thickness ranging from 0.20 – 24.81 m are developed. From international research practice we can conclude that only 0.1-9 m is suitable for Underground Gasification, the range above that is feasible for open pit mining [5]. Clay stone invariably forms the roof and the floor rock of the coal beds. It is poorly to well cleared and compact. The quality of coal used to be better where percentage of clay is usually nominal. The cleaning cost of solid coal is much difficult and expensive as compared to syngas. Therefore block III is suitable only for UCG, because it not economic to drill a mine only for 0.6 m coal 4.6.1 design parameters of CRIP well of on block III (A) at Thar coal.

Table 4. Composition of Syngas achieved during test burn at UCG Thar project

O %	CH_4 %	H_2 %	N_2 %	CO_2 %	C_nH_m%	O_2 %	HV Kcal/Nm^3
8.55	2.79	10.00	61.50	16.94	0.16	0.05	785
8.72	2.92	10.13	61.00	17.06	0.18	0.04	802
9.04	3.20	10.61	59.30	17.56	0.19	0.03	851
9.31	3.28	10.91	58.58	17.72	0.20	0.02	877
9.74	3.26	11.38	57.10	18.31	0.20	0.02	900
9.82	3.24	10.42	57.20	18.15	0.20	0.03	894
9.42	3.13	11.29	57.87	18.06	0.21	0.06	870
9.18	3.11	11.90	58.02	18.16	0.20	0.08	863
7.11	4.48	11.70	57.55	19.47	0.22	0.02	926
6.78	5.59	15.43	49.77	22.16	0.27	0.01	1119
5.47	3.93	14.45	54.14	21.83	0.27	0.01	907

United States Geological Survey Report, the coal seam is available at the depth of about 114 m to 203 m, and accumulative coal seam thickness is about 7.2 to 25 m. By keeping these parameters in mind we can design the depth of the well to maximum that is 203 m. The width of the two wells is not restricted in CRIP Technique of the well designing [18].The major source raw materials for the syn gas production are generally coal and biomass and toxic chemicals like sulfur can be removed easily from them. In a purified state, the syn gas can be used to directly for electricity generation. Syngas can be consumed in reciprocating engines or highly efficient combined cycle turbines for running the generators which generate electricity In other words we say syngas can then be used for eco-friendly power generation [16].Major composition of Syn gas are usually combustible gases like hydrogen and carbon mono oxide and non-combustible like carbon di oxide and density of energy of syn gas occupies less than halve as compared to natural gas. Syngas is the combustible and often used as the fuel source or as an intermediate for the production of various other types' chemicals (catalysts to be used to convert synthesis gas to chemicals). These chemicals include methanol, olefins, and ethylene. Coal is main source of formation of syngas [6]**.**

4.2. Environmental Risk Assessment of UCG

Using underground coal gasification process the production of emissions via this process is relatively low level such as sulfur dioxide and nitrogen oxide are going into the atmosphere resulting causes the acid rain so in this way according to this study showing that by apply UCG technique the combustion carried out which very environmentally friendly and reduce the surface damaging problem also the solid wastes are produced from the open combustion so it's also reliable for the production of solid waste which after cause the problem for degradation of environment. It has little bit impact on composition of underground water [19] but here the situation is different because the Thar coal has already polluted underground water so the environmental risk will be same. Different heavy metals are found in the region of Thar in underground water like phenols, benzene with its derivatives, polycyclic aromatic hydrocarbons, and heterocycles. In the inorganic array, ammonia, cyanides, sulphates, and heavy metals are usually identified. Although the fact that the coal rank affects the contaminants' formation and release processes during the UCG is known, the information is still scarce [20].

4.3. Economical Estimation of UCG

World is focusing on the latest trends of UCG to fulfill the demands of energy. From 50 years Angren, Uzbekistan a power plant is in operation working on UCG. Yet, over 50 billion m^3 gas is produced by using UCG technique from 15 million metric tons of coal. US has gasified 50 thousand tons, while Australia has gasified 35 thousand tons of coal. In japan they considered it a little bit higher capital cost and suggested for 10 year period cost per heating value US$ 0.045/MJ and 0.029/MJ [21]. Hydrogen and Ammonia gasses were obtained by a project of Shanxi Province using UCG techniques. They are also considering 350 MW electric generating plant. The US$112 million will be spent on a project which is a joint venture b/w China University of Mining and Technology (CUMT) and company. According to contract the plant will generate 32.4 million kWh/year and produce methanol of 100,000 tons per year. [22]. In Europe the experiments were done and site was selected on the existing resources of 30 billion ton, in Australia 50 billion ton, in China 70 billion ton, in Russia 90 billion ton while Pakistan possess 175 billion tons of coal reservoirs and this will help to install the equipment and capitol cost will be minimized because of large deposits of coal.

5. Conclusion

The crises of energy has been dramatically increased in Pakistan. The scenario gets relatively worse on sunny days with load shadings of 10 to 12 h per day. If Thar coal reserves are utilized, Pakistan can generate electricity of 2, 50,000 MW for 100 years. The maturity of the reserves in Thar may give a positive contribution for long-term energy solution for Pakistan. The electrical energy generation capability of 100,000 MW usually based on expected usage per year of coal is 536 million tons, leads to the utilization of coal reserve to impose the relief on the national load system of gas.

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